Manual for Highway Storm Water Pumping Stations Vol. I

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Foreword

This manual provides design information for highway storm water pumping stations. Pumping stations are necessary where gravity drainage flow is impossible or uneconomic. The manual should be of interest to hydraulic, construction, and maintenance engineers.

State highway agencies, and the Los Angeles County Flood Control District, provided valuable data for this manual and cooperated in on-site field reviews. The Hydraulic Institute, numerous manufacturers of pumps and pumping equipment, and several experts in the design of stations also provide data and assistance in this study. The assistance of all parties who contributed to this manual is sincerely appreciated.

Additional copies of the manual can be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

R. J. Betsold
R. J. Betsold
Director, Office of Implementation

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William F. Lever

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Consulting Engineers
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CO-Contract Managers: Robert Baumgardner HNG-31
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16. Abstract

The purpose of this manual is to provide a comprehensive source of design information on storm water pumping stations for highway facilities. However, users are cautioned to use proper engineering judgment and must themselves be entirely responsible for any interpretations and applications of the data and opinions set forth herein.

An initial field survey was conducted to determine the present practices and experiences in several States, which proved to be extremely varied, with some basic differences in design concepts. All States were invited to submit information on their installations and most did so. Some of the data presented have been taken from these submittals, and some from relevant literature. Some have been drawn from manufacturers' catalogs. Examples from actual pumping stations have been incorporated whenever possible, by reproducing photographs or construction drawings in simplified form.

Various types of pumping stations are discussed in the early chapters, with guidance as to which might be expected to be most suitable for various conditions.

Later chapters deal with station machinery and features, including electrical systems. A number of appendices cover specifications, construction costs, energy economics, and maintenance.

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TABLE OF CONTENTS

Table of Contents (cont'd)

Table of Contents (cont'd)

Table of Contents (cont'd)

Table of Contents (cont'd)

PAGE NO.

* * * * * * * * *

LIST OF FIGURES

Figure	Subject	Page
4-9	Usable and Unusable Storage in Inlet Line	4-20
4-10	Use of Storage to Reduce Peak Flow Rate	4-21
4-11	Inflow Hydrograph for Example Problem	4-23
4-12	Estimating Required Storage	4-25
4-13	Storage Pipe Sketch	4-27
4-14	Stage-Storage Curve	4-28
4-15	Stage-Discharge Curve	4-30
4-16	Development of Inflow Mass Curve	4-32
4-17	Mass Curve Routing Diagram	4-33
4-18	Pump Discharges	4-36
4-19	Flushing Conditions for Storage Pipe	4-37
5-1	Selection Matrix (Part 1)	5-8
5-2	Selection Matrix (Part 2)	5-9
6-1	Pump Pit and Pumping Terminology	6-2
6-2	Recommended Pump Pit Dimensions per Hydraulic Institute Standards	6-3
6-3	Recommended Criteria for Rectangular Pump Pit Where Depth Is Minimized	6-4
6-4	Vortex Description and Submergence Requirements	6-7
6-5	Required Suction Umbrella Diameter for Pump Inflow Not Exceeding 2 Feet/Second	6-11
6-6	Criteria for Spacing and Submergence of Vertical Pumps in Circular Caisson-Type Pump Station	6-15
6-7	Circular Pit Construction In Open Cut Where Soil Is Favorable	6-18
6-8	Rectangular Pit - Vertical Pumps Under Test by Recirculating through Discharge Manifold	6-18
6-9	Hydraulic and Construction Details for Screw Pumps	6-20
6-10	Small Submersible Pump Arrangements	6-22
6-11	Plan of Station with Four Large Submersible Pumps Manifolded into Common Discharge	6-25
6-12	Section through Station with Four Large Submersible Pumps	6-26

List of Figures (cont'd)

List of Figures (cont'd)

Appendix F

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CHAPTER 1. INTRODUCTION

1-A. GENERAL OUTLINE

Stormwater pumping stations are located throughout the highway systems of the nation. They are necessary where gravity drainage flow is impossible or uneconomic. There are approximately 300 stations throughout California freeways, about 65 serving the Los Angeles area. The Detroit freeways have about 100 stations while the Houston system has only 15. The required number of stations depends more on highway design than climatic factors.

Most pumping stations in service throughout the country are unobtrusive and reliable, primarily because they are well-designed and equipped. However, malfunctions do occur, in some cases due to unsuitable design. Retrofitting should be considered in these cases.

This Manual provides guidelines, criteria and specifications intended to improve understanding of a subject which is made more complex by the mulitiple choices usually apparent for each element of design. Some choices will be found more suitable and effective than others. Each of the various types of station described in this Manual is usually adaptable to whatever size station is required. Refer to Chapter 2. - Review of Current Practice.

Stormwater pumping stations for highway facilities are usually of relatively small discharge capacity (less than 100 cubic feet per second). This is predominantly due to small size catchments tributary to each station. Stations of greater capacity (300 cubic feet per second or more) are sometimes required, and occasionally, even a larger station. Discharge heads may vary from about 10 to 60 feet.

In the use of this Manual, it is assumed that a design inflow hydrograph is available or can be determined from other sources. Some pump stations have minimum upstream storage, resulting in pumps sized to handle large inflows. This is usually not desirable. Pumping requirements and the mechanical and electrical installation can often be reduced by constructing a large upstream storage capacity below the highway pavement or in an open forebay. Refer to Chapter 4. - Collection Systems.

In addition to handling stormwater, some pump stations will be required to pump groundwater containing heavy concentrations of sand or silt. Provisions are often made to remove heavy concentrations of contaminants before being pumped. Care may also be necessary to avoid contaminating receiving waters. Settling basins for suspended solids and separators for hydrocarbons may be required downstream from the pump station.

In private installations, both electric motor and engine-driven pumps may be exposed to the weather, but under public highway conditions a protective structure is generally desirable. The structure will enhance the aesthetics and provide protection against vandalism and the weather.

Most stormwater pumping stations in highway service are electrically powered, with service from a utility company. Protection from a power outage can be provided by dual feeders to the station from two separate electrical sources, or by an emergency generator (gasoline or diesel) which starts automatically in the event of loss of utility power. Alternately natural gas or diesel engines may be used in combination with electric motors to drive individual pumps. With the latter system, each pump may be driven by either its electric motor or its engine.

Another alternative is to drive the pumps by natural gas engines with piped gas supply, and also to provide on-site LPG storage to be available in case of interruption of service. Propane is the usual LPG (liquefied petroleum gas). Regardless of which combination is used, most stations have dual or emergency power sources to ensure reliability. If a single source is to be used, very high reliability is provided by engine-driven pumps with either piped gas or on-site LPG storage only.

All stations are designed to operate automatically. Rising water in the storage or wet-well causes engines or motors to start and drive the pumps without any personnel being involved. As the water level is lowered, pumps will also stop automatically.

Stormwater pumping stations are frequently of the wet-pit type, where the pumping equipment is either suspended into the stormwater or completely submerged. Alternately, stations may be of the dry-pit type where the pumping equipment is housed in a dry chamber beside the wet-well containing the stormwater. The wet-pit is the more common.

Different types of stations are described in general terms in Chapter 2. - Review of Current Practice, so that the designer will be able to identify the alternatives. The actual selection of a type of station and equipment which appears to be best suited to any given situation is covered in more detail in Chapter 5. - Selection of Type of Station and Equipment. Later chapters cover pumps, motors, engines, electrical systems and construction in greater detail, while Appendixes cover specifications and other specialized subjects.

1-B. DATA COLLECTION FOR THE MANUAL

Many State highway agencies throughout the nation have made valuable contributions to this Manual. Additionally, on-site field reviews were made in four large urban areas with different climatic conditions to assess design criteria and operation and maintenance practices. The four areas were: Los Angeles, California, which has long dry periods which create long inactive periods; Detroit, Michigan, which has periods of extreme cold; Houston, Texas, which has frequent and torrential rains; and Phoenix, Arizona, which has an unusually dry, hot climate.

Each of the four State highway agencies responsible for the areas named has successfully developed standardization of design and effective operating and maintenance procedures; however, their designs are markedly different for a number of reasons. Other factors besides climate appear to have a stronger influence. The different designs are:

(a) Michigan (Detroit): Complete dependence is placed on electrical power for multiple vertical pumps in a wet-pit type station. The pumps are set in a circular structure (caisson) which is sunk into the side slope of the depressed section. Soils are favorable for this type of construction.

(b) California (Los Angeles): Stations are the dry-pit type with emphasis on storage upstream, which minimizes mechanical and electrical requirements. Complete dependence is placed on electrical power, but mobile emergency generators are strategically located so that they can be moved to any station where a power outage occurs.

(c) Texas (Houston): A wet-pit caisson-type station is used because of soil conditions. The structure houses two vertical pumps only, with combination electric or natural gas engine drive. Station capacities have been standardized in increments of 4,000 gpm, while the dual power source protects against electrical power outage caused by thunderstorms.

(d) Arizona (Phoenix): A rectangular or circular wet-pit structure is used with two or more vertical pumps. Natural gas engines are used, usually fueled by LPG stored at the station. This solution is highly reliable in thunderstorm areas, since it is not vulnerable to power outages.

The Michigan and California types of station can maintain the inside temperature above freezing better than the Texas and Arizona types, because they are easier to insulate and heat. The latter types require more wall openings, louvers and ducts to serve engine requirements; however, there does not appear to be any reason for climate alone to disqualify any of the various designs from use in any other area, if proper construction features are included.

The Los Angeles County Flood Control District also provided a valuable data base. The District operates about 30 stations, some of which are completely electric, while others depend on a combination of electric motors and natural gas engines. The District's newest stations depend principally on natural gas engines for pumping major flows, with electric power for low flows only, to reduce electrical stand-by charges. Appendix E. - Energy Economics, discusses this subject in some detail.

The Hydraulic Institute, the manufacturers of pumps and pumping equipment, and various experts in the design of stations were valuable sources of data in the preparation of this Manual.

This Manual contains illustrations of eight different types of stations. In addition to photographs of actual construction, various figures have been prepared by simplifying engineering drawings. The benefits of advancing pump technology are explained.

1-C. SELECTION OF TYPE OF STATION AND EQUIPMENT

One question frequently asked is what type of station is best suited to a particular set of conditions. The answer is that there are various types of stations and equipment that will suit any given site and set of conditions. The problem is to select one of the several designs that is most suitable to meet the criteria established, while avoiding those that are less suitable.

A matrix has been developed displaying the various types of stations with their alternates and sub-alternates. This compares each type with the requirements of the site, as well as operating and maintenance functions. A careful and logical comparison of detailed functions and operating conditions with the capabilities of the various station combinations is essential for a satisfactory selection of station type.

1-D. PLANS AND SPECIFICATIONS

It is emphasized that there is usually some considerable complexity in plans and specifications for a pumping station, due to the various engineering disciplines involved. These range from soils and foundation engineering, through civil, hydraulic, structural, electrical and mechanical aspects, as well as architectural and building construction input. Considerations also include operational safety and compiance with current OSHA requirements. Construction features should follow all applicable building codes and in many cases State standard specifications for highway and bridge construction will be found suitable to cover much of the general construction included in a pumping station. Data and details illustrated in this Manual may be used or adapted, and Appendix D. - Specifications, is intended as a guide both for the adaptation of standard specifications and for specifying mechanical and electrical work.

1-E. OPERATION AND MAINTENANCE

Because adequate maintenance is essential, it is discussed in Appendix G. - Maintenance Management, particularly in regard to the effect that design features have on maintenance. Design should facilitate and reduce the cost of operation and maintenance without adding unduly to construction costs, and should minimize possibilities of malfunctions and stations becoming inoperable. Good hydraulic conditions and good provisions for removal of trash and silt are most important.

Guide material on telemetering is also included in the text; this can be used to provide supervisory control of stations from a central point. However, highway patrol officers can observe alarm signal lights on stations and this is often considered to be a sufficient warning system to protect against flooding should a malfunction occur.

I-F. CONSTRUCTION COSTS

Information on construction costs of pump stations has also been included in Appendix C. - Construction Costs. This information is based on actual bid data for a project in the Los Angeles area, where prices as bid were accepted and a contract was awarded in January 1978. Later data from the same locality is also included. The user must adjust the information as necessary by using professional judgement or available construction cost indexes.

I-G. METRIC CONVERSION

The text in this Manual has been written entirely in conventional United States units -- feet, inches, gallons, etc. These units are still the accepted standard in all U.S. manufacturers' literature.

The table of conversion factors permits conversion from U.S. or imperial units to metric or vice versa.

For example:

3.281 ft. = 1 meter
1 ft. = 0.3048 meters

For brevity and convenience, these are combined in the table as:

3.281 ft. 1 m 0.3048

Metric Conversion Factors

Unit	U.S.		Metric
Length	0.6214 miles	1	km 1.609
	3.281 ft.	1	m 0.3048
	1.094 yds.	1	m 0.9144
	0.03937 in.	1	mm 25.40
Area	10.764 $ft.^2$	1	$m^2$0.09290
	1.196 $yd.^2$	1	$m^2$0.8361
	0.3861 sq. mi.	1	$km^2$2.590
	2.471 acres	1	ha 0.4047
Volume	35.315 $ft.^3$	1	$m^3$0.02832
	1.308 $yd.^3$	1	$m^3$0.7646
Capacity	0.220 Imperial Gallons	1	litres 4.546
	0.2642 U.S. Gallons	1	litres 3.785
Velocity	3.281 ft./sec.	1	m/sec. 0.3048
	196.8 ft./min.	1	m/sec. 0.0051
Mass	0.9842 ton	1	tonne 1.016
	2.205 lb.	1	kg 0.4536
	0.0353 oz.	1	g 28.3495
Mass/unit area	0.0014 $lb/in.^2$	1	$kg/m^2$703
Rate of flow or discharge	15.85 US gal/min.	1	litres/sec. 0.0757
	35.31 cusec.	1	cumec 0.0283
	4.414 US gal/min.	1	m^3/h 0.272
	264.20 US gal/day	1	m^3/day 0.0045
Density	0.06243 lb. $ft.^3$	1	$kg/m^3$16.02
Pressure or stress	0.145×10^{-3} $lb./in.^2$	1	$N/m^2$6894.76
Power or Energy	1.341 hp	1	kW 0.7457
Temperature	1.8 deg. F	1	deg. C 0.555

* * * * * * * * * * * *

CHAPTER 2. REVIEW OF CURRENT PRACTICE

2-A. GENERAL

This section provides an overview of a wide range of pumping stations, pointing out the principal features of each design but leaving more detail to be presented in later sections.

Construction contract drawings have been reproduced in simplified form to illustrate the main design features. Photographs of actual stations are included whenever possible. Readers not familiar with pump terminology may wish to review Chapter 8. - Pumping and Discharge Systems, and Chapter 9. - Pumps for Stormwater Applications, before reading this section.

2-B. DRY-PIT EXAMPLE

(Horizontal centrifugal pumps with electric motors, based on criteria developed by the State of California)

To drain a typical depressed highway section, a large collecting chamber or storage box is constructed beneath the pavement adjacent to the station. Water enters the storage box through gratings in the median or shoulder. Storage can be augmented if necessary by longitudinal drain lines. The storage box forms the wet-well and incorporates a sand trap at the low end.

A vertical dry-well, approximately square in plan, is set in the side slope of the highway section. Two or three horizontal non-clog centrifugal pumps in the dry-well take suction from the wet-well through connecting piping. Discharge piping runs vertically up the inside of the dry-well, then horizontally to a receiving channel. (Figures 2-1, 2-3 and 2-7)

This design maximizes storage and minimizes pumping capacity, with a typical station having 5000-8000 gpm (11-18 cfs) discharge. Operating head is typically about 35 feet. (Figure 2-2)

Pumps are electrically-powered. A trailer-mounted diesel emergency generator can be moved to any station which has lost electrical power. In some instances, the emergency generator is garaged in the station superstructure. (Figure 2-4)

The use of horizontal centrifugal pumps in a dry-pit has been adopted in preference to prior use of vertical pumps in a wet-pit. Adoption of the storage box feature preceded the change in type of pumps.

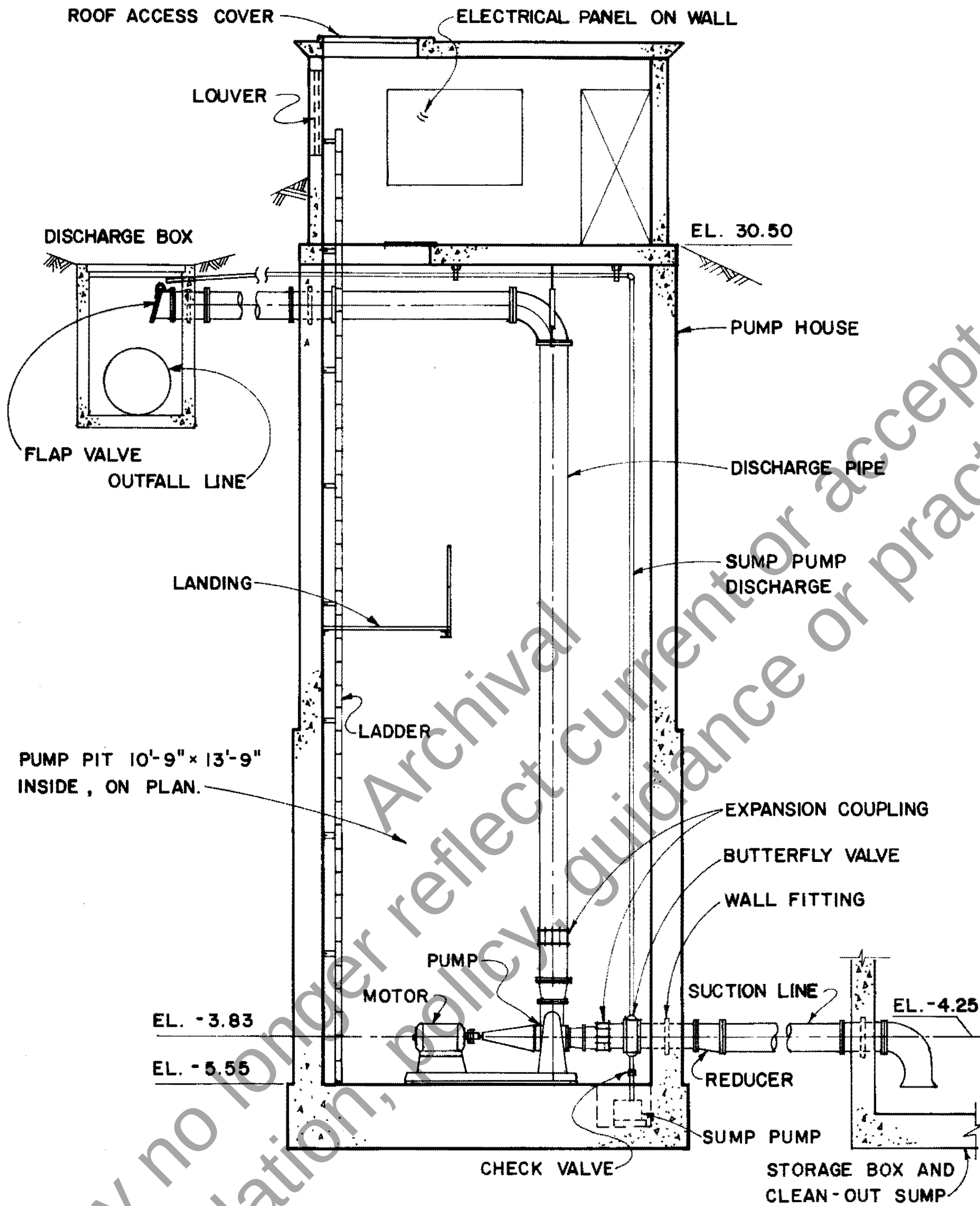


FIGURE 2-1. DRY-PIT PUMP STATION

DIMENSIONS AND ELEVATIONS SHOWN ARE FOR A PARTICULAR CASE AND MAY BE VARIED TO SUIT.

TWO OR THREE MOTORS AND PUMPS MAY BE INSTALLED.

FORCED VENTILATION OF PIT IS PROVIDED, WITH FOUR AIR CHANGES PER HOUR WHEN OCCUPIED, PRECEDED BY TEN MINUTES FREE PURGE BEFORE ENTERING, TO MEET O.S.H.A. REQUIREMENTS.

SUMP PUMP IS SIZED TO HANDLE ONLY THE MINOR FLOWS RESULTING FROM PUMP PACKING-GLAND LEAKAGE, DISMANTLING OF PIPING DURING MAINTENANCE OR UNPLANNED SEEPAGE INTO THE STATION.

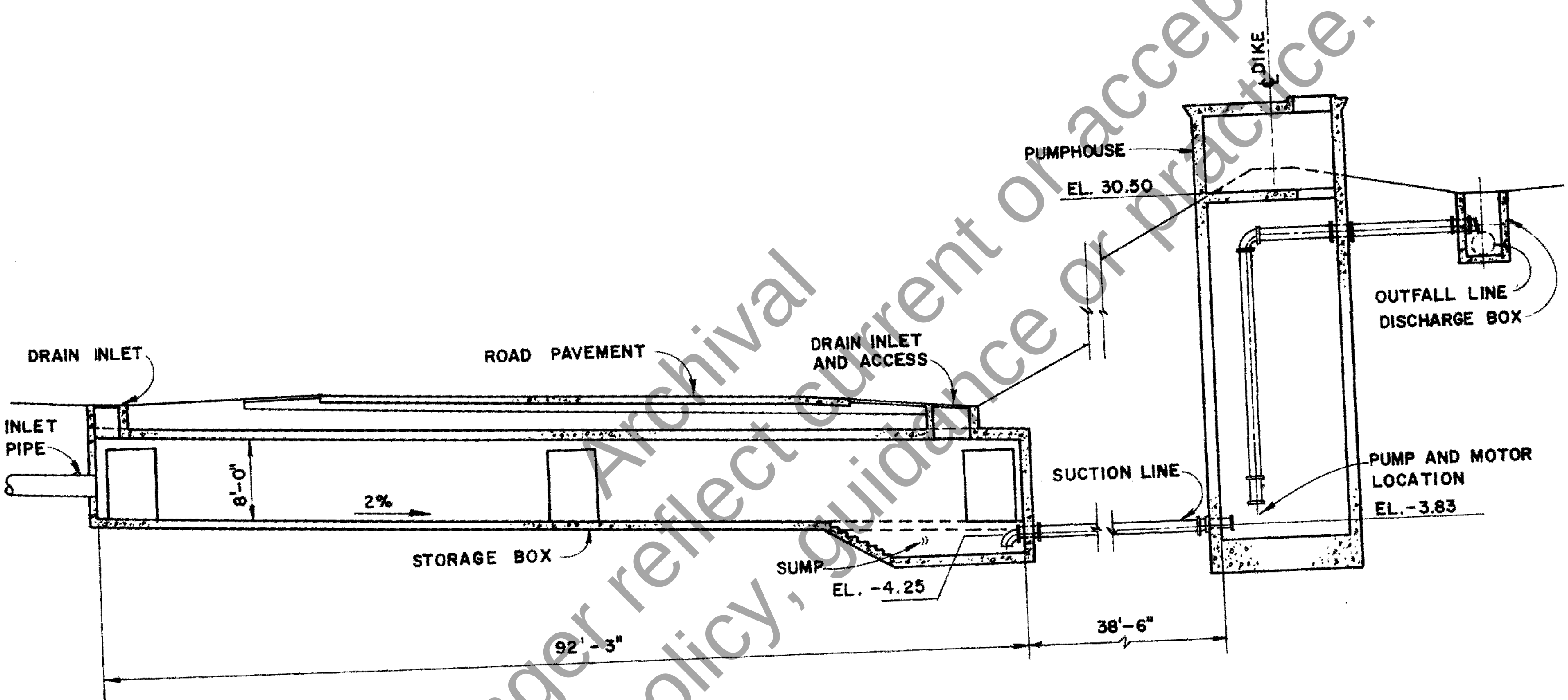


FIGURE 2-2. SECTION THROUGH STORAGE BOX AND DRY-PIT PUMP STATION

DIMENSIONS AND ELEVATIONS SHOWN ARE FOR A PARTICULAR CASE AND MAY BE VARIED TO SUIT.

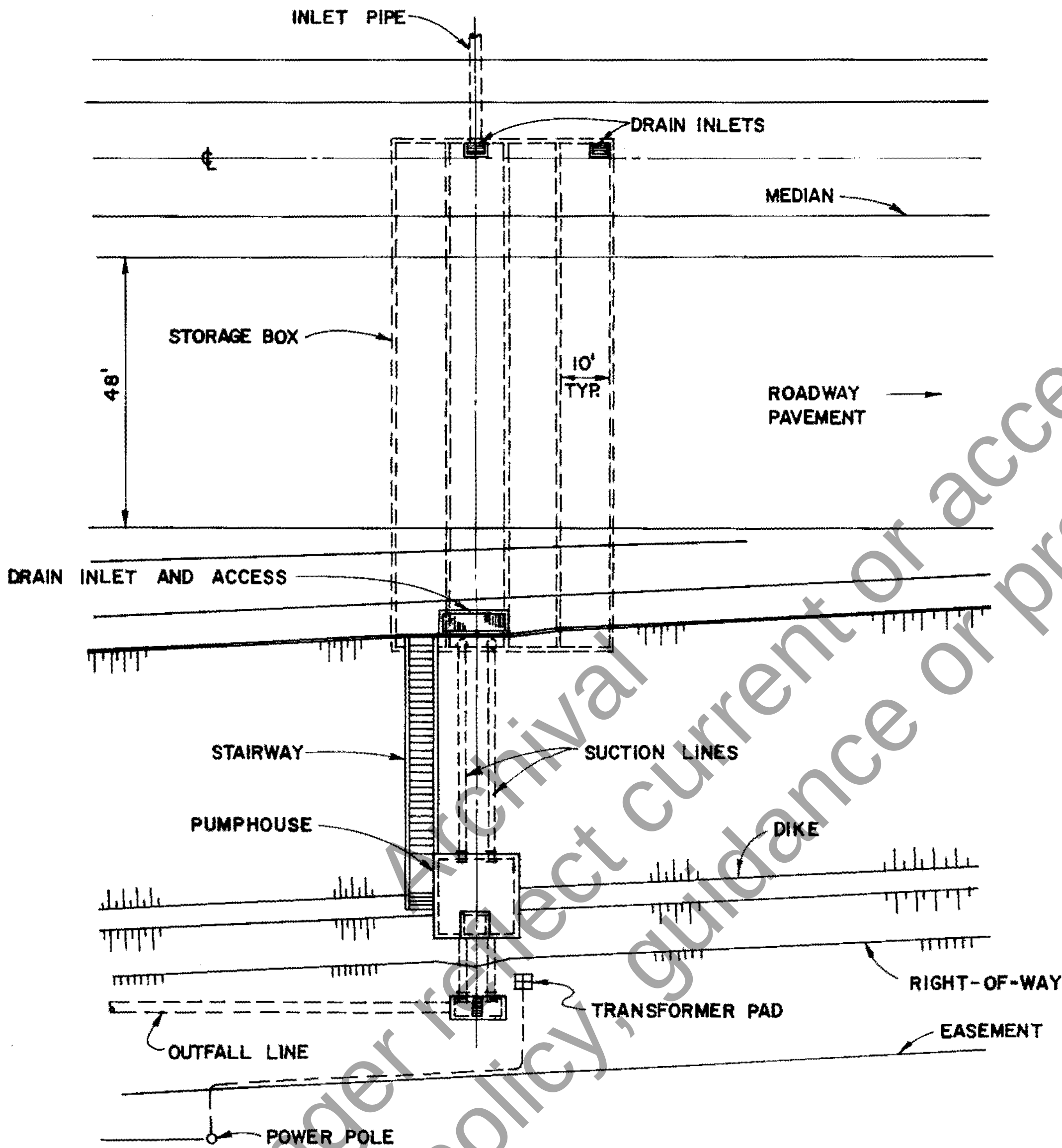
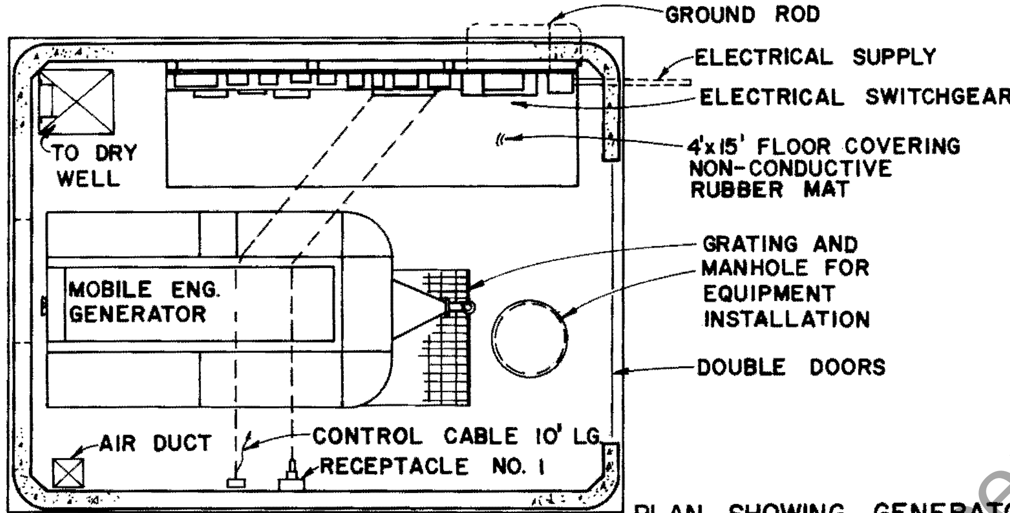
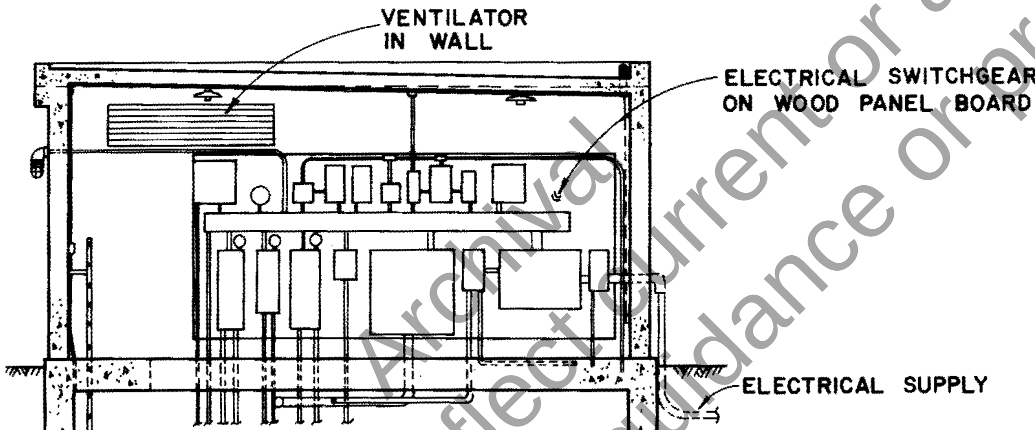


FIGURE 2-3. PLAN OF DRY-PIT PUMP STATION WITH STORAGE BOX

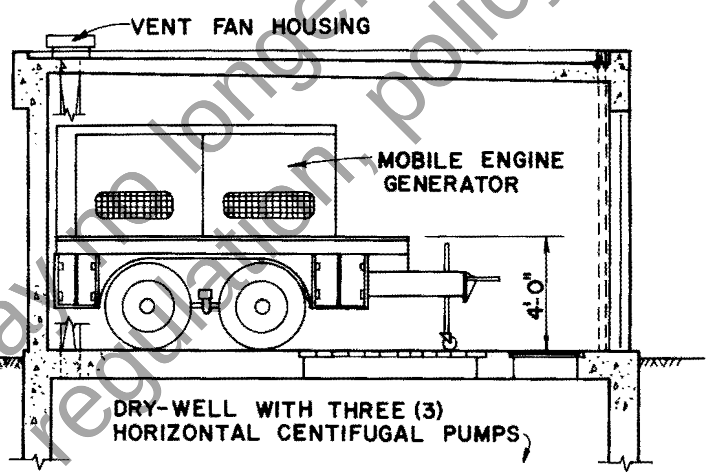
FIGURES 2-1 THROUGH 2-4 HAVE BEEN REPRODUCED FROM DRAWINGS FURNISHED BY THE STATE OF CALIFORNIA.



PLAN SHOWING GENERATOR AND ELECTRICAL SWITCHGEAR



ELEVATION OF SWITCHGEAR 1-20 HP & 2-60 HP PUMPS



EMERGENCY GENERATOR GARAGED

FIGURE 2-4. DRY-PIT PUMP STATION SUPERSTRUCTURE INCORPORATING EMERGENCY GENERATOR

2-C. DRY-PIT EXAMPLE

(Vertical centrifugal angle-flow pumps with electric motors, based on data submitted by the State of Ohio)

For this particular example, pumping capacity totalling 277 cfs is provided by four main pumps, each of 67 cfs capacity and one low-flow pump of 9 cfs capacity. The operating head is 55 feet, which is a much greater head than normally encountered in highway stormwater pumping applications.

All five pumps are housed in the lower part of the dry-pit. The pump room floor is 25 feet below the motor-room floor which is at grade. The low-flow pump is set about five feet lower than the main pumps. The vertical motors for all pumps are set above the motor room floor and connected by vertical shafting to the pumps. Stormwater enters the wet-well through a grit chamber and trash screen. Due to the discharge piping arrangement, with all pumps discharging into a common manifold, a check valve must be provided on the discharge side of each pump to prevent back-flow through the pump into the wetwell when the pump is not operating. In this case the check feature is provided by a pump control valve. Each pump starts against a closed control valve which then opens slowly to allow discharge into the manifold without causing surge or water-hammer. The control valve closes slowly before the pump is stopped, protecting the discharge system. Shut-off (butterfly) valves are provided on each side of each pump so that the pump or control valve can be dismantled or removed for maintenance without water entering the dry-well.

Motors for the main pumps were specified to be a minimum of 450 horsepower and the power supply is at 2,400 volts. Total connected load approximates 2,000 horsepower.

Due to the depth of the structure, massive concrete walls are necessary for this type of station; the underside of the wet-well is 38 feet below the motor-room floor at grade. The motor room is 44 feet by 29 feet on plan, with walls 17 feet high. An overhead crane is provided. (Figures 2-5 and 2-6)

A simpler manifolding is used in one of the wet-pit type stations where small submersible pumps are used (Figure 2-26). Other illustrations of manifolds occur in Chapter 6. - Wet-Pit Design; and in Section 8. - Pumping and Discharge Systems. The expense of manifolds and valving should be compared with the cost of using multiple discharge lines, one for each pump. Alternately, there may be economy in the simplicity of pumping the water to the top of a vertical standpipe open to the atmosphere so that gravity head will cause flow in the discharge line.

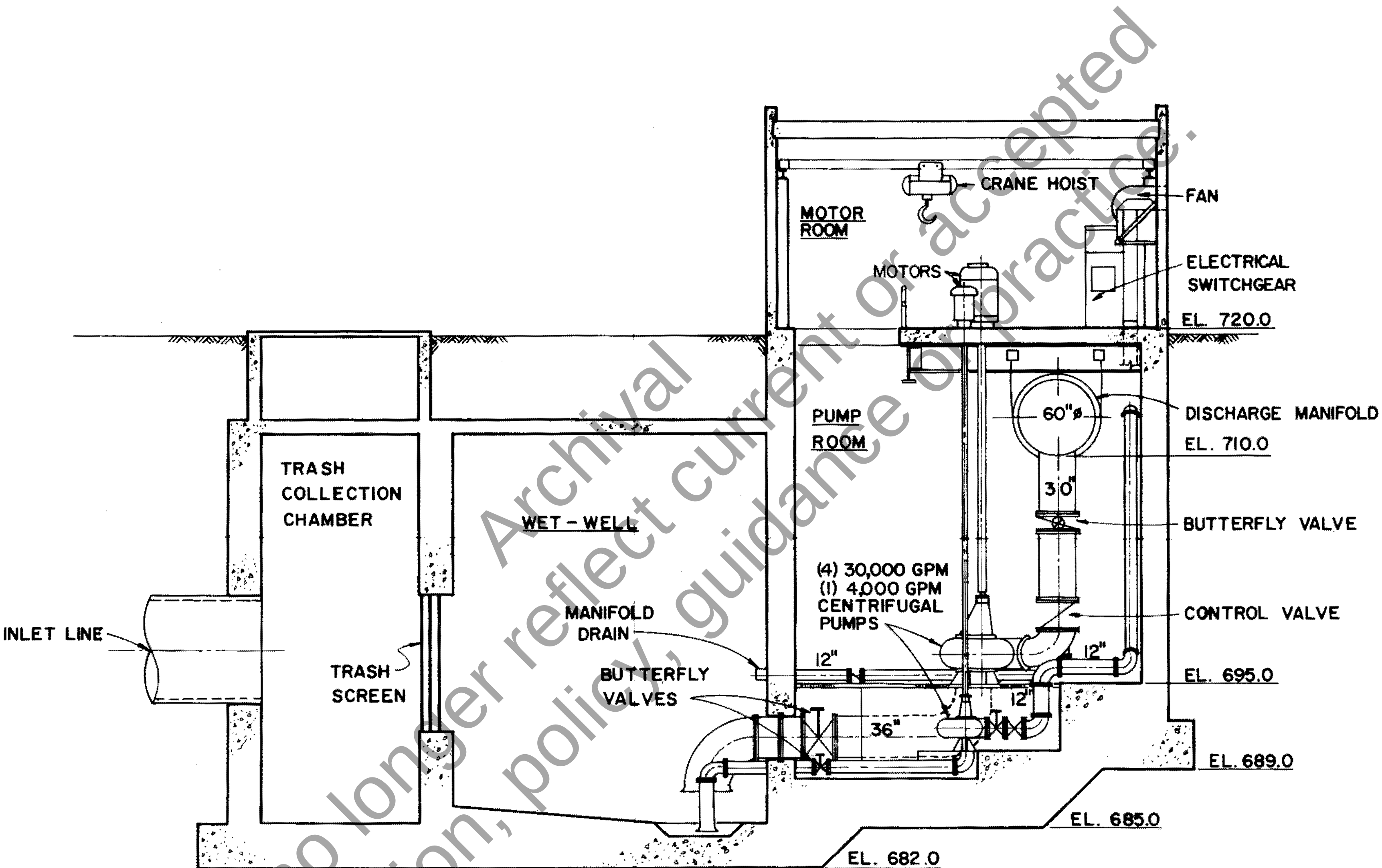


FIGURE 2-5. SECTION THROUGH DRY - PIT PUMP STATION
DATA FURNISHED BY STATE OF OHIO FOR STATION AT COLUMBUS

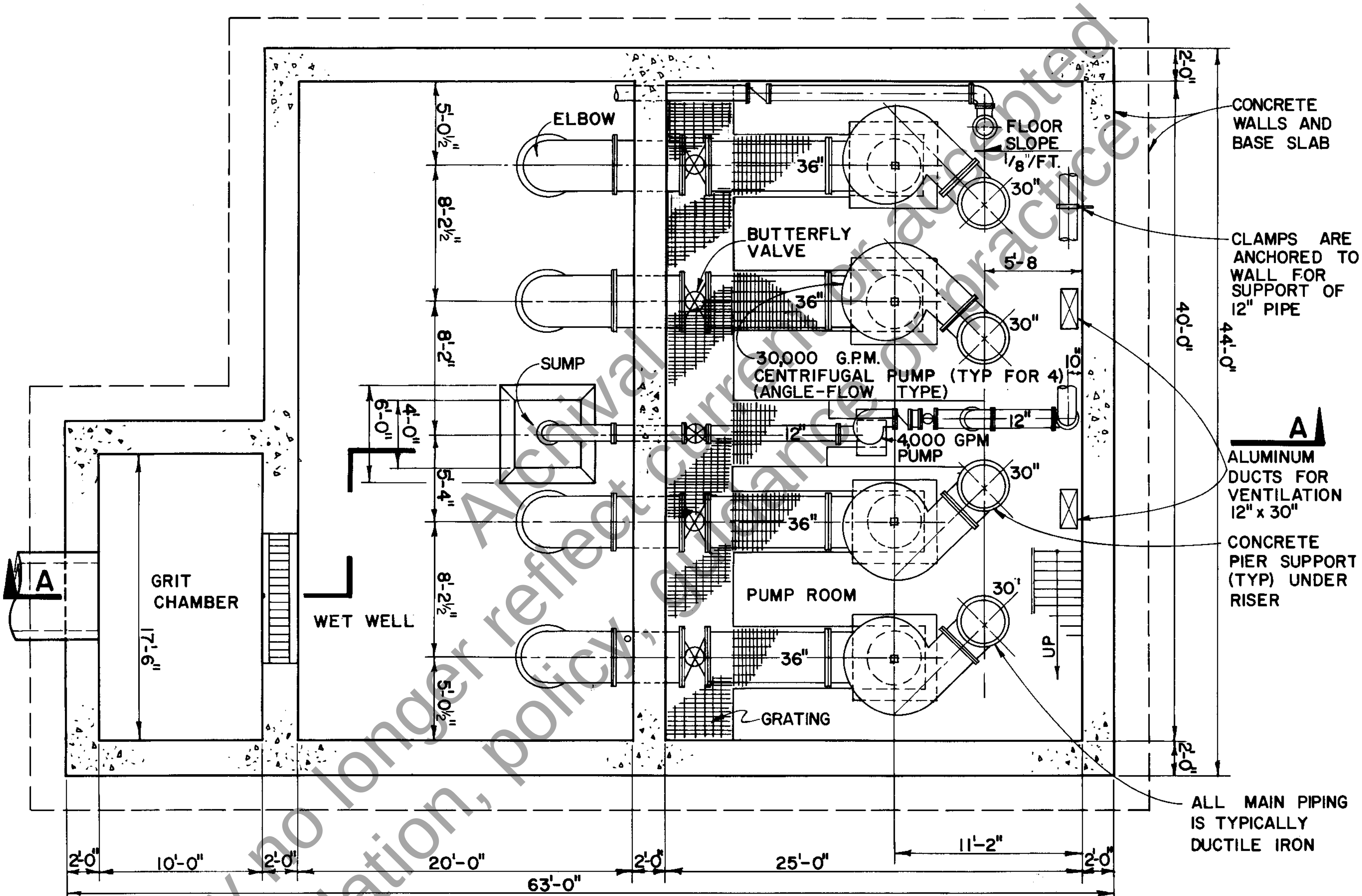


FIGURE 2-6. LOWER PLAN OF DRY PIT STATION

DIMENSIONS SHOWN ARE FOR A PARTICULAR CASE AND MAY BE VARIED TO SUIT
COLUMBUS, OHIO

FIGURE 2-7. DRY-PIT PUMP STATION,
I-50 AT 45TH STREET, SACRAMENTO, CALIFORNIA
(To Criteria established by State of California)

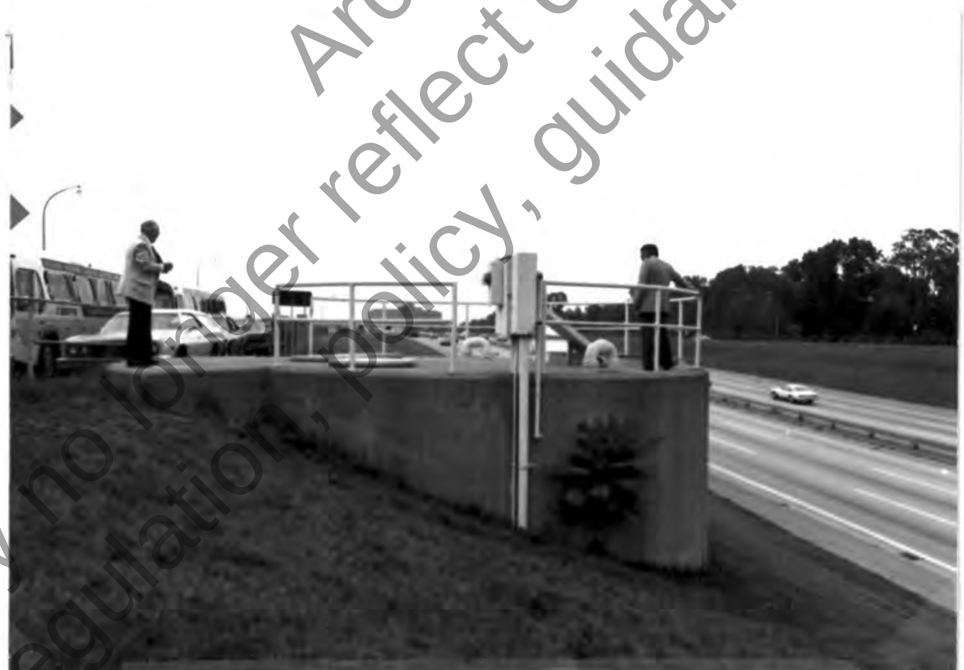


FIGURE 2-8. WET-PIT PUMP STATION, CAISSON TYPE,
SOUTHFIELD FREEWAY AT ROTUNDA DRIVE, DEARBORN, MICHIGAN
(To Criteria established by State of Michigan)

2-D. WET-PIT EXAMPLE

(Circular caisson, multiple vertical pumps with electric motors, based on criteria developed by the State of Michigan)

In the typical case, storm drain lines lead to a concrete caisson-type pit structure, circular in plan, which is set in the side slope of the depressed highway section. The method of construction is to pour the circular exterior wall of the pit structure in successive lifts, excavating inside so that the caisson sinks gradually to its desired elevation. Internal concrete work is then completed.

Three to five vertical pumps are set in a circular pattern concentric with the structure. Pumps may be of propeller or mixed flow type according to discharge head, with capacity depending upon inflow. All pumps are normally of the same capacity and head. Ample submergence of pumps is maintained in the stormwater at the bottom of the pit. The pit is not pumped dry during normal operation. All pumps are powered by electric motors with dual service, in some cases from two different utility companies. In two special cases, the same configuration is used for a larger station for airport drainage, and for a very large (350 cfs) station draining several miles of depressed freeway. (See Figures 2-8, 2-9 and 2-10 for the usual size of station, Figures 2-11 through 2-14 for the large stations.)

2-E. WET-PIT EXAMPLE

(Circular caisson, two vertical pumps with combination drive - electric motors and engines, based on criteria developed by the State of Texas)

Downstream of conventional tributary drain lines, a circular concrete caisson-type substructure is used as the wet-pit with two vertical pumps of the same capacity set approximately on the diameter. The inlet to the station includes a baffle which causes the flow to bifurcate, and each pump sits in a separate chamber with ample submergence. Each pump has an electric motor with combination gear drive and natural-gas engine. This permits either the motor or the engine to be used to drive the pump at any time. An effective standardization has been achieved by limiting station designs to increments of 4,000 gpm (8.92 cfs).

A rectangular concrete superstructure is offset from the caisson sub-structure to house the equipment while providing proper minimum clearance. Roof hatches are provided for removal of

FIGURE 2-9. INTERIOR OF STATION SHOWN IN FIGURE 2-8
Showing three 20 h.p. motors driving vertical pumps with above-floor discharge

FIGURE 2-10. SAME STATION AS FIGURE 2-8
Showing inlet and trash racks. Note concrete pillar at right which causes inflow to bifurcate and flow around periphery of caisson towards pumps

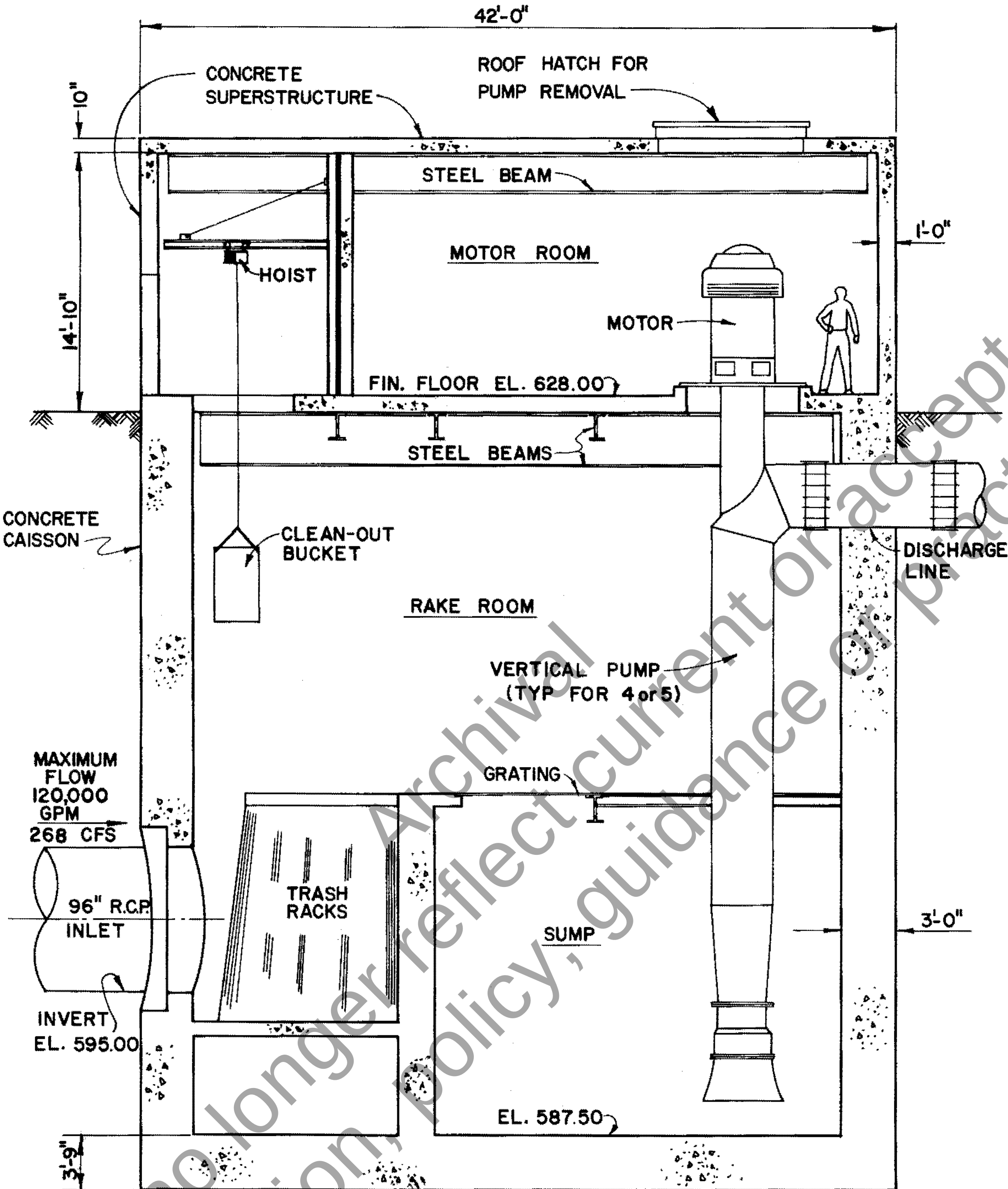
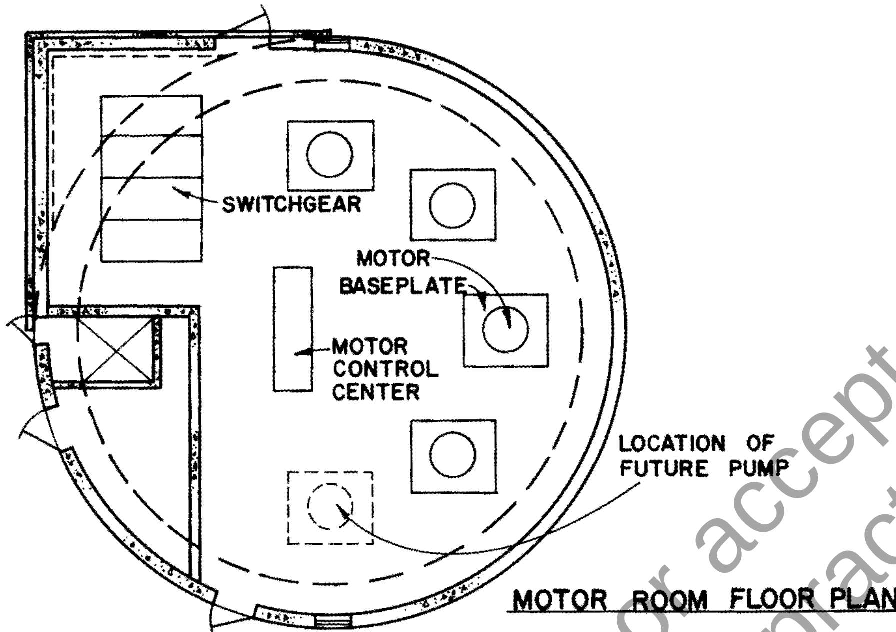


FIGURE 2-11. SECTION THROUGH CIRCULAR WET-PIT TYPE PUMP STATION

DIMENSIONS AND ELEVATIONS SHOWN ARE FOR A PARTICULAR CASE AND MAY BE VARIED TO SUIT.

WAYNE COUNTY AIRPORT, DETROIT, MICHIGAN



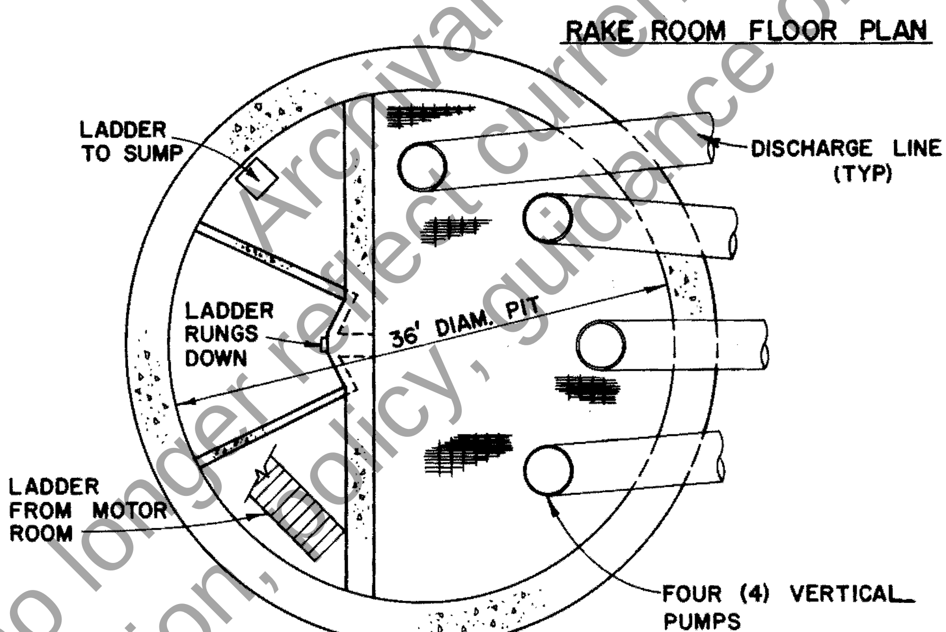


FIGURE 2-12. LARGE WET-PIT TYPE PUMP STATION - PLANS

FIGURES 2-11 THROUGH 2-13 ARE FROM DATA FURNISHED BY STATE OF MICHIGAN FOR STATION AT WAYNE COUNTY AIRPORT, DETROIT.

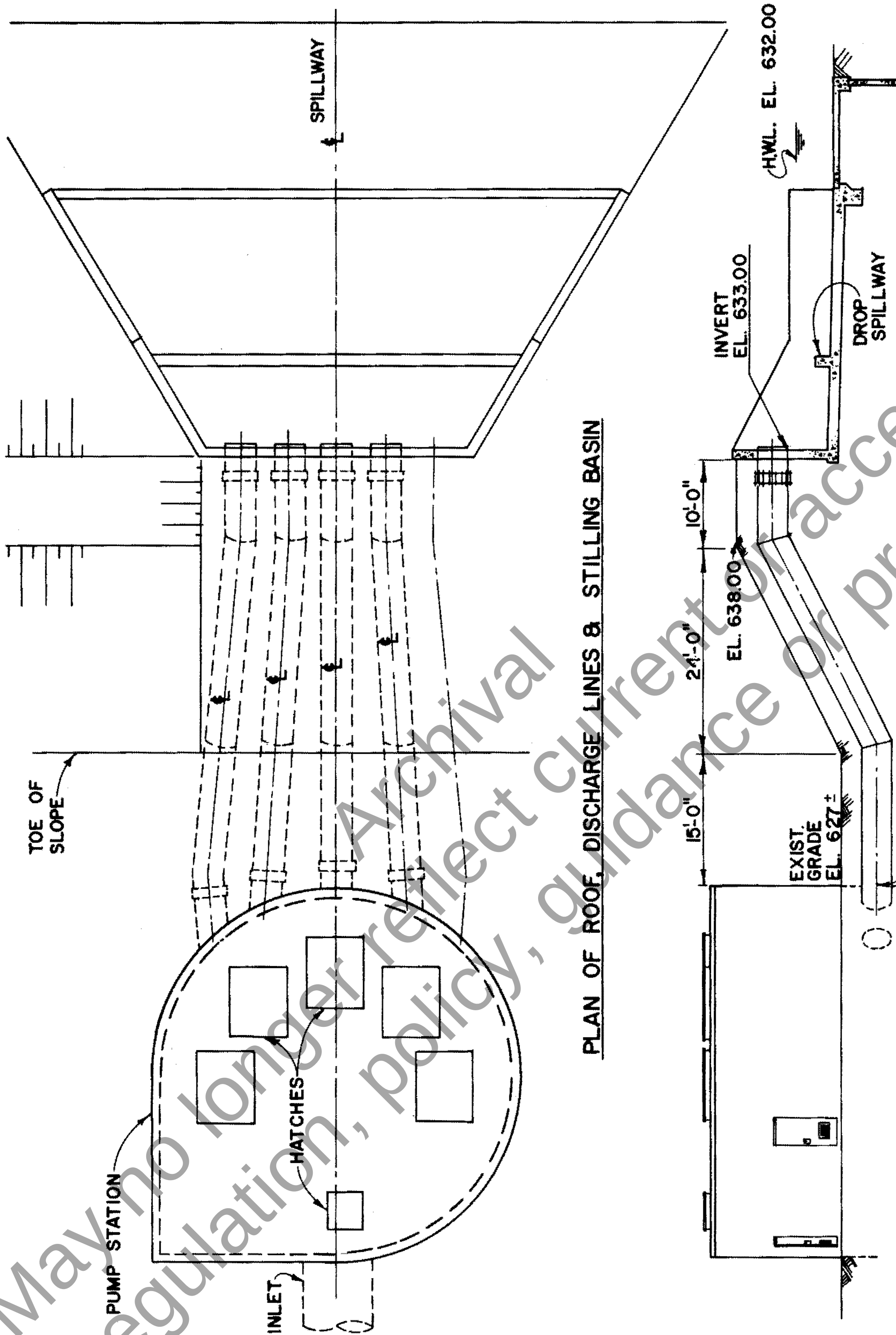


FIGURE 2-13. WET-PIT TYPE PUMP STATION-GENERAL LAYOUT

DIMENSIONS AND ELEVATIONS ARE FOR A PARTICULAR CASE AND MAY BE VARIED TO SUIT

FIGURE 2-14. LARGE WET-PIT STATION (350 CFS), I-696, DETROIT, MICHIGAN
Generally similar to the Wayne County Airport Station but a large separation structure is immediately downstream. Electrical equipment is illustrated in Chapters 10 and 12.

FIGURE 2-15. SMALL WET-PIT PUMP STATION, US 59, TEXAS
Equipped with two pumps with combination electric motor and gas-engine drive.

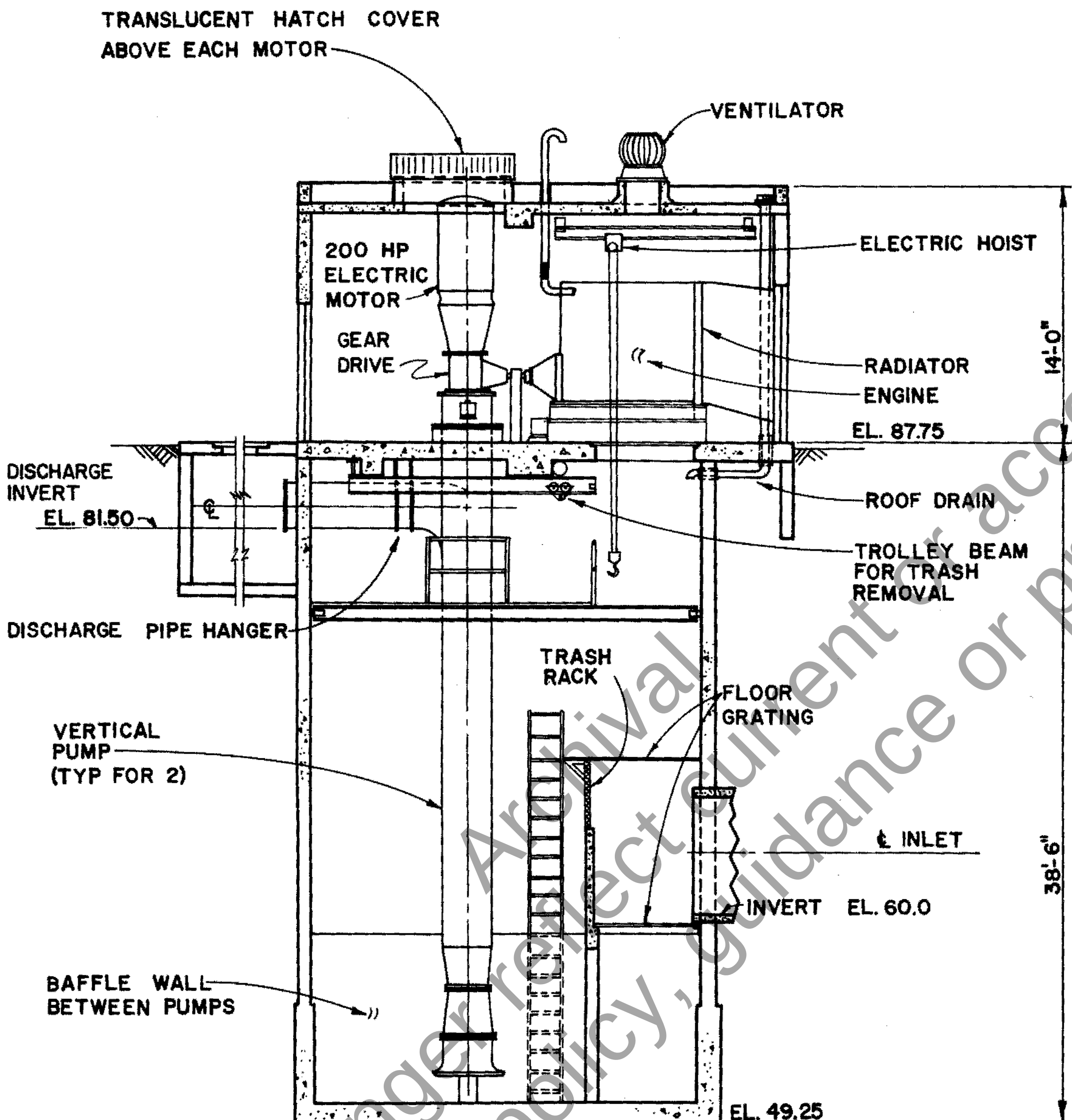


FIGURE 2-16. WET-PIT TYPE PUMP STATION
SHOWING MACHINERY LAYOUT

COMBINATION DRIVE

FROM CRITERIA DEVELOPED BY THE STATE OF TEXAS.

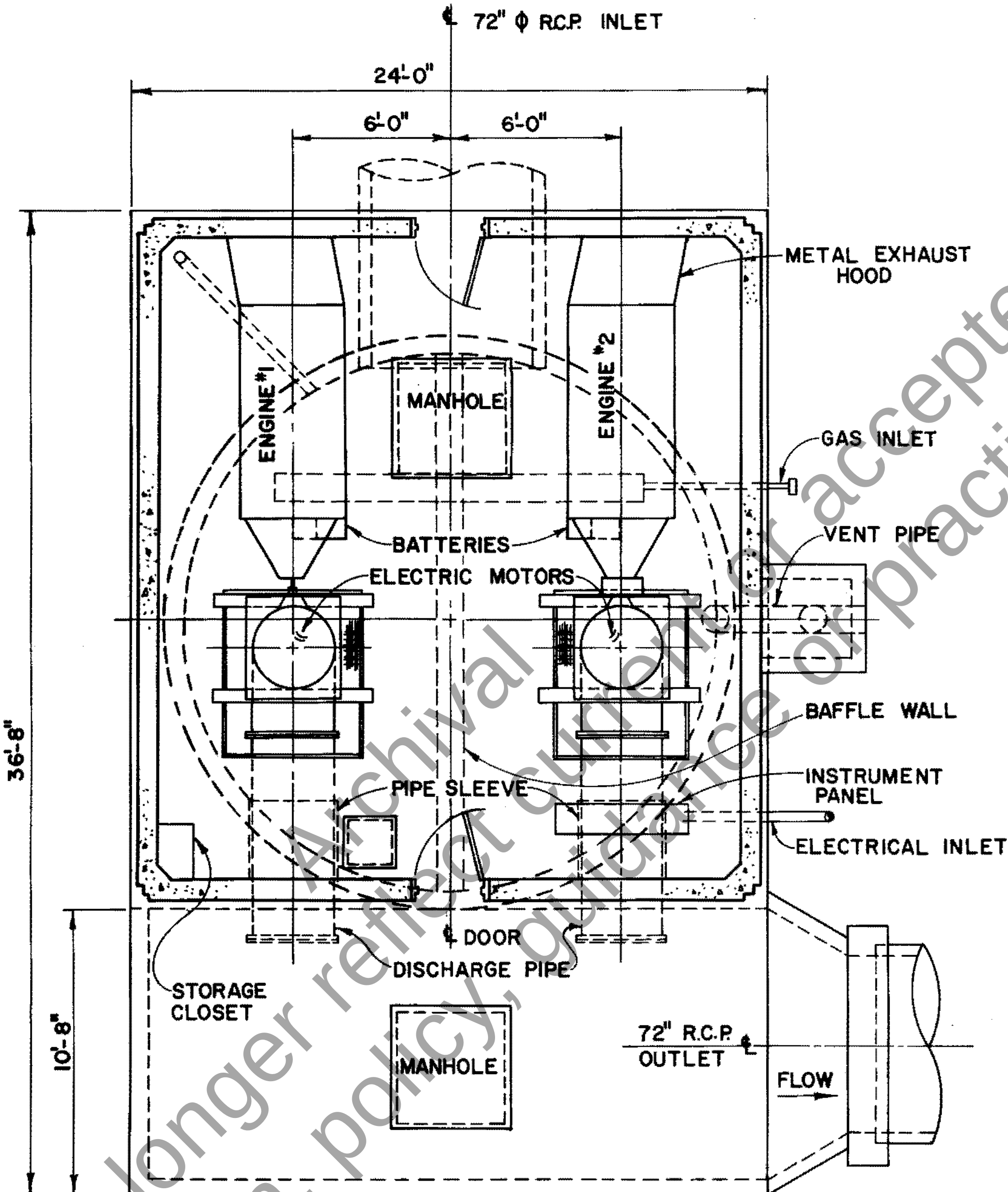


FIGURE 2-17.

FLOOR PLAN OF WET-PIT TYPE PUMP STATION

TWO PUMPS WITH COMBINATION GAS-ENGINE AND ELECTRIC MOTOR DRIVE SET IN CIRCULAR PIT

FROM CRITERIA DEVELOPED BY THE STATE OF TEXAS motors, gears and pumps, while low-headroom hoisting equipment is provided for trash removal and engine maintenance. (Figures 2-15, 2-16, and 2-17)

2-F. WET-PIT EXAMPLE

(Rectangular pit with inlet transition, multiple vertical pumps with electric motors or engines, based on criteria developed by the Los Angeles County Flood Control District)

The rectangular wet pit receives inflow from the inlet drain line through a transition structure, designed to reduce velocities and turbulence and provide an even flow of water to the pumps. The wet pit, transition and pump spacing are carefully proportioned in accordance with the Hydraulics Institute recommendations. The pit is of minimum depth to reduce construction cost. Vertical pumps, usually of two or more sizes, are set close to the back wall of the wet pit with the minimum submergence for satisfactory operation. Suction umbrellas on the pump bells reduce the submergence requirement.

Pumps are all driven by electric motors in some stations; however, a combination of natural-gas engines and electric motors is preferred, with major dependence being placed on the engines. LPG stand-by is provided in the latter case. Some stations have one or two of their pumps powered by a combination electric motor and engine drive.

Operating criteria call for stations to be pumped dry between storms utilizing a separate electrically-powered submersible sump-pump. Mud and debris, which settles out of the inflow due to reduction in velocity, is periodically removed by maintenance forces.

Discharge heads of various stations differ considerably; propeller-type pumps are provided for low heads, while mixed-flow pumps are required for higher heads. Outline drawings of a small electrically powered station with low discharge head are shown in Figures 2-18 and 2-19. A special feature of this station is its low profile (less than 5 feet) above the sidewalk for aesthetic reasons, and discharge into adjacent tidewater in a residential district. Comprehensive calculations and detailed drawings for a natural-gas engine powered station of higher capacity and discharge head are given in Chapter 15. - Station Design Calculations and Layouts.

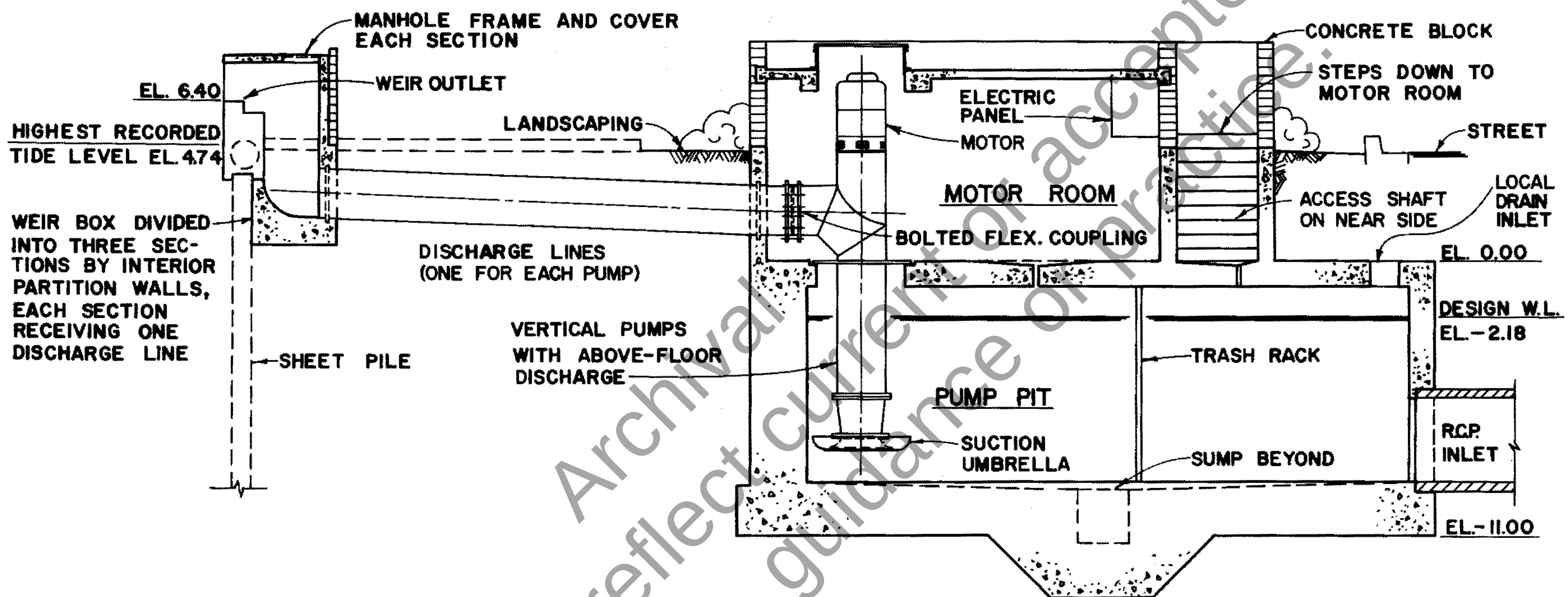


FIGURE 2-18. LONGITUDINAL SECTION

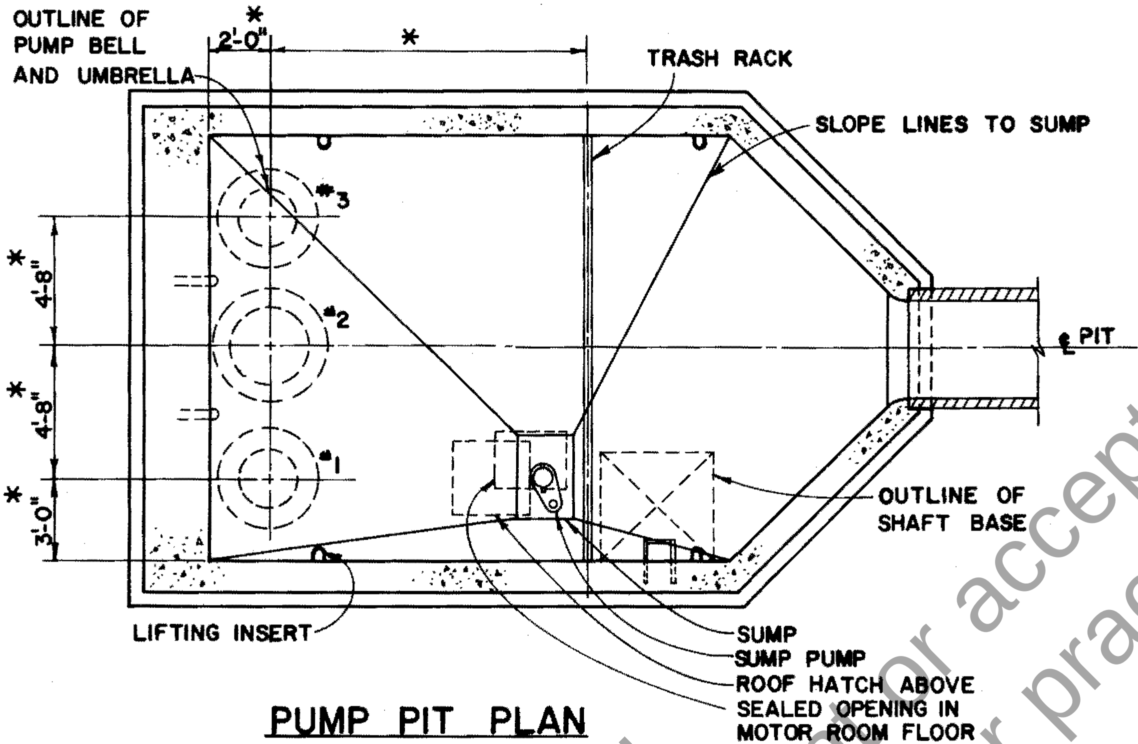
WET-PIT STATION (LOS ANGELES COUNTY FLOOD CONTROL DISTRICT)

DUE TO LAND SUBSIDENCE, STREET PAVEMENT AND RESIDENTIAL LOTS ARE BELOW HIGH-TIDE LEVEL. PUMP STATIONS ARE REQUIRED TO PREVENT FLOODING BECAUSE GRAVITY FLOW OF STORMWATERS INTO TIDEWATER CHANNELS IS NOT POSSIBLE.

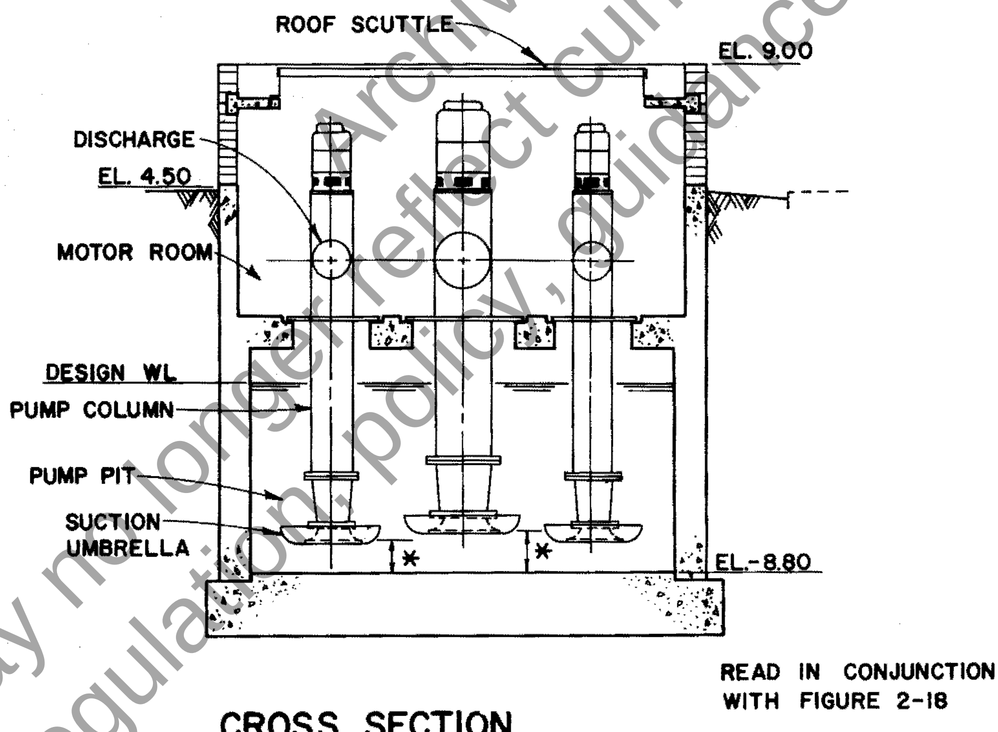
PUMPS #1 AND #3 ARE DESIGNED FOR 5,400 G.P.M. DISCHARGE AT 13.5 FT. T.D.H.
PUMP #2 IS DESIGNED FOR 11,700 G.P.M. DISCHARGE AT 13 FT. T.D.H.

SUCTION UMBRELLAS ARE PROVIDED ON ALL PUMPS TO ELIMINATE VORTEXING AT MINIMUM SUBMERGENCE. UMBRELLAS MAY BE FLAT PLATES IN LIEU OF DISHED TYPE SHOWN.

PUMP SPACING, BOTTOM CLEARENCE AND BACK-WALL DISTANCE COMPLY WITH CRITERIA SET FORTH IN CHAPTER 6 - WET-PIT DESIGN.



PUMP PIT PLAN



READ IN CONJUNCTION
WITH FIGURE 2-18

CROSS SECTION

FIGURE 2-19. WET-PIT PUMP STATION

* DIMENSIONS COMPLY WITH HYDRAULIC INSTITUTE CRITERIA

2-G. WET-PIT EXAMPLES

(Circular pit, two or three vertical pumps with engines, based on criteria developed by the State of Arizona)

A circular pit or caisson is constructed adjacent to the freeway, usually on the far side of an access ramp or frontage road and near a surface street overpass. The motor room floor is at the level of the surface street and thus twenty feet or more above the freeway pavement. Normally, two vertical pumps of the same capacity are suspended into the pit. Each pump has a natural-gas engine driving it through a right-angle gear drive. In larger stations, three engine-driven pumps, all of the same capacity, are used. When the discharge line is of considerable length, the discharge of each individual pump has been combined through a manifold into a single line. Electric-motor driven pumps are not used, but a small submersible electric pump is utilized for low flows and draining the pump pit.

A rectangular concrete block building houses the engines and gear drives to the pumps. It is not considered necessary to include overhead cranes or lifting devices of any sort in the station structures: therefore the size of the building can be reduced. A supply of propane is stored in a nearby enclosure, making the station self-sufficient. Where stations are constructed in open-cut excavations, rectangular pit construction can be substituted for caisson construction. (Figures 2-20 to 2-23, in Chapter 3, Figures 3-7 and 3-8, and in Chapter 6, Figure 6-7.)

2-H. WET-PIT EXAMPLE

(Rectangular structure, two or more screw-type pumps, with electric motors, based on contract documents submitted by the State of Connecticut)

Two or more screw-type pumps are mounted in a simple sloping concrete structure which receives inflow from tributary drain lines through a trash rack. The pumps are powered by electric motors with a diesel engine emergency generator for backup.

The screw-type pump is suitable for stormwater applications, although its use has not been extensive. The operation of the screw is not influenced by the height of water in the sump, and it cannot be clogged by debris. The screw operates at relatively good efficiency, but the head is limited by the permissible length of screw between bearings. Screws are manufactured in a range of diameters from 12" to 108" and can be installed in parallel to meet flow conditions. (Figures 2-24 and 2-25.)

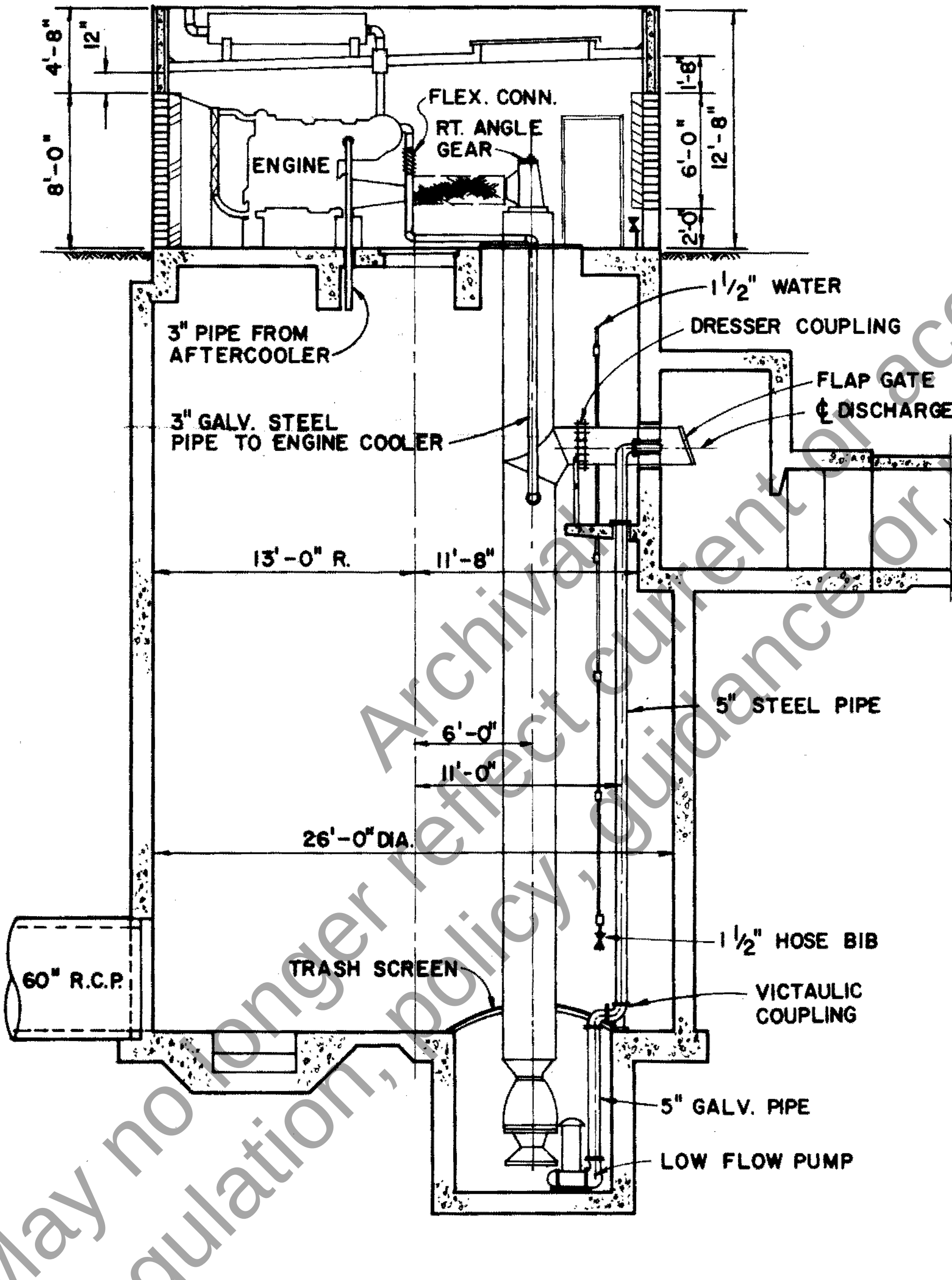
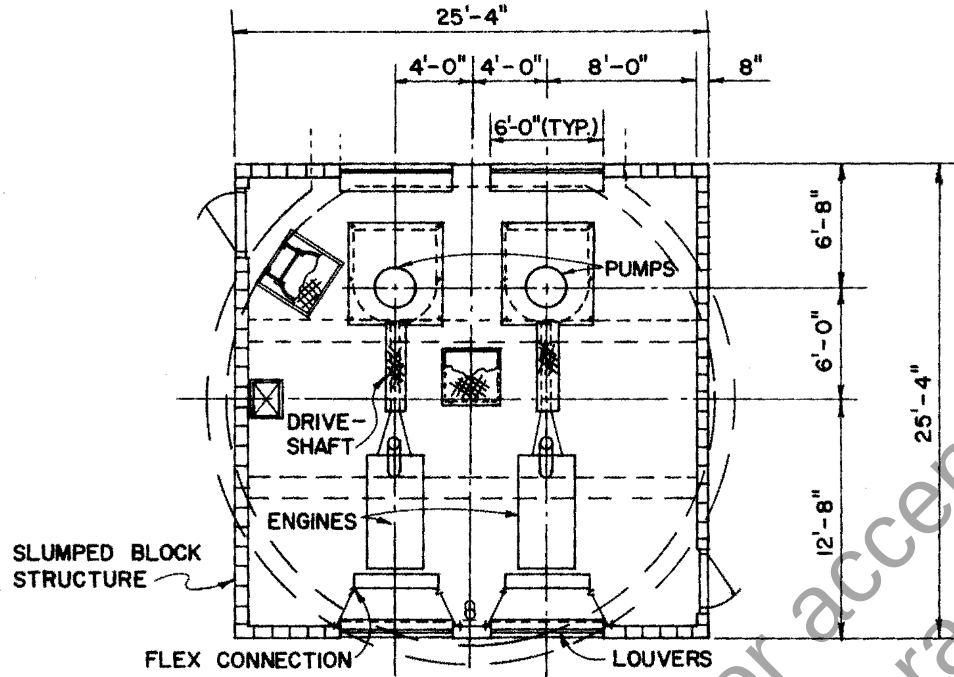


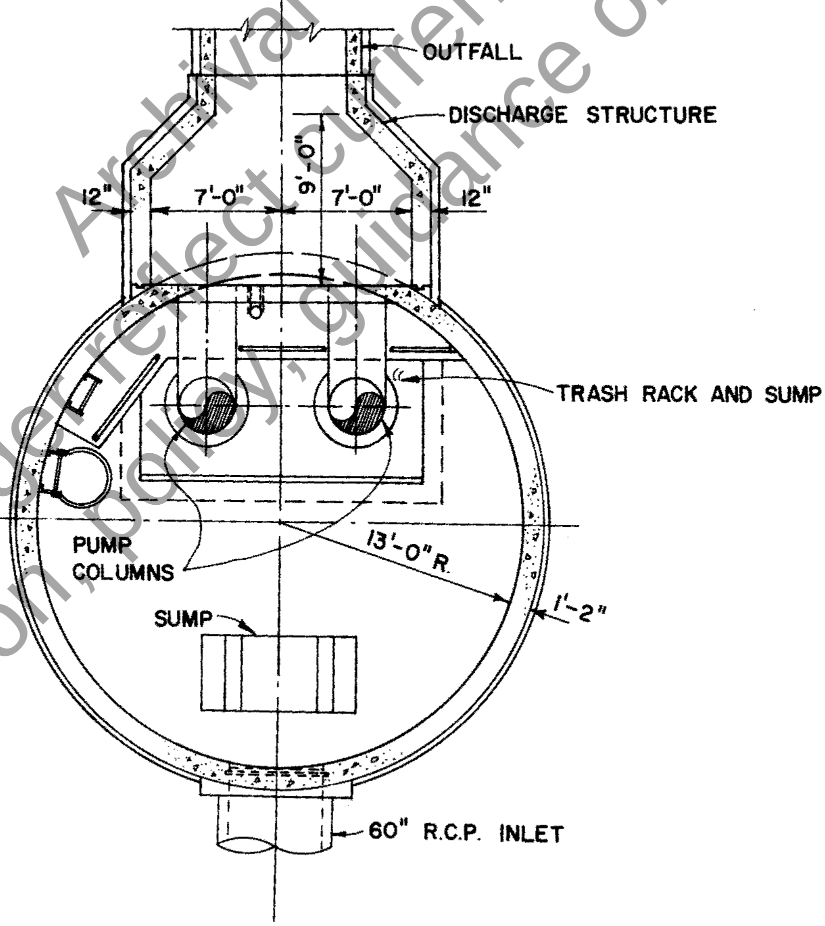
FIGURE 2-20. WET PIT PUMP STATION AT ALMA SCHOOL ROAD, TEMPE, AZ.

(FROM CRITERIA DEVELOPED BY THE STATE OF ARIZONA)



PUMP ROOM FLOOR PLAN

NOTE THAT SQUARE BUILDING IS VISIBLE ABOVE CIRCULAR PIT



PUMP PIT PLAN

FIGURE 2-21. PUMP STATION, TEMPE, AZ.

SEE FIGURES 2-20, 2-22 AND 2-23.

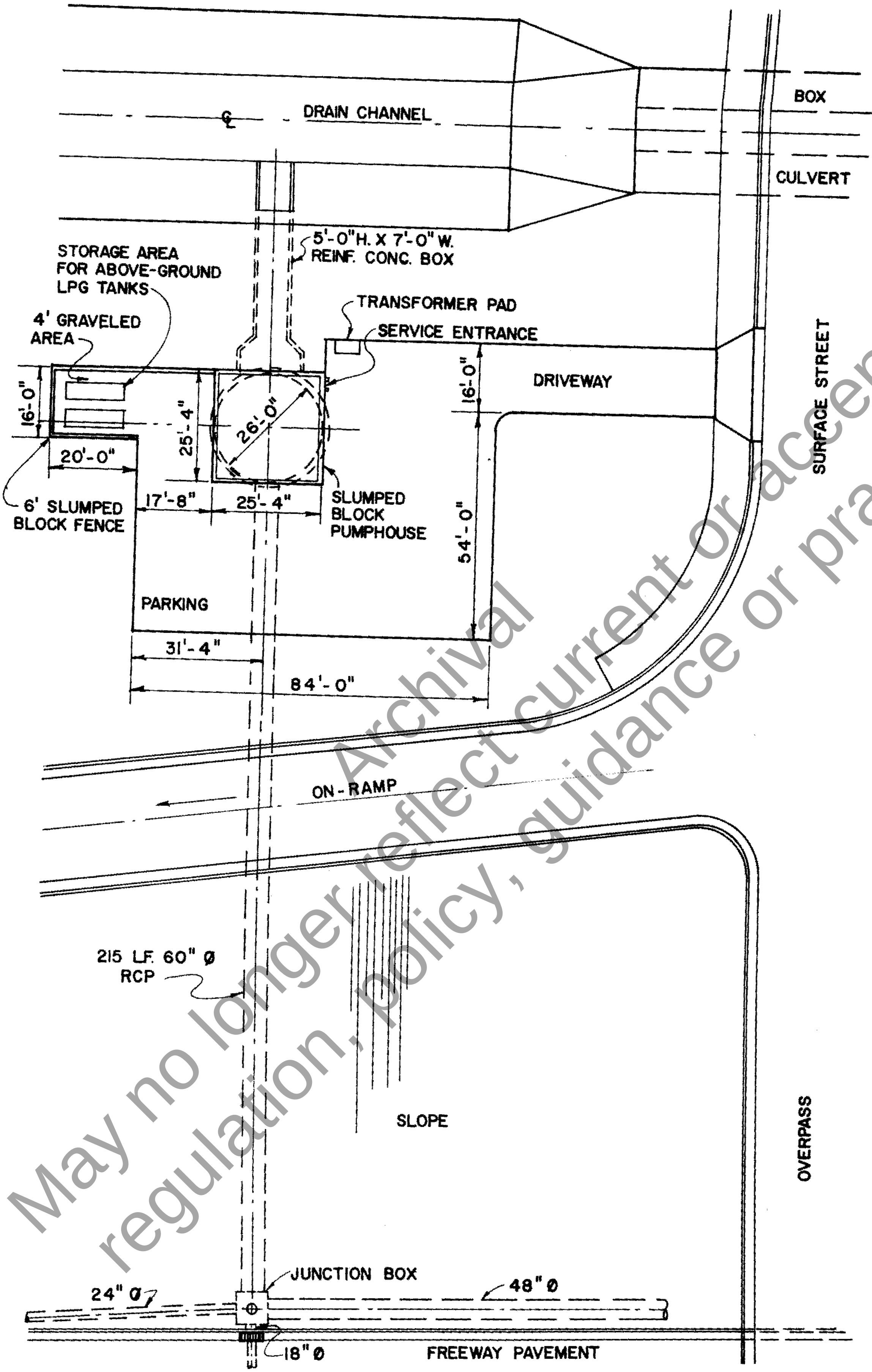


FIGURE 2-22. PUMP STATION LOCATION PLAN

SEE FIGURES 2-20, 2-21 AND 2-23.

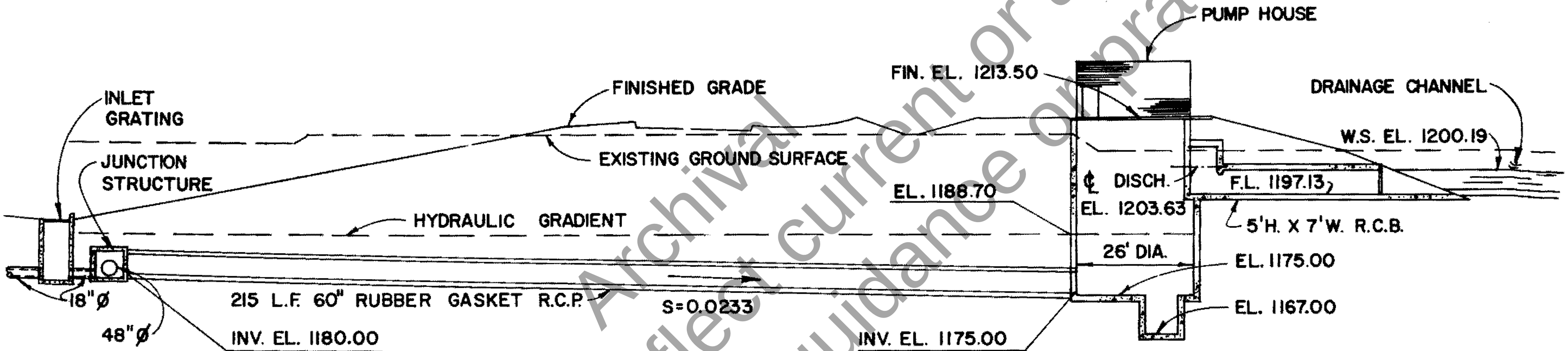


FIGURE 2-23. PROFILE, ALMA SCHOOL ROAD PUMP STATION, TEMPE, AZ.

SEE FIGURES 2-20 THROUGH 2-22

FROM CRITERIA DEVELOPED BY THE STATE OF ARIZONA

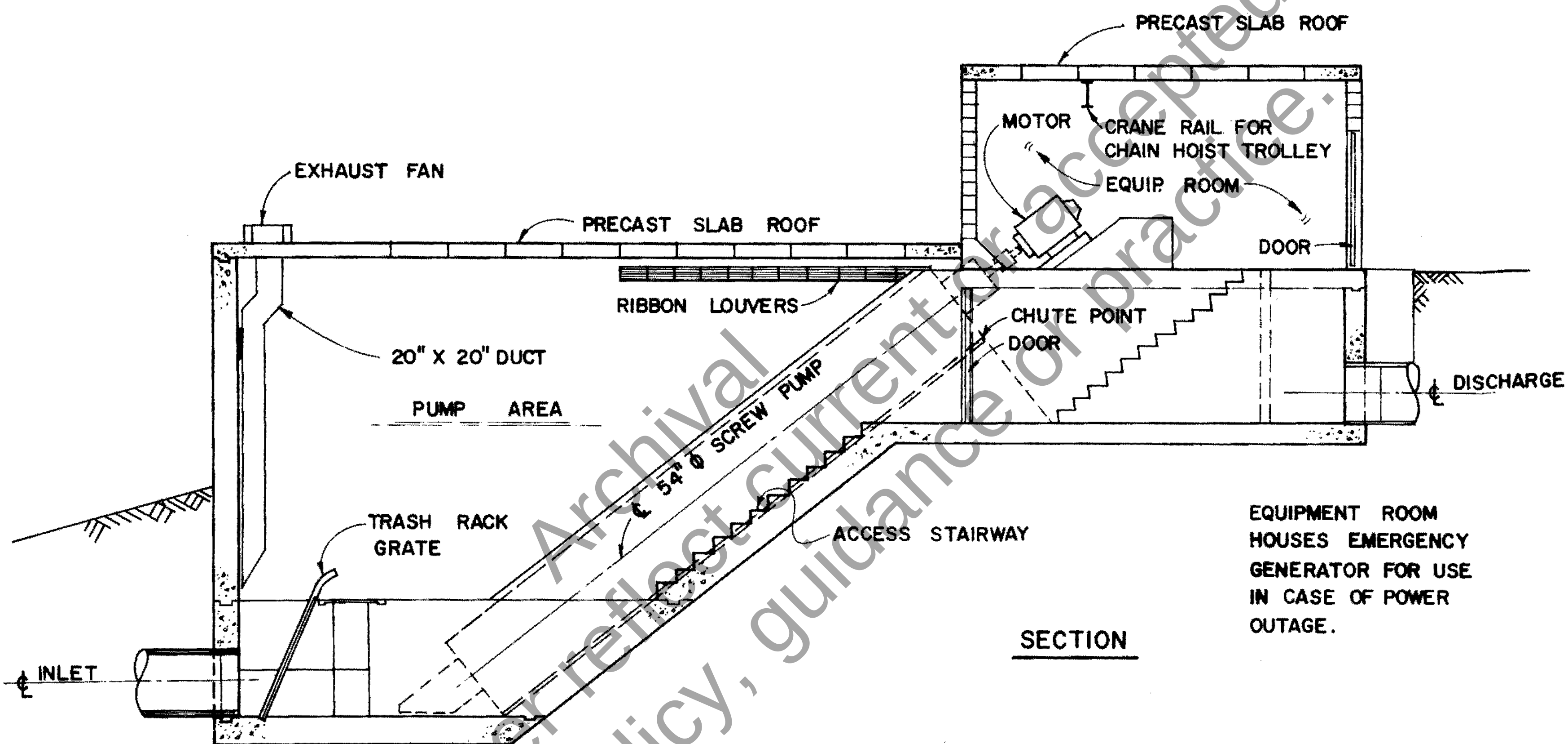
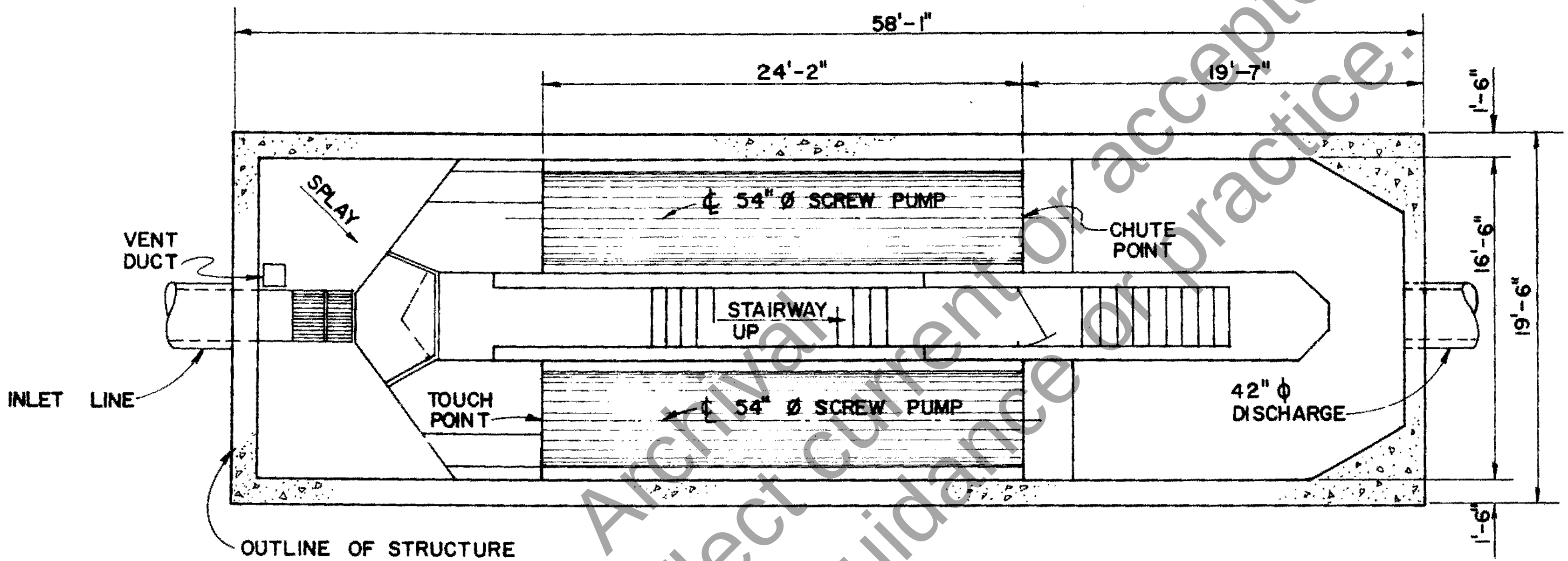


FIGURE 2-24. SCREW-PUMP TYPE OF WET-PIT PUMP STATION

BASED ON DATA SUBMITTED BY THE STATE OF CONNECTICUT



PLAN

FIGURE 2-25. SCREW-PUMP TYPE OF WET-PIT PUMP STATION

FOR LOW LIFT APPLICATIONS, ILLUSTRATION SHOWS 2-5000 GPM PUMPS AT 16.4 FT. STATIC HEAD.

2-J. WET-PIT EXAMPLES

(Circular caisson or rectangular pit with two or more submersible pumps, based on data submitted by the States of Kentucky, Florida and Michigan, and by pump manufacturers)

Submersible pumps suitable for stormwater pumping usually consist of an electric motor with vertical shaft which is mounted above and directly coupled to a centrifugal pump. The pump construction is the non-clog type which will readily pass small solids and debris. The combined pump and motor are set at or near the bottom of the wet-pit, and operate completely submerged until the motor becomes exposed to atmosphere as the pit is emptied. In a typical application, two to five submersible pumps are set in a circular concrete caisson or rectangular concrete wet-well. A minimum superstructure is provided to house electrical switchgear and controls. Pumps can be raised out of the water for inspection or maintenance.

New, larger submersible pumps with capacities of 15,000 gpm (33.5 cfs) or more have recently become available. These can readily operate at the heads usually encountered in stormwater pumping. Therefore this type of station is an interesting and potentially low-cost alternate. An emergency generator or dual service can be utilized, also a spare pump may be held available for replacement where justifiable.

Figures 2-26 and 2-27 illustrate a small station with two small pumps for low flows and two larger pumps set at higher elevation to handle flows of maximum design quantity. Figure 2-28 shows a deep caisson-type wet-pit in the State of Michigan, with five pumps of equal capacity. In this case, the pumps are set at different elevations, the two at the lower elevation to handle low flows without the upper level pumps becoming submerged. Since all pumps are identical, they can be interchanged to equalize usage.

Figure 2-29 shows the use of horizontal propeller-type submersible pumps. The details shown are adapted from manufacturers' literature and do not illustrate actual construction. Each unit may be flange bolted to the discharge line or may be provided with lifting chain and guide rails with boltless connecting flange. The discharge line can be sloped up as necessary to meet the required outlet elevation. The propeller blades are adjustable to meet discharge head requirements, and the pump is provided with an intake hood covering the upper half of the periphery, to reduce turbulence and provide low water pump-down. The horizontal submersible pump has not been widely used, but there is an installation at San Jacinto Battleground State Park, Texas.

* * * * * * * * * * * * *

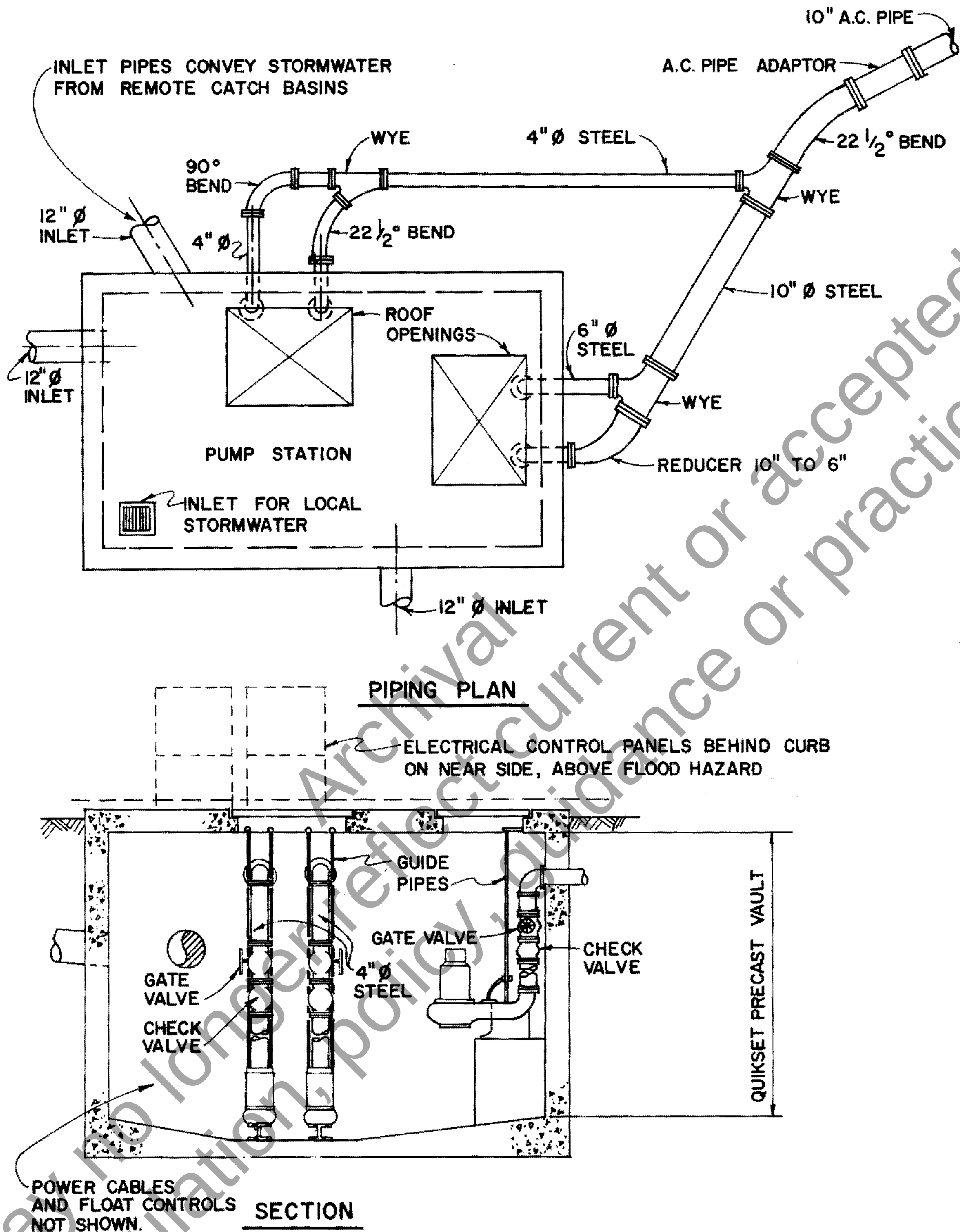
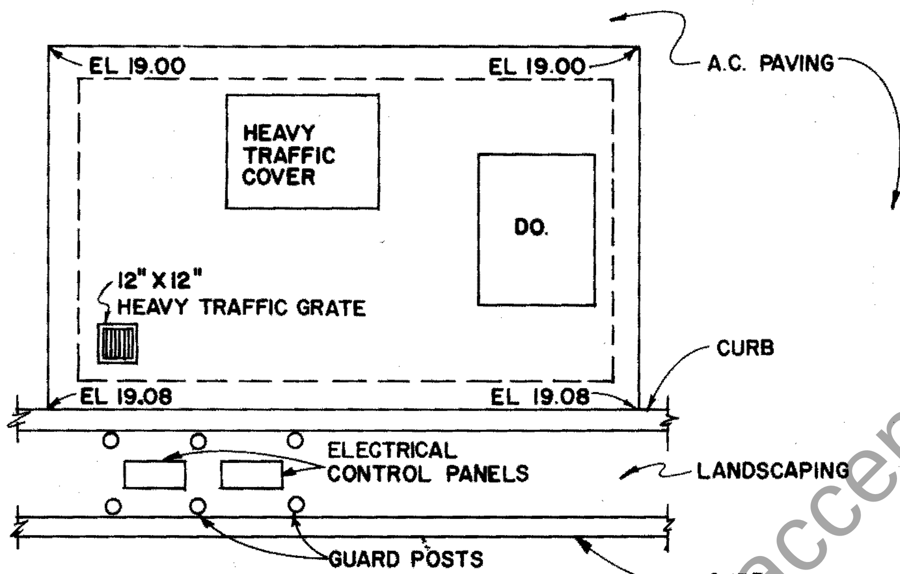
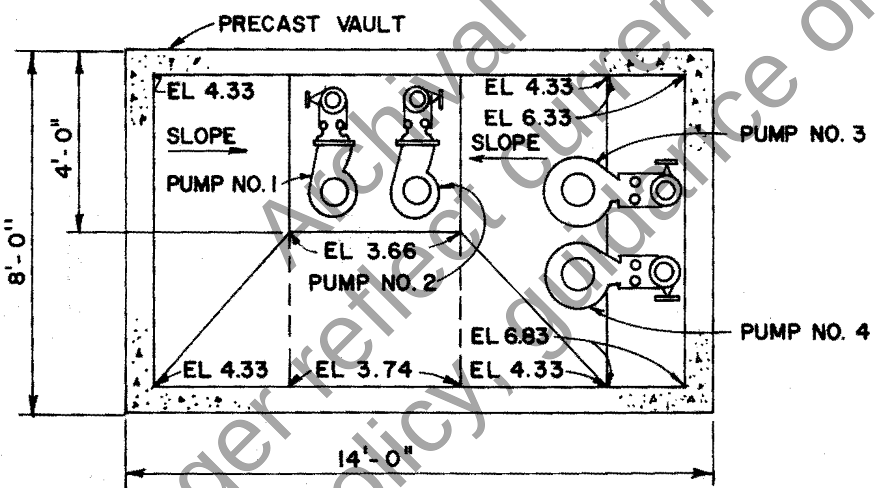


FIGURE 2-26. WET-PIT TYPE PUMP STATION WITH SMALL SUBMERSIBLE PUMPS

DATA FURNISHED BY FLYGT PUMPS



PUMP STATION VAULT TOP DETAIL



PUMP PIT PLAN

FIGURE 2-27
WET-PIT TYPE PUMP STATION
WITH SUBMERSIBLE PUMPS

PUMPS NO. 1 & NO. 2 100 GPM DISCHARGE AT 20 FT. TDH.

PUMPS NO. 3 & NO. 4 200 GPM DISCHARGE AT 32 FT. TDH.

SEE FIGURE 2-26

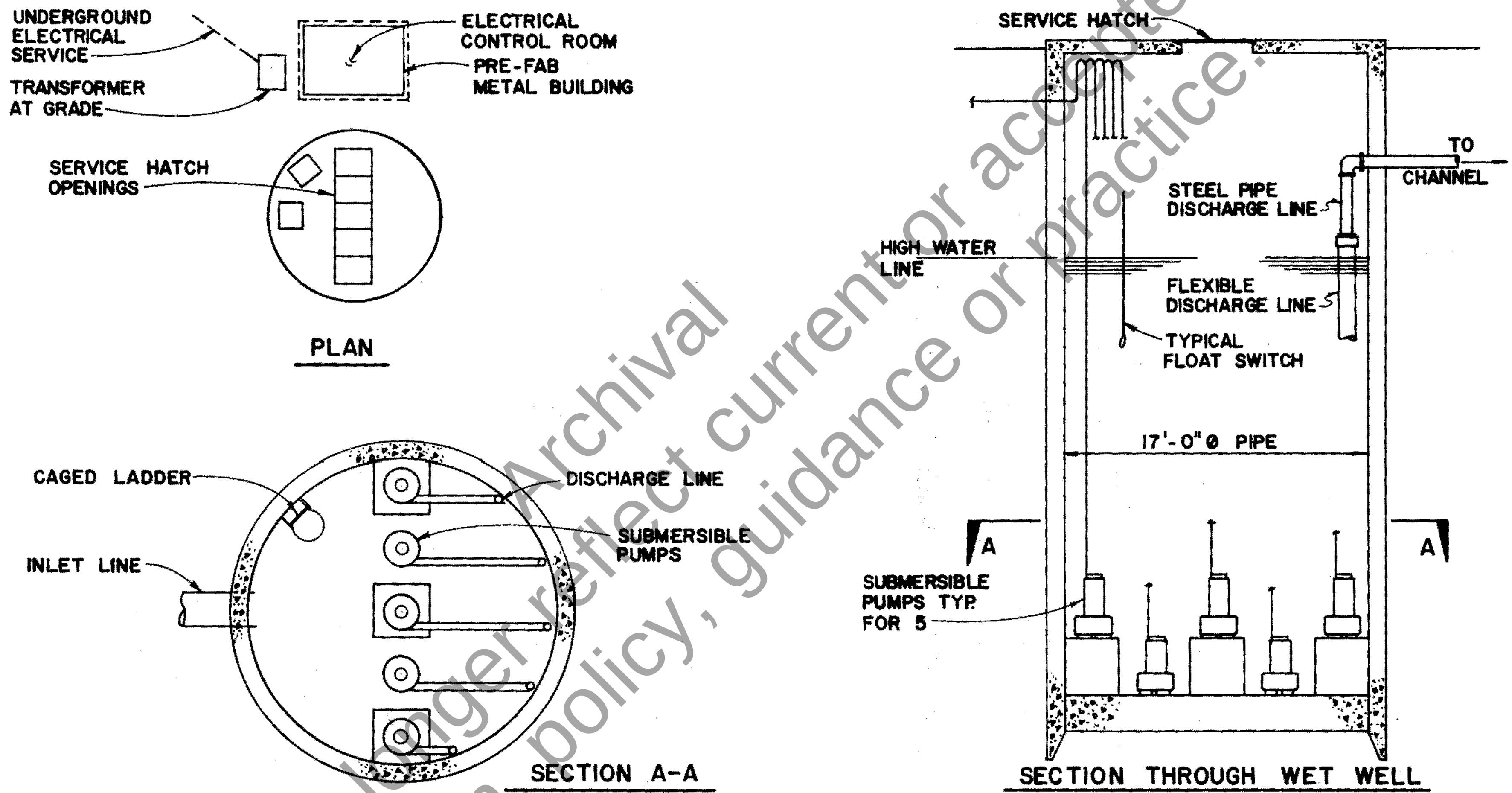


FIGURE 2-28. WET-PIT TYPE WITH FIVE SUBMERSIBLE PUMPS — DETROIT, MI.

WITH FLEXIBLE DISCHARGE HOSE AND ELECTRICAL CABLE AS SHOWN ANY PUMP CAN BE REMOVED FROM THE PIT FOR INSPECTION OR REPAIR.

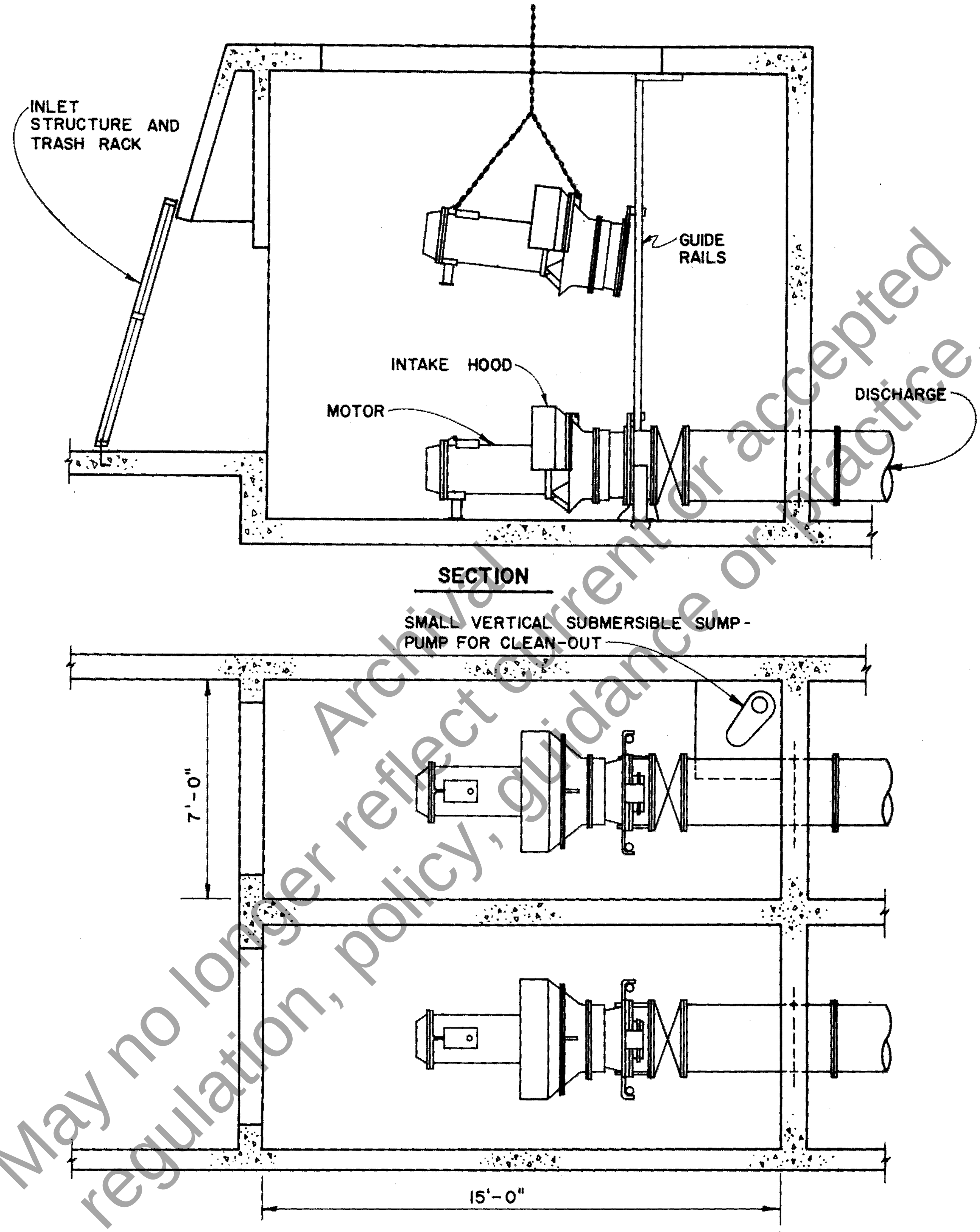


FIGURE 2-29. DUPLEX HORIZONTAL SUBMERSIBLE PUMPS

FROM MANUFACTURERS' DATA.

CHAPTER 3. SITE CONSIDERATIONS

3-A. GENERAL

Stormwater drains to the low point of the highway but it is generally not desirable that the pumping station itself be at the same depressed location. If so, it would usually be very vulnerable to be flooded in the case of malfunction. The station should be at a higher elevation, with inlet from the collecting point. This can result in the station being even outside a frontage road as in the Arizona examples, Figures 2-20 through 2-23. The California and Michigan examples, Figures 2-7 and 2-8, show the station between the freeway pavement and the frontage road. Figure 2-15 shows a pumping station in Texas set at natural grade at the top of a cut slope. The relationship with the highway cannot be seen in the photograph, but the station serves to drain a short length of highway where it is depressed to pass under a local road. An interchange occurs at this point and access to the station is readily provided from one of the ramps with ample space for mobile equipment. There is no possibility for the station itself to be flooded.

Many times a station can be located between the highway and a parallel service or frontage road, near an overpass. Figure 2-8 shows a well-planned siting of this type. The vehicles of the inspecting party are parked in the maintenance area provided, clear of frontage road traffic. Electrical service to the station is underground with the meter section clearly exposed and visible. Adequate safety considerations have been observed.

At locations where the highway or urban street was depressed to pass under railroad tracks, it was earlier practice to construct a pumping station at the low point, sometimes in the bridge abutment. This should be avoided due to design problems, high construction costs, flood vulnerability and possibly inadequate personnel safety. Only if there is no other possible alternative should a pump station be so located.

Figures 3-1 and 3-2 show a California retrofit to overcome earlier siting deficiencies, where a wet-pit station with unsafe access, inadequate storage and unsatisfactory pumps was reconstructed with a new dry-pit alongside. The former wet-pit became a wet-well now serving as storage-box. Access is now provided at railroad level with ample area for equipment. The side slopes of the depressed highway section were lined with gunite to eliminate erosion problems. Figure 3-3 shows a wet-pit station in California with minimal but adequate access.

FIGURE 3-1. DRY-PIT PUMP STATION AT RAILROAD UNDERPASS
(To criteria established by State of California)

FIGURE 3-2. SAME STATION AS FIGURE 3-1
Relationship of wet-well to dry-pit, access to station and electrical service underground to meter box can all be observed.

In the case of small stations with submersible pumps, the wet-well can reasonably be at the low point, provided the electrical control panel is located on higher ground. See Figures 2-26 and 2-27. Inlet gratings can be as observed in Figure 3-1.

In summary, it is essential that siting of any station be planned so that adequate access is possible at all times for safe operating, maintenance and emergency functions. Proper provision for dependable energy supply is essential, including site storage of LPG where needed. Visual aesthetics, sound attenuation and the provision of water and sewer service must all receive proper consideration, although none of the latter may be of sufficient significance to merit added expenditures for siting the station in other than its best location hydraulically. Foundation investigations are essential at any specific site which is under consideration, but may be anticipated to rarely result in rejection of a site as unsuitable. Surface effects on the pump station influent such as soil erosion, or hazardous or contaminated run-off must not be overlooked. Also, and increasingly, the control of stormwater pumping station effluent both as regards rate of discharge and water quality will need to be addressed.

3-B. ACCESS AND EMERGENCY EQUIPMENT PROVISIONS

Good access with off-street parking has been provided in most preceding examples (Figures 2-8, 2-15 and 2-20 through 2-23). However, in many cases there is neither service road nor overcrossing immediately adjacent to the station. This occurs where the station is of necessity at or near a low point, while planning did not or could not include service road access. Prior design in Arizona placed stations in the depressed highway section, but with adequate pull-off or parking areas. Traffic growth required extra lanes or merging capability which was made at the expense of original station access and safety features. In one instance, a subsequent retrofitting was done in a double-deck configuration after malfunction and flooding. See Figure 3-4.

It is essential that a suitable pull-off and parking area for several vehicles be provided, with adequate width to ensure safety of maintenance personnel. It is also highly desirable that it be possible to erect warning markers or barricades without obstructing traffic lanes, and that enough space be allowed for the operation of a crane for equipment removal, or for an emergency generator and its towing vehicle.

3-C. ENERGY SUPPLY

Most stormwater pumping stations have electrical supply from a public utility company, with this being the primary source of power. Underground service is preferred for safety and

FIGURE 3-3. WET PIT STATION IN CALIFORNIA
Minimal access from surface street over
gravelled driveway through ground cover

FIGURE 3-4. POORLY SITED STATION IN ARIZONA
Original construction was adjacent to freeway pavement at low point. Subsequent retro-fit provided access from frontage road

aesthetics, but in most cases the utility company can at best only provide service from high voltage lines on adjacent poles, thence underground to the station. Sometimes the service is overhead to the station, with hazard to crane service for handling equipment. Overhead service should be avoided if possible.

When engines are used, natural gas is normally piped underground to the station by a public utility, but such service is usually available only in urban areas. On-site LPG storage is readily re-supplied by normal distribution channels, but proper access for supply vehicles must be maintained with all locations of storage above the flood hazard.

Many states now have energy-conservation standards which apply to building construction. The total influence of these on any proposed pump station construction should not be overlooked. The dry-pit or caisson largely below grade are energy-conserving solutions.

3-D. AESTHETICS AND SECURITY

Prevailing opinion requires that publicly-constructed facilities be pleasing to the eye and that no noise or gaseous emissions are observed or perceived at any time from them. Sound abatement is of increasing concern. If a station is near a residential area, the use of residential-type mufflers for engines and the enclosure of all motors or engines and driving equipment in a masonry or concrete structure is desirable.

Concealment of equipment such as LPG tanks is also of importance. Compare Figures 2-20 through 2-23 and Figures 3-4 through 3-8. These show a significant improvement in siting factors which has been evolved in Arizona.

3-E. WATER SUPPLY AND SEWER SERVICE

Water supply to any pump station is a great convenience, almost a necessity. Potable water is usually available and should be provided through an appropriate backflow prevention device. A very important reason for providing water supply is care and proper operation of pumping equipment. Pumps, designed to handle and pass a fluid, must not be subjected to an excess of solids such as mud, grit and debris which may have accumulated upstream in a wet-well, storage box or the like. There must always be a sufficiently fluid flow, and an injection of fresh water at adequate pressure is often needed to ensure this, by flushing mud and grit into an acceptable fluid condition before the pumps start. Suitable time delays and solenoid valves in the starting circuitry allow this to be done.

FIGURE 3-5. OLDER STATION WITH POOR SITING
Access is poor and exposed LPG tank is undesirable

FIGURE 3-6. NEW STATION HAS GOOD ACCESS
Appearance of station and equipment are not attractive

Another benefit is that a piped water supply enables the entire wet well or storage box to be washed down periodically as a maintenance function and all mud, grit and silt removed. Many stations are so close to the highway and so vulnerable to airborne dirt and dust that they become and remain extremely dirty unless periodically cleaned up. Water supply provides the ability to wash down and maintain the station and its surroundings clean. It also allows for irrigation of landscaping.

Toilet provisions for personnel are not usually provided. However, such facilities are easily installed where necessary with sewage disposal to holding tank, septic tank or sewer system, according to which is available and meets local requirements.

3-F. FOUNDATION INVESTIGATIONS

Soil borings should be made during the siting phase so that an accurate picture of the sub-surface soil conditions can be obtained. Adequate soil borings will provide the designer with the allowable bearing capacity of the soil and identify any potential problems. Seismic resistance considerations must not be overlooked in those areas where applicable. Some soils are more favorable than others for caisson construction; other sites may require foundation piling for bearing, or to resist uplift due to hydrostatic pressure.

3-G. LANDSCAPING AND ACCESS TO STORMWATER INLETS

Landscaping should be limited to ground cover, as seen in Figures 4-2 and 4-3, and small shrubs or bushes. Vegetation must not be allowed to overgrow doors, stairways, ventilators and the like. Trees, which interfere with crane service, should be avoided. Where the station is located in or at the top of a cut slope, as in Figure 3-3, it is desirable that a concrete stairway lead from the station to the nearest inlet grating in the shoulder of the highway. The stairway may be omitted where the ground cover is limited to grass which is cut short, or to isolated clumps of vegetation in arid areas. Access down steep gunited sloping surfaces should be avoided unless a stairway is provided. Maintenance personnel should be required to keep all gratings free of debris which would prevent flow of stormwater into storage box or pump station. Lack of easy access should not be permitted to discourage this work.

* * * * * * * * * * * *

FIGURE 3-7. ARIZONA STATION TO CURRENT STANDARDS
Note good access and enclosure of LPG storage

FIGURE 3-8. SIMILAR TYPE OF STATION AS ABOVE
Note excellent appearance and access, and relationship to depressed freeway

CHAPTER 4. COLLECTION SYSTEMS

4-A. GENERAL

Highway stormwater runoff is conveyed to the pumping station by a collection system consisting of ditches, gutters, inlets, channels and conduits. These elements have been discussed in Hydraulic Engineering Circular No. 12, Drainage of Highway Pavements; ASCE Manual No. 37, Design and Construction of Sanitary and Storm Sewers; and the FHWA Implementation Division Manual, FHWA-TS-79-225, Design of Urban Highway Drainage - The State of the Art.

It is beyond the scope of this Manual to discuss the collection system design, except to evaluate the storage in the system and its effect on the design of the station, and to draw attention to details of construction such as storage-boxes and their inlet gratings. Current practice includes an increasing trend to use storage to limit the rate of stormwater discharge, gravity or pumped, to levels compatible with watershed management plans.

The inflow hydrograph is the basis for the hydraulic design of a pump station. By the criteria set forth for this Manual, the inflow hydrograph is assumed to be known. It will be provided to the pump station designer by others. Where rates of discharge are to be limited, an outflow hydrograph is also required and must be provided. Under all conditions, the relative quantity of storage provided and the rate of pumping necessary are closely related and are an important interface between the hydraulic engineer and the pump station designer.

4-B. HYDROGRAPHS

Figure 4-1 shows the inflow hydrograph for a given set of conditions, and the relationship between storage and pumping capacity. It was developed by the Los Angeles County Flood Control District for a large retention basin, or forebay, using the District's 50-year design storm. This is a four-day storm with the maximum rainfall quantities occurring on the fourth day. This design storm hydrograph is for Walteria Lake, which was specially excavated to receive inflow from a considerable area. It has a design storm peak inflow of 3,000 cfs and a storage capacity of 1,057 acre-ft. (344 million gallons). A pump station with four main pumps, each of 55 cfs capacity, is used to drain the basin. After a 50-year design storm, nearly sixty hours of continuous pumping would be required to empty the basin. This example is introductory rather than being typical of highway conditions. Later examples in this Chapter are more representative.

Figure 4-1 also gives a representation of optimizing pumping cost and storage cost. It is usually desirable to thoroughly study the costs of storage, pumping equipment, pump station construction, operation and maintenance in order to balance the most economical design with allowable discharge requirements.

Other inflow hydrographs for different conditions will be found to have different shapes, peaking sooner and with less pronounced maximum inflow than the Walteria Lake example. Pumping rate or outflow is plotted on the inflow hydrograph and the excess of the curve above the pumping rate represents the necessary storage. The excess area is usually cross-hatched so as to be properly identified.

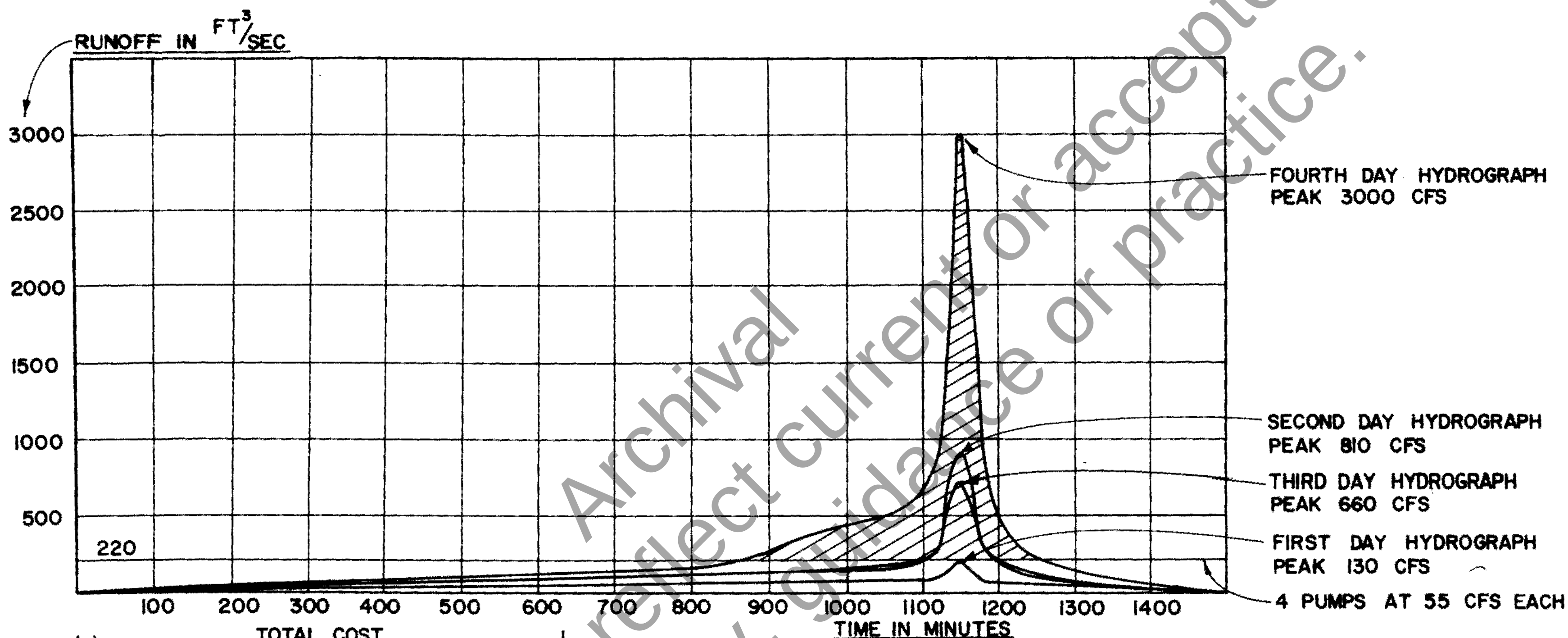
To analyze the effects of storage on reducing the peak pumping rates, an inflow hydrograph must be developed for the contributing watershed. The routing procedures require that a cumulative runoff vs. time relationship be developed. Hydrology methods that only provide the peak flow rate are not adequate.

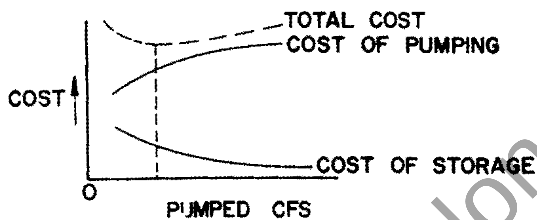
Inflow hydrographs can be developed using the unit hydrograph, Soil Conservation Service, or volume of runoff methods. It is beyond the scope of this Manual to discuss these methods. For the purpose of this Manual, the inflow hydrograph will be assumed.

4-C. DEBRIS AND HAZARDOUS SPILLS

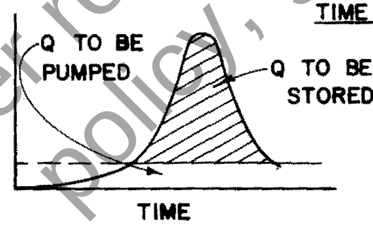
Stormwater flushes slopes and pavements before entering the collection system. Therefore all types of debris will reach the pumping station, carried by mud-laden water. It is important that the pumps be protected by screens to prevent passage of the larger pieces of debris while permitting passage of the smaller ones. Screens may be in the form of gratings at the surface of pavement or gutters, or may be trash racks inside the station. Reduction of velocity in a storage box or large pump pit will result in the benefit of suspended solids which pass the screens being deposited upstream of the pumps.

The possibility of hazardous spills is always present under highway conditions. In particular, this has reference to gasoline, and the vulnerability of pump stations and pumping equipment to fire damage. There is a history of such incidents having occurred and also of spills of oil, corrosive chemicals, pesticides and the like having been flushed into stations, with





COST
STORAGE & PUMPING



TYPICAL HYDROGRAPH
SHOWING Q TO BE PUMPED
AND Q TO BE STORED

STORM DAY	RAINFALL INCHES	RUNOFF INCHES	YIELD PERCENT
FIRST	0.65	0.19	29.2
SECOND	2.60	0.83	31.9
THIRD	2.28	0.71	31.1
FOURTH	6.50	2.47	38.0

50-YR STORM RAINFALL
AND RUNOFF

FIGURE 4-1. WALTERIA LAKE HYDROGRAPH

DATA FURNISHED BY LOS ANGELES COUNTY FLOOD CONTROL DISTRICT.

undesirable results. The usual design practice has been to provide a closed conduit system leading directly from the highway to the pump station without any open forebay to intercept hazardous fluids, or vent off volatile gases. With a closed system, there must be a gas-tight seal between the pump pit and the motor room in the pump station. Preferably, the pump station should be isolated from the main collection system and the effect of hazardous spills by a properly designed storage facility upstream of the station. This may be an open forebay or a closed box below the highway pavement or adjacent to it. The closed box must be ventilated by sufficient grating area at each end.

4-D COLLECTION LINES

Collection lines will be laid out to alignments, elevations and slopes to suit the highway. Stormwater flows into these channels or conduits which usually become progressively of larger capacity as they approach the pump station. The collector lines should preferably terminate at a forebay or storage box. However, they may discharge directly into the station. Under the latter condition, the capacity of the collectors and the storage within them is critical to providing adequate cycling time for the pumps and must be carefully calculated. Cycling is the starting and stopping of pumps, the frequency of which must be limited to prevent damage and possible malfunction. Depending on the relative elevations of the drain lines and the pumping levels, some of the storage may not be usable. Computations for the determination of storage in collection systems are given in Figures 4-5 through 4-9, which are examples taken from actual stations.

As stated in Section 4-A, the collection system design will not be discussed in detail, but a point that needs attention is whether the inlet line to the station is required to flow under pressure, due to the hydraulic gradient established. Figure 4-7 shows the use of rubber-gasketted reinforced concrete pipe due to the pressure head involved. Conditions in the other examples did not require the use of pressure pipe and reinforced concrete pipe with mortar joints was used. Sometimes an unconventional collection system alignment with manholes may be necessary, as shown in Figure 4-8. The Manning formula with n = .013 is generally used for computing flows or sizing lines.

If a wet-pit station with vertical pumps is being designed, changes in the collection system generally have less effect on the caisson-type than on the rectangular-pit type. This is because the generally deeper setting of the pumps in the caisson-type and the lower pump starting level in relation to the inlet of the collection line should result in a greater proportion of the storage in the collection lines being usable. Cycling requirements are then more easily satisfied. Caissons are usually more economically constructed to greater depths than the rectangular-pit type can be.

Where the rectangular-pit type of station (Figures 2-18 and 2-19) is being designed, with minimum pump-pit depth and minimum requirements for pump submergence, there is usually a significant element of unusable storage in the collection lines, and any change in the grade, elevations or sizes of the collection lines must be carefully related back to the pump station design. This is to ensure that usable storage is sufficient to satisfy pump cycling requirements. The required submergence is the depth below the water surface to which the bottom of the pump must be immersed in order to function properly Requirements are given in Chapter 6. - Wet Pit Design.

In a wet-pit station where submersible or screw-type pumps are proposed, consideration of storage in the collection lines may be less critical, due to the less stringent submergence requirements of these alternate types of pumps. Also, submersible pumps can withstand more frequent cycling. There would probably be less unusable storage, but the Manual does not provide any examples of computations of storage which are specifically applicable to submersible or screw-type pumps only. It is believed that these can readily be developed from the text and examples provided.

Where substantial storage in relation to the inflow is to be provided, either in the case of an open forebay (Walteria Lake, Figure 4-1) or a storage box (dry-pit station, Figures 2-2 and 2-3), the effect of changes in the collection system will be much less. Storage boxes can be used equally well with wet-pit stations, although none has been illustrated.

The storage in sloping circular lines can be calculated by recognizing the water forms an ungula, which is part of a cylinder cut off by a plane oblique to the base. The method of computing the ungula volume is shown in Figure 4-5. Alternately, the prismoidal formula can be used. The stored volume is the length of pipe multiplied by the base area and adjusted by factors. A table for determining the area of the cross section of a circular conduit flowing part full is reproduced from Handbook of Hydraulics by King & Brater, and is included as part of Figure 4-5.

4-E. GRATINGS

Under highway conditions, the gratings which are set in or near the gutter flow line also serve to prevent entry of gross trash and debris into the underground collection lines, or into storage boxes. They perform a useful pre-screening function.

Main bars of the gratings must be deep enough to have the strength to carry traffic wheel loads and the clear spacing between bars must be minimized, so that only minor trash will be carried through the gratings. Gross debris and trash retained on the gratings must not be allowed to block passage of stormwater. Periodic removal is a necessary maintenance function. Gratings in the gutter flow line with a collector pipe below are shown in Figure 4-2.

A typical access grating to a storage box is illustrated by Figure 4-3 and a design detail is shown in Figure 4-4. Access gratings are best located in the shoulder above the gutter flow line. Gratings are also essential for the storage box ventilation.

It will be noted that there is actually no bar-screen inside the box. Bar-screens or trash racks are essential in wet-pit pump stations without any other upstream screening.

4-F. STORAGE BOX FEATURES

The storage box is illustrated in Chapter 2. - Review of Current Practice as a component of the dry-pit station, where it also serves as the wet-well. However, the concept is equally applicable to the wet-pit station where it will also serve for fire-protection and as a sand trap. The box derives its name from its similarity to a multiple-barrel box culvert and is usually constructed in this way. Large-diameter concrete pipe would appear to be equally suitable, manifolded as necessary with poured concrete interconnecting laterals.

Single or multiple boxes or pipes are placed parallel to or transversely under the highway at the low point of the collection system and depressed area. The boxes are sized to store as much of the peak flow volume from the design storm as is economically feasible. An advantage of the storage boxes is the provision of a safety factor in respect to power outages. The storage box can be designed to contain the inflow of design storms to a point below allowable high water level, until pump operation can be restored. Also, as described, hazardous highway spills can be contained in the storage box and its sand trap until pumped out. The pump station would not be contaminated or damaged. In the event of a gasoline fire in the storage box, some spalling of the roof concrete might occur, but with the accessibility provided, the damaged area can be readily shored up if necessary and then repaired.

Since the velocity of flow will be reduced in the storage box, sand, silt and debris will tend to settle out; the storage box should be designed to facilitate removal of this material.

Pumps should be designed to pass solids and sediment in the event that these materials are not removed in the wet-well.

Storage boxes are sloped, with a cleanout box or sand trap at the low point. Access is through gratings of ample size set in the shoulder and median as illustrated in Figures 2-2 and 4-3. Through ventilation is provided and the combination of features acts together to facilitate maintenance. When a storage box or structure is constructed adjacent to the pump station, the slope of the box can be neglected and the volume can be computed as a rectangle with depth according to the hydraulic gradient.

The construction cost of a storage box of any size can be readily estimated and this can then be evaluated against the reduced costs of pumping and electrical equipment.

4-G. STORAGE AND PUMP CYCLING

An important initial evaluation in pump station design is how much total storage capacity can or should be provided. Using the hydrograph, various levels of pump capacity can be tried and the corresponding required total storage can be determined. The basic principle is that the volume of water as represented by the shaded area of the hydrograph in Figure 4-1 is beyond the capacity of the pumps and must be stored. If a large part or most of the design storm is allowed to collect in a storage facility, a much smaller pump station can be utilized, with anticipated cost benefit. If the discharge rate is to be limited, ample storage is essential.

To provide ample storage in the simplest form, the channels or conduits draining the highway could discharge into a large open basin or forebay similar to Walteria Lake, which would store a substantial quantity of water upstream of the pump station. The latter would operate as necessary to empty the forebay. Under highway conditions, the ability to provide an area sufficient for a forebay may be infrequent. Also, an open forebay may not be compatible with highway operating requirements. Any forebay design, including earthwork and gunite lining or other erosion control, should be regarded as part of the pump station design. A rectangular pump pit with trash-rack forming its upstream side could be set at the low end of the forebay. Alternately, a screened inlet line could lead to a caisson-type station or a dry-pit station.

The preceding paragraphs apply clearly to both wet-pit and dry-pit stations. Most of the following text applies primarily to the use of vertical pumps in wet-pit stations, but the principles

FIGURE 4-2. GRATINGS IN GUTTER FLOW-LINE

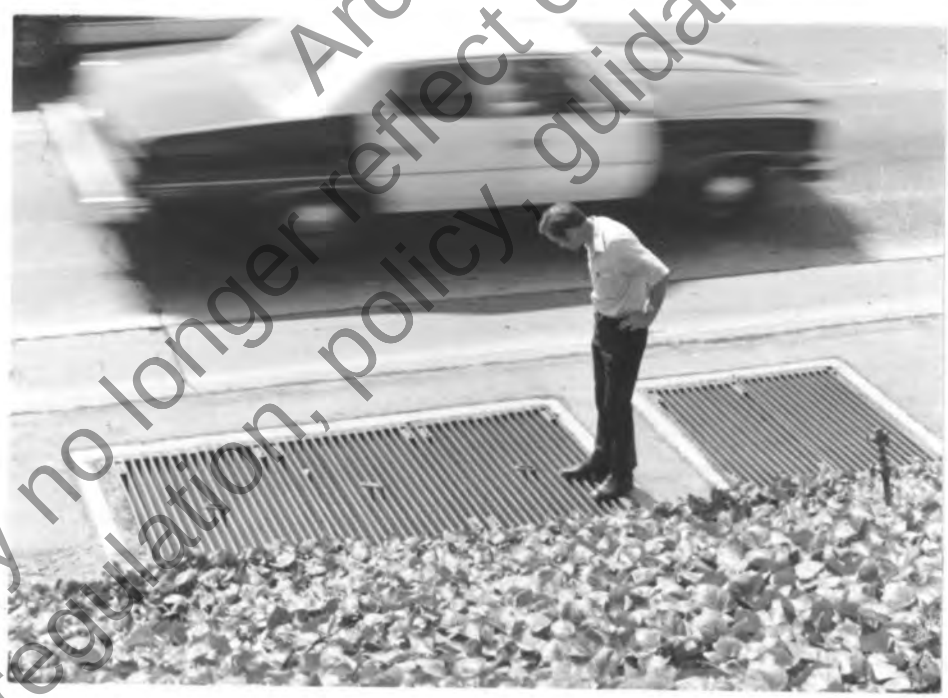


FIGURE 4-3. ACCESS GRATING TO STORAGE BOX
Note location in shoulder and relationship to gutter flow-line

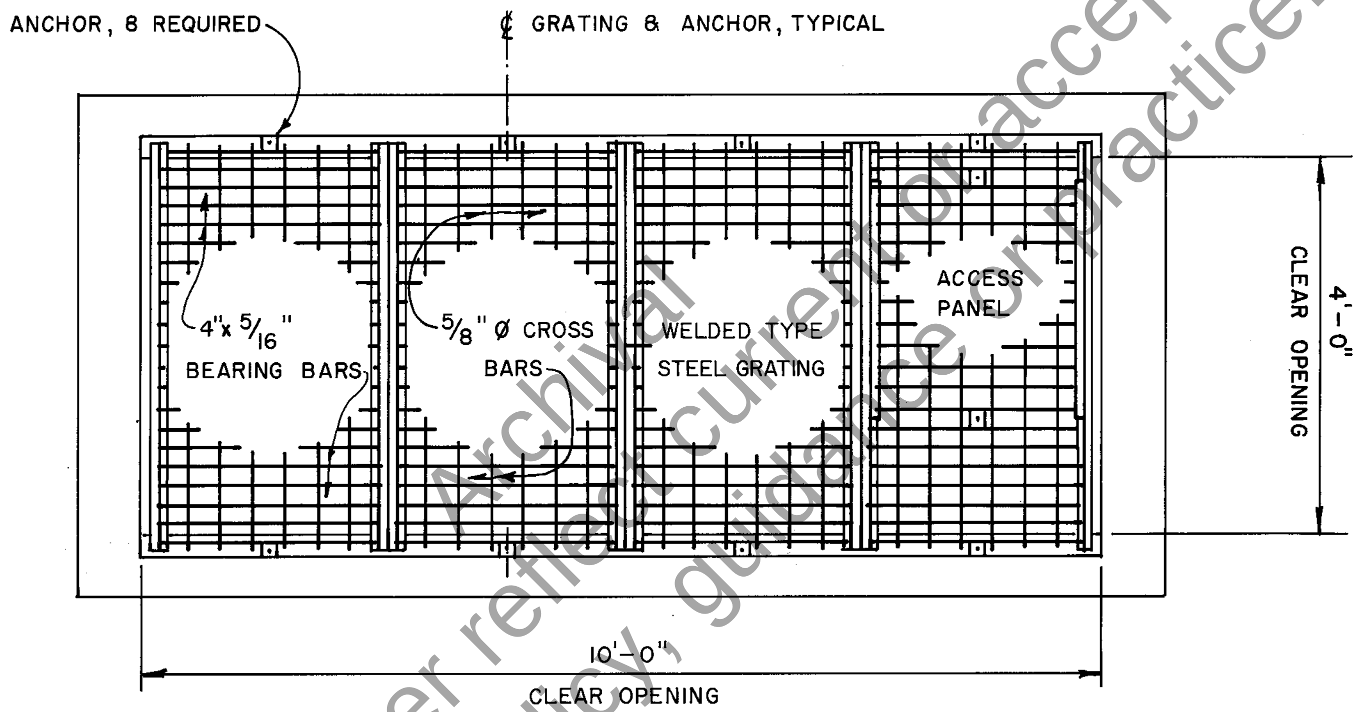


FIGURE 4-4. TYPICAL DETAIL OF GRATING FOR STORAGE-BOX

PROVIDES VENTILATION AND ACCESS FOR CLEAN-OUT
BASED ON DATA FURNISHED BY THE STATE OF CALIFORNIA.

set forth will be found to be generally applicable to other types of pump and also for dry-pit stations. If any inconsistency exists it should be borne in mind that the major reference is to vertical pumps in wet-pit stations.

The inlet lines and the pump pit itself will always provide some storage, but it may be minimal, requiring sufficient pumping capacity to be installed to handle peak flows. This results in equipment which may be over-sized for its normal function and may be required to operate for short periods only. Rapid cycling, which is frequent starting and stopping of pumps, may occur. This is harmful and undesirable due to the possibility of electric motors overheating and becoming damaged. Cycling time is always a necessary design consideration.

It is important at this point to make a distinction between the total storage capacity of the collection system and pump pit and the usable storage capacity applicable to considerations of pump cycling. The total storage in the system will be the water volume below the hydraulic gradient, which is set as described in Section 4-H. Under correct hydraulic conditions, the usable storage capacity will be the water volume in the system corresponding to the pumping range of the first pump to operate, that is the difference in elevation between start and stop of the first pump. Also, when the inflow to the storage is half of the pump capacity the pump will cycle at the fastest rate.

The objective is that usable storage capacity and an inflow equal to half the first pump capacity should result in a satisfactory cycling period. Computation of usable storage capacity in the inlet line depends on hydraulic conditions in the line, which again determine the hydraulically correct pumping range of the first pump. See Section 4-I. for a more detailed explanation. If the pump start and stop are too closely spaced without reference to hydraulic conditions, then usable storage will be minimized, cycling time will be decreased and will probably be too short a period.

Depending on the hydraulic gradient, the design water level and the staging (vertical start-stop intervals) of the other pumps, it may be possible to raise the level of the first pump start and so increase the usable storage. Lowering the first pump stop below its correct hydraulic level is not effective. This only causes the pump to pump down the pump pit where storage volume is minimal and the time added to the cycle will be very little.

To increase usable storage and lengthen the cycling time, the physical volume of the inlet line construction may be increased. However, it is generally much more practical for the pump station designer to reduce the size of the first pump to start, so as to make the pump compatible with available storage. Figures 4-8 and 4-9, and Chapter 15 - Station Design Calculations and

Layouts show an example of the latter procedure. It is not unusual to use one or two smaller pumps to start first, followed by larger pumps to handle the total Q. The percentage of Q that the small pumps should handle can also be related to the shape characteristics of the hydrograph. If the Walteria hydrograph shape is applied to a storage situation, it will be seen that two pumps which could handle thirty per cent of the peak would be suitable. For a four-pump station, 15%, 35%, 35%, 15% would be a good selection of pump capacities. An alternate would be to have one pump of 15% and divide the remaining 85% equally between three large pumps. The all-electric station shown in Figures 2-18 and 2-19 has three pumps of 24%, 52% and 24% peak capacity. What this means is that to suit the Los Angeles County Flood Control District hydrograph, rectangular wet-pit stations where pump pit depth is minimized and storage is minimal require one or more pumps with a capacity of 15% to 25% of peak flow to meet cycling criteria. Under highway drainage conditions where the shape of the hydrograph is flatter, it is more usual to use two or more pumps of the same capacity.

Rapid cycling is primarily due to lack of usable storage and can be damaging to electric motors. However, regardless of pumping considerations both the total and the usable storage may have to be limited for other overriding reasons. Limitation of usable storage is not so significant where engine-driven pumps are concerned, but as with an automobile, frequent starts can drain batteries and cause malfunctions.

4-H. HYDRAULIC GRADIENT AND DESIGN WATER LEVEL

After a quantitative relationship between the total storage and the pumping capacity has been established, it is necessary to tentatively determine several other factors, always with the possibility that any one or more of all the conditions may prove unsuitable and need adjustment as the design is refined. A number of trials may be necessary to get all the factors into proper balance.

The first necessity is to establish the hydraulic gradient from the highway pavement to the pump station. The highest permissible water level at the downstream inlet from the pavement or gutter should be set two or three feet below the finished pavement surface. The lower the elevation the more conservative the design. Depending on the inflow to the station, there will be some head loss in the line from the inlet grating to the pump pit. See Figure 4-7, where at Design Q the head loss will create the hydraulic gradient as shown. The elevation of the hydraulic gradient at the station is the permissible high water level. The <u>Design</u> water level for which the pumps are to be selected may be considered at or as much as several feet below the hydraulic gradient at the pump station. To consider it below would again be conservative, because as a general principle with any given pump the higher the water level in relation to the discharge line from the station, the greater will be the volume pumped. Setting the design level below the hydraulic gradient creates a reserve of extra capacity. Reference to the pump performance curves in Chapter 9 - Pumps for Stormwater Applications, will clarify the foregoing statements.

The selection of pumps for the station should provide for all pumps (except the sump pump) to be operating together at the design water level to deliver the design discharge Q. The type of station with dimensions and elevations, the number and size of all pumps, the inlet line size, and the pumping level for the first pump to start all need to be tentatively set. From this information it is possible to determine the usable storage and from it the cycling time of the first pump. The staging or vertical distance between starting of the first, second and other pumps (usually one to three feet) can then be determined so that all pumps are running before inflow has risen to the design water level.

4-I. PUMP CYCLING CALCULATIONS

For a given pump with a capacity Q_p, cycling will be a maximum (least time between starts) when the inflow Q_i to the usable storage is one-half the pump capcity. The proof is as follows:

t = Time to Empty + Time to Fill usable storage volume V

$$t = \frac{V}{Q_p - Q_i} + \frac{V}{Q_i} \qquad \text{When } Q_i = \frac{Q_p}{2} \text{ cubic feet/sec.} \quad t = \frac{4V}{Q_p}$$

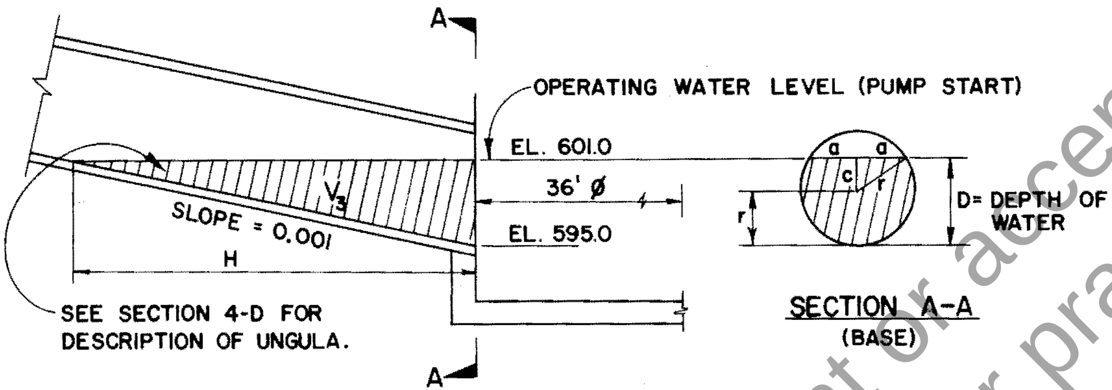
since t is in minutes $$t = \frac{4V}{60\ Q_p} = \frac{V}{15Q_p}$$

Refer to Figures 4-6 and 4-7.

The usable storage volume depends on the pumping range Δh, which is the vertical height between pump start and pump stop elevations. It is therefore necessary to provide enough pumping range at the critical inflow rate Q_i to limit cycling to acceptable minimum time periods based on electric motor size. In general the larger the motor the larger is the starting current required, the larger the damaging heating effect, and the greater the cycling time required. Refer to Chapter 10 - Electric Motors for Stormwater Pumps.

REFER TO FIGURES 2-11 THROUGH 2-13

CALCULATE THE AMOUNT OF STORAGE IN THE 96" DIAMETER INLET LINE OF A PUMP STATION IF THE SLOPE OF THE LINE IS EQUAL TO 0.001, THE INVERT AT THE STATION IS EL. 595.0, THE OPERATING WATER LEVEL (PUMP START) IS EL. 601.00, AND THE PUMP DIAMETER IS 36 FT.. ADD FOR STORAGE IN THE PUMP PIT ABOVE INLET LINE INVERT.



UNGULA VOLUME $V_3 = \dfrac{H(\frac{2}{3}a^3 \pm cB)}{r \pm c}$ $\begin{cases}\text{IF BASE IS GREATER THAN A SEMICIRCLE, USE + SIGN} \\ \text{IF BASE IS LESS THAN A SEMICIRCLE, USE − SIGN}\end{cases}$

WHERE: H= LENGTH OF UNGULA, FT.
r = RADIUS OF BASE, FT.
B = AREA OF BASE, FT^2

KING & BRATER TABLE 7-4, FOR DETERMINING AREA B OF THE CROSS SECTION OF A CIRCULAR CONDUIT FLOWING PART FULL, MAY BE USED.

LET $\dfrac{\text{DEPTH OF WATER}}{\text{DIAM. OF CHANNEL}} = \dfrac{D}{d}$ AND C_a = THE TABULATED VALUE

THEN $B = C_a d^2$

$\frac{D}{d}$	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.0000	.0013	.0037	.0069	.0105	.0147	.0192	.0242	.0294	.0350
.1	.0409	.0470	.0534	.0600	.0668	.0739	.0811	.0885	.0961	.1039
.2	.1118	.1199	.1281	.1365	.1449	.1535	.1623	.1711	.1800	.1890
.3	.1982	.2074	.2167	.2260	.2355	.2450	.2546	.2642	.2739	.2836
.4	.2934	.3032	.3130	.3229	.3328	.3428	.3527	.3627	.3727	.3827
.5	.393	.403	.413	.423	.433	.443	.453	.462	.472	.482
.6	.492	.502	.512	.521	.531	.540	.550	.559	.569	.578
.7	.587	.596	.605	.614	.623	.632	.640	.649	.657	.666
.8	.674	.681	.689	.697	.704	.712	.719	.725	.732	.738
.9	.745	.750	.756	.761	.766	.771	.775	.779	.782	.784

$r = \frac{d}{2} = \frac{8}{2} = 4$ FT.

$c = D - r = 6 - 4 = 2$ FT.

$a = \sqrt{r^2 - c^2} = \sqrt{4^2 - 2^2} = 3.46$

$H = \sqrt{6000^2 - 6^2} \approx 6000$ FT.

$D/d = .75$

$C_a = 0.632$

$B = 0.632(8)^2 = 40.46\ FT^2$

$V = \dfrac{6000\left[\frac{2}{3}(3.46)^3 + 2(40.46)\right]}{4+2} = 108{,}540$ CU. FT.

ADD STORAGE IN PUMP PIT $= \pi \times 18.0^2 \times 6.0 = 6107$ CU. FT.

TOTAL STORAGE $= 114647$ CU. FT.

FIGURE 4-5 STORAGE IN UNGULA

FIGURE 4-5 IS INTRODUCTORY ONLY. ADDITIONAL CONSIDERATIONS ARE REQUIRED TO DETERMINE THE USEABLE STORAGE AND PUMP CYCLING TIME. REFERENCE TO FIGURES 2-11 THROUGH 2-13 SHOWS A MAXIMUM INLET FLOW OF 268 CFS, HANDLED BY FOUR PUMPS WHICH ARE IDENTICAL. EACH PUMP HAS A Q OF 67 CFS AT DESIGN WATER LEVEL. AT THE LOWER LEVEL WHERE CYCLING IS A CONSIDERATION, THE Qp WILL BE LESS. Qp IS APPROXIMATED AS 53 CFS FOR THIS EXAMPLE AND CYCLING TIME IS COMPUTED ACCORDINGLY AFTER CALCULATING USABLE STORAGE. THIS IS DEFINED AS THE VOLUME OF WATER ABOVE THE DEPTH OF FLOW FOR AN INFLOW $Q_i = Qp/_2$.

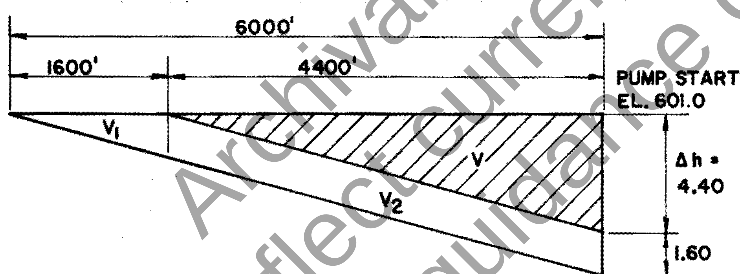
$Q_i = Qp/_2 = \frac{53}{2} = 26.5$ CFS $\quad d = 8 \quad s = .001 \quad n = .013$

FROM KING & BRATER, TABLE 7-14, TO FIND DEPTH OF WATER D IN CONDUIT RUNNING PART FULL.

$Q = \frac{K'}{n} d^{8/3} s^{1/2} \qquad 26.5 = \frac{K'}{.013}(8)^{8/3}(.001)^{1/2} \qquad K' = .04255 \qquad$ INTERPOLATING USE $\frac{D}{d} = .2005$

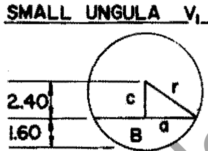
$$\left.\begin{array}{ll} \frac{D}{d} = .200 & K' = .0406 \\ \frac{D}{d} = .201 & K' = .0448 \end{array}\right\} 42 \qquad \begin{array}{r} 4255 \\ \underline{406} \\ 195 \end{array}$$

D = .2005 × 8 = 1.604 USE 1.60 FT.



FROM FIGURE 4-5, TOTAL UNGULA $V_3 = V + V_1 + V_2 = 108{,}540$ CU. FT. = V

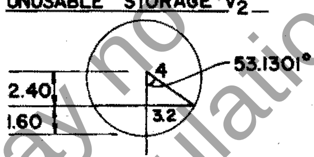
SMALL UNGULA V_1



$\frac{D}{d} = \frac{1.6}{8.0} = .20 \quad Ca = .1118 \quad B = .1118(8) = 7.155 \quad r = 4 \quad c = 2.40$

$a = \sqrt{4^2 - 2.4^2} = 3.2 \qquad V_1 = \frac{1600\left[\frac{2}{3}(3.2)^3 - 2.40(7.155)\right]}{4 - 2.40} = 4673 = V_1$

UNUSABLE STORAGE V_2

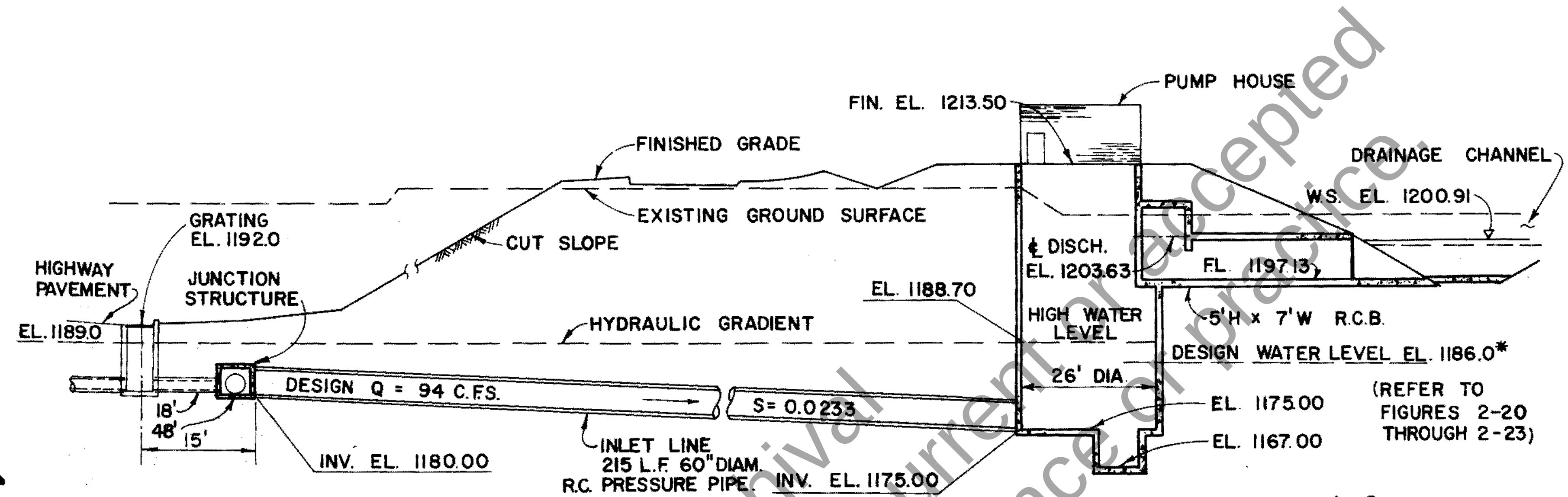


$.7048\pi r^2 + (2.4 \times 3.2) + B = \pi r^2$

$B = .29516\pi r^2 - 7.68 = 7.156 \qquad 7.156 \times 4400 = 31489 = V_2$

USABLE STORAGE V, $V = V_3 - V_1 - V_2 = 108540 - 4673 - 31489 = 72378$
ADD STORAGE IN PUMP PIT $\pi \times 18^2 \times 4.40 = 4479$, $72378 + 4479 = 76857$, CYCLING TIME $= \frac{76857}{15 \times 53.5} = 97.5$ MIN.
SINCE THE MOTOR SIZE WOULD NOT NEED TO BE GREATER THAN 400HP THE CYCLING TIME IS WELL IN EXCESS OF THE 20 MINUTES REQUIRED. THE PUMPING RANGE Δh HAS BEEN TAKEN AS IDENTICAL TO HYDRAULIC CONDITIONS BUT OBVIOUSLY IT WOULD BE POSSIBLE TO SET A LOWER PUMP STARTING LEVEL AND REDUCE Δh AND THE USABLE STORAGE, WHILE STILL MEETING CYCLING REQUIREMENTS. ALTERNATELY THE PUMP START LEVEL COULD BE RETAINED AT EL. 601.0 AND THE STOP LEVEL COULD BE RAISED. IN THIS EXAMPLE USABLE STORAGE IS WELL IN EXCESS OF REQUIREMENTS.

FIGURE 4-6 USABLE STORAGE AND PUMP CYCLING



$\ell = 15 + 215 = 230$ FT.

DESIGN Q IS GIVEN AS 94 C.F.S. $\quad S = \frac{h}{\ell} = \frac{0.30}{230} = .0013$

FROM KING & BRATER, TABLE 6-2, USING $n = .013$ SIZE OF LINE = 60" (BY INTERPOLATION)

OR FROM 6-14, SUBSTITUTING, $Q = \frac{.463}{n} d^{8/3} s^{1/2} = 93.9$ O.K. USE 94 C.F.S.

PUMP NO. 1 START EL. = 1178.0 PUMP NO. 1 STOP EL. = 1175.5 $\Delta H = 2.5$ FT. (SEE TABLE)

PUMP DESIGN Q = 47 C.F.S. (21,100 GPM). USE DESIGN WATER LEVEL = 1186.0*

DESIGN T.D.H. = 1203.63 − 1186.0 + LOSSES, SAY 2.37 FT. = 20.0 FT.*

SELECT 30LS MIXED FLOW,* 82% EFF AT DESIGN POINT.

Q AT EL. 1175.5 (T.D.H. = 30.0 FT.) = 16,400 GPM (36.5 CFS)* 84 % EFF. APPROX.

* ASSUMED FOR FOR PURPOSE OF EXAMPLE.

LARGE UNGULA: V_3 $\quad \frac{D}{d} = \frac{3}{5} = .6 \quad B = Cad^2 \quad d^2 = 25 \quad Ca = .492 \quad B = 12.3$ FT.^{2}

SEE FIGURE 4-5

$c = D - r = 3 - 2.5 = .5 \qquad a = \sqrt{r^2 - c^2} = \sqrt{2.5^2 - .5^2} = 2.45$

$H = \sqrt{(128.75)^2 - 3^2} = 128.71$

$V_3 = \frac{128.71\left[\frac{2}{3}(2.45)^3 + .5(12.3)\right]}{2.5 + .5} = \frac{128.71(9.80 + 6.15)}{3} = 684$ CU. FT.

SMALL UNGULA: V_1 $\quad \frac{D}{d} = \frac{.73}{5} = .146 \quad B = Cad^2 \quad d^2 = 25 \quad Ca = .0710 \quad B = 1.776$ FT.^{2}

$c = r - D = 2.5 - .73 = 1.77 \qquad a = \sqrt{r^2 - c^2} = \sqrt{2.5^2 - 1.77^2} = 1.7655$

$H_1 = \sqrt{(31.86)^2 - (.73)^2} = 31.33$

$V_1 = \frac{31.33\left[\frac{2}{3}(1.7655)^3 - 2(1.776)\right]}{2.5 - .77} = \frac{31.33(3.37 - 3.13)}{0.73} = 10.2$ CU.FT.

$V_2 = 1.776 \times 97.42 = 173.0$

$Q_i = Q_{P/2} = \frac{36.5}{2} = 18.25 \qquad d = 5,\ s = .0233,\ n = .013$

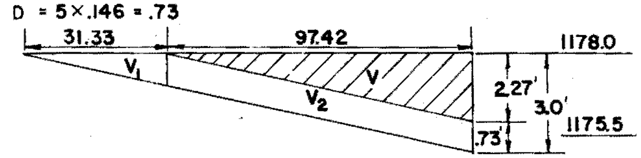
$Q = \frac{K'}{n} d^{8/3} s^{1/2} \qquad 18.25 = \frac{K'}{.013}(5)^{8/3}(.0233)^{1/2}$

$K' = .02126 \qquad \frac{D}{d} = .14 \quad K' = .0195$

INTERPOLATING $\qquad\qquad \frac{D}{d} = .15 \quad K' = .0225 \quad \} 30 \quad \frac{2126}{1950}\ \ 176 \div 300 = .586$

USE $\frac{D}{d} = .146 \qquad\qquad 30$

$D = 5 \times .146 = .73$



USABLE STORAGE $V = V_3 - V_1 - V_2 = 684 - 10.2 - 173.0 = 501$

PUMP PIT $= 26^2 \times \pi/4 \times 2.27 = 1205$

$ 1706$

CYCLING TIME (SEE SECTION 4-I) $= \frac{1828}{15 \times 36.5} = 3.12$ MINS.

$H = \frac{3}{.0233} = 128.75$ FT.

$H_1 = \frac{.5}{.0233} = 21.46$ FT.

FROM CONTRACT DRAWINGS

PUMP START-STOP SEQUENCE			
START	ENGINE NO. 2	EL.	1181.0
STOP	"	"	1178.0
START	" NO. 1	"	1178.0
STOP	" "	"	1175.5
START	LOW FLOW PUMP	"	1171.0
STOP	" " "	"	1168.0

FIGURE 4-7 PUMP STATION AND INLET LINE STORAGE

For Code F induction motors, as normally used for driving vertical pumps, the following limits are recommended.

Motor HP	Cycling Time (t), Minutes
0-200	15
250-300	18
350-500	20

If pump discharge Q_p, minimum cycling time t, pump pit area, and usable storage volume are known or tentatively selected, the pumping range Δh can be expressed as:

$$\Delta h = \frac{(15\ Qp \times t) - \text{Usable storage volume}}{\text{Pump Pit Area}}$$

At the low levels of water in the pump pit when cycling is being considered the discharge of the first pump will be less than the discharge at design water level, which is usually at or only slightly below the level of the hydraulic gradient. Consequently, the cycling time will be greater and the risk of overheating apparently less. However, there is some added complexity to this subject making it more appropriately treated in Chapter 8 - Pumping and Discharge Systems, and in Chapter 9 - Pumps for Stormwater Applications. To avoid the confusion of attempting to explain pumping phenomena in this chapter on Collection Systems, the reader is requested to accept the pumping rates shown in the numerical examples of Figures 4-6 through 4-9 from which the cycling times are computed. After study of Chapters 8 and 9, the reader should come back and study the validity of the pumping rates used, which are shown in two of the three examples as less than the Design Q for the pump operating at Design Water Level. The example given in Figure 4-5 has been simplified by ignoring considerations of the inlet line running partially full, but this is explained in Figure 4-6 and a composite is shown in Figure 4-7.

A more comprehensive example is now given, showing a collection system with awkward layout in which only part of the storage is usable. The inlet delivers to a rectangular pump pit of minimum depth, but cycling period of first pump is shown to be satisfactory. Refer to Figures 4-8 and 4-9. The design inflow Q has been given as 181 cubic feet per second and the size of the first pump to operate is selected as 15% of Q. Thus the pump capacity is 27 cfs (12,100 gpm) and the critical volume of inflow Q_i for cycling considerations is 13.5 cfs. To suit the hydraulic gradient and use of non-pressure R.C.P., the highest permissible water level in the station has been set at El. -4.05. There are to be four pumps which start at one foot intervals at or below this level, so the starting elevation of the first pump will be El. -7.05. Therefore, -7.05 is the highest elevation at which usable storage can be considered. We are, therefore, concerned with the hydraulic conditions in a large pipeline flowing partially full. Referring to King & Brater, Handbook of Hydraulics, Table 7-14, the procedure is to find K' for each portion of line, then the depth of water D, interpolating as necessary. Values of D must be determined to correspond to an inflow rate Q_i equal to half the pump capacity.

Usable storage is now computed as follows:

Line H (72") d = 6.0 $K' = \dfrac{13.5 \times .013}{(6.0)^{8/3} (.001)^{1/2}} = .0467$

D/d (interpolating) = .21 + (19/44 x .01) = .2143

D = 6.00 x .2143 = 1.29 ft. depth

Line H (66") d = 5.5 K' = .0589

D/d = .24 + (4/49 x .01) = .2408 D = 5.5 x .2408 = 1.32 ft. depth

Line F (63") d = 5.25 K' = .0667

D/d = .25 + (33/52 x .01) = .2563 D = 5.25 x .2563 = 1.35 ft.depth

Line F (57") d = 4.75 K' = .0870

D/d = .29 x (21/58 x .01) = .2936 D = 4.75 x .2936 = 1.39 ft. depth

Figure 4-8 can now be drawn, based on Figure 4-7 and the above.

The stepped inverts of the lines have some effect in distorting the ungula, but the length L_1 of V may be computed by similar triangles. Water depth of V is 1.96 ft. at Sta. 0+97.50 and 0.12 ft. at Sta. 11+28.00. Length L_1=1030.5x1.96/1.84=1097.7 ft.

For Sta. 0+97.50:

d = 6.0 D=3.25 c=0.25 $a = \sqrt{(3.00)^2 - (0.25)^2} = 2.99$

D/d = .5417 Ca. = .4347 Wetted Area B = .4347 $(6.0)^2$ = 15.65 sq.ft.

$V_3 = \dfrac{H.2/3a^3 + cB)}{r+c} \quad \dfrac{2039.5\ (\overline{2/3 \times 2.99^3} + \overline{0.25 \times 15.65})}{3.0 + 0.25}$ = 13,638 cu.ft.

For Sta. 11+28:

d = 5.25 D=1.35 c=1.275 $a = \sqrt{(2.625^2 - (1.275)^2} = 2.29$

D/d = .2571 Ca = .1597 Wetted Area B = .1597 $(5.25)^2$ = 4.40 sq.ft.

$V_1 = \dfrac{(H.2/3a^3 - cB)}{r-c} = \dfrac{941.8\ (\overline{2/3 \times 2.29^3} - \overline{1.275 \times 4.40})}{2.625 - 1.275}$ = 1,671 cu.ft.

For Sta. 0+97.50:

$d = 6.0$ $D = 1.29$ $D/d = .2150$ $Ca = .1240$ $B = 4.46$ sq.ft.

For Sta. 6+16:

$d = 6.0$ $D = 1.82$ $D/d = .3033$ $Ca = .2012$ $B = 7.24$ sq.ft.

$d = 5.5$ $D = 1.32$ $D/d = .2400$ $Ca = .1449$ $B = 4.38$ sq.ft.

For Sta. 11+28:

$d = 5.5$ $D = 1.60$ $D/d = .2909$ $Ca = .1898$ $B = 5.74$ sq.ft.

$$V_2 = \left\{\frac{4.40+4.40}{2}x67.2\right\} + \left\{\frac{5.74+4.38}{2}x512\right\} + \left\{\frac{7.24+4.46}{2}x518.5\right\}$$

$$= \underline{5,920 \text{ cu.ft.}}$$

$V = V_3 - V_1 - V_2 = 13,638 - 1,671 - 5,920$

= 6,047 cu. ft. usable storage in inlet line.

Pump Pit Area A (determined in Chapter 15, as dimensionally suitable for pumps selected) = 1,452 sq. ft.

Δh can be set to match hydraulic computations = 1.96 ft.

Pump cycling time T is now computed. $\Delta T = \dfrac{A\Delta h+V}{15\ Q_p}$

With Δh given above as 1.96 ft., and $Q_p = 27$ cfs

$\Delta T = 1,452 \times 1.96 + 6,047/15 \times 27 = 21.9$ minutes

(O.K. 21.9 > 15 minutes minimum for 150 h.p. motor).

Due to the minimum water level condition (See Chapter 8 - Pumping and Discharge Systems) the value of Q_p may be discounted to 25 cfs. This would slightly raise Δh and the usable storage, and increase cycling time.

The preceding examples show that a good deal of care must be taken in computing the storage in collection systems and relating it to pumping requirements. Only the minimum of information on pump characteristics has been introduced, solely for the purpose of assisting the reader's understanding of the effect of the collection system on the pump station design and operation.

PUMP NO. 1

$Q_p = 27$ cfs

START AT −7.05

STOP AT −9.01

$\Delta H = 1.96$

$Q_i = {}^{Q_p}/_2 = {}^{27}/_2 = 13.5$ cfs

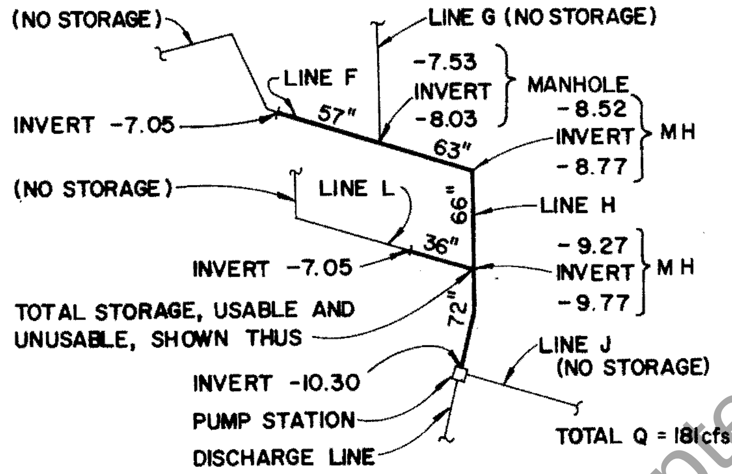
$Q_i = {}^{K'}/_n \, d^{8/3} s^{1/2}$

$K' = \dfrac{Q_i \times n}{d^{8/3} s^{1/2}}$

n = .013 for R.C.P.

d = Pipe Diam. in ft.

S = Slope



THE GOVERNING CONDITION FOR PUMP CYCLING IS WHEN Q_{INLET} IS EQUAL TO HALF Q_{PUMP}. THE DEPTH OF WATER IN THE INLET LINES CORRESPONDING TO Q_{INLET} IS COMPUTED. ONLY STORAGE ABOVE THIS LEVEL IS USABLE.

LINE	SIZE	STATIONING	INVERT	LENGTH	SLOPE	TRANSITION
H	72"	0+97.50 6+16.00	−10.30 −9.77	518.5	.001	72" TO 66"
H	66"	6+16.00 11+28.00	−9.27 −8.77	512.0	.001	66" TO 63"
F	63"	0+90.97 5+95.00	−8.52 −8.03	504.0	.001	63" TO 57"
F	57"	5+95.00 11+00	−7.53 −7.05	505.0	.001	
L	36"	IGNORE —	USABLE	STORAGE	NOT SIGNIFICANT	

D/d	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0		.00007	.00031	.00074	.00138	.00222	.00328	.00455	.00604	.00775
.1	.00967	.0118	.0142	.0167	.0195	.0225	.0257	.0291	.0327	.0366
.2	.0406	.0448	.0492	.0537	.0585	.0634	.0686	.0738	.0793	.0849
.3	.0907	.0966	.1027	.1089	.1153	.1218	.1284	.1352	.1420	.1490
.4	.1561	.1633	.1705	.1779	.1854	.1929	.2005	.2082	.2160	.2238
.5	.232	.239	.247	.255	.263	.271	.279	.287	.295	.303
.6	.311	.319	.327	.335	.343	.350	.358	.366	.373	.380
.7	.388	.395	.402	.409	.416	.422	.429	.435	.441	.447
.8	.453	.458	.463	.468	.473	.477	.481	.485	.488	.491
.9	.494	.496	.497	.498	.498	.498	.496	.494	.489	.483
1.0	.463									

KING & BRATER TABLE 7-14, VALUES OF K' FOR CIRCULAR CHANNELS IN THE FORMULA $Q = \frac{K'}{n} d^{8/3} s^{1/2}$

D = DEPTH OF WATER d = DIAMETER OF CHANNEL

FIGURE 4-8. INLET LINE LAYOUT

DATA FROM WESTSIDE PUMP STATION, LONG BEACH, CA.

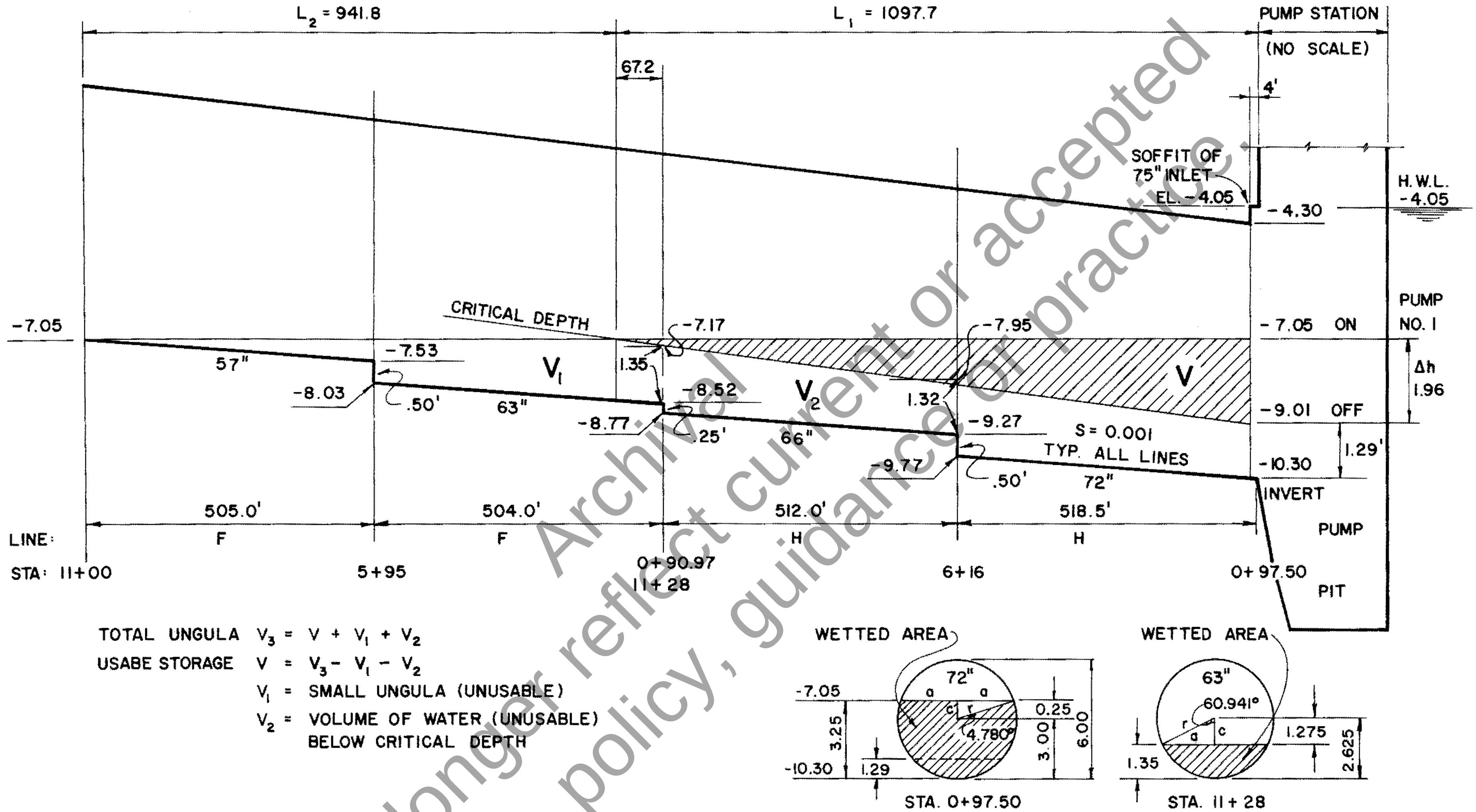
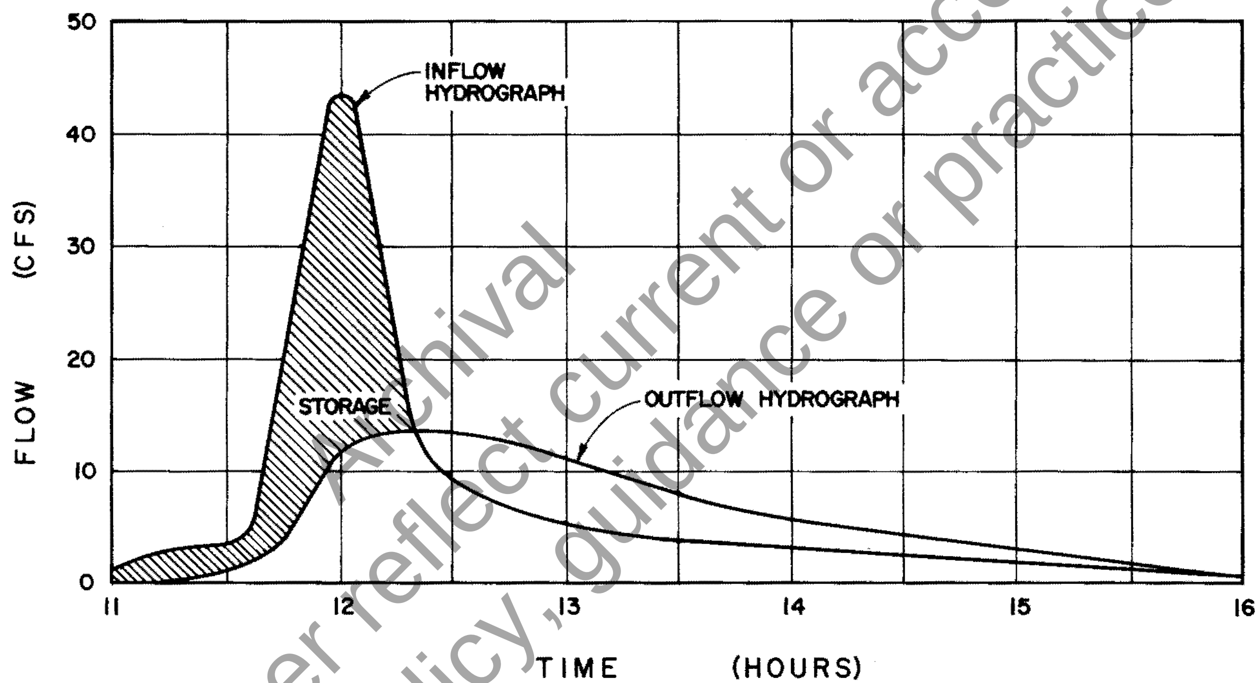


FIGURE 4-9. USABLE AND UNUSABLE STORAGE IN INLET LINE



<u>FIGURE 4—10</u> <u>USE of STORAGE TO REDUCE PEAK FLOW RATE</u>

To round out the limited pumping explanations, it is appropriate at this point to mention Total Dynamic Head since its abbreviation TDH has appeared and various references have also been made to head, operating head, design head and possibly static head. Briefly, a pump always operates at some total dynamic head which consists of the static head through which the water is being lifted, plus various head losses due to water velocity and the friction of the water passing through the pump, piping, valves and fittings to the point of discharge. Chapter 6 - Wet Pit Design, and Chapter 8 - Pumping and Discharge System give more details.

Sections 4-G, 4-H and 4-I have dealt with collection systems and storage for conditions where pump station discharge rate need not be limited. The remainder of Chapter 4 presents methods to be used when discharge rate must not exceed a given level.

4-J. DEVELOPMENT OF A MASS CURVE ROUTING PROCEDURE

The merits of using storage to reduce peak flows have been discussed in previous sections. A generalized case is selected for illustration because the actual pumping station case may be complicated by the varying pumping rates and discontinuities as the pumps turn on and off. This is shown in Figure 4-10.

The shaded area between the curves represents the volume of stormwater that must be stored to reduce the peak flow rate. Storage exists in natural channels, storm drain systems, constructed basins or forebays, and in storage boxes. Engineers must be able to identify the analyze the effect of storage on the discharge rates from the pump station.

Designers must establish the interrelationship between three separate components. First, the inflow hydrograph must be determined for the contributing watershed. Second, the volumetric storage capability of the storage facility must be identified. Third, the stage-discharge curve of the pumps must be determined. Once these three components have been established, a mass curve routing procedure can be used to analyze the problem. This routing procedure will be developed in the following sections.

An example problem is utilized to illustrate the development of the routing procedure; the inflow hydrograph used for this example problem is depicted in Figure 4-11.

4-K. ESTIMATING REQUIRED STORAGE AND PUMPING RATES

Because of the complex relationship between the variables of pumping rates, storage, and pump on-off settings, a trial and error

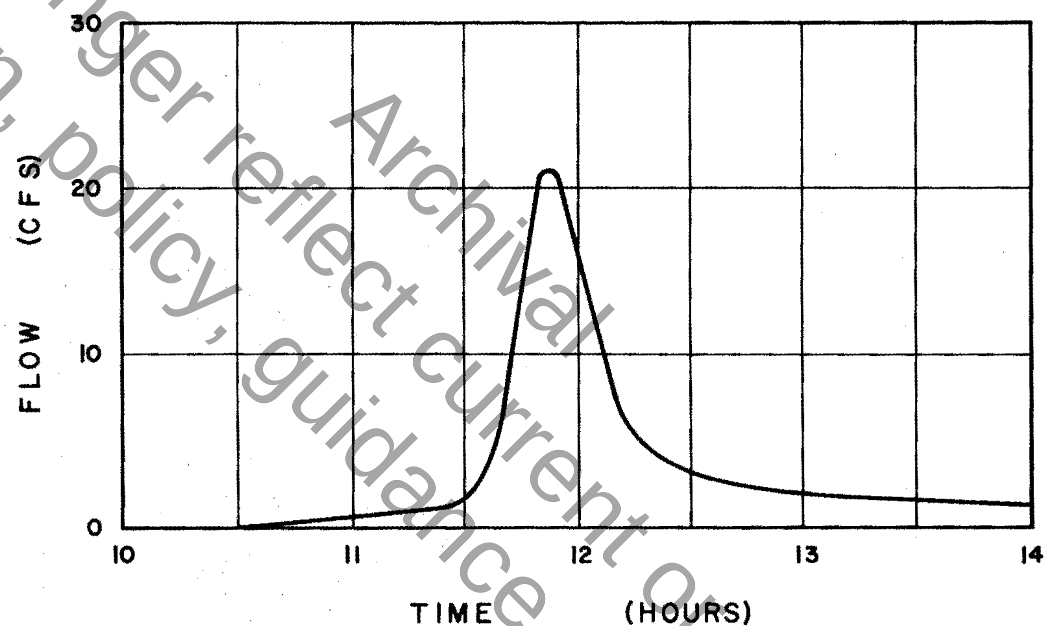


FIGURE 4-11 INFLOW HYDROGRAPH for EXAMPLE PROBLEM

approach is usually necessary for estimating the pumping rates and storage required for a balanced design. There is a wide range of combinations that will produce an adequate design. A desirable goal is to maximize storage capacity so as to minimize pumping capacity.

Some approximation is necessary to produce the first trial design. One approach is shown in Figure 4-12.

In this approach, the peak pumping rate is assigned and a horizontal line representing the peak rate is drawn across the top of the hydrograph. The shaded area above the peak pumping rate represents the volume of storage required above the last pump-on elevation.

The number of pumps and their respective pumping rates are selected together with the pump on-off settings, and trial dimensions of the storage basin are assigned to produce the required volume of storage, represented by the shaded area in Figure 4-12, above the last pump-on elevation.

For the example problem, a peak pumping rate of 14 cfs was assigned; this will be accomplished by two 7 cfs pumps. The pumping rate is plotted as a horizontal line, and the shaded area is measured, determining the required volume (4,500 cu. ft.) above the last pump-on elevation.

4-L. STAGE-STORAGE RELATIONSHIP

Engineers have a wide-range of tools available to them for providing the necessary storage at a pumping station. Earth basins either natural or constructed are the most cost-effective; however, at most highway pumping stations the storm water must be stored underground. This can be accomplished by oversizing the storm drain or providing a concrete storage box.

Routing procedures require that a stage-storage relationship be developed. This is accomplished by calculating the available volume of water for storage at uniform vertical intervals. Usually the stage-storage curve is developed using one-half foot intervals, with the intervals corresponding to the vertical elevations used in the station design.

Storage provided by irregular natural terrain is calculated by determining the area of horizontal planes associated with the vertical intervals. The areas of adjacent planes are averaged and multiplied by the vertical increment to determine an incremental volume. Starting at the bottom of the basin, the volumes are summed to obtain the stage-storage curve.

When a trapezoidal basin is used, the stage-storage curve can be calculated by the prismoidal formula:

$$V = \frac{D}{6} (A_1 + A_2 + 4M)$$

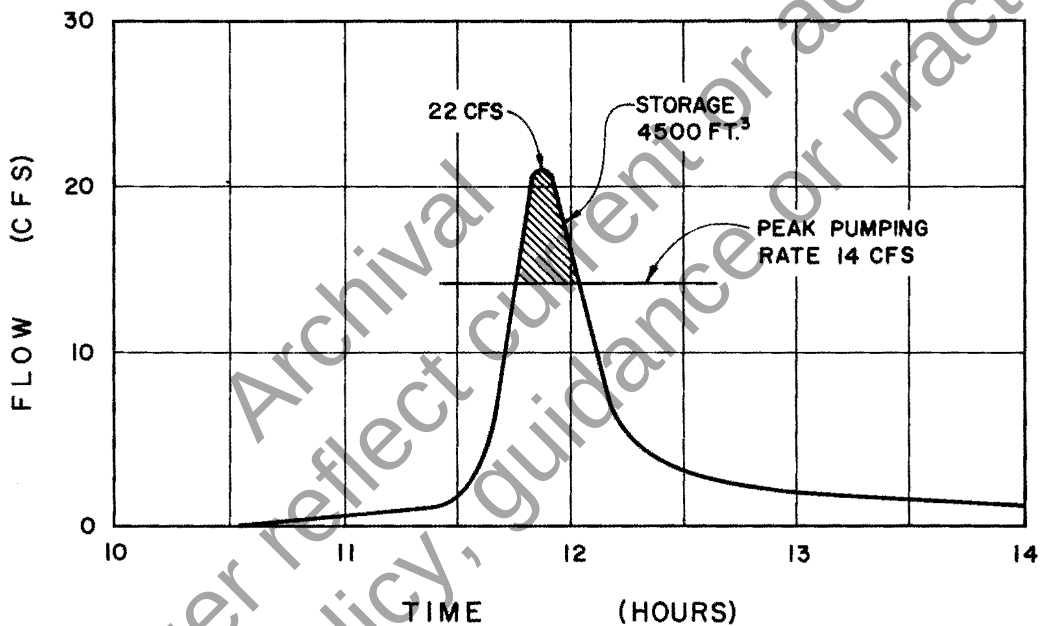


FIGURE 4-12 ESTIMATING REQUIRED STORAGE

where:

- V = Volume of basin at a given depth, cu. ft.
- D = Depth of basin, ft.
- A_1 = Area of water surface, sq. ft.
- A_2 = Area of base, sq. ft.
- M = Area of midsection, sq. ft.

The volumes associated with the assigned depth are calculated and plotted to obtain the stage-storage curve.

A special case occurs when the basin is square (pyramid); the volume of the basin is calculated using the frustum of a pyramid equation:

$$V = \frac{D}{3} (A_1 + A_2 + \sqrt{A_1 A_2})$$

where:

- V = Volume of a basin at a given depth, cu. ft.
- D = Depth of basin, ft.
- A_1 = Area of water surface, sq. ft.
- A_2 = Area of base, sq. ft.

Whenever the pump start elevation is above the invert of the storm drain, the storm drain will perform more as a storage basin than a conveyance vehicle. By oversizing the storm drain, a true storage basin can be created that will provide a meaningful reduction in pumping rates. One section of pipe could be designed to act as a storage basin, or the storage zone could be extended into several lengths of the storm drainage system.

The volumes for establishing the stage-storage curve can be calculated using the prismoidal formula:

$$V = \frac{L}{6} (A_1 + A_2 + 4M)$$

where:

- V = Volume of water in pipe, cu. ft.
- L = Wetted length of pipe, ft.
- A_1 = Wetted cross sectional area of lower end of pipe, sq. ft.

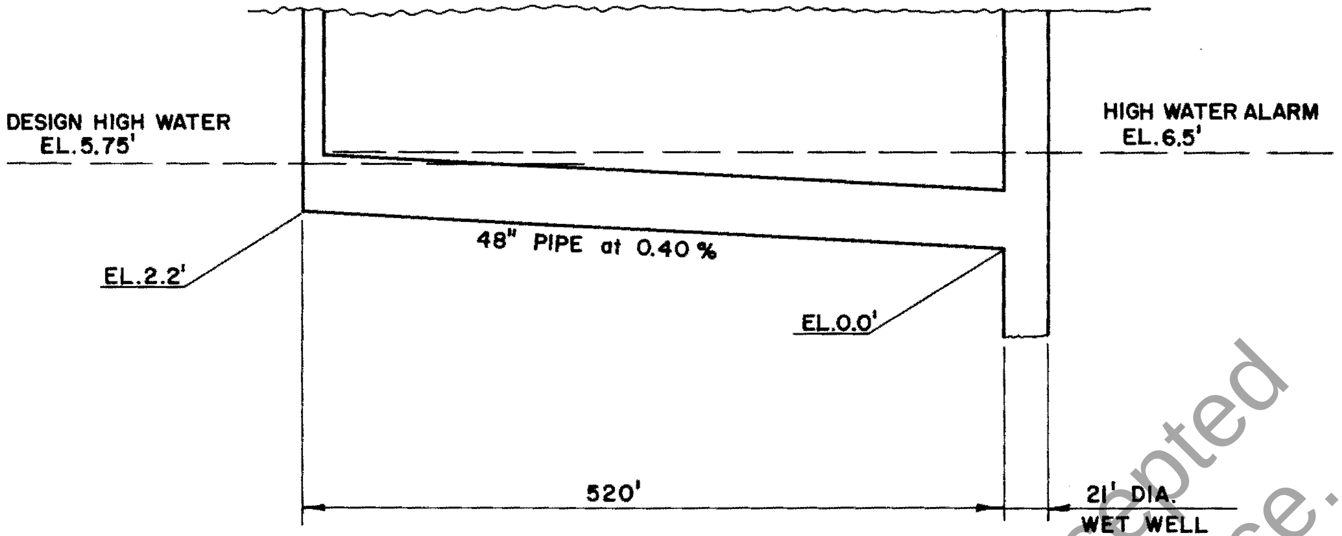


FIGURE 4-13 STORAGE PIPE SKETCH

ELEVATION (ft)	PIPE (ft^3)	WET WELL (ft^3)	TOTAL (ft^3)
0.0	0	0	0
0.5	45	173	218
1.0	251	346	597
1.5	672	519	1,191
2.0	1,333	692	2,025
2.5	2,213	866	3,079
3.0	3,187	1,039	4,226
3.5	4,168	1,212	5,380
4.0	5,072	1,385	6,457
4.5	5,773	1,559	7,332
5.0	6,230	1,732	7,962
5.5	6,468	1,905	8,373
6.0	6,534	2,078	8,612
6.5	6,534	2,251	8,785
7.0	6,534	2,424	8,958

STAGE - STORAGE TABULATION
48" PIPE at 0.40 PERCENT
21' DIAMETER WET WELL

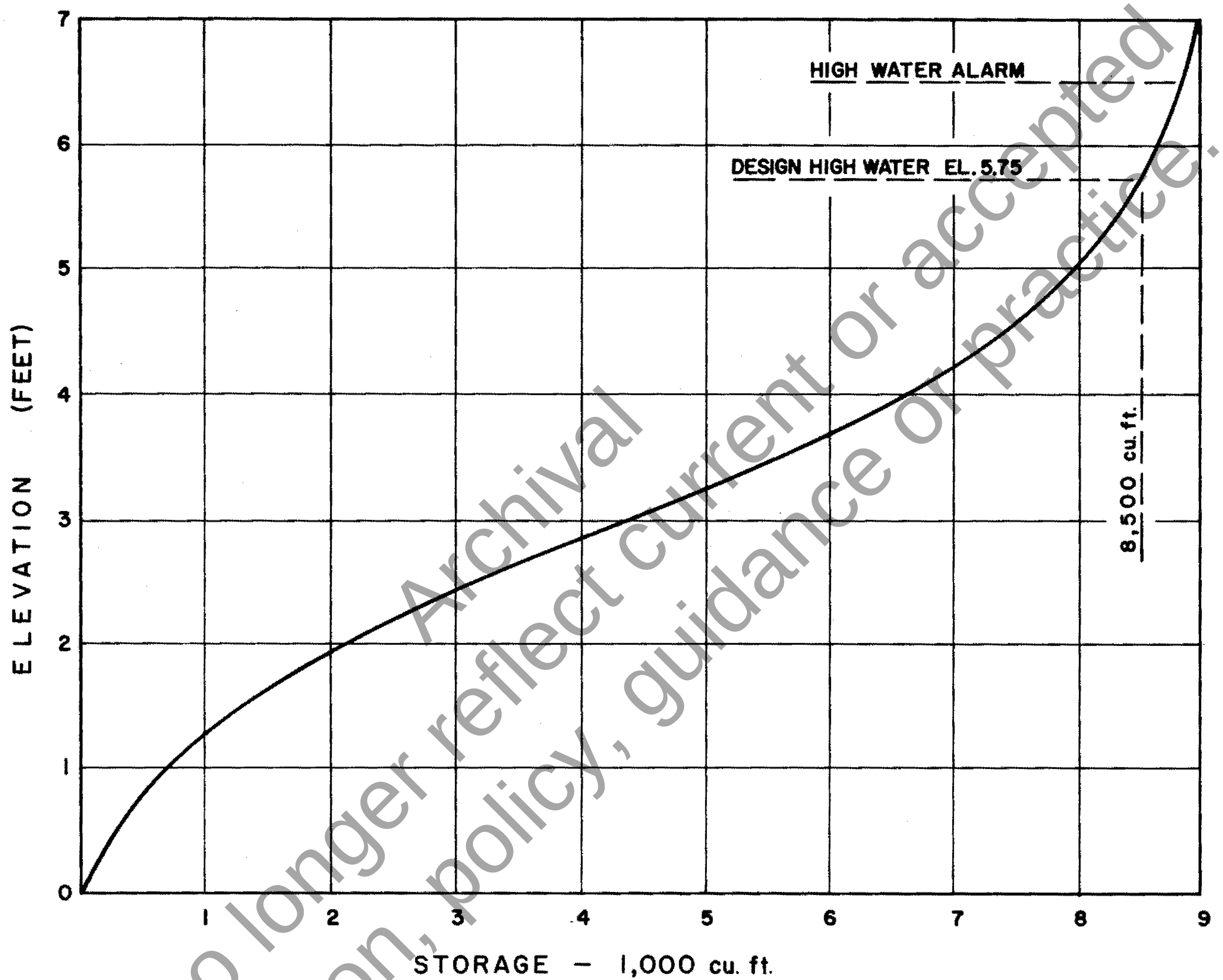


FIGURE 4-14 STAGE-STORAGE CURVE

A_2 = Wetted cross sectional area of upper end of pipe, sq. ft.

M = Wetted cross sectional area of midsection of pipe, sq. ft.

Relative area-depth curves or tables for the particular storm drain shape must be consulted to determine the cross sectional areas. An FHWA report* provides relative area-depth tables for various cross sectional shapes.

If the pipe is circular, a special case exists, and the volume can be calculated using the ungula of a cone formula as discussed in Figure 4-5. The ungula formula should only be used for partially-full flow conditions.

Underground storage boxes would most likely be rectangular reinforced concrete boxes. The volumes at the various stages can be calculated using a combination of formulas for regular prisms and triangular wedges.

In an example problem, a 520-ft. long 48" circular pipe with a 0.40 per cent slope is provided as a storage pipe as shown in Figure 4-13; a 21-ft. diameter wet-well is also provided. The storage volumes for the respective elevations are tabulated in Figure 4-13, and the stage-storage curve is plotted in Figure 4-14.

4-M. STAGE-DISCHARGE RELATIONSHIP

Mass curve routing procedures require that a stage-discharge relationship be established. For the example problem the following stage-discharge relationship was developed:

	Pump-Start Elevation	Pump-Stop Elevation
Pump No. 1 (7 cfs)	2.0	0.0
Pump No. 2 (7 cfs)	3.0	1.0

Figure 4-15 shows the pumping arrangement.

This stage-discharge relationship is based on three design criteria assumptions: (a) Pump No. 1 stops at Elevation 0.0, (b) 2-ft. pumping range, and (c) 1-ft. difference in elevation between pump starts.

*Zelensky, P.N., Computation of Uniform and Nonuniform Flow in Prismatic Conduits, 1972, Federal Highway Administration, Office of Research and Development, Washington, D.C. 20590.

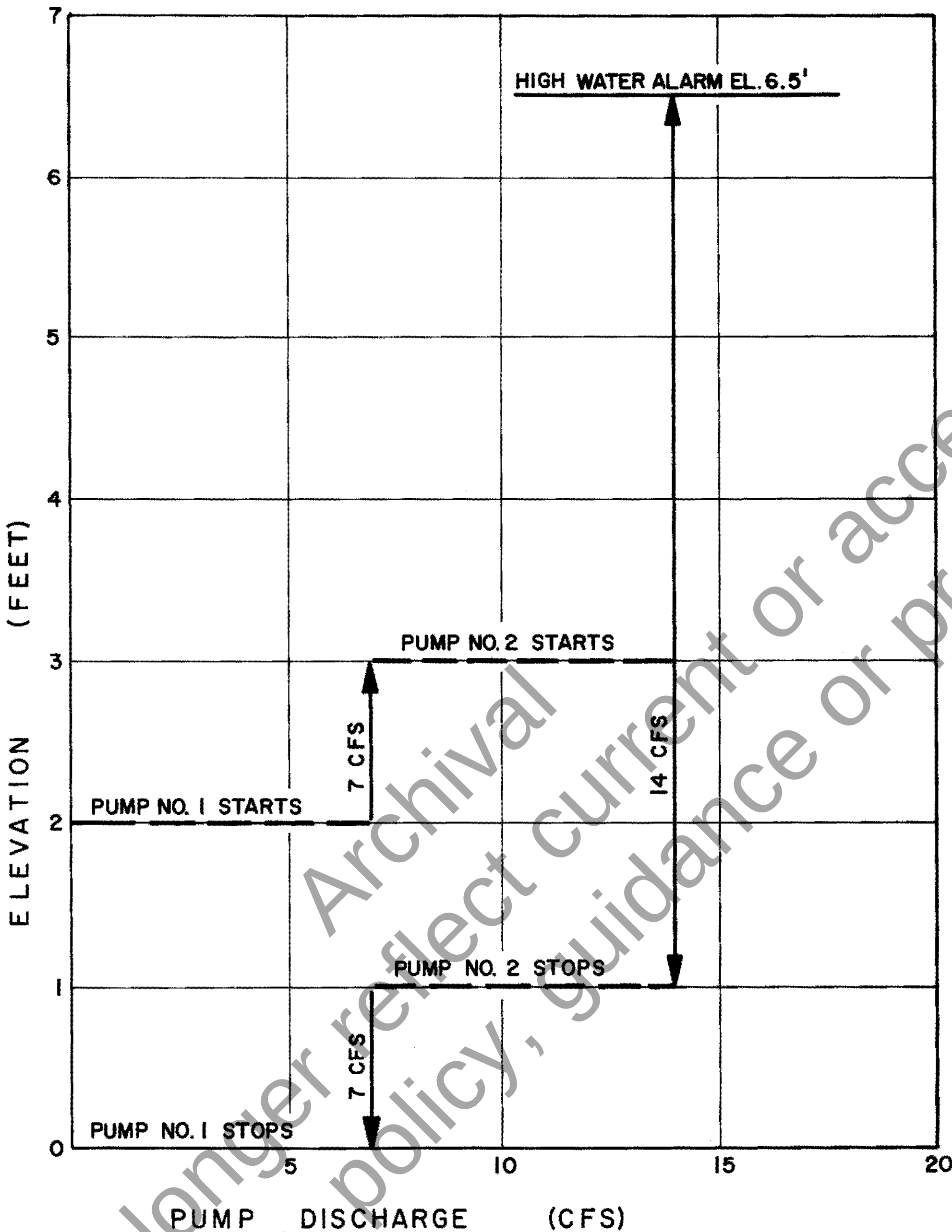


FIGURE 4-15 STAGE - DISCHARGE CURVE

Since pumping station design is basically a trial and error approach, this pumping arrangement should be considered as the first attempt.

4-N. INFLOW MASS CURVE

To obtain an inflow mass curve, the inflow rates at the limits of a time increment are averaged and multiplied by the time increment to obtain an incremental volume. These incremental volumes are then summed to obtain a cumulative inflow and plotted against time to create an inflow mass curve.

The inflow hydrograph (Figure 4-11) for the example problem is summed and plotted in Figure 4-16 as the inflow mass curve.

4-O. MASS CURVE ROUTING

After the three components, inflow hydrograph, stage-storage relationship and stage-discharge relationship have been determined, a graphical mass curve routing procedure can be used. In actual design practice, the inflow hydrograph which is developed by an acceptable hydrologic method is a fixed design component; however, the storage and pumping discharge rates are variable. The designer may wish to assign a pumping discharge rate based on environmental or downstream capacity considerations. The required storage is then determined by various trials of the routing procedure.

As the stormwater flows into the storage basin, it will accumulate until the first pump-start elevation is reached. The first pump is activated and if the inflow rate is greater than the pump rate, the stormwater will continue to accumulate until the elevation of the second pump-start is reached. As the inflow rate decreases the pumps will shut off at their respective pump-stop elevations.

These conditions are modeled in the mass curve diagram by establishing the point at which the cumulative flow curve has reached the storage volume associated with the first pump-start elevation. This storage volume (2025 ft.^{3}) (Figure 4-14) is represented by the vertical distance between the cumulative flow curve and the base line as shown in Figure 4-17. A vertical storage line is drawn at this point since it establishes the time at which the first pump starts.

The pump discharge line is drawn from the intersection of the vertical storage line and the base line upwards towards the right; the slope of this line is equal to the discharge rate of the pump. The pump discharge curve represents the cumulative discharge from

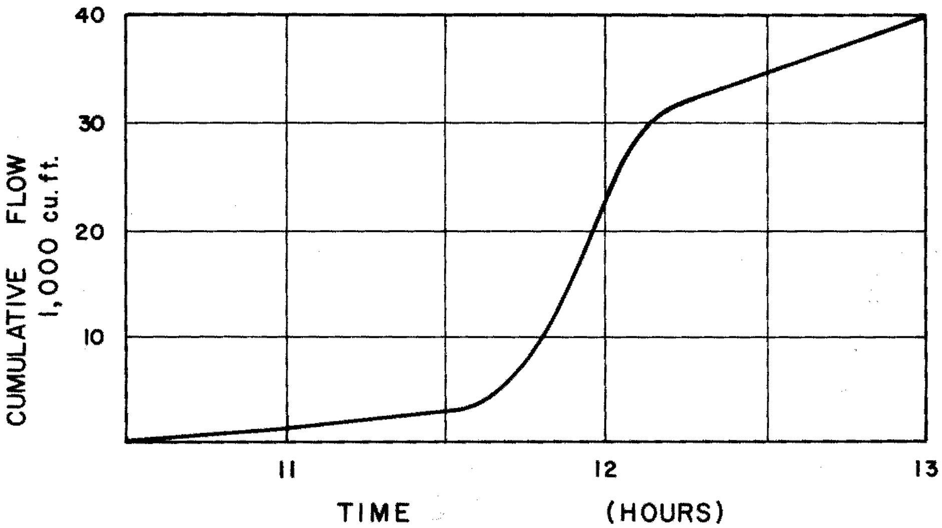


FIGURE 4-16 DEVELOPMENT of INFLOW MASS CURVE

TIME	INFLOW (cfs)	AVERAGE INFLOW (cfs)	TIME INCREMENT (sec)	INCREMENTAL FLOW (ft³)	CUMULATIVE FLOW (ft³)
10:30	0				0
		.05	300	15	
35	.1				15
		.15	"	45	
40	.2				60
		.25	"	75	
45	.3				135
		.35	"	105	
50	.4				240
		.45	"	135	
55	.5				375
		.55	"	165	
11:00	.6				540
		.65	"	195	
05	.7				735
		.75	"	225	
10	.8				960
		.85	"	255	
15	.9				1,215
		.95	"	285	
20	1.0				1,500
		1.05	"	315	
25	1.1				1,815
		1.15	"	345	
11:30	1.2				2,160
		1.85	"	550	
35	2.5				2,710
		3.5	"	1,050	
40	4.5				3,760
		8.0	"	2,400	
45	11.5				6,160
		15.2	"	4,560	
50	19.0				10,720
		20.2	"	6,060	
55	21.5				16,780
		19.2	"	5,760	
12:00	17.0				22,540
		14.5	"	4,350	
05	12.0				26,890
		9.2	"	2,760	
10	6.5				29,650
		5.8	"	1,740	
15	5.0				31,390
		4.5	"	1,350	
20	4.0				32,740
		3.8	"	1,140	
25	3.5				33,880
		3.4	"	1,020	
12:30	3.3				34,900
		3.0	"	900	
35	2.7				35,800
		2.6	"	780	
40	2.5				36,580
		2.4	"	720	
45	2.3				37,300
		2.2	"	660	
50	2.1				37,960
		2.05	"	620	
55	2.0				38,580
		1.95	"	580	
13:00	1.9				39,160

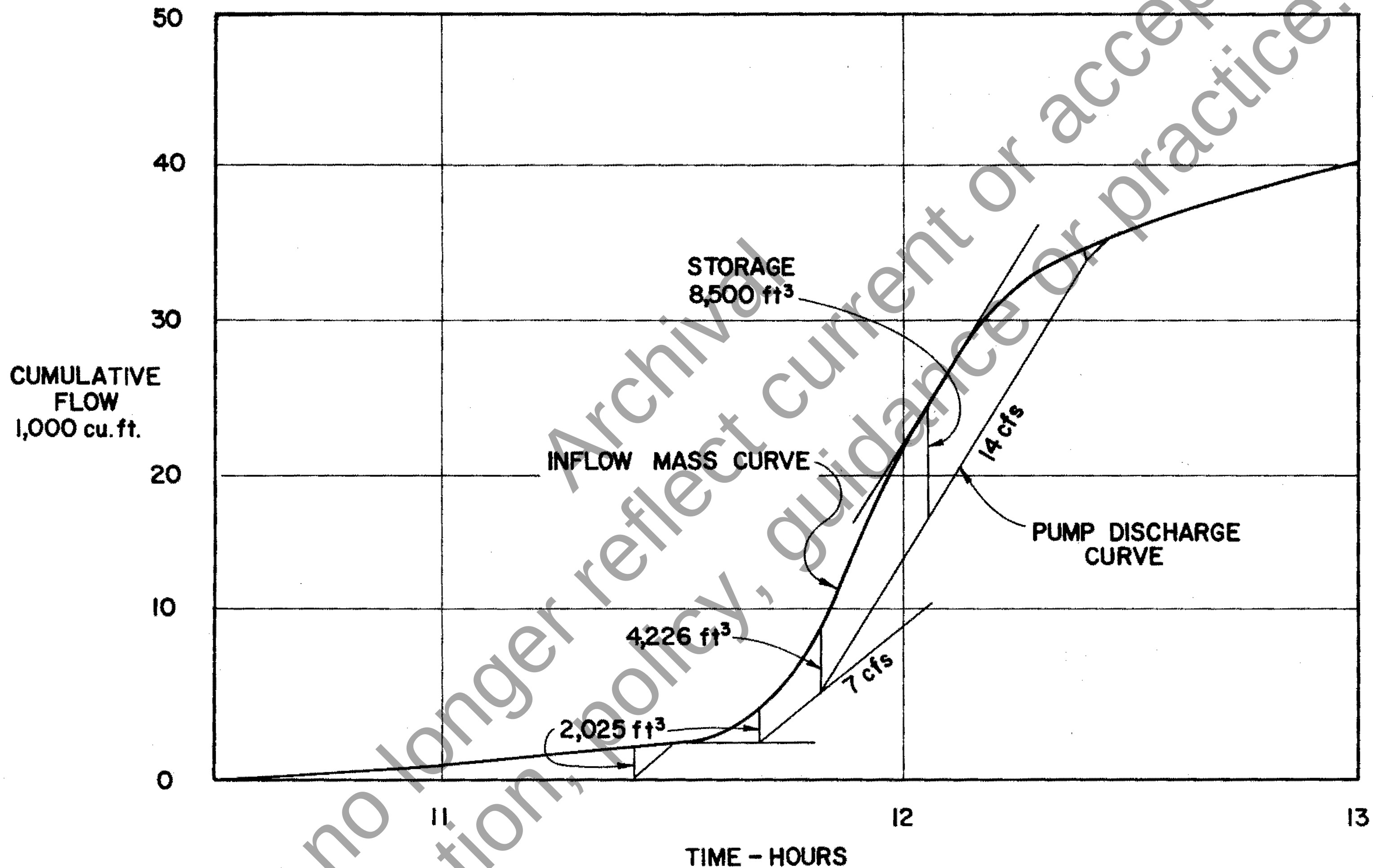


FIGURE 4-17 MASS CURVE ROUTING DIAGRAM

the storage basin, while the vertical distance between the inflow mass curve and the pump discharge curve represents the amount of storm water stored in the basin.

If the rate of inflow is greater than the pump capacity the inflow mass curve and the pump discharge curve will continue to diverge until the volume of water in storage is equal to the storage (4226 $ft.^3$) associated with the second pump-start elevation. At this point the second pump starts, and the slope of the pump discharge line is increased to equal the combined pumping rate.

The procedure continues until peak storage conditions are reached. At some point on the inflow mass curve the inflow rate will decrease, and the slope of the inflow mass curve will flatten. To determine the maximum amount of storage required, a line is drawn parallel to the pump discharge curve tangent to the inflow mass curve as shown in Figure 4-17. The vertical distance between the lines represents the maximum amount of storage required.

The routing procedure continues until the pump discharge curve intersects the inflow mass curve. At this point the storage basin has been completely emptied, and a pumping cycle completed. As the storm recedes, the pumps will cycle to discharge the remaining runoff.

In developing the pump discharge curve, the engineer should remember that the pump's performance curve is quite sensitive to changes in head and that the static head will fluctuate as the water level in the storage basin fluctuates. The designer should also recognize that the pump discharge rate represents an average pumping rate.

In the example problem two 7 cfs pumps are provided. The pumping conditions are as follows:

	Pump-Start Elevation	Pump-Stop Elevation
Pump No. 1 (7 cfs)	2.0 (2,025)	0.0 (0)
Pump No. 2 (7 cfs)	3.0 (4,226)	1.0 (597)

The numbers in parenthesis are the storage volumes (cu. ft.) associated with the respective elevations.

As depicted in Figure 4-17, Pump No. 1 is activated when the cumulative flow fills the storage basin to elevation 2.0 (2,025 cu. ft.). The pump discharge curve is drawn from the base line at a rate of 7 cfs. Since the rate of discharge is greater than the inflow rate, the basin will quickly empty, and Pump No. 1 will shut off. The pump discharge curve will be horizontal because there is no pumped discharge until the inflow builds up to the Pump No. 1 start elevation again.

Pump No. 1 comes on again as the inflow builds up. Since the inflow rate is greater than the discharge rate the curves will diverge until the available storage (4,226 cu. ft.) is reached at Pump No. 2 start elevation. The combined discharge rate is plotted, and a line is drawn parallel to the discharge curve through the point of tangency of the inflow mass curve to determine the maximum amount of storage required as shown in Figure 4-17. The vertical distance between the lines represents the maximum amount of storage required (8,500 cu. ft.).

The peak storage conditions have now been reached, and the storage decreases. The routing continues until the two curves intersect, at which time the basin will have emptied. Pump No. 2 will shut off when the storage volume is equal to the volume (597 cu. ft.) associated with the Pump No. 2 stop elevation (1.0'); Pump No. 1 will shut off when the storage pipe has been emptied at Pump No. 1 stop elevation (0.0). Subsequent inflows will cause the pumps to cycle as the storm flows recede; this additional cycling was not shown for simplicity.

The design is adequate since the available storage at the high water alarm is 8,785 cu. ft. High water design conditions are plotted on the stage-storage curve (Figure 4-14) for reference.

In the final design, fine tuning of mass curve routing procedure can occur after the pumps have been selected. For example, if two equal pumps are selected, the pumping rate when only one pump is pumping most likely would be greater than one-half of the combined rate due to head losses in the piping system. Another refinement can be made for the condition when all of the pumps have come on line and peak pumping conditions have been reached. The pump discharge curve can be adjusted to reflect changes in the pumping caused by changes in the static head. However, it is noted that these refinements do not act on the side of safety.

4-P. DISCUSSION

The designer now has a complete design that allows the problem to be studied in-depth. The peak rate of runoff has been reduced from 22 cfs, the inflow hydrograph peak, to 14 cfs, the maximum pump discharge rate. A reduction of 46.5 per cent is accomplished by providing for 8,500 cu. ft. of storage. This is only one possible design option. The designer may wish to reduce the pumping rate further by providing more storage, and additional combinations of pump discharge and storage can be considered.

It is important that the designer visualize what is happening during the peak design period. To aid in this process, the pump discharge curve developed in Figure 4-17 can be superimposed on the design inflow hydrograph (Figure 4-11), as shown in Figure 4-18, to obtain another picture of the routing process.

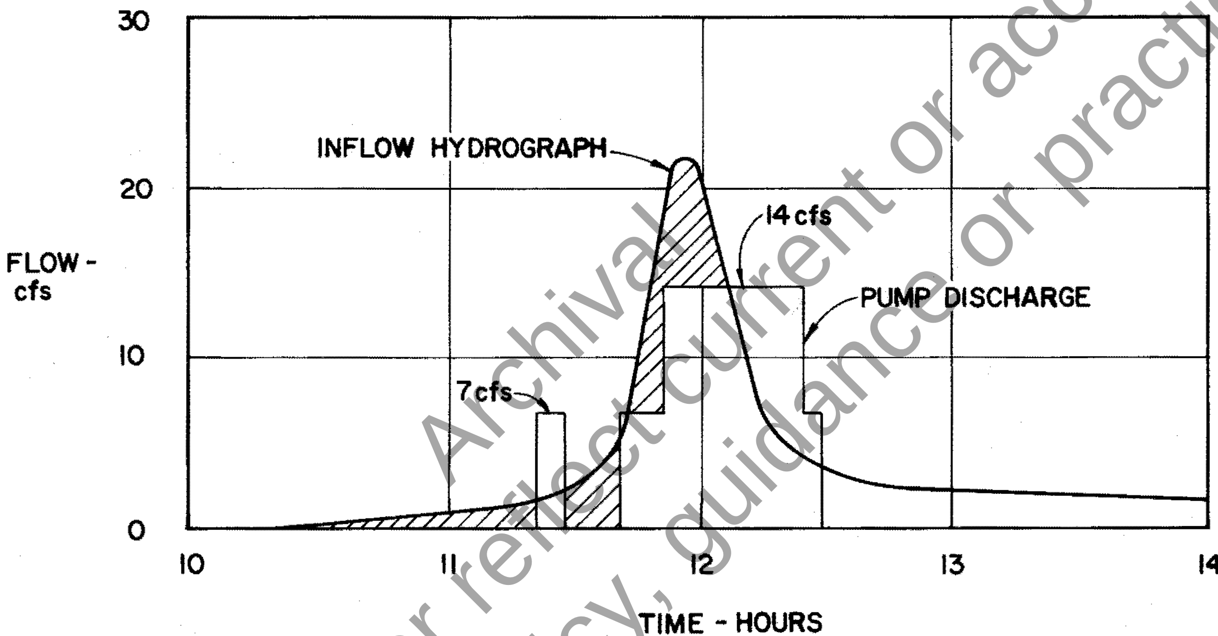


FIGURE 4-18 PUMP DISCHARGE

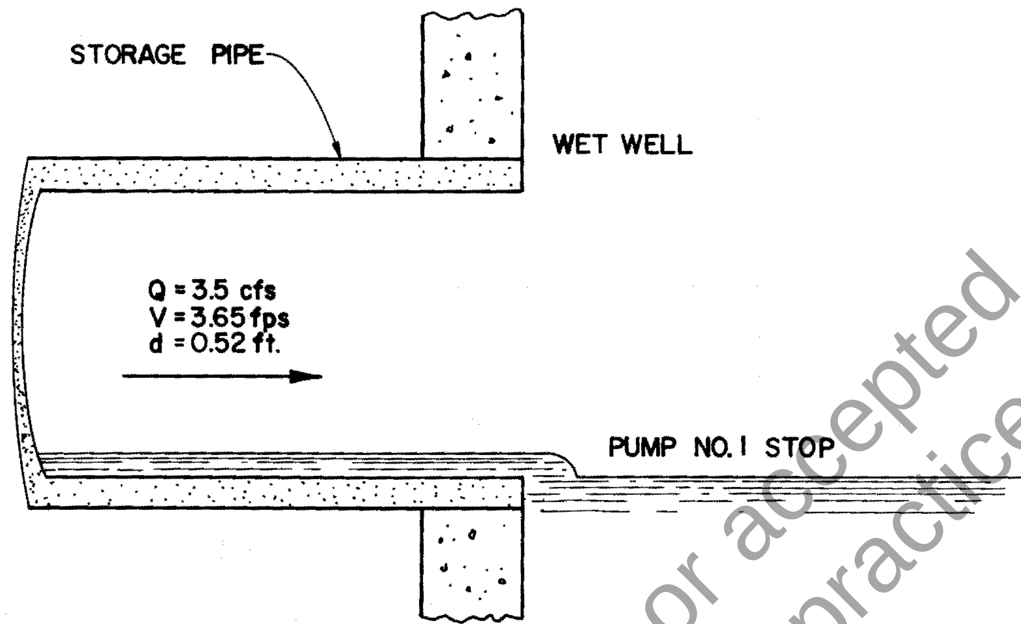


FIGURE 4-19 FLUSHING CONDITIONS for STORAGE PIPE

PIPE SIZE (inches)	PIPE SLOPE (ft/ft)	
24	.0083	
27	.0071	
30	.0062	
33	.0054	
36	.0048	
42	.0039	TRIAL SLOPES
48	.0033	(3 FPS, 1/8 FULL-FLOW, n = 0.013)
54	.0028	
60	.0024	
66	.0021	
72	.0019	
78	.00172	
84	.00156	
90	.00142	
96	.00130	

The shaded area between the curves represents storm water that is going into storage. Again, pump cycling at the end of the storm has been omitted in order to simplify the illustration.

To complete the design, the designer should investigate more frequent storms (2-10 yr. recurrence interval) to evaluate pumping cycles during these storms. Less frequent storms (100-yr. recurrence interval) should also be investigated to determine the amount of flooding that will occur.

Handling of sediment remains a difficult problem in pumping station design. Mechanical engineers prefer that as much sediment as possible be deposited in the storage boxes and wet well to minimize wear on the pumps while maintenance engineers prefer that the sediment be passed through the system so that the station is as maintenance-free as possible. While both of these goals may have merit, they are at cross purposes, and some trade-off must be obtained.

Since the velocity in the storage pipe is quite low (1-2 fps) sediment will tend to settle out in the storage pipe. Some engineers recommend a relatively steep slope of 1-2 per cent to pass the sediment into the wet well. As a general statement, the steeper the grade, the better the sediment removal; however, the steeper grade may cause the station wet well to be driven deeper into the ground, increasing its cost. A steep grade may also limit the length of pipe that would otherwise be available for storage.

It is difficult to analyze flow and sediment conditions in the storage pipe; one approach would be to investigate the "flushing case." Design publications recommend a minimum velocity of 3 fps when the pipes are flowing full; however, in the pumping station case, the pumping rates determine the pipe velocity. For the "flushing case," it is assumed that all main pumps have stopped and that the inflow rate is one-half of the smallest pumping rate to insure cycling. The slope of the storage pipe is then selected to provide a velocity of at least 3 fps. The flushing case for the example is shown in Figure 4-19.

The selection of the storage pipe size and slope is an important element in the trial and error design procedure. Figure 4-19 provides design slopes of various sized concrete pipe that will provide a velocity of 3 fps when flowing at a depth of D/8. While this criteria is quite rigorous, the resulting slopes for the larger pipes are still quite flat. If the storage pipe is depressed or isolated from the upstream storm drainage, a minimum pipe grade of 0.35 per cent is suggested to prevent low spots in the pipe.

In summary, the storage pipe and wet well should be designed to handle sediment; however, the pumping system should be designed to carry sediment-laden storm water in case sediment removal does not occur in the wet well.

* * * * * * * * * * * *

CHAPTER 5. SELECTION OF TYPE OF STATION AND EQUIPMENT

5-A. GENERAL

Some authorities have developed their standard design for pump stations, usually suitable for or adaptable to all conditions found within their area. Where no standards prevail, many options are available to the designer in the selection of type of station and equipment. There may be advantages or disadvantages associated with each option, leading to the necessity of establishing as criteria the desired characteristics of numerous design features.

The selection procedure is to first establish the criteria and then to select from the options available a combination which clearly meets the criteria. Cost, reliability, operating and maintenance requirements are all important considerations when making the selection. It is difficult and beyond the scope of this Manual to develop a totally objective selection procedure to focus on the best or only acceptable solution to any hypothetical case, because of the diverse elements and inputs to be considered. A degree of subjectivity will contribute to and enhance the effectiveness of the selection process.

First costs are usually of more concern than operating costs in stormwater pump stations since the operating periods during the year are relatively short. Ordinarily, first costs are minimized by providing as much storage as possible, with two or three small pumps, electrically-driven. As a guideline for selecting the number of pumps, the extremes of operating conditions can be considered. In a very conservative approach, two pumps can be used, with the inlet system designed to store most or all of the peak inflow. The pumps are both of the same size, but one is sufficient for normal outflow. The second pump is held in reserve, not being required except in case of breakdown or malfunction of the first. Pumps can be controlled to alternate starting so as to equalize usage. At the other extreme three or more pumps can be used with minimum storage, sufficient only to meet cycling requirements. The total capacity of the pumps must be equal to the peak inflow to the station, without provision for any reserve capacity. Much larger pumps would be required in the second case, assuming the same peak inflow. Most pump stations will be designed on a basis which avoids these extremes. No reserve or stand-by pumps are usually provided.

Special circumstances may dictate additional pumping units. Where a pump or driver failure and subsequent flooding could cause extensive property damage, loss, or a hazard to lives, an extra unit should be provided. Such extra units are often powered by natural gas engines which assure operation in the event of a power failure. Substituting a greater number of smaller pumps for fewer large pumps reduces the need for reserve units, since failure of any one pump would be less significant. Often, there will be a reduction in the required pump pit depth with the use of smaller pumps, which helps to compensate for the added cost of multiple units.

5-B. TYPES OF STATION AND EQUIPMENT

Although the criteria for the station design are to be first established, it is preferable for familiarization to initially consider types of station and equipment. The eight types of standard designs and examples illustrated in Chapter 2 - Review of Current Practice, may be considered a sufficient basic variety of combinations capable of meeting all needs. This is especially so when each type is expressed in two configurations, for a total of 16 type-variations. More extensive variations could easily be developed, conceivably even hybrid combinations of different types of pumps, but simplicity should govern and as a practical matter the selection procedures of this Manual are therefore limited to the types illustrated. The types are combined with the criteria in a matrix format to aid selection.

The types of station are:

2-B. Dry-Pit Example: (1) Two, or (2) Three, Horizontal Centrifugal Pumps with Electric Motors.

2-C. Dry-Pit Example: (1) Two, or (2) Three or more, Vertical Centrifugal Angle-flow Pumps with Electric Motors.

2-D. Wet-Pit Example: Circular Caisson with (1) Three, or (2) Multiple Vertical Pumps with Electric Motors.

2-E. Wet-Pit Example: Circular Caisson with (1) Two, or (2) Three, Vertical Pumps with Combination Drive - Electric Motors and Engines.

2-F. Wet-Pit Example: Rectangular Pit with (1) Multiple Vertical Pumps of two different capacities with Electric Motors, or (2) similar Vertical Pumps, some with Gas Engines and one or more with Electric Motors.

(Endless variations and alternates of pumps and drivers are possible with this type of station.)

2-G. Wet-Pit Example: Circular Pit with (1) Two, or (2) Three, Vertical Pumps with Engines (LPG).

2-H. Wet-Pit Example: Structure, with (1) Two or (2) Three Screw-type Pumps, with Electric Motors.

2-J. Wet-Pit Examples: (1) Two, or (2) Multiple Submersible Pumps, in Circular Caisson or Rectangular Pit.

5-C. STATION CRITERIA

It is difficult to concisely and uniformly express diverse station design features in the form of criteria, but the following is a listing of features to be considered. The listing should be of assistance in making comparisons and selections.

The three categories, (a), (b) or (c) are intended to convey a high, medium or low condition respectively, and apply to all features except 22, which is a gathering of generally unrelated special features which must not be overlooked, even if none is found to be applicable.

1. Station Design Capacity
   - (a) Maximum exceeding 300 cfs
   - (b) Maximum between 100 and 300 cfs
   - (c) Maximum less than 100 cfs

2. Station Design Head
   - (a) Over 35 feet TDH
   - (b) Between 15 and 35 feet TDH
   - (c) Less than 15 feet TDH

3. Storage Upstream of Pumps
   - (a) For velocity reduction, settlement of solids, minimizing equipment
   - (b) Utilized if available
   - (c) Not required or available

4. Quality of Water to be Pumped
   - (a) Turbid and sand-laden inflow
   - (b) Moderate contamination
   - (c) Minimal contamination

5. Inflow Rate
   - (a) Rapid increase
   - (b) Normal hydrograph
   - (c) Slow increase

6. Weather Conditions
   - (a) Extreme cold in winter
   - (b) Moderate winters
   - (c) Mild winters, no freezing

7. Discharge Conditions
   (a) Long rising outfall from each pump
   (b) Short free outfall from each pump
   (c) Limitation of discharge rate

8. Sump Dewatering
   (a) Sump pump required
   (b) Vacuum truck preferred
   (c) No provision

9. Electric Power Reliability
   (a) Completely dependable - dual service
   (b) Very dependable - single service
   (c) Undependable - frequent outages

10. Natural Gas/LPG Desired as Fuel
   (a) Completely dependable - dual service
   (b) Very dependable - good storage
   (c) Not readily available - supply unreliable

11. Station Siting
   (a) Good access from frontage road or similar
   (b) Good access from highway
   (c) Poor access, alongside highway

12. Soil Conditions
   (a) Rock
   (b) Hard, steep unshored cuts
   (c) Clay or soft soil

13. Foundation Conditions
   (a) Acceptable bearing strata
   (b) Piling required for bearing
   (c) Extensive dewatering with piling required because of uplift

14. Above-Ground Structure
   (a) Large acceptable
   (b) Modest preferred
   (c) Smallest possible desired

15. Structure Visibility
   (a) Large structure acceptable
   (b) Modest structure desired
   (c) Minimum only acceptable

16. Initial Cost
   (a) High capital cost acceptable
   (b) Moderate cost acceptable
   (c) Lowest cost mandatory

17. Maintenance Capability
   (a) Excellent with complex machinery
   (b) Reasonably good
   (c) Mediocre

18. Operating Cost
(a) High cost acceptable
(b) Moderate budget desired
(c) Lowest budget desired

19. Equipment Handling Devices-Built-in
(a) Elaborate type considered essential
(b) Simple type acceptable
(c) Minimum or none required

20. Equipment Handling Devices-Mobile
(a) Use preferred for all requirements
(b) Used to supplement built-in
(c) Not required due to elaborate built-in

21. Trash Handling Devices
(a) Elaborate built-ins preferred
(b) Simple built-ins found adequate
(c) Vacuum trucks preferred

22. Special Features
(a) Pre-screening of debris from inflow
(b) Vulnerability to hazardous spills
(c) Epoxy coating and lining of pumps
(d) Grease lubrication for pumps
(e) Galvanizing of steelwork
(f) Manifold to pressure discharge
(g) Sediment and hydrocarbon removal from discharge
(h) Emergency generator
(i) Supervisory control (telemetering)

5-D. SELECTION PROCEDURE

In the selection of type of station and equipment, the designer will experience a number of inputs from various sources in developing the criteria.

First are the site constraints, in other words, the items over which the designer has little or no control. These would mainly be the items listed in 5-C under:

1. Station Design Capacity
2. Station Design Head
4. Quality of Water to be Pumped
5. Inflow Rate
6. Weather Conditions
7. Discharge Conditions
11. Station Siting
12. Soil Conditions
13. Foundation Conditions

The next consideration might be Item 3, Storage Upstream of Pumps. That is to study what effects the addition of storage and the resulting reduced inflow rate would have on the design. This would generally be the designer's own input as also might be Item 9, Electric Power Reliability. If sufficiently reliable electrical power is available at a reasonable cost, the designer would probably go with the option and eliminate the others from consideration; otherwise, consideration for the use of engine driven pumps or standby generator may be necessary, Item 10, Natural Gas/LPG reliability. Items 14 and 15, Above-Ground Structure, and Structure Visibility, respectively, are more likely to rest with others than with the designer.

Operation and Maintenance may be expected to offer strong input regarding the items listed in 5-C under:

8. Sump Dewatering
17. Maintenance Capability
19. Equipment Handling Devices-Built-in
20. Equipment Handling Devices - Mobile
21. Trash Handling Devices
22. The various Special Features

It is assumed that Administration will set requirements regarding Item 16, Initial Cost, and Item 18, Operating Cost. For our example to follow, it is assumed that Administration has also decided on inclusion of Item 22 (i) Supervisory Control (telemetering).

The following hypothetical example is described in narrative form so as to be more illustrative, but the criteria items are covered in numerical sequence. <u>Example</u>: To drain a section of highway running parallel to a tidal inlet, a pump station with discharge Q of about 75 cubic feet per second is required, having a maximum total dynamic head of about 20 feet. The collection system is extensive and provides good storage. Run-off is not highly silt-laden and prescreening at grating inlets is to be provided. Inflow rate is normal and weather conditions not severe, with long dry spells. A free discharge from pumps to receiving tidewater can be provided, with station sited in the rear face of a levee which extends well above highest recorded tides. Soils are clay with no severe foundation difficulties anticipated. Electrical power is reliable, but single source, with no natural gas adjacent to site, so that electrically powered pumps are preferred with stand-by emergency generator. Operation and Maintenance prefers to dewater the sump with a view to minimizing corrosion, but sees little need for built-in handling devices except a simple electric hoist or jib-crane for trash handling. The economy of totally eliminating a protecting structure has been considered, but a simple low-profile enclosing structure is favored with access easily provided from the top of the levee. This is in part due to the desire for maximum protection against vandalism. Telemetering is to be installed, largely to provide continuous intrusion alarm. It is considered that capital cost with the range of features listed will be moderate and acceptable. An assessment of operating cost and the feasibility of an emergency generator to run the entire station, if necessary, depends on data explained in later Chapters, but simply stated here. Assuming a pump efficiency of 75%, three pumps of 75 hp would be suitable. An emergency generator capable of starting the third pump with two pumps running would not be of excessive size or horsepower.

On the basis of the foregoing description of station features, the following Criteria Table is set up:

1	(c)	7	(b)	13	(a)	19	(b)
2	(b)	8	(a)	14	(b)	20	(b)
3	(a)	9	(b)	15	(b)	21	(b)
4	(b)	10	(c)	16	(b)	22	(a)
5	(b)	11	(a)	17	(a)	"	(c)
6	(b)	12	(c)	18	(b)	"	(e)
						"	(h)
						"	(i)

5-E. SELECTION MATRIX

Figures 5-1 is a matrix which matches the 16 type-variations of station and equipment options with the 22 items of criteria in (a) (b), (c) or other category.

To each match a rating on a scale of 0 to 9 is given, 0 being represented by a black dot. Numerical values have been assigned with as much thought as possible, but some subjectivity is inevitable, and uniformity of the meaning of values assigned for different features is difficult to achieve. If a zero or black dot score is encountered at any point, that type of pump station should be considered unsuitable. Whereas the highest total score is intended to indicate the most suitable selection, it is more practical to consider that a score of 150 or more represents an acceptable choice. The Detroit type station 2-D (1) with emergency generator scores 195 when considered against the Example in 5-D. The rectangular pit 2-F (1) scores 193.

The matrix should be used as a guide, not an absolute authority. But it is very helpful in deciding between alternates and as a check list.

SELECTION MATRIX	TYPE OF STATION	(1) Dry-Pit, 2 Horiz. Centrifugal (2) do. 3 do. do.		(1) Dry-Pit, 2 Vert. Angleflow (2) do. 3 or more do. do.		(1) Circ.Caisson, 3 Vert. Electric (2) do. Mult. do. do.		(1) Circ.Caisson, 2 Vert.Comb. Drive (2) do. 3 do. do. do.		(1) Rect. Pit, Mult. Vert. Elect. (2) do. do. do. do. Engines		(1) Circ.Caisson, 2 Vert.Engine (LPG) (2) do. 3 do. do. do.		(1) Screw Pumps, 2 @ 30° Inclin. (2) do. do. 3 do.		(1) Submersibles, 2 Same Size (2) do. Mult. do.	
DESIGN FEATURES		2-B		2-C		2-D		2-E		2-F		2-G		2-H		2-J	
1. Design Capacity	a b c	. 1 9	. 2 8	. 4 2	9 6 .	. 5 9	9 7 6	. 4 9	4 6 6	9 8 7	9 8 .	. 4 9	6 7 6	. 2 9	. 4 6	. . 8	9 8 4
2. Design Head	a b c	4 9 7	6 9 7	9 7 4	9 7 4	6 9 7	6 9 7	6 9 7	6 9 7	6 9 7	6 9 7	6 9 7	6 9 7	. 5 9	. 5 9	6 9 9	6 9 9
3. Storage Upstream	a b c	9 5 .	9 5 .	9 6 2	9 6 2	8 8 8	8 8 8	8 8 8	8 8 8	9 9 8	9 9 8	9 9 8	9 9 8	9 9 9	9 9 9	6 6 9	6 6 7
4. Water Quality	a b c	8 4 2	8 4 2	8 4 2	8 4 2	2 6 9	2 6 9	2 6 9	2 6 9	2 6 9	2 6 9	2 6 9	2 6 9	9 6 2	9 6 2	8 6 4	8 6 4
5. Inflow Rate	a b c	9 9 8	9 9 8	9 9 8	9 9 8	6 9 8	8 8 8	4 9 8	6 8 8	9 8 6	9 8 6	6 8 9	8 9 9	2 6 9	2 6 9	9 8 6	9 8 6
6. Weather Condition	a b c	9 9 9	9 9 9	9 9 9	9 9 9	9 9 9	9 9 9	6 9 9	6 9 9	9 9 9	6 9 9	6 9 9	6 9 9	2 9 9	2 9 9	9 9 9	9 9 9
7. Discharge Condition	a b c	6 9 9	6 9 9	4 9 4	4 9 4	9 9 6	9 9 4	9 9 6	9 9 4	9 9 4	9 9 4	9 9 2	9 9 2	. 9 .	. 9 .	8 9 6	8 9 9
8. Sump Dewater	a b c	. . 9	. . 9	9 5 .	9 5 .	9 5 9	9 5 9	9 5 9	9 5 9	9 5 9	9 5 9	9 5 9	9 5 9	9 5 9	9 5 9	9 5 9	9 5 9

FIGURE 5-1. SELECTION MATRIX (Part 1)

SELECTION MATRIX / DESIGN FEATURES	TYPE	2-B (1)	2-B (2)	2-C (1)	2-C (2)	2-D (1)	2-D (2)	2-E (1)	2-E (2)	2-F (1)	2-F (2)	2-G (1)	2-G (2)	2-H (1)	2-H (2)	2-J (1)	2-J (2)
9. Elec.Pwr. Reliab.	a	9	9	9	9	9	9	6	6	9	6	2	2	9	9	9	9
	b	6	6	6	6	6	6	9	9	6	6	8	8	6	6	6	6
	c	2	2	2	2	2	2	8	8	2	9	9	9	2	2	2	2
10. Nat. Gas/ LPG Des.	a	.	.	.	.	.	.	9	9	.	9	9	9	.	.	.	.
	b	.	.	.	.	.	.	6	6	.	6	6	6	.	.	.	.
	c	9	9	9	9	9	9	.	.	9	.	.	.	9	9	9	9
11. Station Siting	a	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
	b	6	6	6	6	6	6	4	4	6	4	6	6	8	8	8	6
	c	2	2	.	.	2	2	2	2	4	4	2	2	4	4	4	4
12. Soil Condition	a	2	2	2	2	.	.	.	.	2	2	.	.	4	4	2	2
	b	9	9	9	9	2	2	2	2	6	6	2	2	8	8	4	4
	c	9	9	8	8	9	9	9	9	8	8	9	9	6	6	8	8
13. Found. Invest.	a	9	9	9	9	6	6	6	6	9	9	6	6	9	9	9	9
	b	6	6	6	6	2	2	2	2	6	6	2	2	4	4	4	4
	c	2	2	4	4	.	.	.	.	2	2	.	.	.	.	.	.
14. Above Gr. Struct.	a	2	2	9	9	4	4	9	9	9	9	9	9	8	8	4	4
	b	9	9	6	6	6	6	8	8	8	8	8	8	9	9	6	6
	c	4	4	2	2	8	8	3	3	2	2	2	2	8	8	8	8
15. Struct. Visible	a	2	2	9	9	6	6	8	8	8	9	8	9	9	9	2	2
	b	9	9	4	4	8	8	8	8	6	6	8	6	8	8	6	6
	c	4	4	.	.	9	8	6	6	2	2	6	4	4	4	9	9
16. Initial Cost	a	2	2	9	9	6	7	7	8	7	9	7	8	6	6	2	2
	b	9	9	3	3	9	9	8	8	7	6	7	7	6	6	6	6
	c	2	2	.	.	8	8	6	4	4	.	4	4	4	4	9	9
17. Maint. Capab.	a	6	6	9	9	6	6	9	9	8	9	9	9	6	6	6	6
	b	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
	c	9	9	2	2	8	8	6	6	7	6	6	5	8	8	8	8
18. Oper. Cost	a	6	6	9	9	6	6	8	8	9	9	8	8	8	8	4	5
	b	8	8	4	4	8	8	6	6	8	8	6	6	6	6	6	7
	c	9	9	2	2	8	8	4	4	8	6	6	6	6	6	9	9
19. Handling Built-in	a	2	2	9	9	4	5	8	8	6	8	4	4	8	8	.	.
	b	6	6	4	4	6	6	8	8	8	8	8	8	8	8	6	6
	c	8	8	.	.	8	8	4	4	9	8	9	9	8	8	9	9
20. Handling Mobile	a	9	9	.	.	9	9	8	8	9	8	9	9	9	9	9	9
	b	6	6	6	6	6	6	6	6	6	6	8	8	6	6	4	4
	c	2	2	9	9	2	2	2	2	2	4	2	2	2	2	.	.
21. Trash Handling	a	2	2	9	9	3	3	8	8	4	6	4	4	4	4	2	2
	b	4	4	8	8	6	6	9	9	2	2	6	6	6	6	6	6
	c	9	9	2	2	9	9	9	9	.	.	9	9	9	9	9	9
22. Special Features	a	9	9	4	4	6	6	6	6	6	6	6	6	4	4	6	6
	b	9	9	4	4	4	4	4	4	4	4	4	4	4	4	2	2
	c	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
	d	9	9	9	9	9	9	9	9	9	9	9	9	9	9	.	.
	e	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
	f	4	3	4	3	4	3	4	3	4	3	4	3	.	.	4	3
	g	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
	h	9	9	9	9	9	9	.	.	9	.	.	.	9	9	9	9
	i	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9

FIGURE 5-2. SELECTION MATRIX (Part 2)
(Read in conjunction with Figure 5-1)

5-F. SUMMARY AND CHECK LIST

The type of station selected must balance capital cost, operating cost and reliability. The following are helpful in determining this balance:

1. Electrical power, the cheapest, should have dual service to minimize the risk of expensive service interruptions. Where dual service is not available, an emergency generator is recommended.

2. Large engines running on natural gas are very reliable, but costly to install, particularly if a large building and overhead crane are provided. Reliability is increased even more with on-site LPG storage.

3. Reliable protection is afforded by smaller engines with LPG storage only, housed in a minimum structure without overhead crane facilities. These drivers do not require expensive maintenance. The capital cost will be higher than the cost of electric motors.

4. One gas-engine driven pump with two or more electric driven pumps of the same size provides a compromise of annual energy costs at reasonable additional capital outlay, while enhancing reliability.

5. The use of combination drive with electric motor and engine being interchangeable is not advised unless a magnetic clutch is provided. This disengages the motor in the event of power failure and the engine then starts automatically in response to sensing of water level.

6. All pumps for a given station should be of the same type, except for the sump or clean-up pump, if used. Vertical pumps are the usual type, with a submersible sump pump.

7. Screw pumps provide an interesting and apparently cost effective solution, especially for the lowest heads.

8. Three vertical motor-driven pumps or multiple submersible pumps with minimum sump construction are the most cost effective. An emergency generator increases reliability.

9. The expense and complexity of manifolding a number of pump discharges into a single discharge line is seldom warranted in normal stormwater pumping applications.

10. Simplicity in mechanical and electrical design reduces operating and maintenance costs, as typified by the drypit station with non-clog horizontal centrifugal pumps.

* * * * * * * * *

CHAPTER 6. WET-PIT DESIGN

6-A. GENERAL

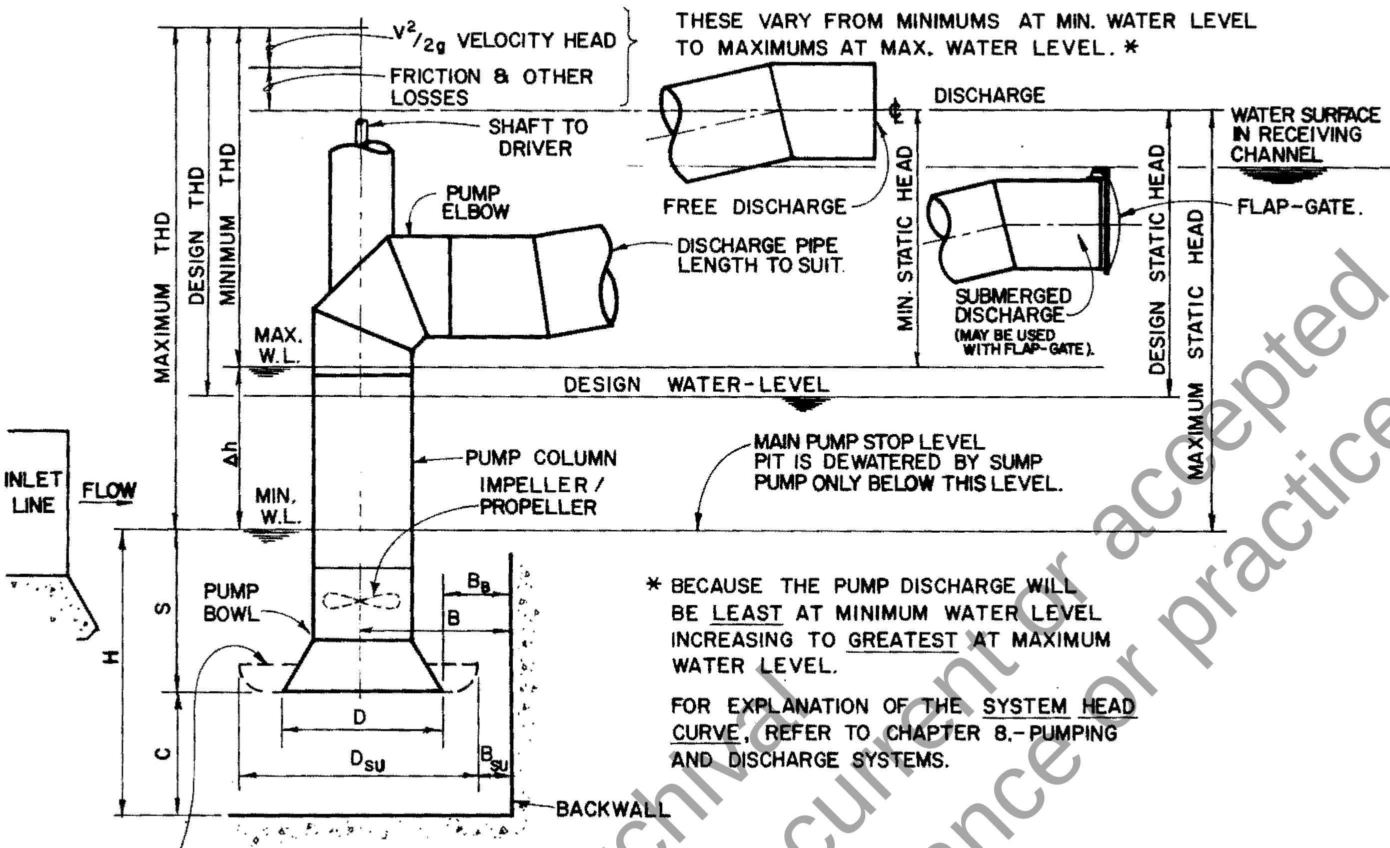
Examples of wet-pit stations were illustrated in Chapter 2. - Review of Current Practice. This chapter discusses the design of wet-pit stations with attention concentrated on the pump pit configurations required or utilized for the various types of pumps and pump settings. Consideration is also given to necessary details of the pumps and accessory equipment which are installed. These details may vary from one type of wet-pit to another, even though the same basic type of pump is used.

Pumps used in wet-pit pump stations are of three types - vertical, screw or submersible. Vertical Pumps are the most commonly used, and the Hydraulic Institute has conducted extensive research on the rectangular pits in which they are usually installed. This has resulted in comprehensive dimensional criteria based on the pumps suitable for a particular application. Because pump pits complying with these criteria were believed by other researchers to be deep and expensive, they developed alternate criteria whereby shallower pits could be used. This involves modifying the pump bells by adding suction umbrellas.

Sometimes vertical pumps are installed in circular caissons, and criteria for this type of wet-pit are also given in this chapter. Screw pumps are frequently designed for 30° inclination and as this approximates to a 1-1/2:1 slope ratio, this inclination is utilized and illustrated. For submersible pumps, a manufacturer has developed criteria which can be applied when multiple pumps are used in a rectangular pit. These subersible pump criteria become important when the pumps are in the larger sizes; for smaller submersible pumps it is satisfactory to use simple rectangular or circular pits, often precast boxes or pipe sections.

The submersible pump is now also becoming available in a vertical propellor configuration, where in higher capacities at lower heads it competes more directly with the conventional vertical pump. Similar types of pump pit configuration are required.

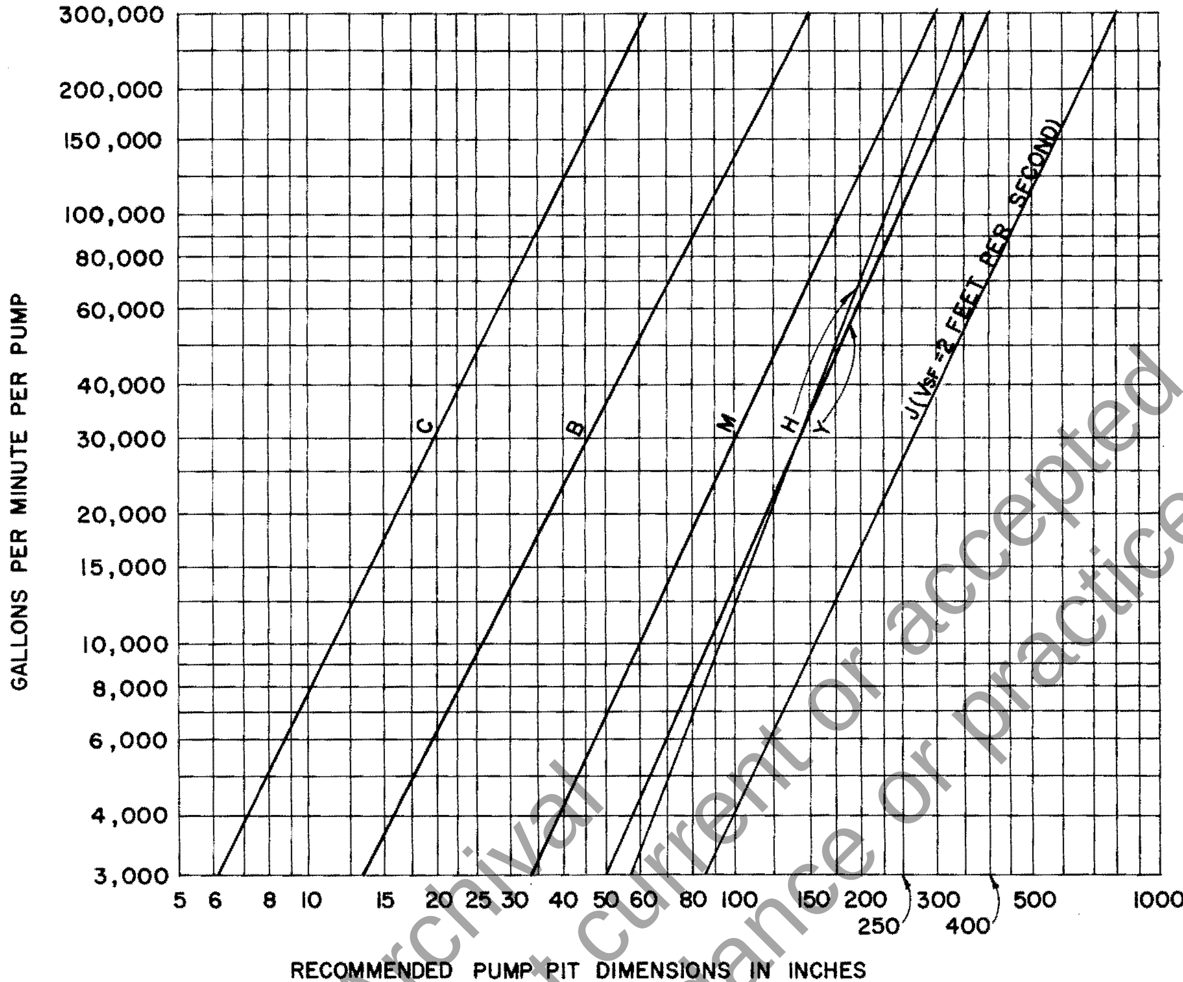
This chapter is primarily descriptive in nature, comparing various types of wet-pit. Numerical examples based primarily on Section 6-B will be found in Section 6-C and in Chapters 8, 9 and 15. An example on large submersible pumps is included in Section 6-H.



ALL UNITS BELOW ARE IN FEET, FT^2, FT/SEC OR GALS/MIN

A_P = CROSS-SECTIONAL AREA OF THE PUMP COLUMN
B = MAXIMUM DISTANCE FROM CENTERLINE OF PUMP TO BACKWALL
B_B = BACKWALL CLEARANCE WITHOUT SUCTION UMBRELLA
B_{SU} = BACKWALL CLEARANCE WITH SUCTION UMBRELLA
C = BOTTOM CLEARANCE (UNDERSIDE OF BELL TO BOTTOM OF PIT)
D = PUMP BELL DIAMETER (WITHOUT SUCTION UMBRELLA)
D_{SU} = PUMP SUCTION UMBRELLA DIAMETER
g = ACCELERATION OF GRAVITY - FEET PER $SECOND^2$
H = MINIMUM DIMENSION FROM MINIMUM WATER-LEVEL TO BOTTOM OF PIT
Δh = PUMPING RANGE FOR MAIN PUMPS OF STATION.
h_f = FRICTION HEAD LOSSES
h_p = COLUMN AND ELBOW LOSS
h_s = STATIC HEAD
h_v = VELOCITY HEAD LOSS
M = SPACING OF PUMPS, CENTER-TO-CENTER
n = MANNING FRICTION FACTOR USUALLY = .013, APPLICABLE TO DISCHARGE PIPE.
Q = FLOW - G.P.M. FOR PUMPS - C.F.S. FOR INLET AND DISCHARGE LINE.
S = MINIMUM SUBMERGENCE AS REQUIRED FOR PROPER PUMP OPERATION.
TDH = TOTAL DYNAMIC HEAD; TOTAL OF STATIC HEAD, VELOCITY HEAD, FRICTION & OTHER LOSSES
V_B = VELOCITY OF FLOW AT PERIPHERY OF SUCTION BELL
V_C = VELOCITY OF FLOW IN PUMP COLUMN (USE FOR VELOCITY HEAD, $V^2/2g$).
V_D = VELOCITY OF FLOW IN DISCHARGE LINE(S)
V_I = VELOCITY OF FLOW IN INLET PIPE.
V_{SF} = VELOCITY OF STREAM FLOW IN PUMP PIT.
V_{SU} = VELOCITY OF FLOW AT PERIPHERY OF SUCTION UMBRELLA.
V_{TR} = VELOCITY OF FLOW AT TRASH RACK.

FIGURE 6-1 PUMP PIT AND PUMPING TERMINOLOGY



THE ABOVE IS REPRODUCED FROM HYDRAULIC INSTITUTE STANDARDS
(NOTE: DIMENSIONS J AND M AND VELOCITY V_{SF} ARE SHOWN AS A, S & V_C RESPECTIVELY IN THE ORIGINAL)

J = MINIMUM DISTANCE FROM TRASH RACK TO BACKWALL (LENGTH OF PUMP PIT).

V_{SF} = MAXIMUM VELOCITY OF STREAM FLOW (0.5 FT./SEC. RECOMMENDED).

B = MAXIMUM DISTANCE FROM CENTERLINE OF PUMP TO BACKWALL.

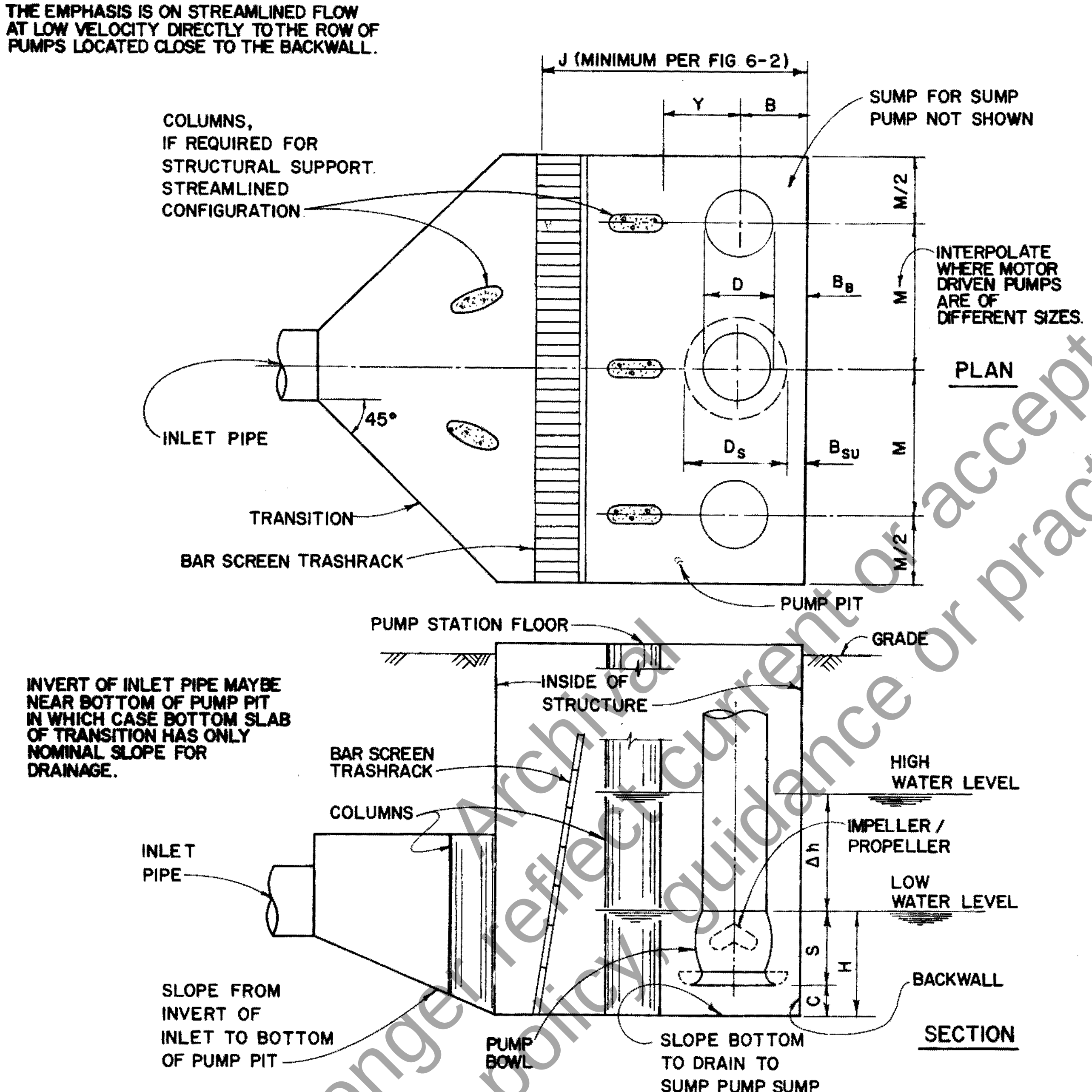
C = AVERAGE DIMENSION FROM UNDERSIDE OF BELL TO BOTTOM OF PIT.

H = MINIMUM DIMENSION FROM MINIMUM WATER-LEVEL TO BOTTOM OF PIT.

M = MINIMUM CENTER-TO-CENTER SPACING OF PUMPS.

Y = MINIMUM DISTANCE TO PUMP CENTERLINE FROM DOWNSTREAM END OF ANY OBSTRUCTION IN SUMP (OBSTRUCTION MUST BE STREAMLINED.)

FIGURE 6-2. RECOMMENDED PUMP PIT DIMENSIONS PER HYDRAULIC INSTITUTE STANDARDS



B = .75 D
B_B = .25 D
B_{SU} = .10 D
C = .50 D MINIMUM
D = FROM MANUFACTURERS' DATA (VARIES).
D_S = AS REQUIRED FOR V_{SU} = 2 FT/SEC (REFER TO FIGURE 6-5)
M = AS FIGURE 6-2, BUT 2 D MINIMUM FOR MOTORS AND 10'-0" MINIMUM RECOMMENDED FOR ENGINES
S = SUBMERGENCE REQUIREMENT FROM MANUFACTURERS' DATA (VARIES).
Y+B = J MIN. (OBSTRUCTIONS DOWNSTREAM OF TRASHRACK NOT RECOMMENDED BUT MAY BE NECESSARY FOR SUPPORT OF ENGINES)

V_B = 4.0 FT/SEC IS USUAL MAXIMUM BUT MAY DIFFER FROM ONE MANUFACTURER TO ANOTHER.
V_C = 10.0 FT/SEC MAXIMUM, LESS PREFERRED
V_D = 7.0 FT/SEC RECOMMENDED MAXIMUM
V_I = 7.0 FT/SEC RECOMMENDED MAXIMUM
V_{SU} = 2.0 FT/SEC MAXIMUM, LESS RECOMMENDED
V_{TR} = 2.0 FT/SEC MAXIMUM, LESS RECOMMENDED
V_{SF} = 2.0 FT/SEC MAXIMUM, LESS RECOMMENDED

FIGURE 6-3. RECOMMENDED CRITERIA FOR RECTANGULAR PUMP PIT WHERE DEPTH IS MINIMIZED.

6-B. VERTICAL PUMPS IN RECTANGULAR PITS

Figure 6-1 shows the relationships between pump, water levels, submergence and total dynamic head, with applicable terminology explained. Figure 6-2 shows sump dimensions plotted against pump capacities. Figure 6-3 shows a typical rectangular pump pit with various items and critical dimensions identified. The information set out in these three figures is a composite which has been developed from the recommended criteria of the Hydraulic Institute Standards and further research by Los Angeles County Flood Control District. If reference to original sources is desired, see the Hydraulic Institute Standards themselves, and the Los Angeles Country Flood Control District Design Manual Pump Station, as referenced in Appendix B - Bibliography.

The basic criteria of the Hydraulics Institute are shown in Figure 6-2 and their utilization is recommended, with the proviso that the latest revisions be utilized, if differing from the examples or figures herein. Attention is drawn to the use of symbol M for center-to-center spacing of pumps in lieu of S in the original. The symbol S, with or without sub-scripts, is more appropriately used for pump submergence. Some other symbols are also changed to avoid incompatibilities between the sets of criteria illustrated.

An important feature of the Hydraulic Institute and the Los Angeles County criteria is that water velocity in the pump pit should be low and that the two or more pumps should be set at right angles to the direction of flow, with minimum clearance between pumps and back wall. Pump submergence below low water level is equal to or greater than manufacturers' published figures, except when suction umbrellas are used. Note that some manufacturers may use smaller bells than others for pumps of the same capacity. Required submergence may also differ, in general varying inversely with the bell diameter. Definition of terms will be found in Section 6-C and more details will be found in Chapter 9. - Pumps for Stormwater Applications.

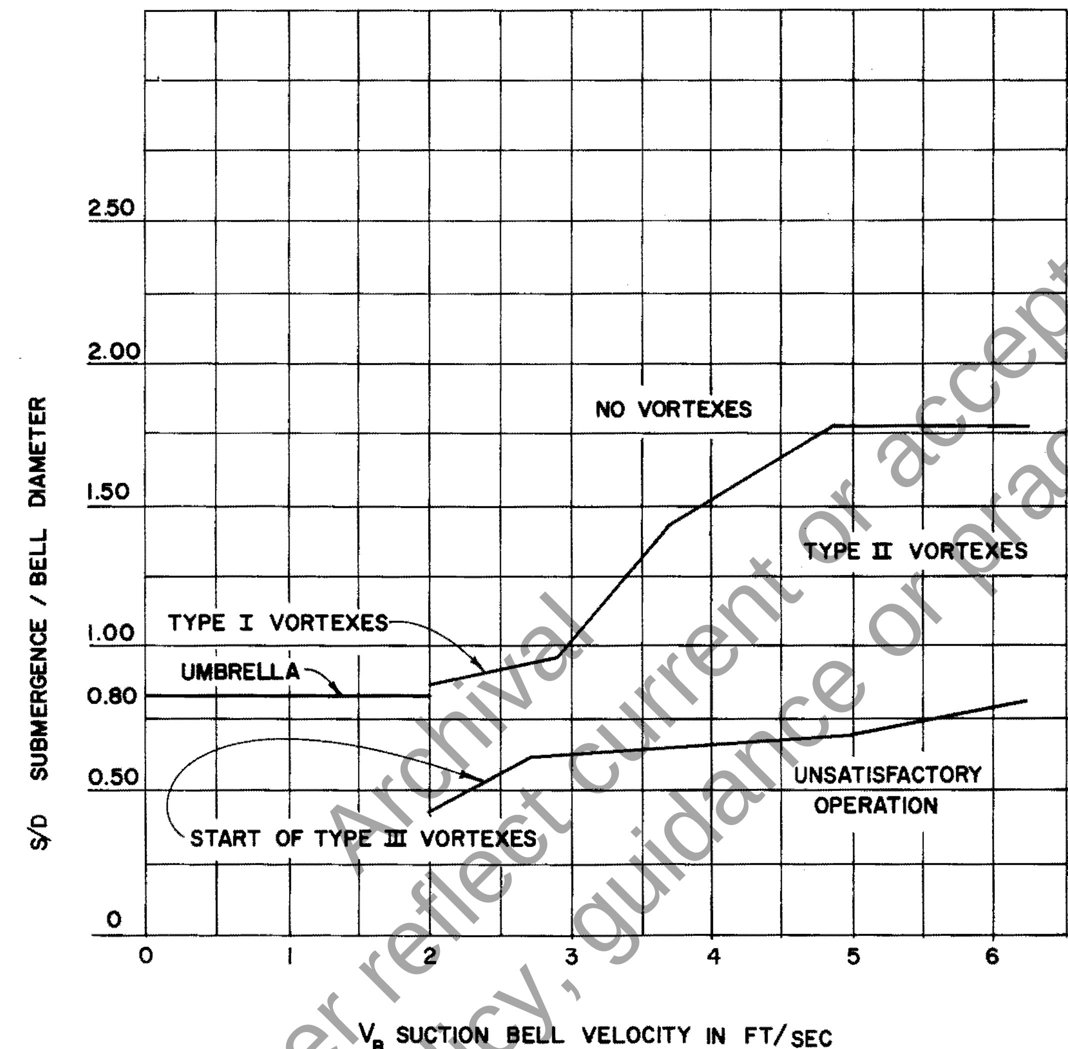
The criteria emphasize an upstream trash rack and streamlined flow throughout the length of the pit, without disturbances which would cause eddy currents and contribute to the formation of vortexes. Vertical columns may be placed in the pump pit between the trash rack and the pumps, provided they are streamlined and dimensional limits are observed. Sometimes these vertical elements are used to more directly channel the flow to the pumps, or to form cells for individual pumps. On other occasions, their primary purpose is to provide direct support under engines or other equipment which might otherwise cause vibration. Model tests formed an important part of the development of the Hydraulic Institute criteria.

Research of the Los Angeles County Flood Control District, who also had the capacity to conduct model tests, was directed in part to the use of umbrellas to reduce the submergence requirements and the required depth of the pump pit. The length and breadth of the pit conform to the Hydraulic Institute recommendations but the District's Standards as set forth in their Design Manual appear to represent that there should ideally be no obstruction in the pump pit between the trash rack and the pumps to interfere with streamlined flow. When pumps are driven by reciprocating engines upstream of the pumps, this may introduce an incompatibility. Such engines usually require direct vertical support beneath them to absorb unbalanced vertical forces generated during their operation. Therefore vertical columns or walls of some streamlined configuration should be provided under any engines utilized as pump drivers. It is inadvisable to carry engines on members spanning as beams because dynamic effects may cause objectionable vibrations. Unless direct support for engines by columns is provided, it is essential that deep members subject only to minimal flexural stress be provided to transfer all forces to the exterior of the pump pit structure.

In the recommended configuration of a rectangular pump pit, the pumps are placed in a straight line perpendicular to the direction of flow, with certain minimum spacings between pumps, depending on pump capacity and bell diameters. Ten feet minimum spacing is recommended when pumps are driven by engines. Spacing can be less with motors, but to meet electrical requirements at least 3 feet clear between motors is recommended. This is usually compatible with 2D minimum shown for M in Figure 6-3. In a multiple pump installation, all pumps may have equal capacity, but as explained in Chapter 4. - Collection Systems, study of the inflow hydrograph may indicate that pumps of two sizes would be more suitable. Where more than one size of pump is selected, it is satisfactory to interpolate conservatively to determine the minimum spacing between pumps. Smaller pumps will be closer to the backwall than larger pumps.

Clearance of pump bells from the backwall and from the bottom of the pit are closely controlled, as is the minimum submergence of the pump bells below the lowest water surface. Failure to observe these recommendations can result in a pump not operating satisfactorily, or in one pump interfering with the operation of another. This results in reduction in performance below design levels, coupled with possible damage to pumps due to cavitation, a condition which is described in Section 6-C.

Only when pumps are very small (about 5 cfs capacity) should an integral suction basket be considered. For larger pumps, a trash rack is essential to protect the pumps by screening out objects



PHENOMENON IS NOT RELATED SOLELY TO BACKWALL AS ILLUSTRATED.
VORTEXING OCCURS AT RANDOM LOCATIONS ACCORDING TO PUMP PIT CONDITIONS.

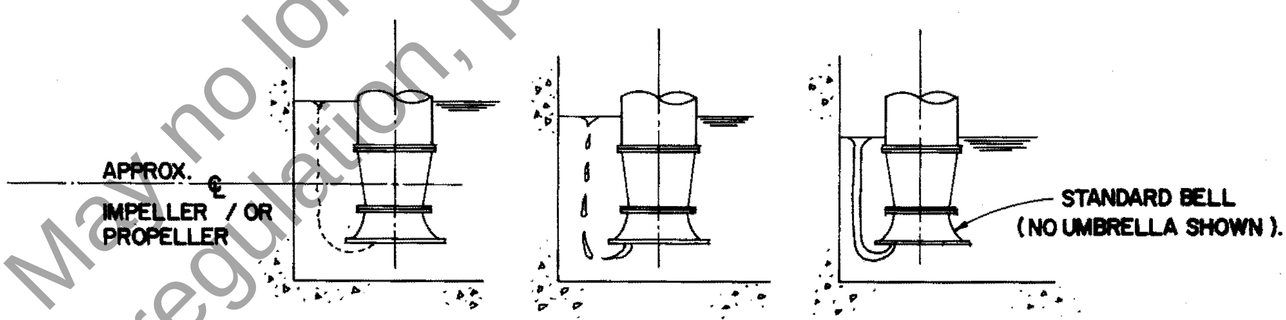


FIGURE 6-4. VORTEX DESCRIPTION AND SUBMERGENCE REQUIREMENTS

(COURTESY OF J. L. DICMAS)

large enough to cause damage. The distance from trash rack to backwall should be a minimum of five pump bell diameters to ensure smooth flow to the pumps. This should be checked against J in Figure 6-2 and Y & B in Figure 6-3. If inconsistencies result, it is better to have a longer distance in front of the pumps. Backwall clearance must always be kept to a minimum.

The inlet drain line should be located on the station center-line with a symmetrical flared transition from the inlet drain line to the full width of the rectangular pit. This reduces the velocity of the water approaching the pumps. Approximately 0.5 ft./sec. is desirable. This in turn encourages settlement of suspended solids on the bottom of the pit, reducing the wear-and-tear on the pumps. For flow velocities and quantities encountered in stormwater pump station design, the divergence angle of the transition walls should be 45°. Where the invert of the inlet is above the bottom of the pump pit, the bottom slab of the transition should slope down uniformly to the bottom of the pump pit. Provided the recommended dimensional limits are observed, there will be an evenly distributed flow of water to the pumps.

Close attention must be paid to ensuring a streamlined flow and eliminating obstructions which cause eddy currents and promote the formation of vortexes. Stairways, for instance, should not be located in the flow to the pumps. Vortexes are a swirling action related to a partial vacuum in the pump bowl. They begin at the water surface and can become a hollow piping drawn down through the water until air can enter the pump below the suction bell. A placid water surface helps minimize vortexes. J.L. Dicmas, an independent researcher studying reduced submergence, related the effect of vortexes to suction bell velocity and submergence. This is illustrated in Figure 6-4 and described in Section 6-C.

Vertical pumps are available with several different types of drive-shaft construction and lubrication. Pumps with oil-lubricated lineshaft bearings in an enclosing tube are to be preferred, but pumps with open shafts and grease lubricated bearings have been successfully used. Vertical pumps in rectangular pits can be driven by electric motors or by engines. With the usual size of pump that would be suitable, the permissible center-to-center spacing with electric motors would be less than the ten-foot spacing recommended for access and clearance around engines.

With the emphasis on absence of obstructions in the water flow in shallow pits, there may be some reluctance to provide interior columns to support engines, but without columns or other direct support, completely vibration-free operation is unlikely. To provide a satisfactory minimum value of Y (Figure 6-2), the pump pit may need to be lengthened more than would be required to meet other minimums. Longer-than-normal drive-shafts between engine and pump gear-head are sometimes necessary so that the supporting column under the engine is far enough upstream from the pump. With electric motors dimensional criteria can usually be satisfied with a shorter pit than would be required for engines. Computations for sump dimensions to suit selected equipment are given in Chapter 15. - Station Design Calculations and Layouts.

Rectangular pits are usually designed with a sump pump which can be used as needed to dewater the pit partially or completely. Sometimes there will be a continual minor inflow of water into the station so that the sump pump will operate frequently to discharge this. Sump pumps, sometimes termed low-flow pumps, are conveniently of submersible type and need have a capacity of only 300 - 500 gpm. Because this discharge is very small compared with the main pumps, it is usual to install a high-level cut-off switch to shut off the sump pump when the main pumps are operating.

Accumulations of trash upstream of the trash rack and deposits of mud and silt in the pit itself need to be removed as a maintenance function. Adequate access, working room and hoisting equipment must be provided, with good water supply.

6-C. SUBMERGENCE, NPSH, NON-VORTEXING CRITERIA AND PUMP PIT DEPTH.

The definition of several terms is appropriate at this point for proper understanding of the manner in which a vertical pump operates, and the necessity for maintaining conditions under which operation will be satisfactory. Referring to Figures 6-1 and 6-3, the pump bowl and impeller will be observed. The impeller rotates inside the bowl and imparts energy to the water which is raised up the pump column. In order for this operation to be satisfactory, the submergence, which is the distance from the water level to the underside of the pump bell, must be equal to or exceed a dimensional value established and published by the pump manufacturer. The internal relationship of the impeller to the underside of the pump bell is determined by the pump manufacturer and need not concern the pump station designer. He works with the manufacturer's published dimension for submergence which has been determined to be the minimum sufficient to avoid cavitation. This phenomenon is the condition of partial vacuum which occurs inside the pump bowl due to insufficient net positive suction head caused by insufficient submergence of the bottom of the bowl below the water level. As a result a vortex forms and air is drawn into the pump with the water. At the best, cavitation reduces the efficiency of the pump performance; at the worst, it can cause severe damage to the pump by erosion of metal from the pump impeller or bowl.

Another definition required at this point is the difference between the term propellor as used in Figure 6-1, and impeller as used in Figure 6-3 and subsequently. A propeller, named because it is so shaped, is used in low-head axial-flow vertical pumps; an impeller, of more complex shape, is used in mixed-flow pumps required to operate at higher heads. See Chapter 9 - Pumps for Stormwater Applications. Submergence, cavitation, vortexing and NPSH apply fully to both propeller pumps and pumps with impellers. The terms propellor or impeller may be used interchangeably in this section.

Net positive suction head, NPSH, is the pressure required to prevent cavitation at the pump impeller. This required or minimum NPSH is determined by test and is stated by the pump manufacturer. The operating or available NPSH must be equal to or greater than the required NPSH if cavitation is to be prevented.

$$\text{NPSH available} = \frac{Pa - Pvp}{\rho} + S - h_f$$

where: Pa = absolute pressure at water surface

Pvp = vapor pressure of liquid being pumped corresponding to the temperature at the pump inlet

S = elevation difference between liquid level and impeller eye (positive or negative)

h_f = friction head between suction line and impeller inlet

ρ = density of liquid being pumped.

<u>Note</u>: Provision of sufficient NPSH should always be checked. It applies to all types of pumps.

The units in the above equation must be chosen so that each term represents feet of the fluid being pumped. For vertical wet-pit pumps, h_f can be ignored, and ρ is 1.0. When pumping 70°F water at sea level, an NPSH of 33 feet is equivalent to zero water depth over the impeller eye. If the NPSH required by the pump is greater than 33 feet, the difference is the required water depth over the impeller eye. Note that the manufacturer states his required submergence which the pump station designer must provide or exceed. The designer is not directly concerned with the numerical value of NPSH which is discussed here solely for better understanding of pump operation. It may be likened to a person drinking a fluid through a straw by creating internal suction. Within limitations, atmospheric pressure will force the fluid up the straw.

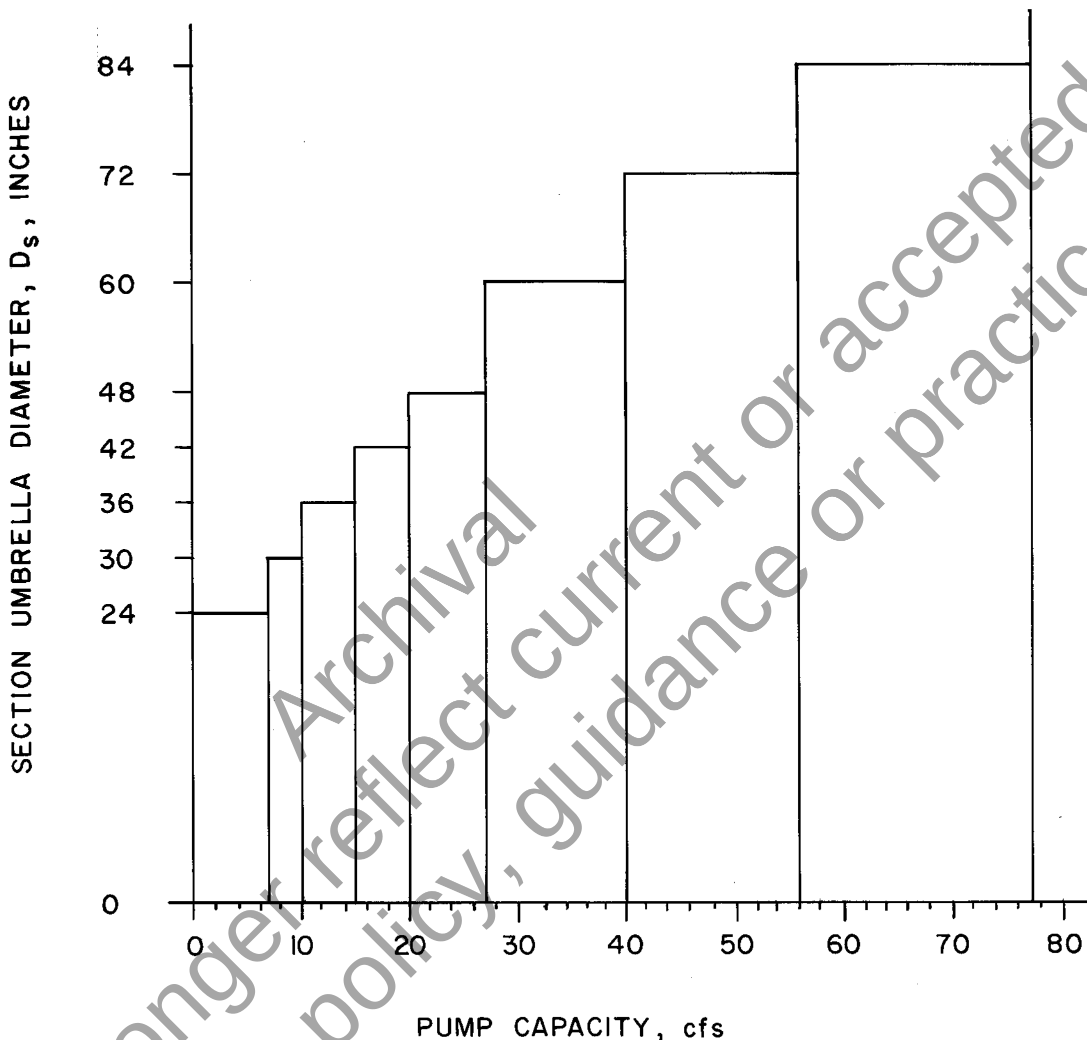


FIGURE 6-5. REQUIRED SUCTION UMBRELLA DIAMETER FOR PUMP INFLOW NOT EXCEEDING 2 FEET/SECOND.

J.L. Dicmas in his work provided a relationship between the velocity of the water at the periphery of the suction bell, and the submergence requirement in terms of the suction bell diameter. In general, the greater velocity the greater the submergence required. Referring to Figure 6-4, it will be seen that Dicmas described three types of vortex:

> Type I vortexes are the very start of vortex action as tiny bubbles of air are pulled into the pump. They are not detrimental to pump performance.
>
> Type II vortexes form for less than 30 seconds and pull air and floating debris into the pump, intermittently affecting capacity and horsepower.
>
> Type III vortexes are continuous and allow large amounts of air and debris into the pump accompanied by sucking noise. This is the cavitation condition, which is to be avoided.

Pump operation should be in the no-vortex range if possible. However, excursions into the Type I range are permissible and may occur when the pump-pit depth is minimized by the use of suction umbrellas, as described in Section 6-B, and explained in more detail hereunder.

The suction bell velocity is used in determining submergence requirements for non-vortexing. 4.0 ft./sec. is the usual maximum as shown in Figure 6-3, resulting in a required submergence of about 1.5D, see Figure 6-4.

The suction bell velocity is given by

$$V_B = \frac{\text{flow}}{\text{area}} = \frac{\text{cfs}}{.785D^2}$$

where: V_B = suction bell velocity, fps

D = bell diameter, ft.

The pump discharge at the minimum water surface elevation should be used in calculating bell velocity. This discharge and the resulting bell velocity will be less than at design water level. See Chapter 4, Section 4-I. Even so, it becomes evident that the standard manufactured pump bell is too small in diameter to provide the minimum submergence which is necessary to reduce the pump pit to minimum depth. Therefore a pump bell is frequently enlarged by the use of an umbrella, which is a dished or flat plate bolted to the underside of the pump bell. The umbrella is sized so that the velocity of water at its periphery is not more than 2 feet per second. Figure 6-5 relates standard umbrella diameters to pump capacity, based on this velocity. Other figures in Chapter 9. - Pumps for Stormwater Applications, illustrate the actual pumps and their components, and accessories such as umbrellas.

Therefore, as an alternate approach to the manufacturer's required submergence, the following non-vortexing criteria may be used. They apply only to rectangular pits with vertical pumps, and depend on suction umbrellas. The umbrellas are used to lower the inlet velocity and reduce the submergence requirements. They should be employed whenever the reduction in submergence will allow a more economical pump pit. When suction umbrellas are used, a submergence-to-bell diameter (S/D) ratio of 0.8 may be used, or 0.85 to be conservative.

Sometimes the inlet velocity cannot be reduced to two feet per second because of insufficient pump spacing. In such cases, the umbrella may be made smaller in diameter but the submergence must be correspondingly increased. Two hypothetical operating circumstances meeting the no-vortex condition can be investigated:

(a) For a 24" mixed flow pump, bell diameter is 33-1/2" and bell area is 6.12 ft.^{2}. At a flow of 15,000 gpm (33.33 cfs) suction bell velocity V_B is 5.44 ft./sec. From Figure 6-4, a value of S/D of 1.80 is required for the no-vortex range. Therefore submergence requirement is 1.80 x 33-1/2 = 60.3". Manufacturer recommends 59" minimum submergence.

(b) With the same pump use a suction umbrella 60" in diameter (see Figure 6-5). Umbrella area is 19.63 ft.^{2} and V_B is 1.69 ft./sec. Submergence can be reduced to 0.80 bell diameter, say 27".

There is therefore a possible saving on the pit depth of approximately 33 inches.

A numerical example can now be constructed, based on the station shown in Figure 4-9, for which storage and cycling computations were made. The first pump (Pump No. 1) with 27 cfs capacity at design head was shown with Δh = 1.96 feet and a pump-stop level of El. -9.01. A discounted Q of 25 cfs may be used on account of operation at minimum water level being considered. Using 25 cfs and an umbrella diameter of 48 inches results in V_B = 1.99 ft./sec. <2.0. This can be verified from Figure 6-5. A suitable pump selected from a manufacturer's catalog on the basis of design Q and design head has a bell diameter D of 34 inches. Using 0.8D, the submergence required is 27.2 inches = 2.27 feet. Bottom clearance C (Figures 6-3) is 0.50D = 17 inches = 1.42 feet. Therefore, elevation of bottom of pump pit to suit Pump No. 1 is El. -9.01 - 2.27 - 1.42 = -12.70 minimum.

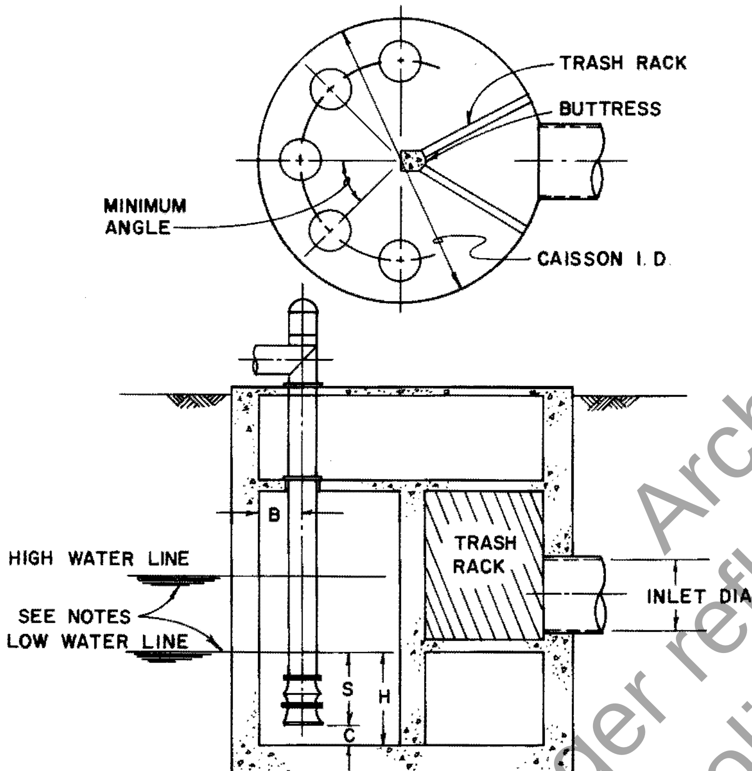
However, we are also concerned with the staging of the other pumps. Chapter 15 - Station Design Calculations and Layouts will show that Pump No. 2 stop-level is El. -8.05. This pump, selected as above, has a bell diameter D of 48 inches and an umbrella diameter of 72". 0.80D Submergence is 3.20 feet and bottom clearance is 0.50D = 2.0 feet. Therefore, the elevation of bottom of pit to suit Pump No. 2 is El. -8.05 - 3.20 - 2.0 = El. -13.25 minimum. In the actual construction, a bottom elevation of -14.22 was used at the perimeter of the pump pit slab, sloping down to -14.50 to drain into the sump pump pit. An S/D ratio of .85 was used in the design but bottom clearance was allowed to govern and actual S/D was 1.04.

A circumstance which also adds its complications is that different manufacturers often have different established diameters for the bowls of pumps of the same capacity, and different requirements for submergence. As an example, four different makes of mixed-flow pumps delivering 23,000 gpm at 24.5 tdh had bowl diameters varying from 37 inches to 48 inches. Since any one of the makes would meet specifications, it was necessary in the design to provide for this variation. Also, for the same size of pump, bowls for propellor pumps are larger than for mixed flow pumps. Since a suction umbrella sizing based on velocity of 2 ft./sec. is recommended, it would be possible to rewrite backwall and bottom clearances in terms of umbrella diameters based on this velocity.

To summarize, it will be realized that it is a complex procedure to effectively optimize storage, pumping equipment, drivers and pump pit dimensions when vertical pumps are to be installed in a rectangular pit of minimum depth. Model testing as recommended by the Hydraulic Institute may be desirable to verify satisfactory operation prior to completion of construction plans and specifications, unless above criteria have been closely followed.

6-D. VERTICAL ELECTRIC PUMPS IN CIRCULAR CAISSONS

A caisson is a hollow structure below the surrounding ground level. It may be of circular, rectangular or more complex shape on plan and may be constructed in various ways using poured concrete, cast-iron rings, steel sheet piling or precast concrete pipe. In this example, we will consider the circular type constructed by pouring a concrete ring wall at or above grade, then excavating inside the ring to cause it to sink into the ground. By adding concrete and continuing to excavate the bottom of the exterior structure will reach the intended elevation. At this point, the bottom is sealed, and the hollow shaft or pit is created, with internal work as required. The above-grade construction may be of the same circular plan and dimensions if sufficient floor area is provided. Figures 2-8 through 2-10 illustrate a small station of this type. Figures 2-11 through 2-13 show how the superstructure is readily enlarged to provide more area for equipment. Three to



UNIT PUMP G.P.M.	MAXIMUM STATION G.P.M.	CAISSON I. D. FT.	MIN. ANGLE DEGREES	MIN. INLET DIA. IN.	MAX. B INCHES	MIN. C INCHES	MIN. S INCHES	MIN. TOTAL TRASHRACK AREA-FT^2
2000	10 000	17	30	36	18	9	28	80
3000	15000	17	30	36	18	12	32	90
4000	20000	20	30	6	24	12	36	112
5000	25000	20	30	42	24	15	40	128
6000	30 000	20	30	42	24	15	42	150
7000	35 000	20	40	48	30	15	45	160
8000	40 000	20	40	48	30	15	48	170
9000	45 000	20	45	54	30	18	54	185
10 000	50 000	20	45	66	36	21	60	280
15 000	75 000	25	45	72	42	24	66	375
20 000	100 000	30	45	84	48	24	76	465
25000	125 000	35	45	96	54	30	84	600
30000	150 000	40	45	96	60	30	90	650
35 000	175 000	40	45	108	60	36	96	750
40 000	200 000	40	45	108	60	36	96	800

NOTES

- DEPTH OF WATER BETWEEN HIGH WATER LINE AND LOW WATER LINE SHOULD BE DETERMINED BY MINIMUM STORAGE REQUIREMENT TO ALLOW FOR NORMAL MOTOR "ON-OFF" CYCLING.
- INLET DIAMETER AND TRASHRACK AREA ARE BASED ON MAXIMUM STATION GALLONS PER MINUTE.
- FACE OF BUTTRESS CAUSES BIFURCATION OF INFLOW.

FIGURE 6-6. CRITERIA FOR SPACING AND SUBMERGENCE OF VERTICAL PUMPS IN CIRCULAR CAISSON-TYPE PUMP STATION five pumps, all of the same size, are usually installed. Upstream storage can be provided as shown in Figure 4-6 and in the example referenced, the usable storage is ample to satisfy cycling criteria. If storage were minimal and cycling a problem, there is no reason why a smaller pump should not be used to start. If two small pumps were used, symmetry could be preserved and alternating of starting could be arranged.

Due to the layout of the pit, the inflow from the storm drain is forced to bifurcate and flow more or less equally in opposite directions around the circular centerline of the pumps, after passing through the trash racks. This effect and flow pattern is vastly different from the recommendations of the Hydraulic Institute in regard to rectangular pump pits, but the resulting operation is completely effective. It appears to depend primarily on providing ample submergence for the pumps which can be readily obtained by deepening the caisson. This is usually a minor cost. Criteria relating station capacity and dimensions, pump size and spacing, submergence and bottom clearance were lacking until developed specifically for this Manual by J.L. Dicmas, as shown in Figure 6-6.

Many circular caisson wet-pit stations have been built without sump pumps to dewater them. The pump bowls and bells remain immersed below the low water level, unless a sump pump or ejector device is provided. Immersion is undoubtedly detrimental to the pumps, although no specific data is available. Of particular concern are periods of low flow where salt-laden run-off will stand in the wet well. Significant amounts of sand and silt may also accumulate. A preferred treatment is to remove the standing water. A sump pump may repay its cost by cleaning the station of accretions and by reducing wear and corrosion of the main pumps.

Because of the relatively small trash and debris storage capability provided in the caisson it is important to design the trashracks so they can be easily maintained. Access ladders, manholes, power operated crane hoists and provision for debris disposal must be built into the design. It is also important to have access to the area around the pump intakes as sand and silt may collect there.

The caisson has a very small hydraulic storage and maximum storm drain inlet velocities of the order of 7 feet per second may occur. Therefore a great deal of the sand and silt that enters a station of this type passes immediately through the pumps. For this reason, the pumps should have special features differing from pumps for a rectangular pit. They should have a lineshaft enclosing tube packed with a light hydraulic grease instead of the usual drip oiler system, and should have individual grease lines with Alemite fittings for each pump bowl bearing, with grease seals to limit entrance of silt. The usual pump bypass port should also be modified to accept a grease line and fittings. Mixed flow pumps should be used exclusively at reduced speeds, if necessary, rather than axial flow propellor pumps. See Chapter 9 - Pumps for Stormwater Applications. Impellers should be cast in aluminum bronze or similar abrasion resisting alloy. Compared with the rectangular pump pit, the caisson configuration provides simpler design solutions, but much of the text in Sections 6-B and 6-C will help basic understanding and should not be ignored.

Note also that the rectangular wet pit and the storage-box shown for the dry-pit stations in Figures 2-2 and 2-3 provide for depositing grit, debris and suspended solids upstream of the pumps. This results in a cleaner effluent, important where water quality is a consideration. By contrast, a downstream separation structure was required for the large caisson-type wet pit station shown in Figure 2-14 in order to satisfy environmental considerations.

6-E. CIRCULAR CAISSONS WITH ENGINE-DRIVEN VERTICAL PUMPS

Two designs utilizing caisson construction with engine-driven pumps are illustrated in Chapter 2. - Review of Current Practice. See Figures 2-15 through 2-17 and 2-20 through 2-23. The specific criteria used for pump spacing and submergence in these stations is not known. Generous submergence appears to be the primary reason for the good performance level reported. Accommodating the pumps in a circular caisson is not difficult, but when engines are used as drivers, more area is required. Consequently the engines are housed in a separate above-ground rectangular structure. This may be concentric with the caisson or may be suitably offset to provide necessary clearances. The design illustrated in Figures 2-15 through 2-17 utilizes true caisson construction; that is, the concrete sections are sunk into the ground. The invert of the storm drain inlet is set well above the bottom slab of the caisson and there is ample submergence for the pumps. A baffle wall is constructed on the centerline of the pump pit, thus limiting the influence of one pump on the other. A deflector wall constructed near the mouth of the storm drain inlet divides the flow between the two pumps.

The design illustrated in Figures 2-20 through 2-23 utilizes a circular pit. Only minimal usable storage results in the example shown, which is in accordance with design data. See Figure 4-7. Rapid cycling has been observed in operation. However, if the first pump start level were raised closer to the assumed design water level, the usable storage and the cycling time could be substantially increased. Since pump start-stop

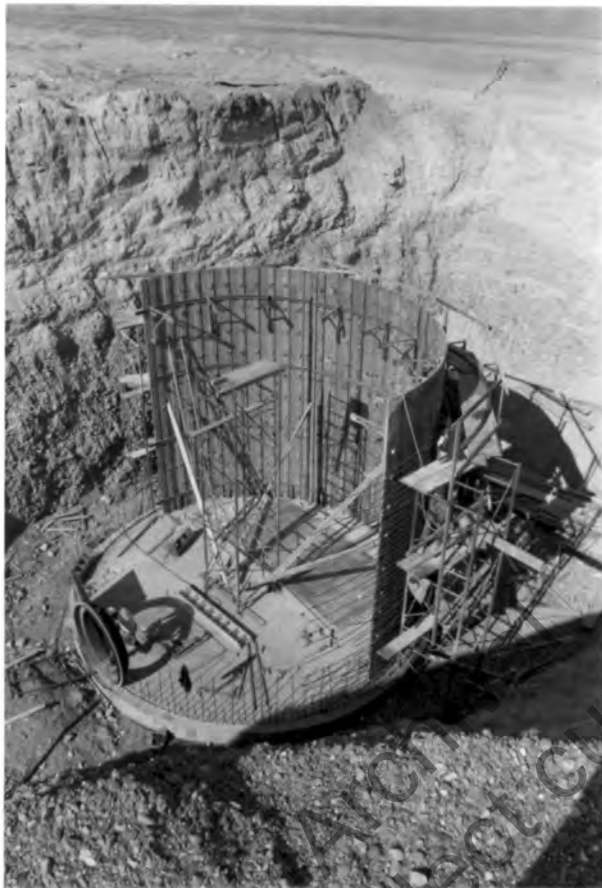
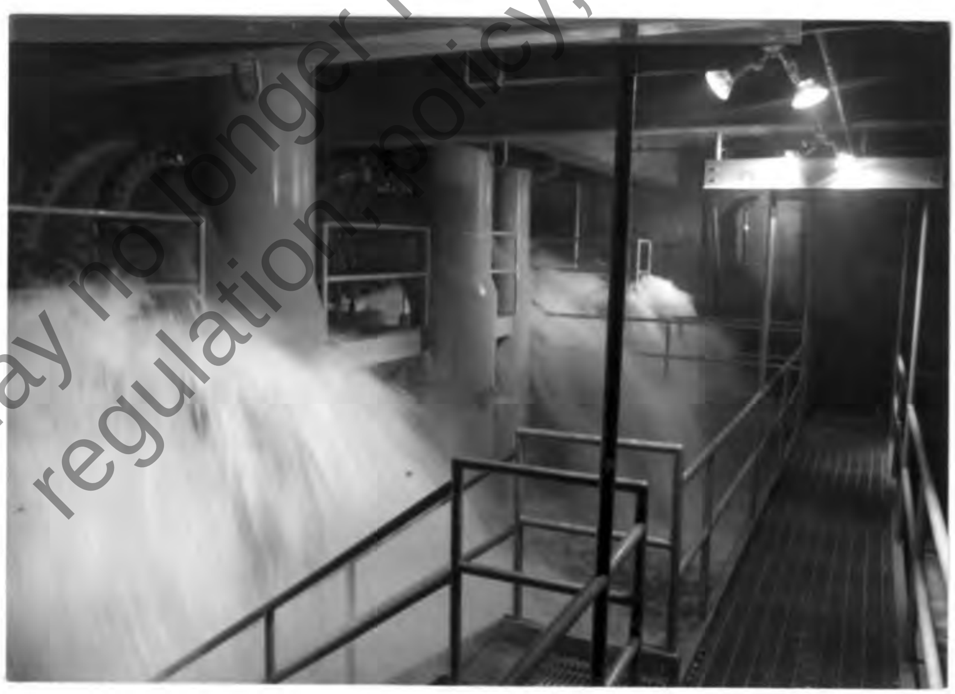


FIGURE 6-7.
CIRCULAR PIT
Construction in open cut where soil is favorable.

FIGURE 6-8.
RECTANGULAR PIT
Vertical pumps under test by recirculating through discharge manifold



elevations are easily changed as an operating and maintenance function, this may have been done.

The pump bowls are set in a small pit or sump below the main bottom slab of the circular pit. This provides greater submergence for the pumps, but also serves to accumulate sand, silt and grit with potentially harmful effects on the pumps. Grease lubrication and other features as set forth in Section 6-D would be recommended. The curved trash rack which is only large enough to cover the pump sump appears to be susceptible to blockage; a vertical or steeply sloped trash rack near the drain inlet is preferable.

A submersible low-flow pump serves to dewater the sump, but the small diameter discharge riser is susceptible to blockage by grit and rock particles, particularly since it has several elbows which restrict the flow. Enlargement of the discharge line and the elimination of elbows would be helpful. There should also be a flexible hose or slip-joint connection with guide-pipes to facilitate sump pump removal for inspection and maintenance.

A number of stations to this standard design have been constructed. Caisson construction may have been used or intended but Figure 6-7 shows construction in progress in open-cut. Hard soil which can safely stand on a steep cut is favorable to this type of construction.

6-F. SCREW PUMP STRUCTURES

Figures 2-24 and 2-25 illustrate an enclosed structure which is rectangular in side elevation. Inlet, trash rack and stairway will be observed for a two-pump arrangement. An inlet transition is recommended with splay walls at 45°, combined with a trash rack across the entire width of all the screws installed. Figure 6-9 gives general data drawn from manufacturers' catalogs. In the figure, the distance between the trash rack and the touch-point has been exaggerated to display the hydraulic relationship. Notes address other pertinent features.

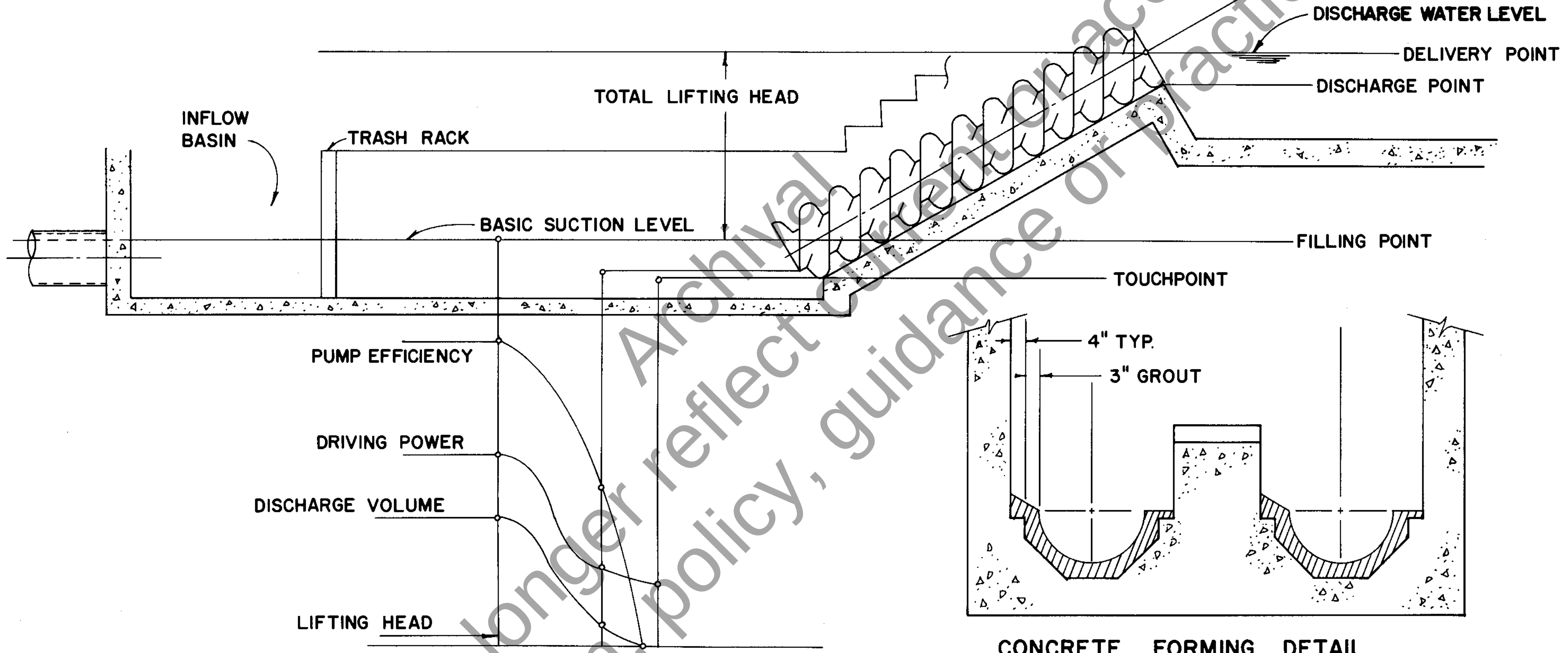
An access stairway is usually constructed between a pair of screws, or in the case of multiple screws, sufficient stairways are provided for access to each screw. All screws should be covered for safety and handrails must be provided on the stairways. It would be possible to construct a pump station with screw pumps more or less concealed in the side slope of a cut section, with the storage box below the pavement, inflow basin at the shoulder, and low profile screw pump installation set in the side slope, without the rectangular structure. The motor-room would be at the top of the slope, with frontage road access,

INFLOW BASIN

INFLOW BASIN SHOULD BE OF SUFFICIENT SIZE TO REDUCE VELOCITY OF INFLOW SO THAT SUSPENDED SOLIDS WILL BE DEPOSITED. BASIN MAY SLOPE TOWARDS TOUCHPOINT OF SCREWS AND MAY BE DRAINED BY SUMP WITH SMALL SUMP PUMP.

SCREW PUMP OPERATION

THE FILLING POINT IS THE INTAKE WATER LEVEL AT WHICH THE SCREW PUMP REACHES ITS FULL CAPACITY, BEST EFFICIENCY AND HIGH POWER CONSUMPTION. IF LEVEL RISES ABOVE THIS POINT, CAPACITY REMAINS UNCHANGED BUT POWER CONSUMPTION AND EFFICIENCY WILL DECREASE. IF LEVEL FALLS BELOW THE FILLING POINT, CAPACITY, EFFICIENCY, AND POWER CONSUMPTION WILL BE REDUCED. IF LEVEL FALLS BELOW THE TOUCHPOINT, PUMPING WILL CEASE.



HYDRAULIC AND CONSTRUCTION DETAILS

CONCRETE FORMING DETAIL

CONCRETE AREA CROSS-HATCHED SHOULD BE PLACED IN A FINISHING POUR AFTER SCREW INSTALLATION, AND SHAPED TO MATCH THE SCREW BY ROTATING SAME.

FIGURE 6-9. HYDRAULIC AND CONSTRUCTION DETAILS FOR SCREW PUMPS

similar to Figure 2-7. This would appear to be a cost-effective and reliable type of installation.

There is some limitation on the operating head of the screw pumps which is a function of the length and deflection of the screw. Larger screws are capable of spanning greater lengths and lifting through greater heads. Twenty-five feet of static lift is considered to be a maximum; this would suit many highway conditions.

A gravity discharge into a receiving channel or drain line is essential, since there is no capability of pumping through check valves into a manifold and discharge line under pressure.

Although domestic manufacturers of this type of pump refer only to electric motor drive, a foreign manufacturer shows details of diesel engine drive through a reduction gear. An emergency generator could be installed, or it would be possible to install natural gas engines to drive screw pumps if this type of driver is preferred because of reliability.

6-G. CAISSONS OR PITS FOR SMALL SUBMERSIBLE PUMPS

Compared with the other types of pump discussed in this chapter, small submersible pumps create fewer problems and less expense in the construction of a suitable pump pit. Figure 2-28 shows the use of large diameter precast concrete pipe as a caisson to accommodate five pumps. In addition to providing for low-flow conditions, the setting of the pumps at different elevations is a precaution in case of build-up of sand or silt in the bottom of the pit, lessening the number of pumps subject to risk of damage from this cause. Usually there will be a minimum of two pumps, but conceivably there are circumstances where a single pump would be satisfactory.

For very small stations with only one or two pumps, smaller circular pits can be constructed of concrete pipe, as illustrated in Figure 6-10. Pumps can discharge through flexible hoses, or through rigid pipe with a slip-joint connection at the pump. With either arrangement, any pump can be withdrawn as necessary for inspection or maintenance. In the one case, the pump is removed by raising it up vertical guide pipes reaching the full height of the pit. In the other case, the flexibility of the discharge line permits removal. Other illustrations in Chapter 2 show a rectangular pit for four pumps of two different sizes, and a rectangular pit with a trash rack suitable for horizontal submersible pumps.

With small design inflows and with little sand or silt, special design considerations can be minimal. Rectangular pits with

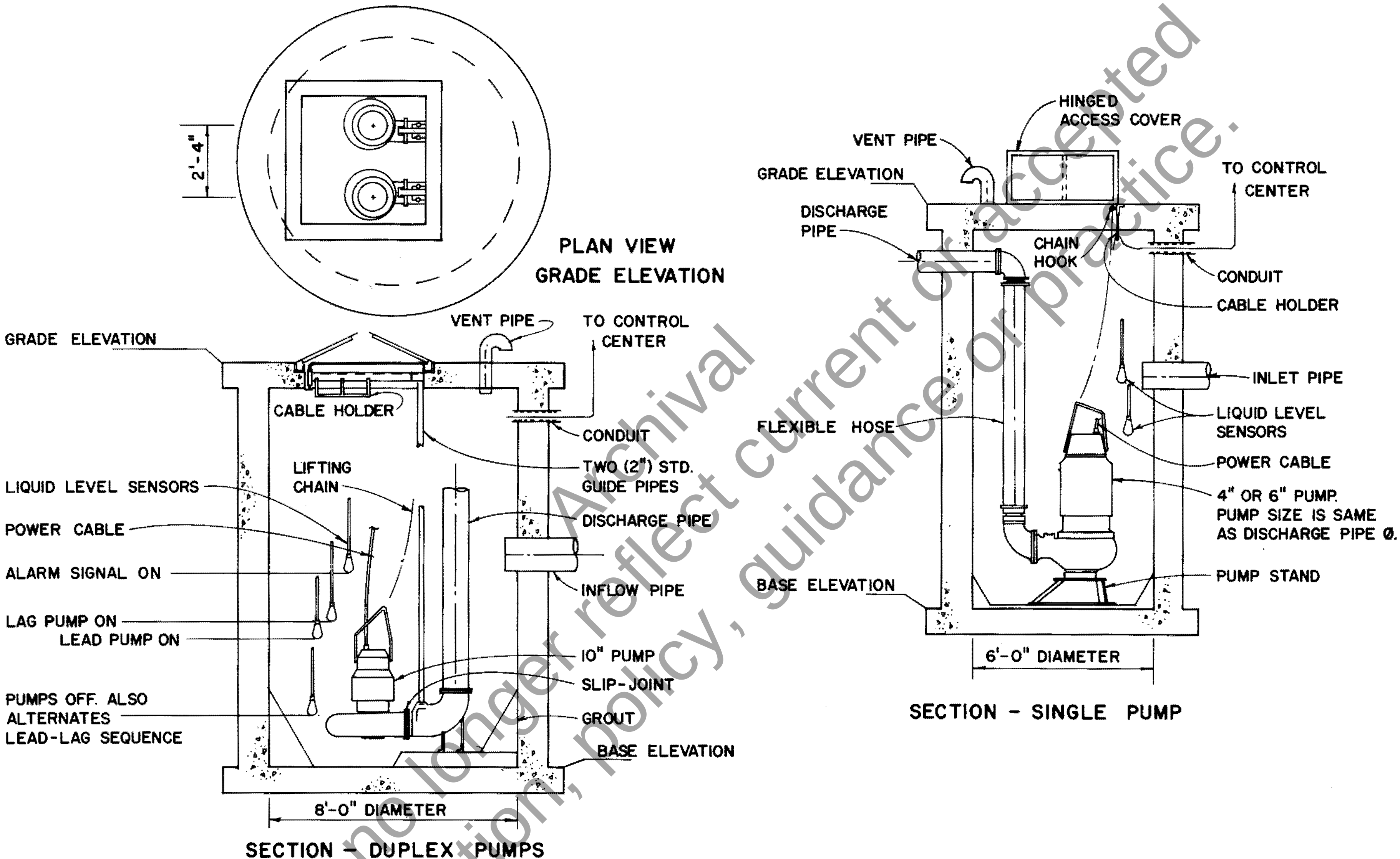


FIGURE 6-10. SMALL SUBMERSIBLE PUMP ARRANGEMENTS.

(COURTESY OF FLYGT CORPORATION)

irregularly spaced inlets may be used, as shown in Figure 2-26. Setting the pumps at differing elevations is advantageous, provided a correct start/stop sequence is also developed.

Since this type of pump is frequently used for sewage flows where the incidence of sand and silt is less, the designer should not be misled by illustrations in manufacturers' catalogs and attempt to apply details to stormwater which are more suited to sewage. These are small storage and retention time to avoid septicity and a lack of need to usually consider heavy sand and silt inflows.

Submersible pumps are usually the vertical type which has a bottom suction and side discharge, the motor being mounted vertically above the pump volute. The impeller is directly mounted on the motor shaft extension. In a newer concept specifically applicable to stormwater, the motor is mounted horizontally and drives a propeller. Water is drawn axially past the motor and through the propeller into the discharge line. The ease of withdrawing any pump for inspection and maintenance and any necessary repair is a significant advantage with either type of submersible pump. However, this advantage is sometimes coupled with necessity, because if fluidizing precautions are not observed, then the sand, silt and other debris entering the station may cause the pumps to be damaged.

Submersible pumps of the vertical type have impellers either of full or partially recessed type, or, in any case, of a non-clog type not generally susceptible to damage by solids. However, sand or silt entering the pit or caisson through the inlet line presents a definite hazard in operation which is frequently overlooked. When this inflow build-up or accretion reaches sufficient quantity, the pumps may become entirely blinded-off, and the whole station rendered inoperable.

Removal and repair or replacement of the pumps and cleaning-out of the station then becomes necessary. This is an expensive procedure, and the station would be out of service. In the case of the simple pit or caisson, it is obviously desirable to provide an agitating system to ensure that the pump always handles a fluid mixture and the pit is continually cleansed. This is quite easily done by piping potable water into the caisson and installing a spray ring system to agitate the sand and silt prior to pump start. If no piped water supply is available, then a very small submersible pump mounted well above the pit bottom can be used to recycle the stormwater for the same purpose before main pump start. In any case, the passage of sand and silt through the pumps must be tolerated as there is no attempt to settle out this foreign material nor to screen out large floating debris at the station, except with the horizontal type of pump where this is facilitated. Inlet gratings, as referred to in Chapter 4. - Collection Systems, must be relied on for the screening function.

Storage and cycling should be regarded differently when submersible pumps are used. Storage may be minimized because small submersible motors can tolerate much more frequent starting, as many as fifteen times per hour. This is due to the cooling effect of the water on the motor which is not normally exposed to ambient air temperatures. Reduced storage and wet well dimensions lead to higher self-cleansing velocities which may reduce accretions, but the agitator spray ring is a simple device which is recommended. Details will be found in Chapter 14. - Construction Details.

6-H. PITS AND LARGE SUBMERSIBLE PUMPS

Concurrently with the increasing size of submersible pumps, there has been effective research on configurations of rectangular pump pits which provide the best possible conditions of flow into and through the pit, and consequently the best possible pump performance.

There is a need to depart from the use of the very simplest pit or caisson configurations as the size of pumps and capacity of the station increases. An inlet chamber with baffle wall is recommended to prevent the inflow from directly splashing into the pump chamber and entraining air with it. A self-cleansing action is obtained both for the inlet chamber and the pump chamber based on minimizing dimensions as far as possible. The avoidance of eddy currents and vortices, the spacing of the pumps, and their clearance from walls has been as closely observed and researched as has been done for vertical pumps by the Hydraulics Institute. The research was sponsored by and is reproduced by courtesy of Flygt Corporation.

The pumping station configuration which has been tested and is recommended by Flygt is shown in Figures 6-11 and 6-12. Dimensional data related to pump discharge in gallons per minutes are shown in Figure 6-13. The pump pit volumes presented herein must be regarded as minimums for satisfactory operation under the most unfavorable conditions, namely when the inflow to the sump is half the output capacity of the pump. This case results in the maximum number of starts per hour. The maximum allowable number of starts may be as many as ten with large submersible pumps. This is not as many as with the small pumps, but still reflects the beneficial cooling effect of the water. This permissible increase in cycling leads, of course, to reduced storage requirements and so to less anticipated construction cost. Note that the pump pit is intended to be minimized in size to avoid settlement, at the expense of effluent quality. Of course, if settlement was to be encouraged, the pump pit could be enlarged and the possibility of agitator spray rings considered.

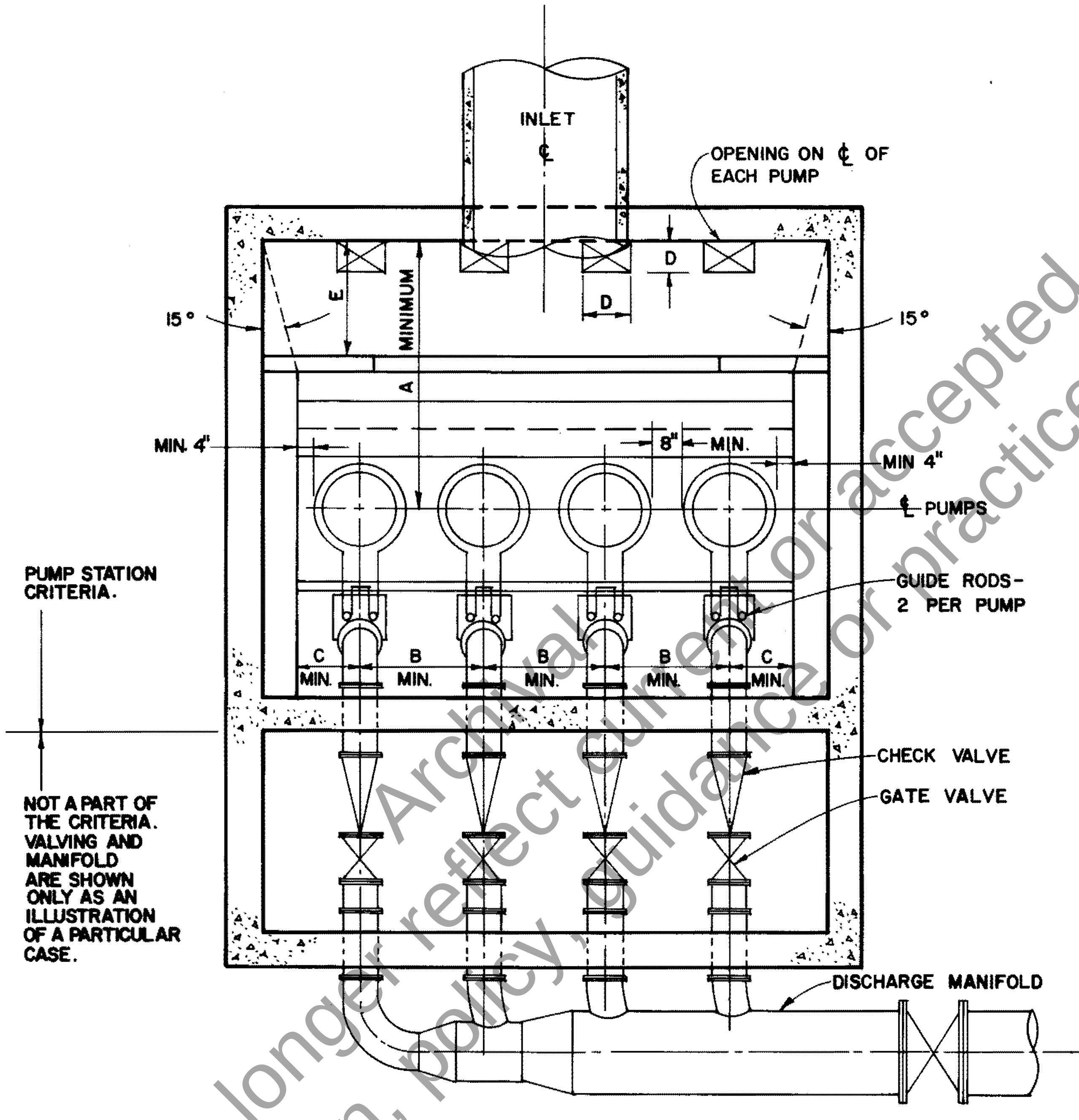


FIGURE 6-11.
PLAN OF STATION WITH FOUR LARGE SUBMERSIBLE PUMPS MANIFOLDED INTO COMMON DISCHARGE

(COURTESY OF FLYGT CORPORATION)

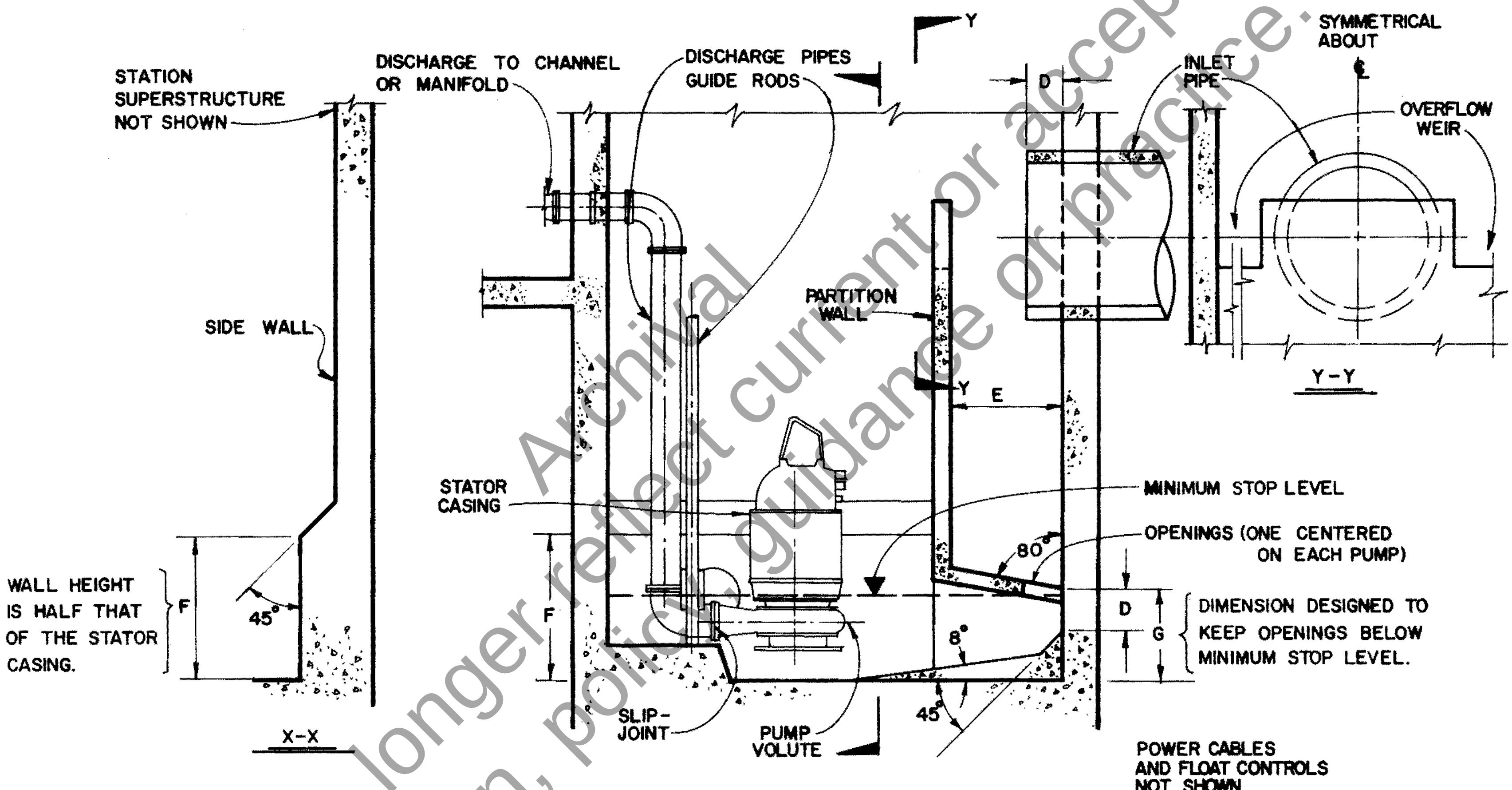
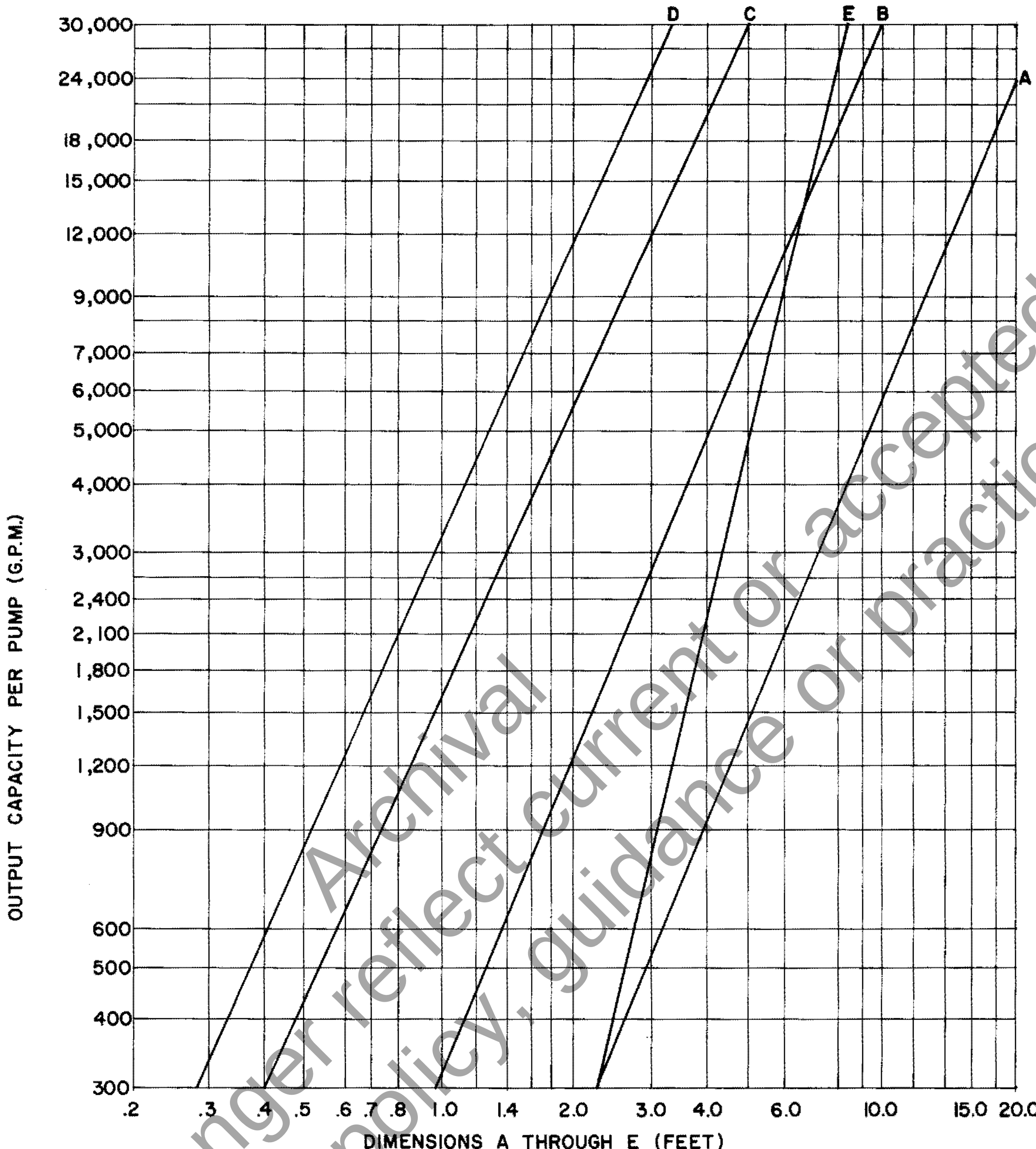


FIGURE 6-12. SECTION THROUGH STATION WITH FOUR LARGE SUBMERSIBLE PUMPS

(COURTESY OF FLYGT CORPORATION)



A = UPSTREAM WALL OF STATION TO CENTERLINE OF PUMPS.

B = CENTER-TO-CENTER SPACING OF PUMPS. (CLEARANCE BETWEEN CASINGS NEVER LESS THAN 8 INCHES.)

C = CENTERLINE OF END PUMP TO INSIDE OF SIDE WALL. (CLEARANCE BETWEEN CASING AND SIDE WALL NEVER LESS THAN 4 INCHES.

D = PROJECTION OF INLET LINE INTO STATION FROM UPSTREAM WALL AND PLAN AND VERTICAL DIMENSION OF BOTTOM OPENINGS IN INLET TROUGH.

E = LENGTH OF INLET TROUGH IN DIRECTION OF FLOW.

SEE FIGURES 6-11 AND 6-12 FOR ILLUSTRATION OF ABOVE.

FIGURE 6-13. DESIGN OF LARGE SUBMERSIBLE PUMP STATIONS.

(COURTESY OF FLYGT CORPORATION)

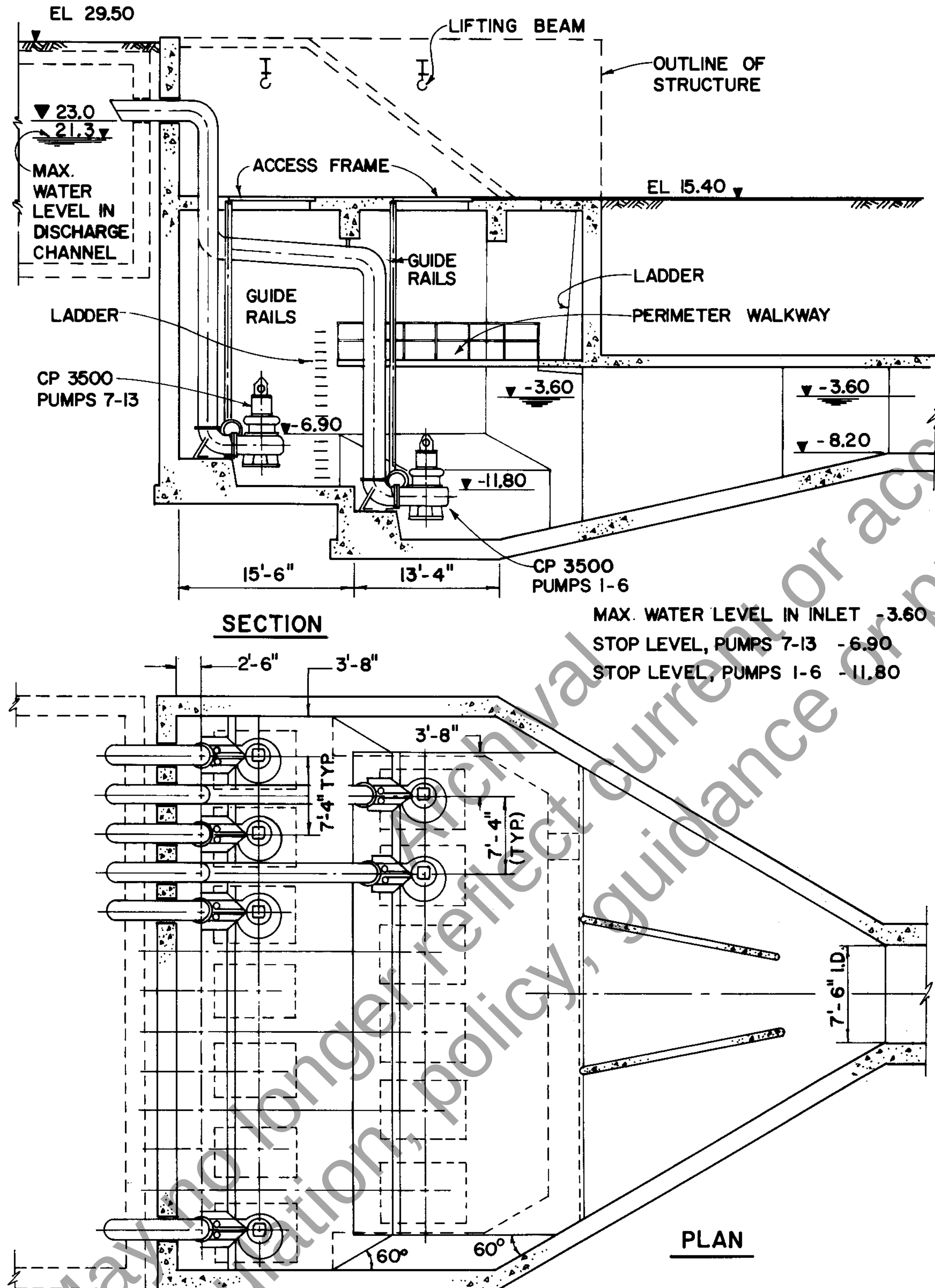


FIGURE 6-14. PUMP STATION WITH 13 SUBMERSIBLE PUMPS EACH 12000 G.P.M. AT 28 FT TDH WITH 122 HP MOTOR

(COURTESY OF FLYGT CORPORATION)

The distinction between what is a small submersible pump and what is a large pump is not clearly defined, but use of Figure 6-13 appears to lead to values of B (pump spacing) less than the pump volute dimension as capacities decrease. It is assumed that this denotes a break-point above which the large pump criteria should be used.

Other configurations have tested where the relationship of the inlet line to the pumps was far less favorable, such as from one side of the station or from one side of the station and at the bottom of the pump pit. A symmetrical flared configuration similar to Figure 6-3 could also be used. This is illustrated in Figure 6-14. Note always that the emphasis is on self-cleansing action, not sedimentation.

Referring again to Figures 6-11 and 6-12, the inlet pipe need not be located centrally in the wall opposite the pumps though it is advantageous to locate it somewhere in the middle region. The overhang of the pipe should be selected so that the water which enters under conditions of high inflow strikes the vertical partition wall before it is deflected to the bottom of the inlet settling chamber. In the case of reduced inflows and low water level, the water must not fall directly onto the openings in the bottom of the inlet chamber.

The vertical wall located in front of the inlet pipe prevents the incoming water from splashing directly into the pump chamber and entraining air with it. The kinetic energy of the water is reduced when it strikes the wall, and satisfactory deaeration takes place in the inlet chamber.

The top of the partition wall between the inlet chamber and the pump chamber should be slightly higher than the center line of the inlet pipe. Overflow weirs can, if necessary, be provided on the sides to prevent the water from backing-up into the inlet pipe under conditions of high incoming flows and a high water level in the inlet chamber. See Figure 6-12.

These overflow weirs also prevent any scum from collecting in the inlet chamber. When the water level is high, this floating material can flow over to the pump chamber and be pumped away.

The design of the pump chamber ensures an even flow of water to the pumps without vortices or eddies. The inflow is distributed through the holes in the bottom of the inlet chamber opposite each pump.

In order to prevent the formation of air-entraining vortices between the outer pump and the side wall, the wall has been brought closer to the pump for a vertical distance half that of the stator casing (Dimension F in Figure 6-12).

Any air bubbles which enter with the water into the pump chamber rise upwards along the sloping underside of the inlet settling chamber and escape from the surface of the water near the vertical partition wall.

Since the water is in motion everywhere, there is little risk of sedimentation so long as the minimum recommended dimensions are not exceeded by a significant amount.

The best dimension to increase in order to obtain a larger sump volume is the distance from the inlet chamber to the pumps (Dimension A, Figure 6-11). Since the water flows to the pumps over this path, sedimentation is unlikely.

The model tests have shown that any bases or supporting structures in the form of walls etc., underneath the partition wall and the bottom of the inlet chamber cause eddy turbulence which then spreads to the pumps. Such structural components should therefore be avoided.

The minimum water level in the pump chamber, i.e., the minimum stop level for the pumps, must be high enough so that the square holes in the bottom of the inlet chamber are always submerged (Dimension G, Figure 6-12). In addition, it should be noted that the lowest water level is determined by the required NPSH for the pump and in any event this should not be lower than the top of the pump volutes.

Figures 6-11 and 6-12 show a plan and vertical section through a pump station, illustrating the design which has been verified by tests with one, two, three and four pumps. The dimensions of the station are determined by the number and physical size of the pumps, and by the output capacity per pump. Dimensions A, B, C, D and E are presented as functions of the output capacity per pump in Figure 6-13. They can be used to determine the plan area of the pump pit. If the available height is sufficient, the required sump volume is usually obtained by increasing the Dimension A.

All dimensions fixing the location of the pump in relation to the discharge connection base and the distance between the bottom of the pump sump and the pump inlet are specified in the manufacturer's catalog.

Figures 6-11 through 6-13, together with the preceding text on pits for large submersible pumps, introduce the dependence which the designer must place on acquiring and utilizing manufacturers' published data in the selection of equipment and the design of any pump station. The use of this data is continued in the following numerical example, where the dimensions of a hypothetical station with four large submersible pumps can be determined. Each pump is to be capable of discharging 23.5 cfs (10,550 gpm) at a total dynamic head of 20 feet, making the example comparable with the assumptions made for the wet-pit station shown in Figure 4-7, which had a caisson 26 feet in diameter, and a Q of 94 cfs, with two pumps.

From Flygt Corporation catalog, 20" C-3500 pumps are suitable. Bottom clearance is 16-3/4" and half-height of pump stator, Dimension F, is taken as 6'-3". From Figure 6-13, A = 12'-6", B = 5'-8", C = 2'-10", D = 1'-10", E = 6'-0". Pump ℄ to riser ℄ = 5'-6". Riser ℄ to backwall is taken as 3'-0". (℄ = Centerline)

Referring to Figure 6-11, tan 15^{o} (E + 8" baffle wall) = 1'-10"

Station Width = 2 (1'-10") + 3B + 2C = 26'-4"

Station Length = 12'-6" + 5'-6" + 3'-0" = 20'-6"

Internal Area = 540 sq. ft.

Internal Area of caisson = 26^2 x .7854 = 531 sq. ft.

Therefore, the area of the rectangular pit and the caisson are virtually the same and an interesting comparison can be made between the different types of pumps and drivers. In Figure 4-7 the cycle time for two pumps is shown to be very short (3.34 mins.) and not suitable for conventional electric motors. With the four submersible pumps, the critical inflow Q_i would be reduced to 11.75 cfs and the cycling time correspondingly doubled to 6.67 minutes. This would meet criteria for an allowable ten starts per hour with this type of submersible pump. In a sense this comparison justifies the claim that the shorter permissible cycling time of the submersible pump results in less cost of construction.

An example of a very large station utilizing multiple submersible pumps is shown in Figure 6-14. This station would have a total discharge capacity of approximately 350 cubic feet per second, depending on the design water level. It is not known whether this station has actually been constructed, but the proposal is referenced to European practice, where it is claimed by the manufacturers that the submersible pump in its larger versions has now replaced the vertical centrifugal pump as the most favored type of pump for stormwater service.

The pump spacing, backwall and bottom clearance, and the general configuration of the pump pit show a remarkable similarity to the requirements and criteria for vertical pumps. However, the overall arrangement is simpler. There is an obvious advantage from an operating and maintenance standpoint of having multiple units of the same type, easily removable for maintenance without seriously reducing the capability of the station. A trash rack is not shown, but the actual construction would presumably include such a feature, and other accessories of various sorts.

Large capacity vertical axial-flow submersible pumps using a propellor in a vertical tube body are now becoming available and may be considered for heads up to about thirty feet. The concept, together with some relevant detail is shown with other submersible pumps in Chapter 9.- Pumps for Stormwater Applications. These vertical propellor-type submersible pumps compete directly with the conventional vertical pump. Research shows that pump spacing, submergence requirements and pit configuration are much as for the conventional vertical pump. However, the design is simpler and the installation less expensive, in part because of reduced cycling time and consequently less storage requirement.

6-I. ACCESS, SAFETY AND MISCELLANEOUS EQUIPMENT

Most stormwater pump stations of the wet-pit type will have no open forebay or natural ventilation. Hydrocarbons washed off pavements are thus conveyed directly to the stations and the possibility of the creation of explosive mixtures exists. It is therefore essential that the motor room be completely sealed off from the pump pit or chamber. Gasketed floor plates or bulkhead doors are required, and means must be provided for operating personnel to test the atmosphere before entering the pump pit.

Stairways are preferred to ladders for access into stations where the pump or engine room floor is not at grade. Stairways are preferable for access to pump pits or other lower chambers in the station. If ladders are used, safety cages and landings should be provided if needed for compliance with safety regulations.

Details of stairways, trash-racks, hoisting equipment and many miscellaneous items required in the construction of a pump station will be found in Chapter 14.- Construction Details.

* * * * * * * * * * *

CHAPTER 7. DRY-PIT DESIGN

7-A. GENERAL

Examples of dry-pit stations were illustrated in Chapter 2. - Review of Current Practice. This chapter discusses the design of dry-pit stations with attention concentrated on the pump-pit configurations developed by the State of California, where an adjacent underground storage box (or wet-well) is an integral and indispensable part of the design. Note that the storage-box (wet-well) is normally separated from the pump-pit (dry-well) by a distance of about forty feet, being connected only by a suction line for each pump. The forty feet corresponds to the side-slope of a depressed freeway section but the separation could be more or less depending on site conditions. Emphasis is placed on providing considerable storage in relation to run-off, resulting in a significant reduction in pumping capacity and simplicity in mechanical and electrical details.

Appropriate attention is also given to the type of dry-pit station which combines wet-well and dry-well integrally in one structure set deep below grade. Pumps with vertical shafts are located at the bottom of the dry-well and take suction directly from the wet-well alongside and upstream. Pump motors are set above grade and long shafts connect to the pumps. Although it is not typical of all cases, the station illustrated in Figures 2-5 and 2-6 has all pump discharges manifolded into a single discharge line to the receiving channel. The result is a complex electro-mechanical system in a massive subterranean structure, creating a solution too complicated, too expensive and unattractive for most highway applications. This type of installation would appear to be more applicable to pumping main sewerage flows rather than stormwater, but applications have been justifiable, therefore reasonable detail is included.

As with Chapter 6, this chapter is primarily descriptive in nature, but some numerical examples are given based on the State of California design. Data in Chapter 8. - Pumping and Discharge Systems and in Chapter 9. - Pumps for Stormwater Applications will be also found appropriate.

7-B. STORAGE BOXES FOR DRY-PIT STATIONS WITH HORIZONTAL CENTRIFUGAL PUMPS

In the State of California design, the wet-well consists of a large storage box under or adjacent to the pavement (see Section 2-B). The storage box is similar to a multiple-barrel culvert and settlement of solids takes place due to reduction in velocity. The cleanout box or sump at the low end is designed for trapping silt and other depris passing through the catch basin gratings at the highway pavement level. The pumps draw from the cleanout box through intake piping leading to the dry-well.

Note the locations of the drain inlets and access shafts, which in conjunction with the openings in interior walls provide cross ventilation. 8-foot headroom and 10-feet width are provided in each barrel for access and removal of accretions, with two per cent slope for positive drainage to the cleanout box. Below the access grating at the shoulder, a short stair flight descends to the bottom of the sump. Clean-out is accomplished by a suction truck working from the shoulder. The capacity of the storage box illustrated in Figures 2-2 and 2-3 is approximately 220,000 gallons; some storm drain line storage may be added, giving at least 30 minutes of storage with both pumps running. This detention time results in the removal of a high percentage of suspended solids.

Ductile iron pipe is used for the suction lines from the storage box to the dry-pit. A separate parallel line is provided for each pump. Because of the height of fill over the pipe and the cost and inconvenience of any replacement which might be necessary due to failure, it is usual to specify the pipe in its greatest available wall thickness, which is Class 6. This approximates a one-half-inch wall for pipe sizes between 10-inch and 16-inch diameters. These sizes should be the lower and upper limits of suction line sizes for this type of dry-pit station. Suction line velocities should be limited to a maximum of 9 feet per second at design head for 10-inch pipe, increasing at 1 fps for each two-inch increment of line size up to a maximum of 12 feet per second for 16-inch diameter. The maximum length of each line should be limited to about 45 feet. Where this length can be reduced, it is advantageous to do so in order to reduce head loss and obtain maximum NPSH for the pumps. The suction lines are preferably installed with about 1% slope to drain back to the storage box when pumping ceases. At the storage box, the line begins with a line-size long-radius 90-degree suction elbow set vertically, with flared inlet at the bottom. A bottom clearance equal to the suction pipe diameter is provided, with the flanged connection to a cast-iron wall fitting determining the backwall clearance. The pumps will effect almost complete emptying of the storage box and sump with this configuration. From the storage box the lines should run straight to the dry-well, without any intervening elbows or offsets.

A bubbler tube in conduit runs from the dry-well of the pump station to the top of the storage box and extends vertically into the sump. As the water level rises up the tube, the increased air pressure trips switches to start pumps. See Figure 7-1.

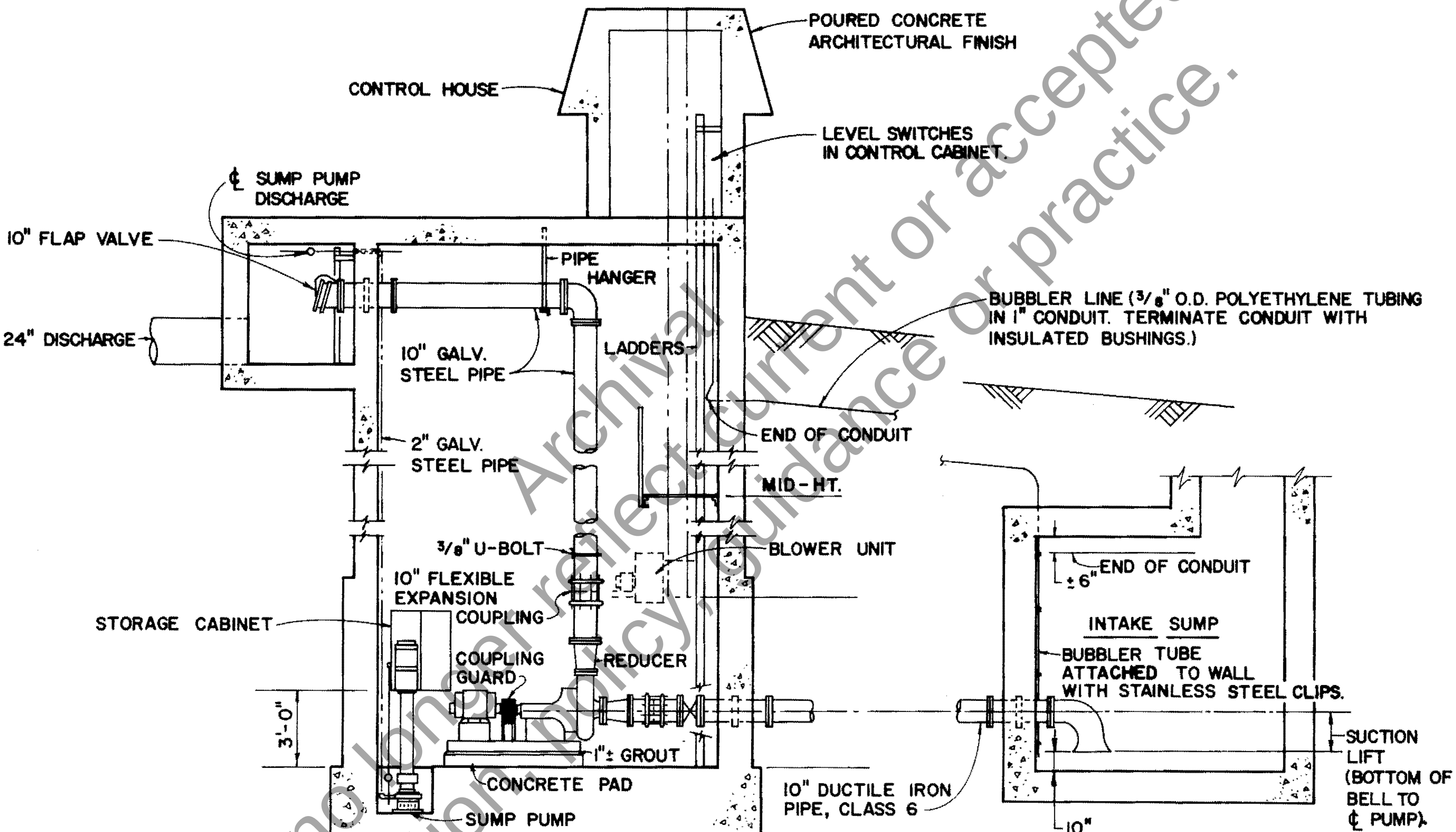


FIGURE 7-1. SECTION THROUGH DRY-PIT STATION

7-C. WET-WELLS FOR DRY-PIT STATIONS WITH VERTICAL CENTRIFUGAL ANGLE-FLOW PUMPS

Figures 2-5 and 2-6 illustrate this type of station. In the example, the wet-well is of quite limited capacity; therefore it is assumed that adequate usable storage exists in the inlet line to meet pump cycling criteria. Pump suction elbows are similar in style to those as described in 7-B, except for size. It is recommended that the pipe inlet be centered on the wet-well and that construction be similar to the transition and trash rack for rectangular wet-pit stations as described in Section 6-B. This will ensure even distribution of inflow to all the pumps. The bottom of the wet well is suitably dished to drain to the pump suction elbow for the small pump. This can be extended vertically a small amount to suit necessary elevations.

7-D. DRY-WELLS FOR DRY-PIT STATIONS WITH HORIZONTAL CENTRIFUGAL PUMPS

The dry-well is a simple rectangular structure in the State of California standard design. From Figure 2-1 it will be noted that it may be about 36 feet from floor slab at grade to the bottom of the well. The well is rectangular on plan and only about 150 square feet in internal area as will be noted both from Figure 2-1 and from Figure 7-2. The plan area will be larger if three pumps are installed as was the case with the retro-fit shown in Figures 3-1 and 3-2. In that case minimal storage required more pumping capacity, but the standard design relies on two pumps only. A small sump pump is installed to handle water spilled as a result of piping or pump disassembly during maintenance or unplanned infiltration into the station. There may also be some pump packing gland leakage. Normally the whole pit is dry and clean because it is cut off from the outside atmosphere.

Simplicity is the keynote of the California design and many of the features can be observed by study of the figures already referenced in this Chapter. A number of other figures appear in Chapter 10 - Electric Motors for Stormwater Pumps and in Chapter 12 - Electrical Systems and Controls. Note that the superstructure or control house is included in this Section and regarded for convenience as part of the dry-well.

The small size of the centrifugal pumps enables them to be spaced at less than six feet on centers and the inside width of the pit to be less than eleven feet with adequate clearance being provided. Access shafts and switchgear require only a small portion of the area of the pit so that unless it is necessary to provide for garaging an emergency generator at the station the superstructure

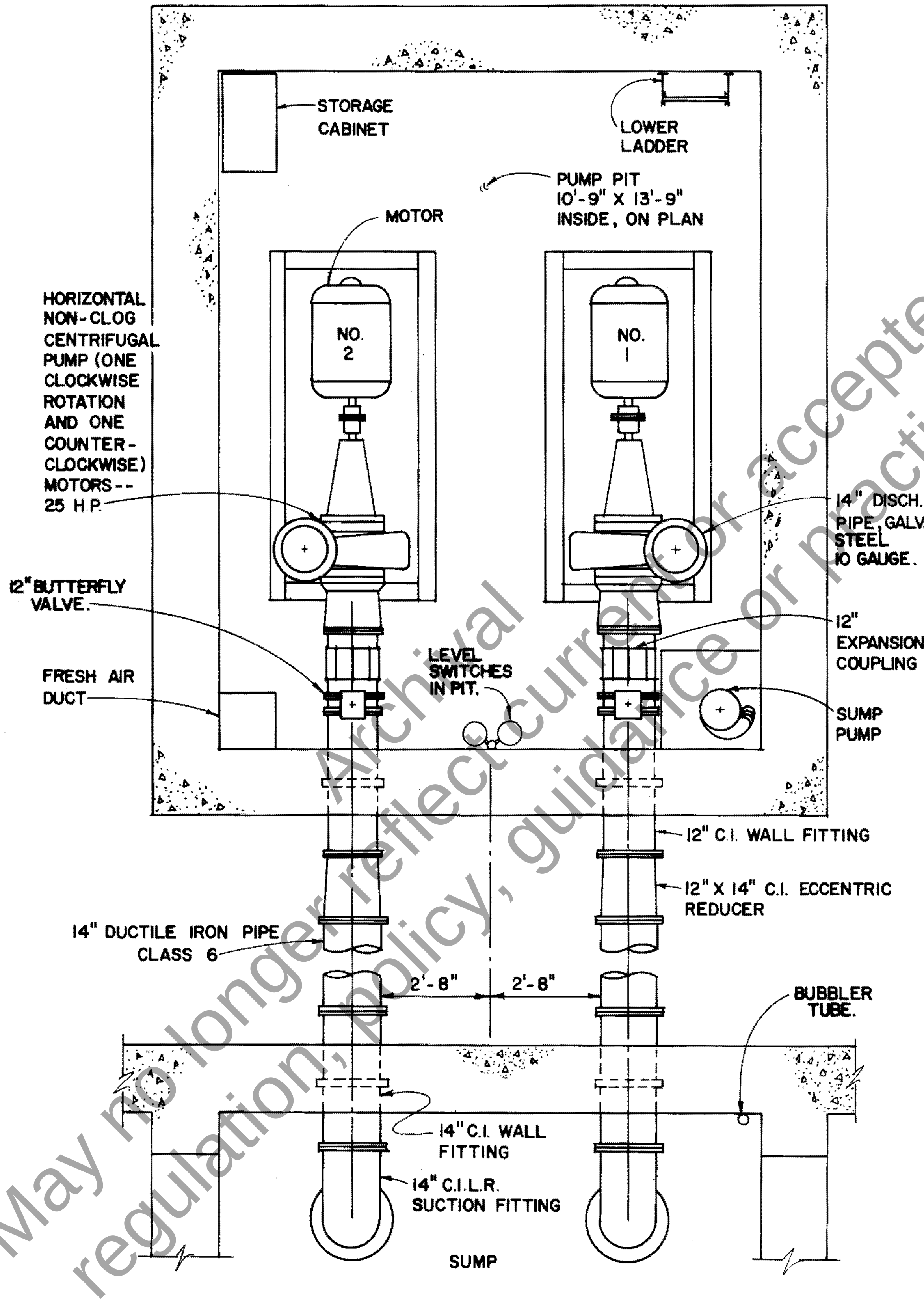


FIGURE 7-2. PLAN AT BOTTOM OF PUMP PIT

can be small indeed, as illustrated in Figure 7-1. Figure 7-2 shows a plan at the bottom of the dry-well to illustrate the compact layout and also shows the relative locations of sump pump, ladder and fresh air duct. In some cases the electrical switchgear has been placed below grade so that only the top slab of the rectangular shaft is visible.

It will be seen from the figures that details vary from one station to another. For instance, the valves in the suction piping upstream of the pump may be rising-stem gate valves or may be butterfly valves. It is believed that the latter are preferable as causing less disturbance of the pump inflow. It is often recommended that a minimum distance of 6 pipe diameters should be allowed between a butterfly valve and the pump suction, to prevent the vena contracta caused by the valve from interfering with the pump performance, but this seems to have been safely ignored for intermittent stormwater service.

Flow to the suction intake flange of the centrifugal pump should be of uniform velocity to avoid impeller disturbance. This ideally needs a straight run of suction piping at least 8 diameters in length immediately upstream of the pump suction nozzle but this is not usually provided. The suction pipe should be at least as large as the pump nozzle, a requirement which is easily met by the 10-inch minimum pipe size. If a reduction from line size to pump suction is required, an eccentric reducer should be used with the bottom sloped to permit drainage. The suction lines leading to the pump inlet flanges should not have any elbows close to the pump in any plane, or other fittings which change the direction of flow or velocity and which may initiate any spinning effect or pre-rotation to the flow of water. Centrifugal pumps not designed for pre-rotation will suffer loss of efficiency and an increase in noise if it occurs. Rotation with the impeller can result in an increase in pump head and power requirement, with possible driver overload. However, no adverse effects are known due to the close-coupled California design as illustrated.

The elevations should be so planned that pump in the dry-pit will not start until the level of the water in the cleanout box sump is at least up to the center line of the pump, thus it will be self-priming.

Available NPSH is 33.9 feet (due to atmospheric pressure) less suction lift (See Figure 7-1) and head loss in inlet line. Available NPSH must not be less than required NPSH for pump determined from manufacturers' performance curves.

Pumps are of the horizontal centrifugal non-clog type. These do not operate at efficiencies as high as pumps having closely fitting impellers, but this type of pump is better suited to contaminated stormwater by being more resistant to wear from abrasion. Efficiency is not a significant factor in considering stormwater pumps, since their annual energy consumption is very low. Pumps are furnished right and left hand (clockwise and counter-clockwise rotation) to permit a symmetrical piping arrangement. Flexible bolted couplings are used in both suction piping and discharge risers to permit easy assembly and dismantling. A separate riser is used for each pump; this is simpler than manifolding the two or three pumps into one discharge. The discharge piping is light gage galvanized steel, flanged, with cast iron fittings, and terminating in a flap valve. The latter is normally well above the outlet pipe from the receiving box or channel, to avoid accidental back-flow.

Various examples of this type of station have static heads ranging from about 23 feet to about 31 feet. Obviously, greater or lesser static head could easily be provided for. Line sizes, both inlet and discharge, range from 10" to 16" diameter for the stations studied. 20 HP or 25 HP motors are sufficient for the lower heads and smaller lines. For a station with 14" diameter discharge lines and a total dynamic head of 35 feet, it would be necessary to provide 60 HP motors if a pump efficiency of 70% is assumed and the velocity in the discharge line is limited to 10 ft./sec., which are reasonable criteria. Assuming three pumps at 35 feet TDH and 70% efficiency, two with 14" discharge lines and one with a 10", then the total horsepower would be less than 150 for a discharge of 11,500 gpm.

In another example, the pumping rate with 2 pumps at 20 HP each was 4,370 gpm average, at a static lift between 14.65 feet and 24.25 feet. Storage was 11,950 cu. ft. in storage box and 1,250 cu. ft. in collector pipes. The suction line was 10" diameter and 48'-6" in length from bottom of suction bell flare to face of pump suction. The discharge lines were both 10" diameter and 37'-6" in combined vertical height and horizontal length, including one 90-degree elbow, and terminating with flap gate and free discharge into receiving channel.

7-E. DRY-WELLS FOR DRY-PIT - STATIONS WITH VERTICAL CENTRIFUGAL ANGLE-FLOW PUMPS.

The example in Section 2-C represents a far more complex solution than the previously described dry-pit with storage box, but there may be compelling reasons for its selection.

Particular attention should be paid to the buoyancy of the massive box structure. It may well be that hydrostatic uplift is a serious factor for the structure as a whole. Foundation piles may be required, not primarily to carry such a structure, but to anchor it down, particularly when empty. Where seismic considerations are a factor, the combination of static and dynamic soil pressure becomes difficult to resist in deep structures. The necessary stiffening ribs lead to difficult structural analysis and reinforcing steel patterns, even if uniform concrete thicknesses are maintained to ease construction difficulties.

In the station illustrated, the motor sizes justify a power supply of 2,400 volts, rather than the conventional 480 volts.

The vertical shaft centrifugal volute-type pump is called the angle-flow pump by some manufacturers. The suction elbow transitions from horizontal to vertical below the pump. This has been a standard type of pump for sewage applications for many years. It is able to pass solids, but has an inherent weakness in the long drive shaft required between pump and motor. This is frequently a source of trouble due to whirling and vibration, so that it is a point to be very carefully treated in the design.

Pumps must be capable of isolation by butterfly valves or gate valves upstream and downstream when discharge is into a common manifold. Pump control valves are also necessary to insure that the pump starts and stops against a closed valve and also that the opening and closing time of the valve is controlled to prevent water-hammer. The required center-to-center spacing of the pumps depends on their size, but is over 8 feet in the example shown. This compares with a recommended 10 feet center-to-center of gas engines. A small sump pump will usually be necessary in the dry-well to discharge water resulting from leakage from dismantling during maintenance or from infiltration through the structure.

In conclusion, it is evident that this type of station is costly and requires a high standard of maintenance to insure that operational problems do not occur. Special site conditions or difficulties would appear to be necessary to jusity its selection.

7-F. Access and Safety

Forced ventilation of the lower portions of dry-wells is essential and fans and ducting must be provided. Fans must be operated for a specified period prior to personnel entry in order to insure compliance with OSHA regulations. It is suggested that current regulations be reviewed at the time of design.

Where ladders are used, it is necessary that vertical distances between landings be limited to avoid the use of safety cages. One or two intermediate landings will be required. Also width of ladder, rung size and spacing and toe clearance to adjacent wall must be made to comply with OSHA regulations. Ladder side rails must also extend above the landing or control room floor and should be splayed out to increased width if personnel must pass through. Safety chains may also be required at the opening.

Refer to Section 6-I and to Chapter 14.- Construction Details for other comments on this subject.

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CHAPTER 8. PUMPING AND DISCHARGE SYSTEMS

8-A. GENERAL

The content of preceding chapters has been arranged in the most logical sequence which appeared possible, intended to guide the reader first through examples of existing stations and their siting. Collection systems, including storage and cycling were then discussed. In that chapter, it was necessary to step forward and give some explanations of pumps and their operation, but only sufficient to make clear the importance of the relationship between the collection system and the pumping system.

The criteria and selection process was intended also to provide a check list on the many factors involved in pump station design, after which it was possible to treat wet-pit and dry-pit stations in more detail.

We are now at the point where the complete pumping system can be examined, from the pumps through the details of the components of the discharge system. Pump performance, total dynamic head, manifolding of discharges and the resulting system head curves will be explained with the intent of amplifying and rounding-out details which have of necessity only been partially covered in prior chapters. This chapter will complete the basics, leaving later chapters to cover the details governing selection of equipment and details of electrical systems, pump station construction, and calculations and station layouts.

8-B. DISCHARGE CONFIGURATIONS

The simplest system configuration is where each pump has its own discharge line, entirely independent of the other pumps. In the California dry-pit stations each centrifugal pump at the bottom of the pit discharges into a vertical riser and thence through an elbow and a more-or-less horizontal line to an exit flap-gate at the receiving channel. The same general configuration will be observed for most of the wet-pit stations. The discharge line conveys pumped water from the pump discharge elbow to a channel or conduit. The discharge line frequently terminates in a flap gate to prevent backflow from the receiving channel such as would occur after the pump stopped, if the invert of the discharge line were below the maximum water surface elevation in the channel. The pump column and elbow, the discharge line and the flap gate, all taken together, constitute the pump discharge system. Sometimes a check valve is also needed to prevent backflow from the discharge line and then this is also part of the system. Usually there is no need for any gate valves or check valves, nor in some instances even any discharge flap gates. These are obviously construction economies and reduce items needing maintenance, while also reducing head losses and power requirements.

However, this simplicity is only achieved at the expense of furnishing a complete length of adequately-sized discharge line from the pump to the receiving channel. When excessive length and cost makes individual discharge lines impractical, it is usual to manifold the individual pump discharges into a common discharge line large enough to carry the combined discharge at an acceptable velocity. To prevent recirculation, each pump discharge must have a check valve at the point where it enters the manifold, and the manifold itself may become a large and complex fabricated pipe section. In spite of these complications it is sometimes economical to manifold the discharges of a number of pumps. Figures 8-1 through 8-3 show details of such a manifold of 181 cfs discharge capacity.

All of the foregoing components of the system have to be considered and their head losses computed, together with the velocity head. These are all added to the static head in order to determine the total dynamic head at which the pump must operate. The total of all these losses is usually a significant addition to the static head. They must never be ignored. Where there is a manifold and common discharge line, there is more head loss and higher TDH as each pump adds its discharge to the common line.

Operational factors must not be overlooked. For instance, in the conventional case a short discharge line from a vertical pump slopes up to some type of discharge structure at a higher elevation. When the pump stops, the column of water in the discharge line will also stop, then reverse flow to drain back into the pump pit. Since the quantity of water is relatively small, it is readily handled by the small sump pump as part of the final clean-up. The sump pump requires a check valve in its discharge line to prevent backflow. This line is only a small size.

The gravity flow of water from a discharge line as large as 36 inches will have sufficient velocity and energy to rotate the pump in reverse. This is not usually harmful to the pump, but it could unscrew the pump drive shaft couplings. A non-reverse ratchet fitted to the motor would prevent this possibility; however, the ratchet is a noisy mechanical device possibly subject to jamming or failure and, therefore, not regarded by all as completely satisfactory.

Reverse rotation may be preferable to a non-reverse ratchet. However, a time-delay relay should be used so that motor cannot accidentally re-start while the pump is running backwards. In any case, with engine driven pumps a non-reverse ratchet is required on the right-angle gear to prevent engine backfire.

A special problem may occur when a significant length of the discharge line of a manifolded system has an elevation above the pump discharge elbow. When pumps are shut down the flow reversal toward the pumps could cause dangerous water hammer surges if regular check valves are used. A pump control valve is needed which opens and closes slowly and is controlled so that the pump always stops and starts against a closed valve. Under such a control system, the pump will operate at shutoff head for some seconds on start-up when water is in the line and the valve is opening. The shutoff horsepower must be considered when sizing the drivers for such an installation. Pump curves usually show shut-off horsepower requirements.

Other accessories which may be required in the discharge system are air-release and vacuum valves, flexible couplings and tie rods, flange connections and fasteners, and steel-to-concrete pipe adaptors. They are described later in this Chapter, but they do not usually make much contribution to head loss.

8-C. PUMP PERFORMANCE

A pump is a machine which receives energy from its driver, either engine or motor. It converts this energy into useful work in raising water from the pump pit to the discharge.

Chapter 4 - Collection Systems, made introductory reference to certain characteristics of pump performance, based on conditions encountered in stormwater service. Pumps must be capable of raising the water to the fixed discharge level regardless, within set limits, of whatever the water surface level may be in the storage or pump pit. This differential between the lower and upper water surfaces is the static head.

When the pump is raising the water from the lowest level the static head will be greatest and the discharge will be the least. When operating at the highest level the static head will be the least and the discharge will be the greatest. The capabilities of a pump must always be expressed in both quantity of discharge and the total dynamic head at a given level. This is the Design Point for the pump.

Total dynamic head was also explained in Chapter 4. It is the combination of static head, velocity head and various head losses in the discharge system due to friction. It is usual to minimize these various head losses by the selection of correctly sized discharge lines and other components.

A pump is selected to operate with the best possible efficiency at its Design Point, corresponding to the Design Water Level of

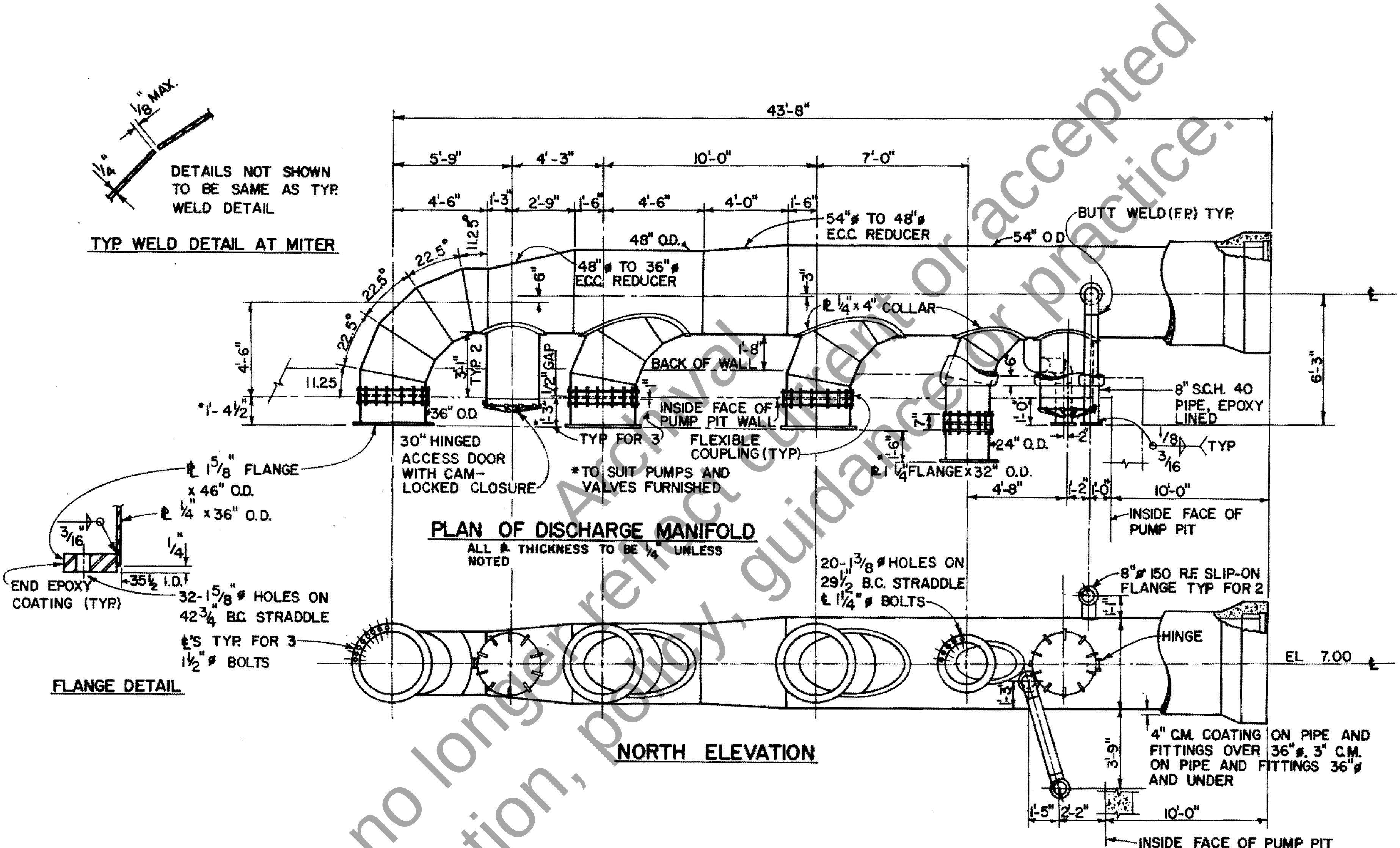


FIGURE 8-1. DISCHARGE MANIFOLD

Portion of Manifold Showing 36" Inlets
and 30" Access Door
Figure 8-2

Installation of Manifold
Figure 8-3

the station, and its performance is expressed as the required discharge in gallons per minute at the resulting total dynamic head. The efficiency of a stormwater pump at its design point may be 75 or 80% or even more, but this will depend on the type of pump.

When the static lift is greatest (low water in sump) the energy required (horsepower) may be the greatest even though the quantity of water raised is less. This is because the pump efficiency may also be much less. The pump selection should be made so that maximum efficiency is at the design point.

Pumps for a given station are selected to all operate together to deliver the Design Q at a Total Dynamic Head computed to correspond with the Design Water Level. Because pumps must operate over a range of water levels the quantity delivered will vary significantly between the low level of the range and the high level. Typically, a pump could be required to have a capacity of 23,000 gpm at a total dynamic head of 24.5 feet (the Design Point) and to operate between a range of 14.0 and 26.5 feet tdh. The discharge at 14.0 ft. tdh would be found to be 28,400 gpm (123% of design point) and at 26.5 ft. tdh to be only 19,800 gpm (86% of design point). A curve of total dynamic head versus pump capacity is always plotted for each pump by the manufacturer. When running, the pump will respond to the total dynamic head prevailing and the quantity of discharge will be in accordance with the curve. More details will be found in Chapter 9.- Pumps for Stormwater Applications.

8-D. TOTAL DYNAMIC HEAD

Figure 8-4 illustrates a pump station with manifolded discharge system. All the items contributing to head losses are identified and representative calculations are given. This is an extreme case; most pump stations will have fewer items in the discharge system to be considered. Because of the length of the discharge line, it contributes almost half of the total dynamic head.

Figures 8-5 and 8-6 show the method of determining head loss in various components of the system. Standard text-books and manufacturers' catalogs can also be consulted.

To summarize, the Total Dynamic Head (TDH) is equal to

$$TDH = h_s + h_f + h_v + \Sigma h_p \text{ where:}$$

h_s is the Static Head or height through which the water must be raised,

h_f is the Friction Loss in the discharge line,

h_v is the Velocity Head, and

Σh_p is the loss due to friction in water passing through the pump valves and fittings and other items.

The Manning formula expressed as $h_f = L \left[\frac{Q \times n}{1.486\ A \times R^{2/3}}\right]^2$ is generally used for discharge lines, where:

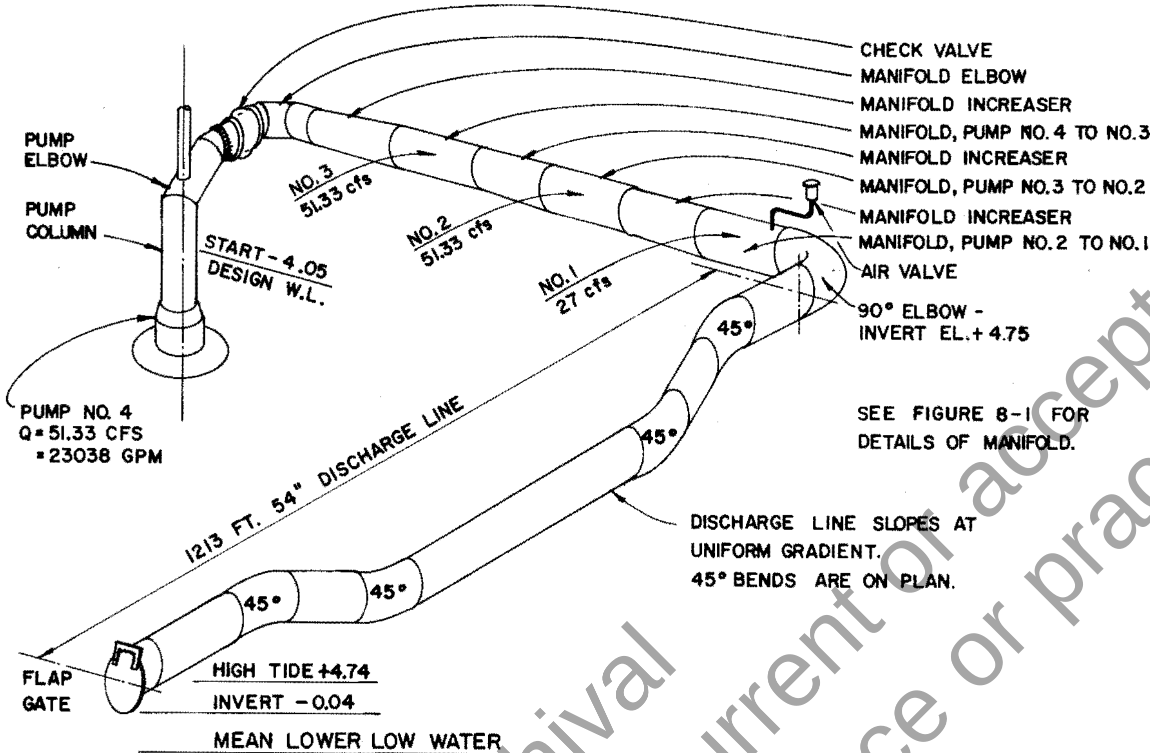
- Q = Discharge in cfs
- L = Length of pipe in feet
- n = .013 for steel or concrete pipe
- A = Cross sectional area of discharge pipe in square feet
- R = Hydraulic Radius of discharge pipe in feet (R = diameter/4 for line running full)

Friction losses can also be computed by the Darcy Formula. This requires computation of the relative roughness of the pipe, the Reynold's number and the friction factor. The more complex procedure does not appear to justify its use in lieu of the simpler Manning Formula.

8-E. SYSTEM HEAD CURVES

A system head curve is a graphical representation of total dynamic head plotted against discharge Q for the entire pumping and discharge system. It is useful for establishing the required design point of a pump and then after the pump curve is superimposed it gives a visual representation of both system and pump. As usually drawn, the system head curve starts from a low point on the χ-ordinate representing the static head at zero discharge. It then rises to right as the discharge increases and the friction losses increase also. A design point can be selected on the system head curve and a pump can be selected to suit that point. The usual pump curve is the reverse of the system head curve so points of intersection are clearly identifiable. System head curves are often drawn for several different static heads, representing low, design and maximum water levels

SEE CHAPTER 15 - STATION DESIGN CALCULATIONS AND LAYOUTS



PUMP COLUMN

FRICTION FACTOR $f = .012$

COLUMN LENGTH $L_e = 30$ FT.

COLUMN DIAM. $D = 3$ FT.

$hp = f\frac{L_e}{D} \times \frac{v^2}{2g} = .012\ \frac{30}{3} \times \frac{(7.26)^2}{2 \times 32.2}$ $hp = .10'$

PUMP ELBOW (FIGURE 8-5)

36" DIA. AT 23,038 GPM $hp = .29'$

CHECK VALVE

PER APCO (AMER. VALVE & PRIMER) CURVE $hp = .25'$

MANIFOLD ELBOW (FIGURE 8-6) D = 36"

4-MITER 90° $\Delta = 22\frac{1}{2}$ %

$hp = .08\frac{V^2}{2g} \times 4 = .08 \times \frac{(7.26)^2}{2 \times 32.2} \times 4$ $hp = .26'$

MANIFOLD INCREASERS (FIGURE 8-6)

$hp = .1\left[\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right]$ V_1 = 36" DIA. AT 51.33, V_2 = 54" DIA. AT 181. $hp = .12'$

MANIFOLD, PUMP NO. 4 TO NO. 3 D = 36"

CONSIDER AS STRAIGHT-THROUGH TEE

20 D = 60 FT $f = .012$

$hp = f\frac{L_e}{D} \times \frac{v^2}{2g} = .012 \times \frac{60}{3} \times \frac{(7.26)^2}{2 \times 32.2}$ $hp = .20'$

MANIFOLD, PUMP NO. 3 TO NO. 2 D = 48"

10 FT. ACTUAL + STRAIGHT THROUGH TEE

10 + 20 D = 90 FT. $f = .011$

$V = \frac{2 \times 51.33}{4.0^2 \times \pi/4} = 8.17$ FT/ SEC.

$hp = f\frac{L_e}{D} \times \frac{v^2}{2g} = .011 \times \frac{90}{4} \times \frac{(8.17)^2}{2\ 32.2}$ $hp = .26'$

MANIFOLD, PUMP NO. 2 TO NO. 1 D = 54"

10 FT. ACTUAL + STRAIGHT THROUGH TEE

10 + 20D = 100 FT. $f = .0105$

$V = \frac{3 \times 51.33}{4.5^2 \times \pi/4} = 9.68$ FT./SEC.

$hp = f\frac{L_e}{D} \times \frac{V^2}{2g} = .0105 \times \frac{100}{4.5} \times \frac{(9.68)^2}{2 \times 32.2}$ $hp = .34'$

FLAP GATE (FIGURE 8-6)

EXIT LOSS $hp = .04'$

$\Sigma\ hp = 1.86'$

$h_s = (-)4.05 + 4.74 = 8.79'$

ACTUAL LENGTH OF DISCHARGE LINE J	=	1213
1. 4-MITER 90° BEND (20D)	=	90
4. 45° BENDS (4 AT 5D)	=	90
Σ EQUIVALENT LENGTH	=	1393

$h_f = L\left[\frac{Qn}{1.486\ AR^{2/3}}\right]^2 = 1393\left[\frac{181 \times .013}{1.486 \times 15.90 \times \left(\frac{4.5}{4}\right)^{2/3}}\right]^2 = 11.81$

FOR 36" DISCHARGE $A = 3.0^2 \times \pi/4 = 7.07$ SQ. FT.

$V = \frac{51.33}{7.07} = 7.26$ FT./SEC.

FOR 54" DISCHARGE $A = 4.5^2 \times \pi/4 = 15.09$ SQ.FT.

$V = \frac{181}{15.90} = 11.38$ FT./SEC.

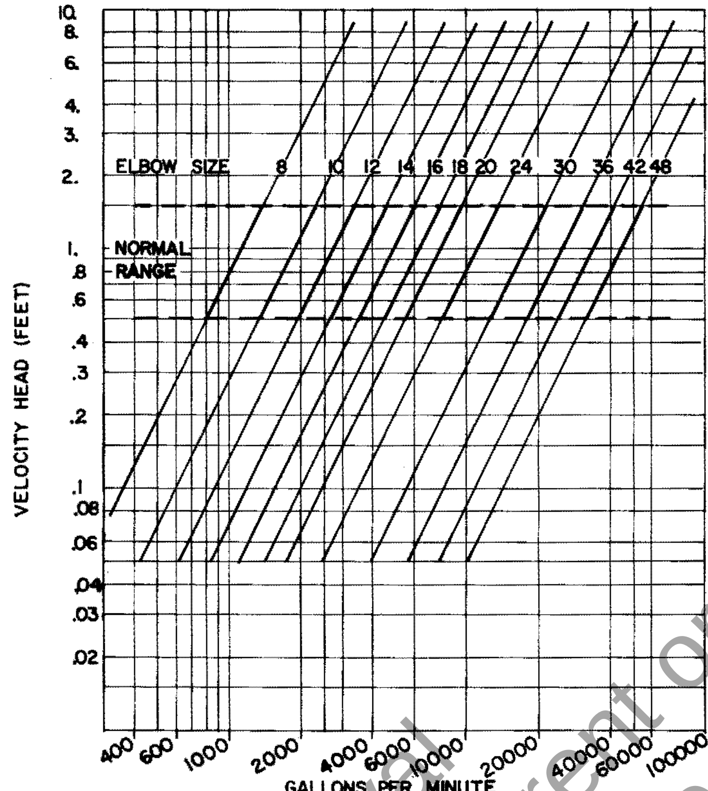
$h_v = V^2\frac{MAX.}{2g} = \frac{11.32^2}{2} \times 32.2 = 2.01'$

$TDH = h_s + h_f + h_v + \Sigma\ h_p$

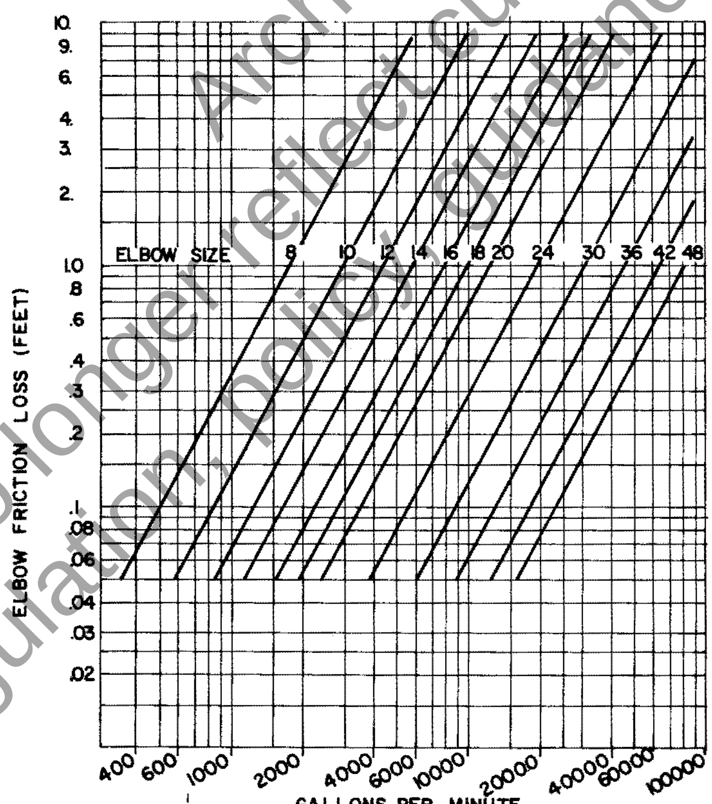
$= 8.79 + 11.81 + 2.01 + 1.86$

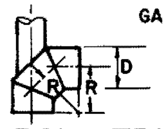
$= 24.47$ USE 24.5 FT.

FIGURE 8-4. CALCULATIONS FOR TOTAL DYNAMIC HEAD



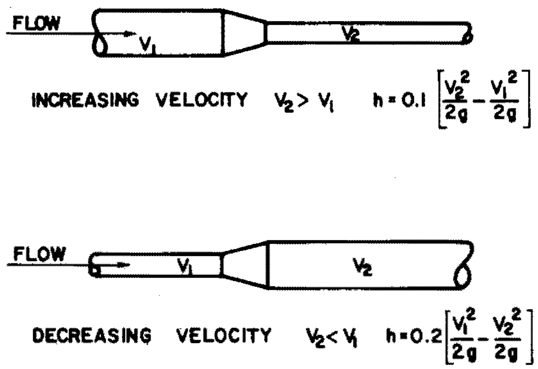
VELOCITY HEAD CHART



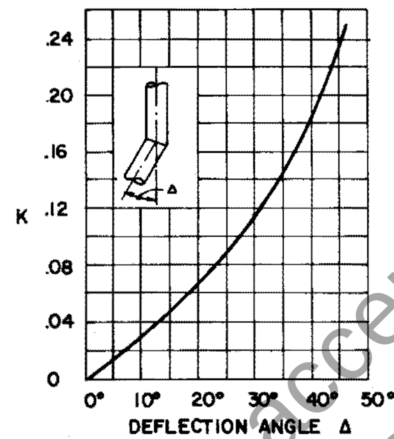


D	8	10	12	14	16	18	20	24	30	36	42	48
R	12	14	16	18	22	24	26	28	34	38	46	52

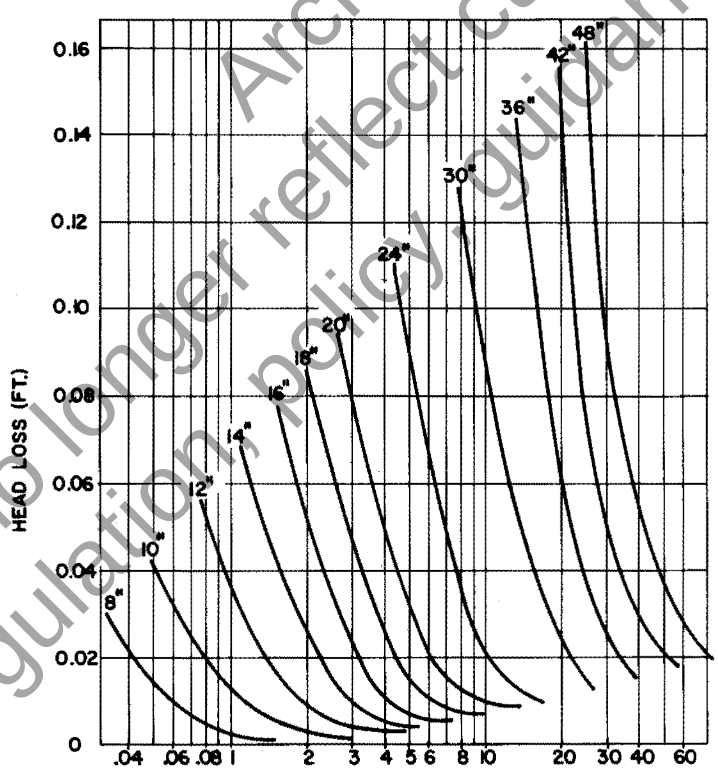
ELBOW FRICTION LOSS CHART
FIGURE 8-5



TRANSITION LOSS



ANGLE POINT LOSS $= K\frac{V^2}{2g}$



HEAD LOSS FOR FLAP GATES

FIGURE 8-6. HEAD LOSSES

in the sump. One, two or more pump curves can be plotted over the system head curves and conditions examined. If a change of discharge line size is contemplated, a new system head curve for the changed size (and changed head loss) is easily constructed. Figure 8-7 shows the same system with one pump and then with two identical pumps delivering into the same system. Note the increased head loss and reduced capacity of each pump when both are operating.

8-F. DISCHARGE LINE SIZING

When sizing the discharge pipeline or pipelines, a general guide is that construction costs are directly proportional to the pipe diameter. Friction loss, and therefore some element of pumping costs, are inversely proportional to the pipe diameter. Therefore, the optimum pipe size is not readily evident, but where a vertical pump is concerned, it is usual to make the discharge line the same size as the pump. For a 36" pump, a 36" discharge line would be conventional. A smaller line size would result in too high a velocity and too much head loss, and a larger line would probably be unnecessary. Variables such as annual operating hours, choice of materials and future deterioration of the pipe must also be considered.

Suggested criteria for design are that if the individual discharge lines exceed fifty feet in length, they should be constructed of concrete pipe. Steel pipe or cast iron discharge lines should be limited to fifty feet or less. Velocities of water should be limited to twelve (12) feet per second in concrete pipe flowing full (under pressure) and to ten (10) feet per second in steel or cast iron pipe.

If the distance from the pump station to the outlet structure exceeds two hundred feet, the combination of individual discharge lines by manifolding into one single larger line should be investigated.

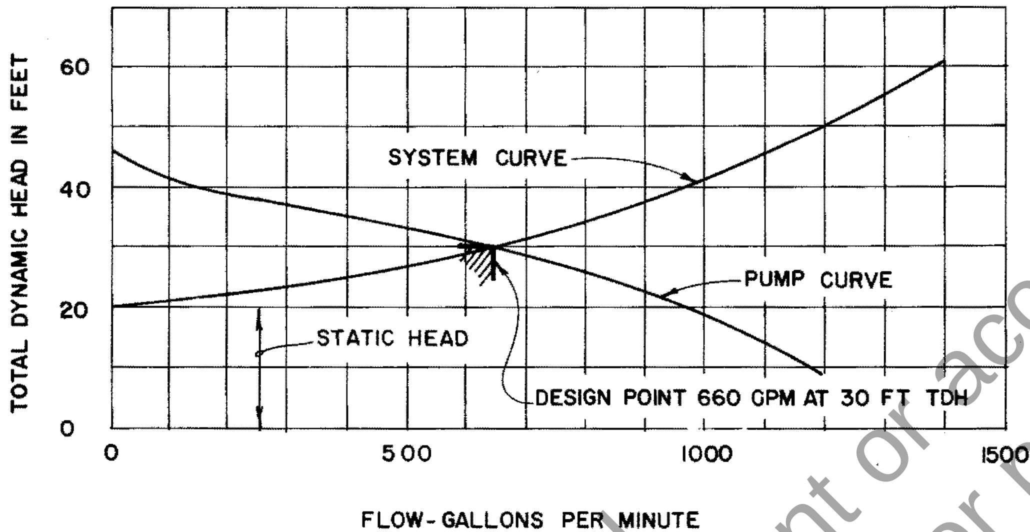
8-G. DISCHARGE LINE PIPE MATERIALS

The choice of materials is usually between steel pipe and concrete pressure pipe, with the determining factor usually being the length and consequent cost of the discharge line or lines. Since it is relatively simple to provide an adaptor from steel to concrete pipe, there is no special merit in using steel only.

Discharge heads or pressures are normally relatively low (less than 50 feet) so that a nominal one-quarter inch thickness of steel pipe wall will suffice. However, the stresses due to both internal pressure and external loading of backfill need to be checked. Pipe of ASTM A53 quality is satisfactory, or where fabrication is required, such as for a manifold, ASTM A36 steel is normally used. Although on occasions, ASTM A 283 Grade C has

SYSTEM HEAD CURVE

FOR SINGLE PUMP



SYSTEM HEAD CURVE FOR PARALLEL OPERATION

TWO PUMPS

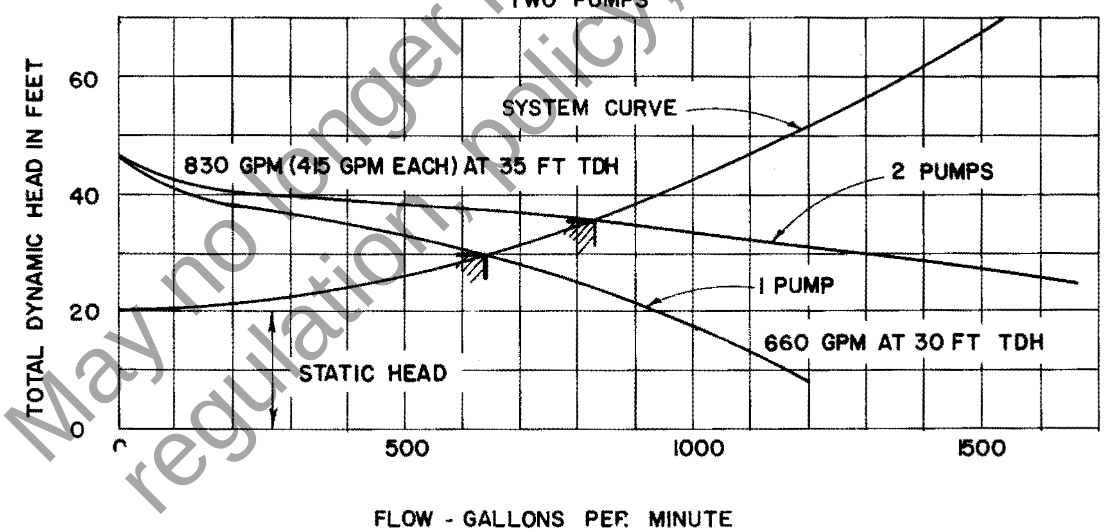


FIGURE 8-7

been specified for discharge lines and manifolds, its use is not usually justified if any premium price is involved compared with A36.

Steel pipe and accessories require galvanizing or epoxy lining and coating as protection against corrosion, the former being preferable for interior and exterior coating of lines up to about sixteen-inch diameter, whether exposed inside the station structure or buried outside. Coal tar coating and pressure sensitive tape wrap are also used to protect buried steel pipe. For larger lines, the coatings mentioned are sometimes replaced by cement mortar, which is particularly applicable to manifolds buried outside the station. See Figures 8-1 through 8-3.

Buried flanged joints in steel pipe are frequently a source of leaks or internal corrosion in later years and should be avoided if possible by fabricating the discharge lines in one piece, or making field welded joints. Internal corrosion and rough surfaces increase the friction and head loss.

For longer lines, concrete pressure pipe is usually more economical than steel and is less subject to corrosion damage. Bevelled pipe ends or elbow specials are standard with the concrete pipe industry, so that vertical or horizontal bends are readily laid. Thrust blocks to avoid separation of the line should be provided at bend points where resultant forces are significant. Joints should be of rubber-gasket type to withstand the internal pressure of the water and avoid leakage. The pipe wall thickness and pipe strength must be sufficient to withstand external pressures. Rubber-gasket jointed pipe is also very suitable where differential settlement of pump station and discharge line may be anticipated.

Ductile iron or asbestos cement pipe can be considered for use as discharge lines and if economically favorable may be used, although the applications are likely to be limited.

8-H. FLANGES, FLEXIBLE COUPLINGS AND STEEL-TO-CONCRETE PIPE ADAPTORS

The most common method of joining steel pipe is by forming or attaching a flange to each end of the pipe, and then by bolting the flanges together face-to-face, with a compressible gasket interposed between the flanges to form a water-tight joint.

For stormwater pump station construction, mild steel ring flanges of moderate rating are satisfactory. These have flat faces. AWWA (American Water Works Association) Standard C207-55, Class D, is an applicable specification, with such flanges being electrically-welded to the discharge piping. At least one pair of flanges is usually required in a wet-pit station, such as when a check-valve is included in the discharge line. However, on occasions, flanges are not required.

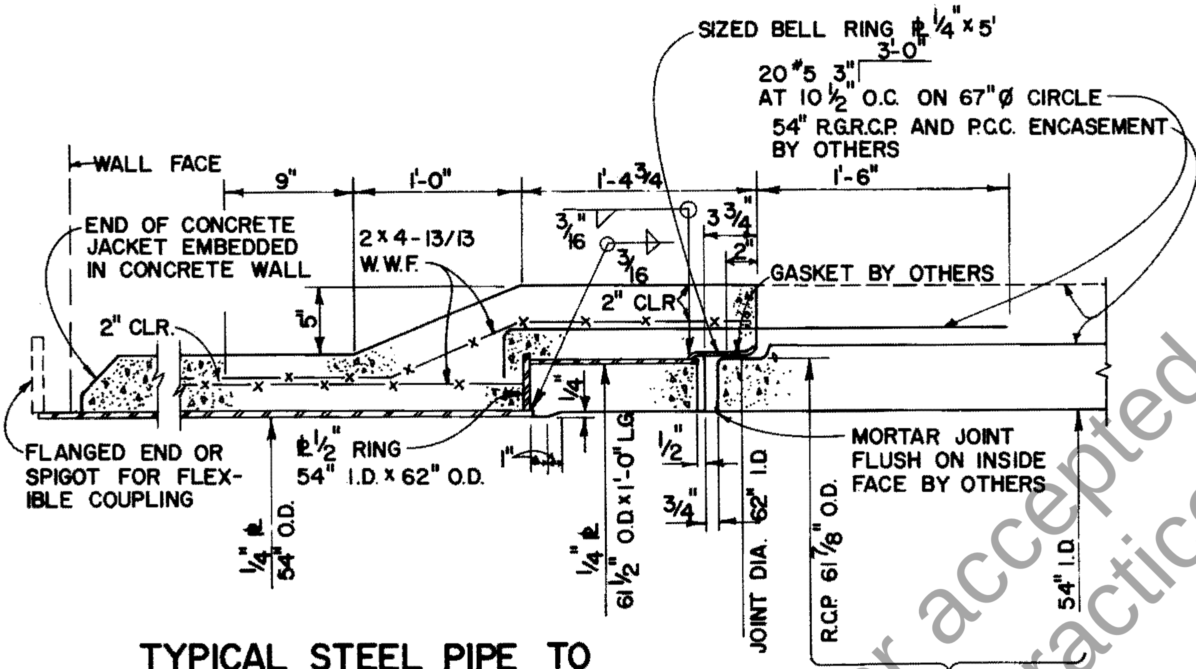
Bolts and nuts (fasteners) required to make up flanges inside the pump station may be specified as carbon steel, but the exposed threads should be thoroughly cleaned and coated to prevent corrosion and remain workable in the event dismantling is required. The added cost of stainless steel fasteners is not usually warranted. Gasket material should be specified as cloth-impregnated neoprene.

To facilitate assembly of the steel piping system and to allow for dimensional clearances and variations, it is necessary to include one or more flexible couplings in each line. These couplings are frequently known as Dresser couplings, relating to the name of the original manufacturer of couplings of this type. See Figure 8-8.

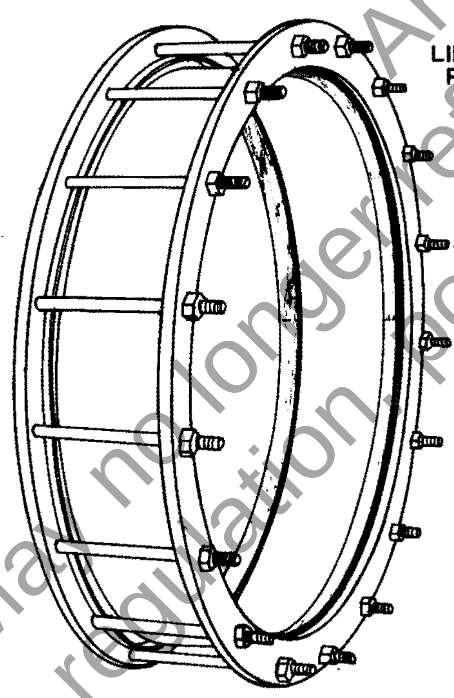
In general, the coupling consists of two flange rings spaced apart by a sleeve and connected by a series of long parallel bolts around the periphery. The sleeve fits loosely over the adjoining spigot ends of the line pipe and rubber ring gaskets are compressed between the flanges, the sleeve and the line pipe to form a water-tight joint which is tolerant of some clearance and misalignment of the spigot ends; hence the description flexible. Just as the flexible coupling is essential for making up the system, it permits ready disassembly of the system when required. The flanges and sleeve should be epoxy coated (or galvanized). To prevent corrosion, the bolts (or fasteners) are often of stainless steel. The cost savings of mild steel or galvanized finish is a judgment factor for the individual designer.

The flexible coupling is limited in its resistance to longitudinal forces or thrusts. It is often necessary to provide tie rods parallel to it on each side. These are sometimes more-or-less integral with the coupling and attached to the line pipe, but in a pump station it is often convenient to provide the same effect by tie-bolts between the pump and the structural concrete, again embracing the coupling. The sizing of the tie rods is determined by the cross-sectional area of the discharge line and the maximum discharge pressure of the pump. With proper tie rods or other restraint from the pump station structure, the flexible coupling will remain sealed and tight indefinitely while subjected to shock, vibration, pulsation or other adjustments of the discharge line.

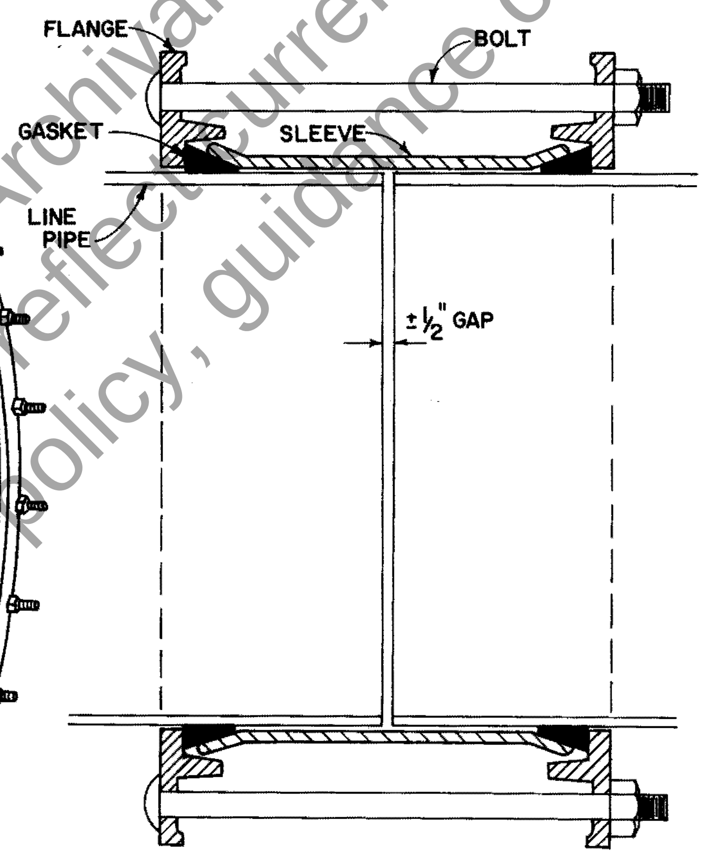
A steel-to-concrete pipe adaptor is required whenever such a change of material is included in the design. The adaptor is often conveniently located in the concrete back wall of the pump station. This enables the steel adaptor to be adequately



TYPICAL STEEL PIPE TO CONCRETE PIPE ADAPTOR



SIDE VIEW OF LARGE DIAMETER FLEXIBLE COUPLING



SECTION SHOWING COMPONENTS OF FLEXIBLE COUPLING

FIGURE 8-8

anchored in the thickness of the wall, often with a circumferential ring or flange set on the center of the wall to serve also as a water-stop. Inside the station, the adaptor may have either a steel flange or a spigot-end according to need. At some point in its length, the steel pipe size of the adaptor is enlarged and at the downstream end a specially-sized bell ring is welded on. The sizing of the bell ring is performed by or for the concrete pipe manufacturer so as to match the spigot end of his concrete pipe with allowance for the necessary rubber gasket ring which ensures water-tightness under the discharge head. Internally for a part of its length, the adaptor is cement mortar lined, and the remainder is epoxy coated.

The exterior of the adaptor which is inside the station is also epoxy coated, while the portion which is embedded in the wall or projecting outside is coated with a cement mortar jacket. Figure 8-8 shows details of an adaptor. A similar design was used for the downstream end of the manifold shown in Figure 8-1.

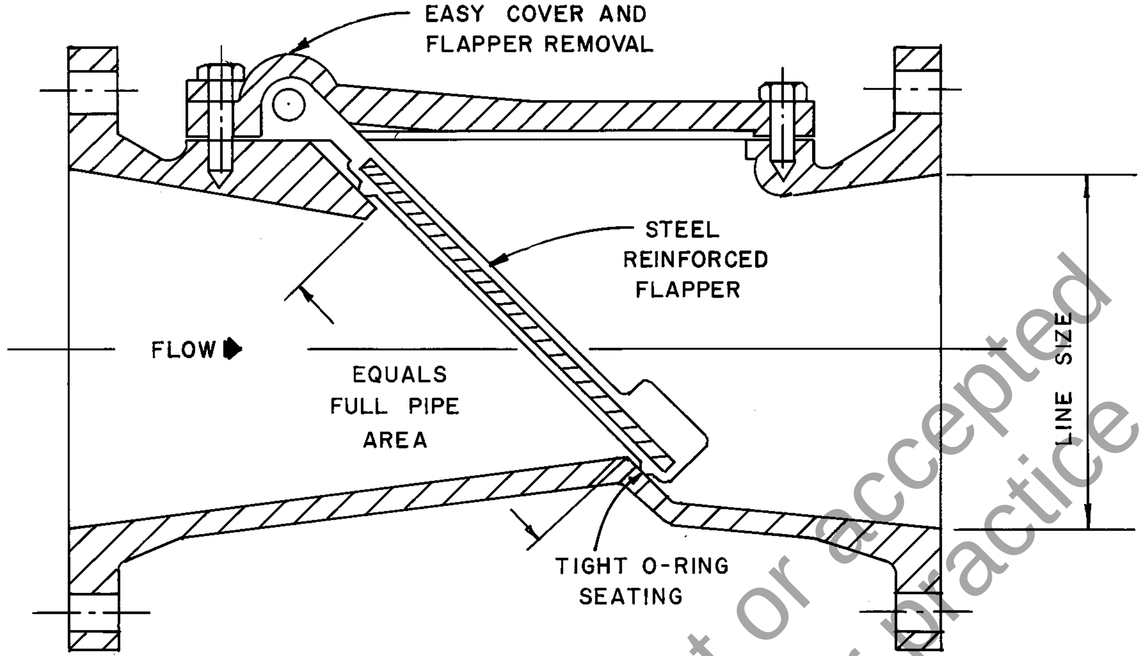
8-I. AIR AND VACUUM VALVES

In many cases it is necessary to provide an air release valve at the high point of a vertical pump discharge elbow, because the pump column will contain air which should be discharged to permit smooth starting of the pump and passage of a full body of water through the check valve. This valve should be the combination air and vacuum type, so that on pump shut-down, the valve also permits entry of air to avoid the harmful formation of a vacuum in the pump column. The sizing of these valves depends on the pump capacity and the volume of air to be released, and reference accordingly must be made to manufacturers' catalogs. Appendix D. - Specifications, gives the manner in which these valves may be specified, and a simple illustration is included in Figure 8-9.

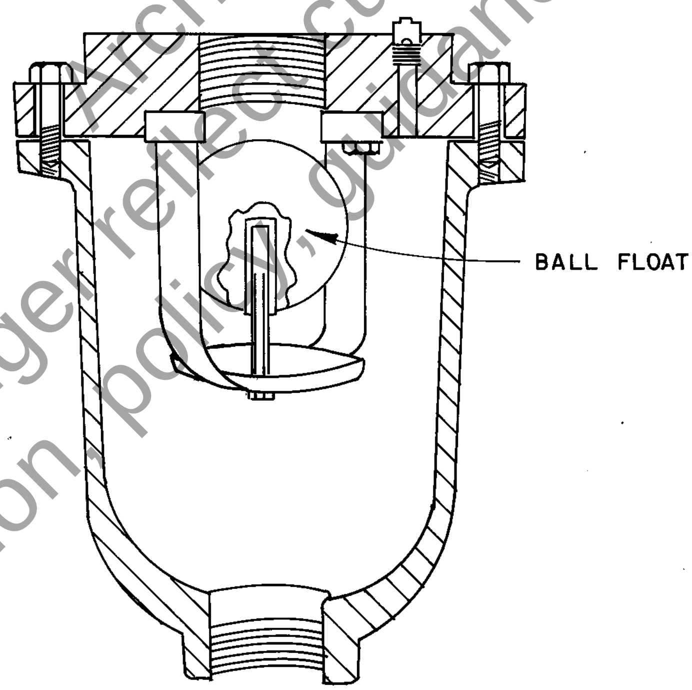
Some very short pump discharge lines terminate with a flap-gate at the outlet structure. In such cases, a standard weight galvanized steel vent pipe installed vertically on top of the end of the discharge pipe at the outlet structure may serve as a suitable substitute for the air-vacuum valves. The pipe should be capped on top to prevent entry of foreign objects, and should have holes drilled as air ports in the upper part of the pipe before galvanizing. An illustration of this type of air vent is shown in Figure 8-13.

8-J. CHECK VALVES

Check valves are of two distinct types to suit different requirements -- those required in the discharge lines adjacent to the



RUBBER FLAPPER SWING CHECK VALVE



AIR AND VACUUM VALVE

FIGURE 8-9

main pumps, such as where the system includes a manifold, and those which are required in the discharge lines of sump pumps.

The check valves for the main pumps ensure that when any given pump is not operating, the flow of water being delivered to the manifold by other pumps cannot flow back through the non-operating pump. Besides this recirculation being possibly harmful to the pump, it would be wasteful of energy in proportion to the amount recirculated compared with that actually flowing out of the discharge line to the receiving channel. The flow velocity through the main check valves and consequently the head loss that they add to the system should be minimized. Therefore, it is usual to specify the main check valves to be the same size as the columns and discharge elbows of the vertical pumps they protect.

Vertical pumps predominate in wet-pit stations, where discharge into a manifold is more likely to be found. Assuming that such a pump delivers 25,000 gpm, a column diameter and, therefore, a valve diameter of 36 inches is required to meet a maximum velocity criteria of 10 ft./sec. Valves of this size are readily available from domestic or foreign sources, but their price is considerable. At 1978 prices, the installed construction cost for valves, manifold and fittings required to combine several pumps totalling 181 cfs discharge into a single discharge line would have cost approximately $200,000. Appendix C - Construction Costs will show the various unit costs.

Despite this relatively high cost per cubic foot of water pumped, it will be found that significant savings result if the discharge line downstream of the manifold is of necessity of considerable length.

The slanting-disc type is preferable, with an oil dash-pot feature to ensure slow-closing (non-slam) action of the flapper. See Figure 8-10. Another feature that should be provided is a hand-hole for cleaning. This allows inspection and maintenance of the movable parts at any time between pump operation. It is, of course, very necessary that the plant operator be sure that the valve has re-seated and is providing a water-tight seal, or if this is not the case, he can remedy the situation by removal of any debris which may have lodged in the valve.

Check valves are also required on the discharge lines of sump pumps. Any regular non-slam check valves with cast-iron body may be used, but again the possibility of clogging is a consideration. Rubber seated or rubber flapper swing check valves in accordance with Figure 8-9 are recommended, while the ball-type check valve illustrated in Figure 8-11 is a suitable alternate.

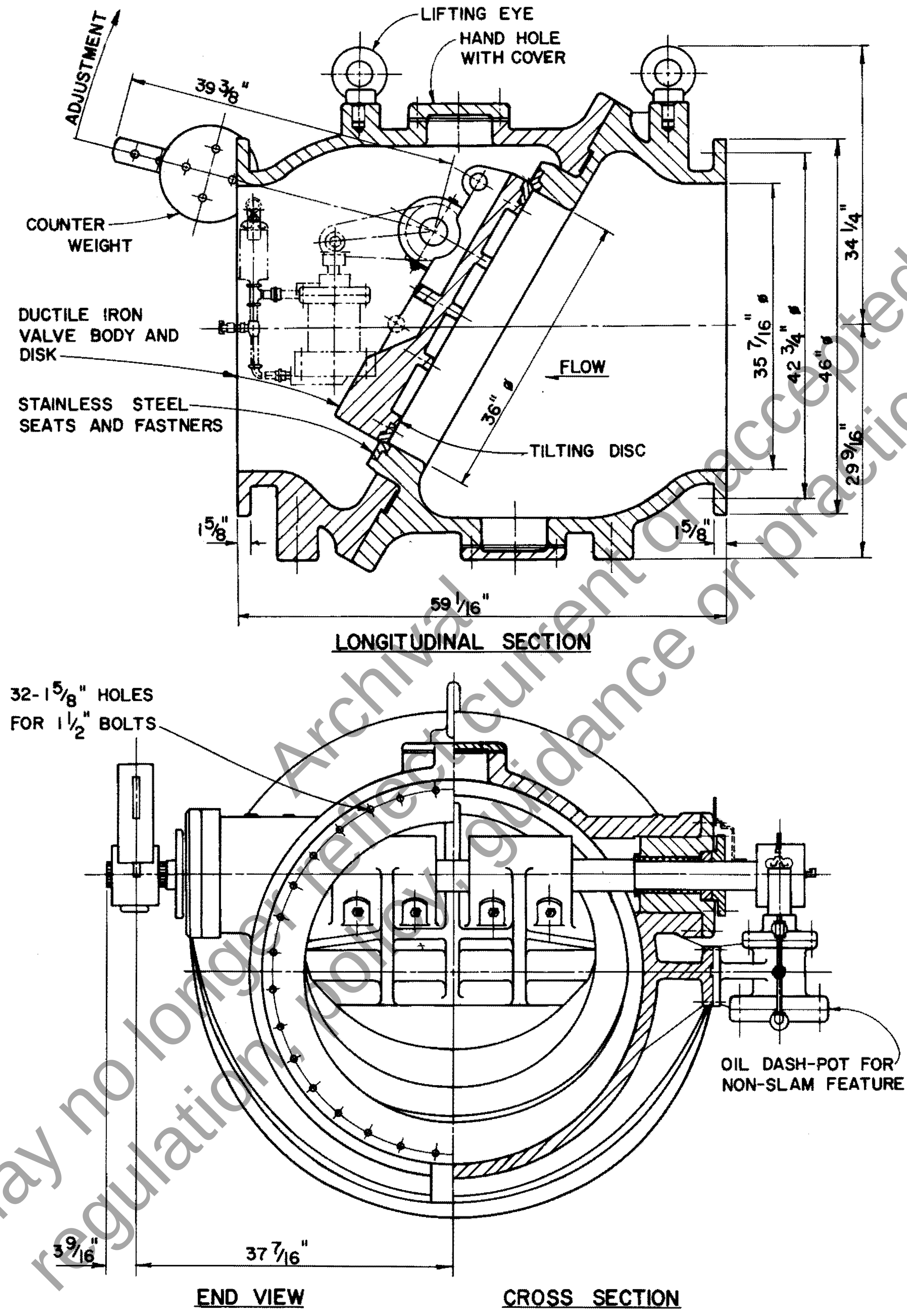
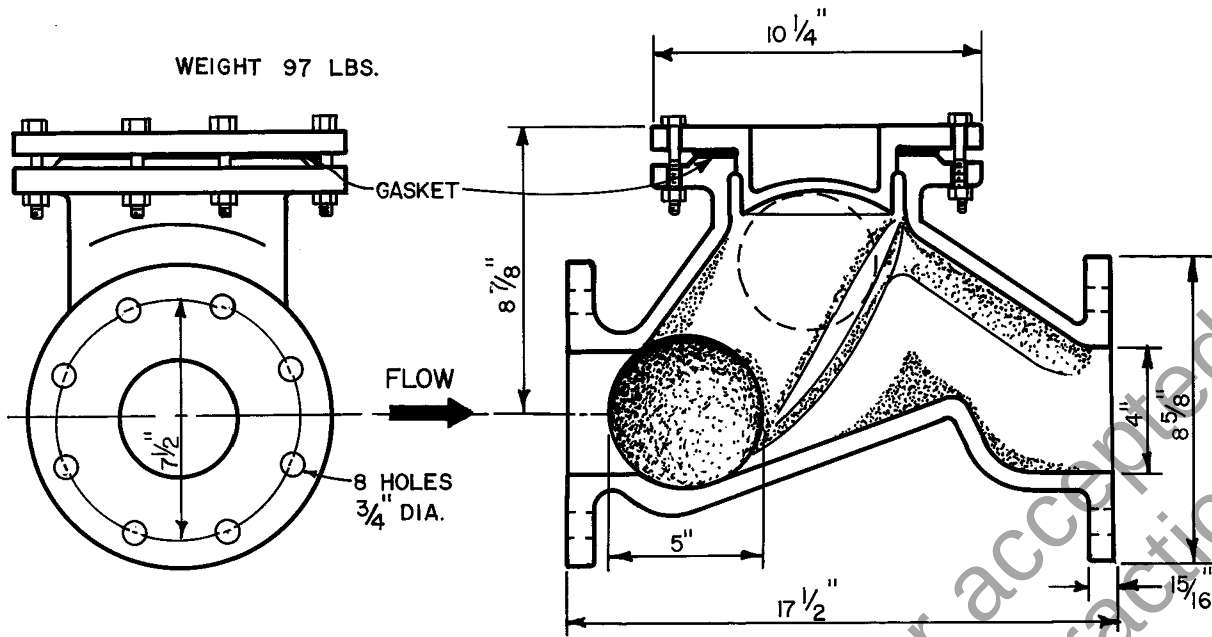


FIGURE 8-10. 36" CHECK VALVE
25 P.S.I. WORKING PRESSURE



DIMENSIONS SHOWN ARE FOR 4" VALVE. VALVES ARE AVAILABLE FROM 2" TO 30". DIMENSIONS AND WEIGHTS VARY ACCORDINGLY

SPECIFICATIONS:

BODY: CAST IRON: ASTM A159-72 CLASS 35
FLANGE DRILLING: ANSI B16.1 CLASS 125 FLAT FACED BOLT HOLES STRADDLE CENTER LINE.

BALL: HOLLOW STEEL WITH VULCANIZED NITRIL RUBBER
SINKING TYPE: SP. GR. GREATER THAN 1.
FLOATING TYPE: SP. GR. LESS THAN 1.

WORKING PRESSURE: 150 P.S.I.G. MAX TEMP.: 185° MAX.

SERVICE: GENERALLY USED FOR SEWAGE. FOR OTHER FLOWING MEDIA, VARIOUS TYPES OF COATINGS AND BALL ELASTOMERS ARE AVAILABLE. DETAILS ARE REQUIRED FOR PROPER EVALUATION.

FIGURE 8-11
BALL CHECK VALVE
FLYGT HDL TYPE 2016

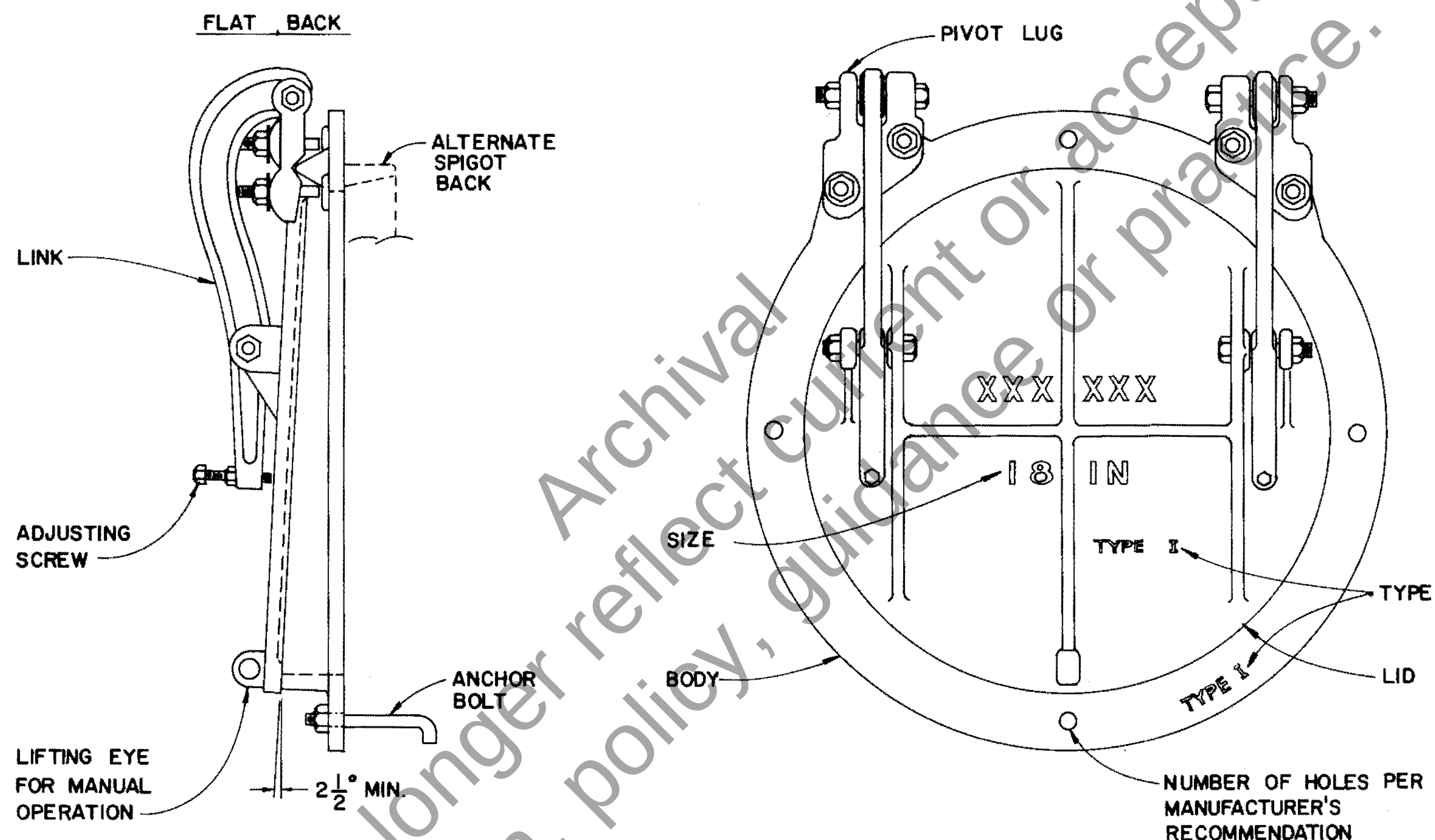
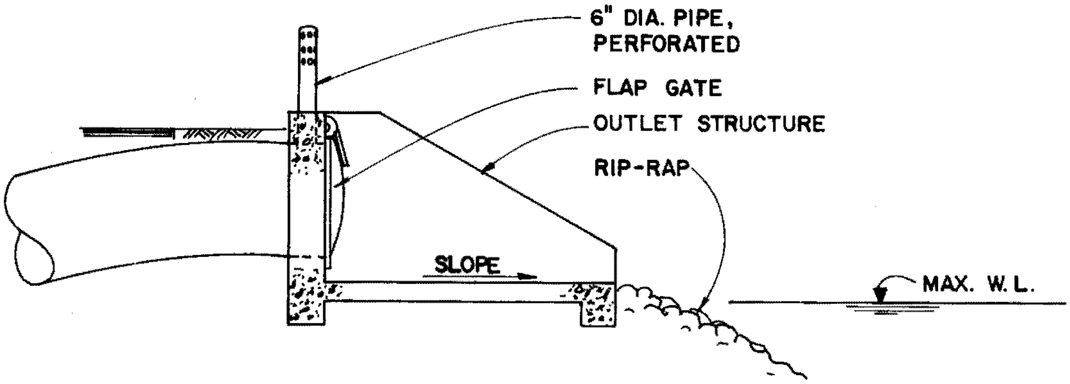
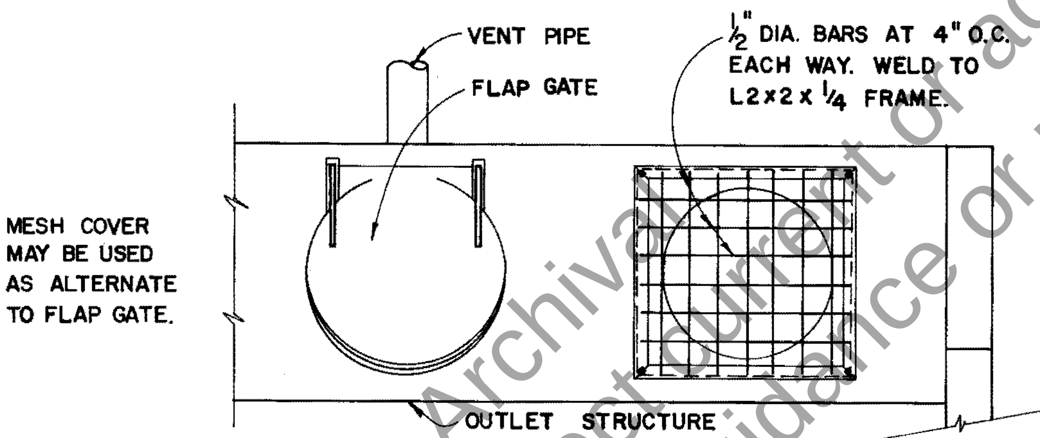


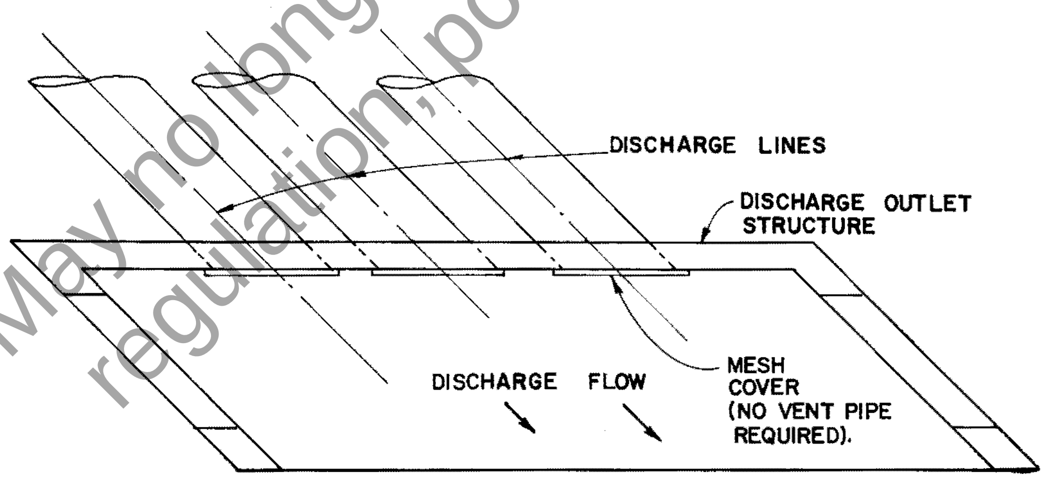
FIGURE 8-12. TYPICAL FLAP GATE



ELEVATION, OUTLET STRUCTURE



ELEVATION, DISCHARGE COVERS



PLAN, ANGULAR OUTLET STRUCTURE

FIGURE 8-13. TYPICAL DETAILS FOR OUTLET STRUCTURES

8-K. FLAP-GATES

A flap-gate is a simple device intended to close the end of a pipe discharging into a receiving channel. It consists of a heavy metal casting, or lid, circular in shape, hinged at the top from a body in such a manner as to close the end of the discharge pipe by gravity. Water being pumped through the discharge line will raise the flap sufficiently to permit discharge. However, in so doing, there will be a head loss.

Due to corrosion and debris, flap-gates cannot be relied upon to close tight. Flap-gates should not be partially submerged in normal operation unless the intent is only to prevent the entry of fish or wildlife or to protect against waves or tidal action. Figure 8-12 shows a typical flap-gate. Where possible, the outlet should be above the flood level of the receiving channel or reservoir.

Where the discharge is into a tidal waterway and the discharge line is set to drain at low tide, leakage around the flap-gate is likely. Tide water will enter the discharge line and as the tide rises, air will be expelled at or near the station through an air valve. See Figure 8-4. Should a pump start up during high tide, the discharge line will be rapidly filled and the pump will churn or operate at shut-off head until it has accelerated the static tide water and the pump discharge, and flow has been established out of the discharge line. The horsepower required at the pump shut-off head is greater than at the normal design point and where such a condition could occur the motor and pump must be selected accordingly.

Flap-gate bodies and lids are normally cast from grey iron conforming to ASTM A 48, Class 30, with hinge bars or links of cast steel conforming to ASTM A 27, Grade 30 - 60. Alternately, flap-gates may be fabricated from structural steel conforming to ASTM A 36. The entire flap-gate body, hinge bars or links, pivot lugs and lid should be epoxy coated.

8-L. SUMP PUMPS

It is always necessary to provide a small sump pump in a dry-pit. (Section 7-D) Sump pumps in wet-pit stations are optional, although certainly recommended. In semi-arid areas, a sump pump minimizes mosquitoe breeding. After the rainy season, the sump can be flushed clean of all debris and dry-weather inflows can be pumped out as they occur.

Areas which experience year-round rainfall apparently find that complete emptying of the sump between storms is not essential, especially in caisson-type stations where the deposition of suspended solids is less and the pump bearings are grease-lubricated to inhibit damage from abrasives.

Where sump pumps are installed in wet-pit stations, it is recommended that they be of submersible type with recessed impeller to readily pass small solids. They should be protected by the agitator spray ring accessory. Illustrations of the agitator spray ring will be found in Chapter 14 - Construction Details.

A check valve should be placed in the sump pump discharge line. The ball-type or rubber seated flapper-type check valve is preferred over the swing-disc type because it is less prone to jamming. (See Figures 8-9 and 8-11).

The sump pump discharge line should be a minimum of six inches in diameter. Sump pumps used for wet-pit service should be able to pass spheres or cylindrical objects up to three or more inches diameter. Therefore, the discharge line must be larger and free from elbows or reverse bends which could obstruct the passage of these objects.

The sump pump is sized after the sump has been designed. Once the sump area is known, the volume of water in the sump below the lowest pump suction bell can be calculated. The sump pump should be capable of pumping this volume in approximately one-half hour. Usual sump pump capacities range from 500 gpm to 1,000 gpm.

It is desirable to limit the sump pump motor size to about 30 horsepower. Consequently, the one-half hour limit may be exceeded in extremely large sumps. Where the pumping time exceeds one and one-half hours, more than one pump may be required. See Chapter 9 - Pumps for Stormwater Service, where suitable sump pumps are described.

8-M. VARIABLE SPEED PUMPING

In some pumping applications, sewage or wastewater, for example, it is advantageous to equip pumps so they may operate at two different speeds or even a variable range of speeds, with either electric or gas motors.

Provided that the speed regulation is done manually by the station operator, no additional equipment is required. Normally, engines will start automatically and unattended, then run at a pre-determined speed, such as 1,200 rpm, which is the normal maximum permissible speed for larger engines. With a smaller engine, by taking manual control, the operator could decrease the speed to 1,000 rpm or increase it to 1,400 rpm with resulting decrease or increase in pumping capability. However, due to the operation of what are known as the Laws of Affinity, the pump performance and horsepower requirements change more dramatically than the linear change in speed. Pump delivery varies directly as the change in speed, head capability varies as the square of the change, and horsepower requirements vary as the cube of the change.

When a gas engine is run at higher speed, its developed horsepower is obviously greater, but the greater pumping horsepower required increases faster than the engine's power output. Therefore, a speed increase from the design level of 1,200 rpm to a maximum of 1,400 rpm is sufficient to raise the horsepower requirement to the intermittent range. Prolonged operation at this speed is harmful. Nevertheless, in some emergencies and for a short period of time, the increased pumping capability could be safely utilized by manually increasing the speed of the engines. Devices for automatically changing the throttle setting in response to water level have also been developed.

The exact significance of being able to increase the pumping capability is that if a retention basin or storage box were utilized, it would be possible to pump it down in less time. On the other hand, assuming that the system design is based on a 50-year storm, then if this intensity of storm were exceeded, the additional pumping capability could be utilized.

Variable speed pumping is not usually of significance, but is an option that can be exercised with gas engine drivers without incurring additional capital cost. Two-speed or variable-speed electric motors do not normally find an application in storm-water pumping. More details on the Laws of Affinity will be found in Chapter 9 - Pumps for Stormwater Applications.

8-N. THE MERITS OF SIMPLICITY

Much of the complexity and high capital and maintenance costs of a pumping station can be avoided by using the natural laws of hydraulics. The force main shown in Figure 8-14 slopes upward from the station to the discharge channel, and a whole array of manifolding, slow-closing check-valves, non-reverse ratchets and the like is envisioned. However, use of a simple gravity stand-pipe is also possible. Each pump could have its own vertical riser, with free discharge over a weir at the top. The water would then flow in the common discharge line to the receiving channel. When pumping stops, the force main could drain back into the pump pit. A sump pump with a check valve to retain the flow in its own small force main could be used to remove the water.

The sump pump also could discharge over the standpipe weir. Although these discharges would contain a high proportion of silt and suspended matter, the flushing action of discharge from the main pumps would later remove this material. The result would be a simple and efficient system. The only objection might be on grounds of aesthetics if the appearance of the standpipe was judged incompatible with the surroundings.

Another simple installation has recently been designed for a West Coast port. The necessity was to drain a large paved area utilized for storage of imported automobiles, and to discharge into tide-water. The area had been filled, but drainage was away from a dike at tidewater to inshore areas slightly below highest tides. The pump station is located near the dike and gravity drain lines

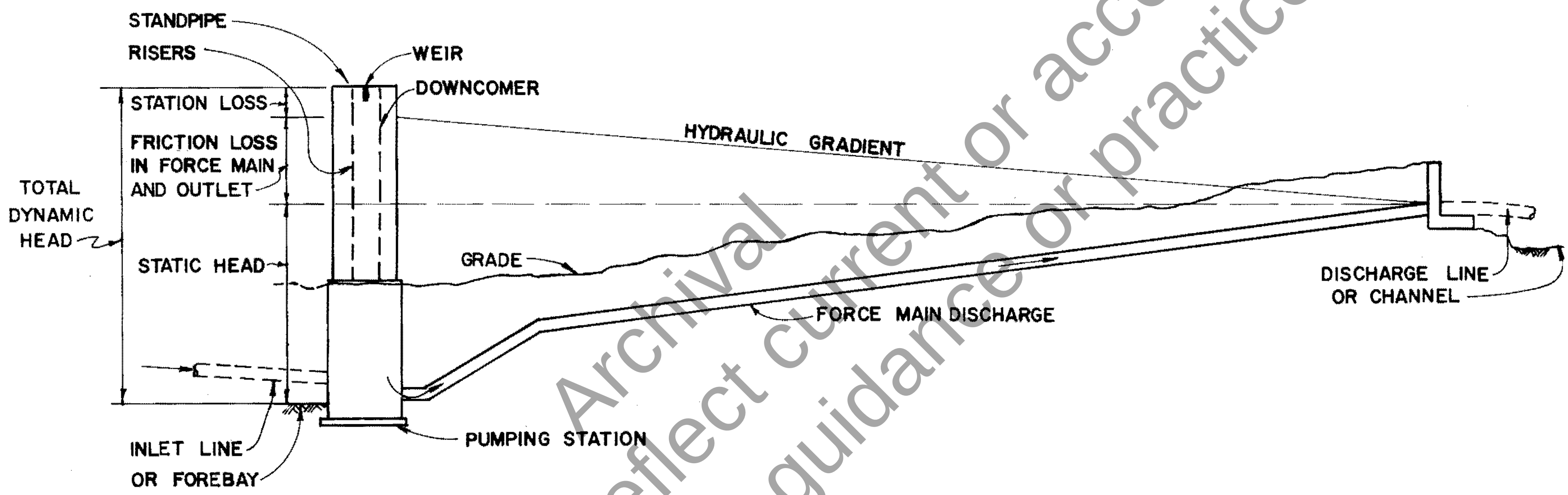


FIGURE 8-14. GRAVITY STANDPIPE AND FORCE MAIN

TDH = STATIC HEAD + FRICTION LOSS + STATION LOSS + OUTLET LOSS form a collection system, one line extending over 4,000 feet to the station from the furthest upstream catch basins. A rectangular wet-pit station where pump pit depth was minimized was designed with three pumps, all of equal size. Station Q is 160 cfs at 12.5 feet TDH. The discharge from the station to tidewater is a single gravity line, no manifolding of the three pumps being necessary. The tidal range of approximately 10 feet influences the level to which the pumps may be required to discharge when two or more are operating. This is accomplished very simply by utilizing a submerged discharge into a discharge basin when two or all three pumps are operating at highest tide levels. At lower tide levels there is a free discharge at slightly lower head, with consequent energy savings. Figures 8-15 and 8-16 illustrate the major details. See Figure 6-1 also.

The design criteria required the simplest possible station capable of functioning properly. Due to the industrial nature of the area no enclosing structure was considered necessary, though one could have been provided. See Chapter 1. - Introduction. Three vertical pumps all of the same size in a rectangular wet-pit station of minimum depth represent the simplest possible choice: with two pumps only it might not have been possible to satisfy cycling criteria. There is no trash rack in the station structure because full advantage is taken of the pre-screening effect of the inlet gratings. There is no inflow to the system other than through these gratings. A flap-gate on the free discharge of each pump serve to prevent backflow into any pump not operating. If slight leakage occurs due to uneven seating, this is unimportant. A non-reverse ratchet on top of each motor prevents counter-rotation and insures that each motor can start when called on.

Pump pit dimensions meet the criteria set forth in Chapter 6. - Wet-Pit Design, and pumps are equipped with suction umbrellas to permit submergence to be limited to 0.8 bell diameter. This reduced the pit depth and facilitated construction by the caisson method, especially since no waterproofing membrane outside the pit was considered necessary. Soil reports showed sandy clay or silty clay suitable for caisson construction, with a late-winter water table at El. -3.0. With bottom of pump pit slab at El. -8.0, the factor of safety of empty pit against buoyancy was 3.30. Incoming lines were properly joined together with junction structures outside the station, while inside the station a 45° transition and sloped bottom slab provided for reduction in velocity and streamlined flow to the pumps. The structure is concrete throughout with no steelwork other than galvanized embedded bases for pumps, grating, handrails, pit access ladder and work platform. Free ventilation is provided to eliminate danger from possible gasoline spills. The only floor grating used is behind each pump.

Some minor accessories and features were felt necessary. These were a sump pump to completely dewater the pump pit after storms. A water-supply is provided to an agitator spray ring for protection of the sump pump, which is of recessed impeller type. A conveniently located work platform in the pump pit enables the pit to be hosed down and all accretions to be removed by the sump pump. Solenoid valves control the spray ring and the oil-lubricators

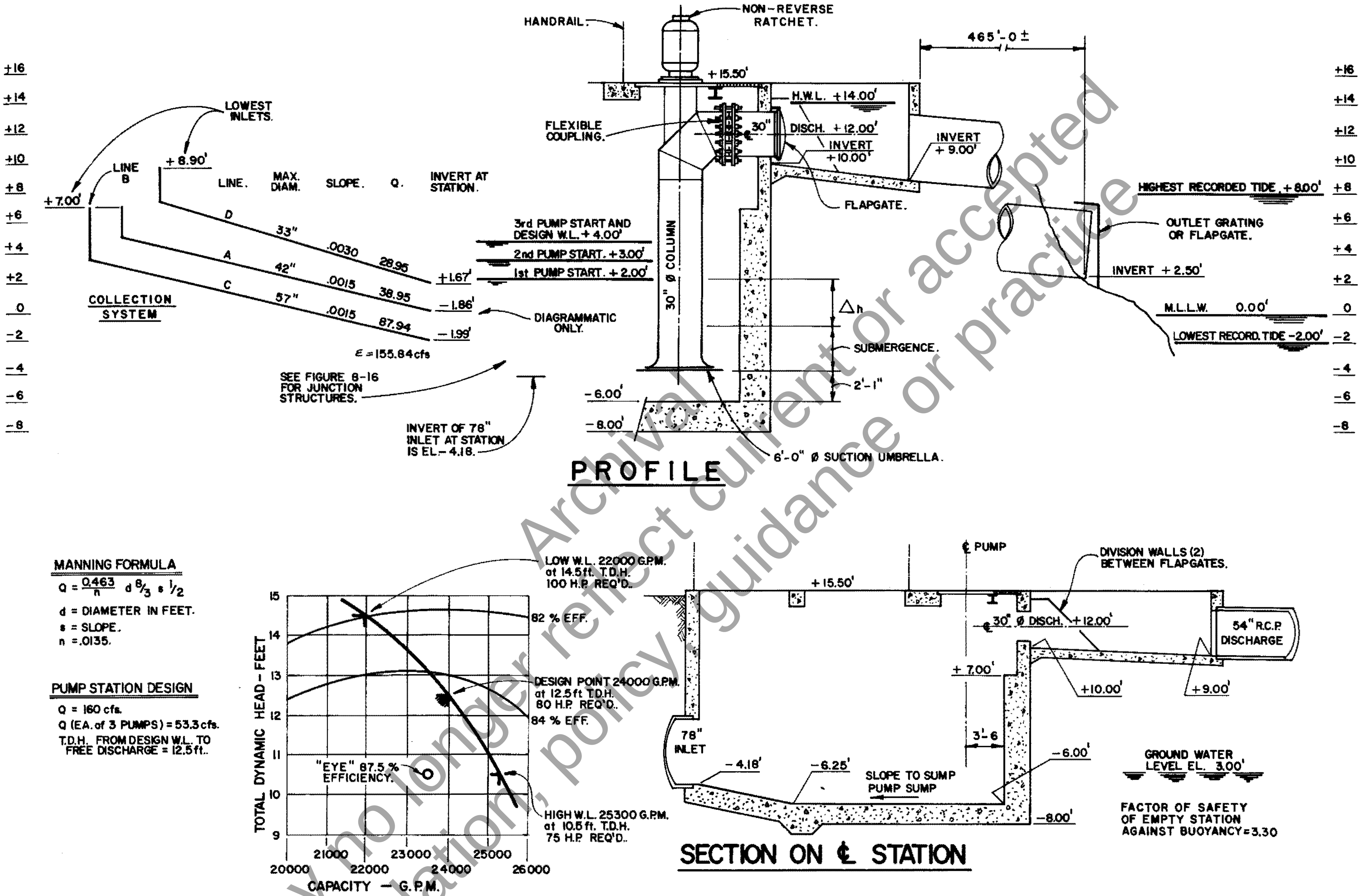
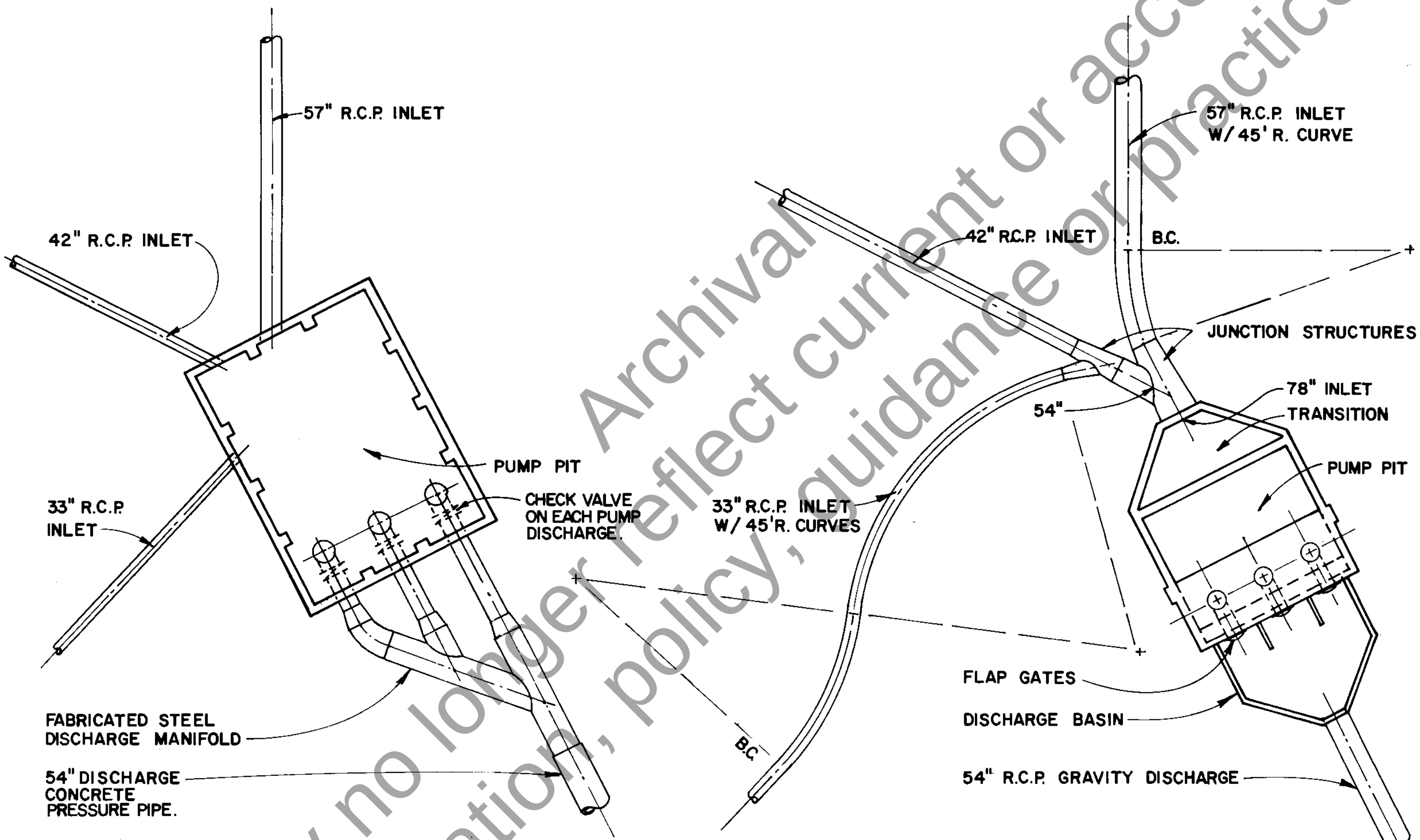


FIGURE 8-15 PROFILE AND SECTION, WET-PIT STATION



ORIGINAL CONCEPT

REVISED DESIGN USING PRINCIPLES SET FORTH IN THIS MANUAL

FIGURE 8-16. PLAN VIEWS OF WET PIT STATION for the enclosed-shaft pumps. An emergency generator is provided to be operative in the event of power failure. Electrically, the system is simplified, because each pump motor is only 100 hp. No expensive reduced voltage starting is needed and switchgear is housed in a weathertight enclosure.

Simplicity only evolved after an unsatisfactory initial concept. Development proceeded along the lines reommended in this Manual, the content of which provided a very suitable guide for the work. Chapter 5. - Selection of Type of Station and Equipment, contains an example modelled on this station, though the example and the end result are not identical. Of particular interest and value was Chapter 4. - Collection Systems. Computation of usable storage was carried out with considerable care because it was found to be critical in regard to pump sizing and cycling requirements. The computation involved several trial and error cuts, leading to a first pump start level of El. +2.0, second pump start of El. +3.0 and a third pump start (Design Water Level) of El. +4.0. The design water level thus becomes three feet below the lowest inlet grating, which is acceptable (See page 4-11). Low water shut-off of first pump is El. 0.0 to limit TDH to 14.5 and avoid overload of motor. In making the calculations of usable storage, the design Q of the pumps (53.33 cfs each) was not discounted because the TDH of 12.5 ft. occurs at first pump start, then reduces as water level rises, but can occur again with three pumps operating under highest tide conditions. Taking Qi as 26.7 cfs (see page 4-12), a proportioning of this amount between the several lines tributary to the station was necessary in order to compute usable storage and minimum cycling time. Sufficient information is given on Figures 8-15 and 8-16 for the reader to verify the storage and cycling time shown. The tedious trial-and-error procedure can be eliminated by using the known values given herein and the exercise will be found most instructive in understanding the close interrelationship between the design of the collection system and of the pump station. Figures 4-5 through 4-9 should be used to gain a thorough understanding of computing usable storage, even accounting for the usual system complications, such as line size and slope changes. During the actual design, a program was written for a small programmable calculator and this proved very useful.

To sum up, where only two pumps of equal size are used, the limited usable storage in the collection system may easily lead to cycling problems. When three pumps of equal size are used, cycling criteria can be more readily met. However, it is not unusual to find two large and two small pumps installed instead of three, simply to meet cycling criteria. Even when engines are used as drivers, computations of usable storage should be thoroughly made so that the whole system characteristics are thoroughly understood and can be adjusted if necessary for best results.

The late 1981 construction cost of the station has not yet been finally determined, but it is expected to be less than $500,000. This includes structure, pumps, electrical work and discharge basin, but excludes inlet line junction structures, gravity discharge line and emergency generator. At $3,000 per cfs pumped, this cost is as low as could be expected.

* * * * * * * * *

CHAPTER 9. PUMPS FOR STORMWATER APPLICATIONS

9-A. GENERAL

Large pumps that operate at relatively low heads are usually needed for stormwater pumping. The main types of pumps used are described in this Chapter. These are:

(a) Vertical Pumps - propeller and mixed flow types;
(b) Submersible Pumps - vertical and horizontal types;
(c) Centrifugal Pumps - horizontal non-clog type;
(d) Screw Pumps; and
(e) Volute or Angleflow Pumps - vertical type.

Electric motors are generally used as drivers for all the foregoing types of pump, but diesel or gas engine drivers are sometimes used for vertical pumps and could be used for screw or angleflow types.

Vertical pumps have been used more frequently than the other types. They are available in a wide range of capacities and discharge heads. Single-stage propeller pumps are used for low heads and mixed-flow pumps for higher heads. Two-stage propeller pumps are also manufactured. The two-stage propeller approximately doubles the head capacity of a single stage. A typical vertical stormwater pump is shown in Figure 9-1.

Next in importance are submersible pumps. These are usually a vertical type, although horizontal submersible pumps are also manufactured. Except for small stations, submersible pumps up to the present have been generally considered accessory pumps to deal with low (dry weather) flows, groundwater infiltration, and clean-up and pump-out of the pump-pit after a storm. This role has been changing as the available size of submersible pumps has increased. It is now possible to design large stormwater stations with sole reliance on submersible pumps.

Centrifugal pumps of a special type are used in dry-pit stations. In order to be resistant to suspended solids and debris which passes the screens, these pumps must be the end suction, non-clog type, with enclosed impellers and hand-hole on the casing which permits inspection and removal of foreign material. Small centrifugal pumps combined with upstream storage are well-suited to small catchments.

Screw pumps have not been used extensively in the United States, but their simple principle of operation and their performance in other countries justifies their consideration. The compatibility of the slope of the screw pump and the side slope of a depressed section of highway forms an interesting subject for innovative design with possibilities for economy.

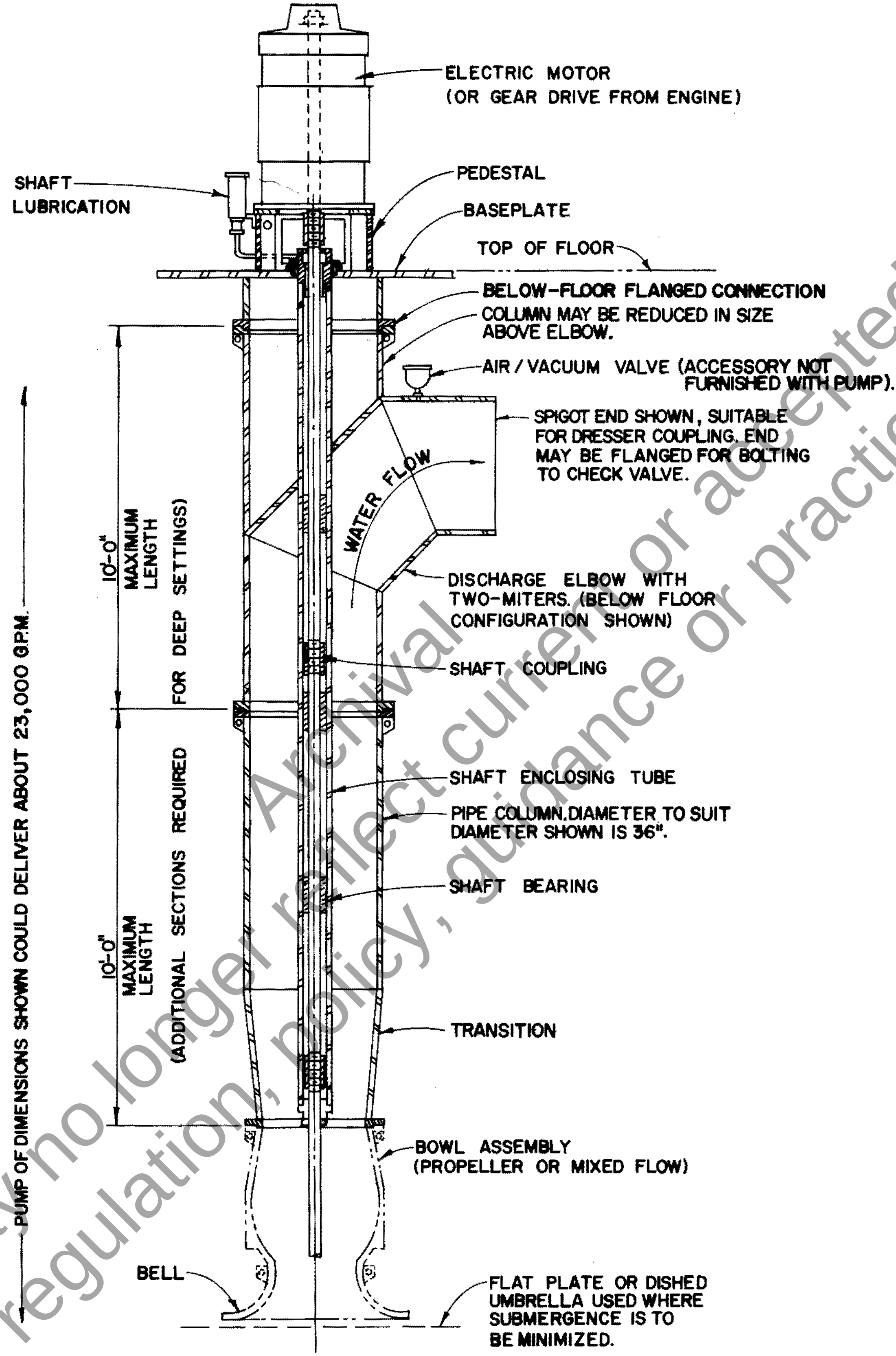


FIGURE 9-1. TYPICAL VERTICAL STORMWATER PUMP

OIL-LUBRICATED ENCLOSED SHAFT SHOWN

The fifth and final type of pump considered is the volute or angleflow pump, sometimes described as a dry-pit angleflow pump, or a single-suction centrifugal mixed-flow pump. It can be mounted in a horizontal or, more usually, vertical position, with the motor above the pump room operating floor and the pump mounted as much as twenty-five feet below. Only the vertical setting is considered here because the horizontal setting would be similar to the end-suction centrifugal pump already described. Volute or angle flow pumps, mounted vertically, have for many years been a standard for sewage pump station installations. However, due to the complex accessories needed with these pumps, they are not recommended for stormwater pumping unless operating head necessitates their use.

9-B. PUMP CHARACTERISTICS AND PERFORMANCE CURVES

All pumps possess a characteristic termed specific speed, N_s, denoted by the equation: $N_s = \frac{RPM\sqrt{GPM}}{H^{3/4}}$.

Pump impellers for high heads have low specific speeds, and impellers for low heads usually have high specific speeds. Figure 9-2 shows the relationship of different types of impellers to the useful range of specific speeds.

Pumps of the axial-flow type have impellers shaped like ship propellers, and as the name implies, the flow of liquid is discharged axially through the impeller.

Pumps of the mixed-flow type have impellers with vanes integral with a conical hub. The pumping head is developed partly by centrifugal force and partly by a lifting action of the vanes. The application of the mixed-flow pump is similer to that of the vertical axial-flow propeller type of pump, but each type has its own range of operating heads and capacities. Pumps of the centrifugal type have impellers which develop head entirely by centrifugal force.

As an example, find the type of pump necessary to deliver 2,500 gpm at 81 ft. head using a speed of 1,760 rpm (usual for conventional electric motors). Specific speed is found to be 3,259, corresponding to the centrifugal type of pump. At 85% efficiency, a 60 horsepower motor would be needed, because

$$\text{Horsepower (HP)} = \frac{\text{GPM x 8.33 lbs./ft.}^3 \text{ x Head in feet}}{\text{33,000 x Efficiency}}$$

The example illustrates work performed being expressed in horsepower, with a factor being introduced to account for the

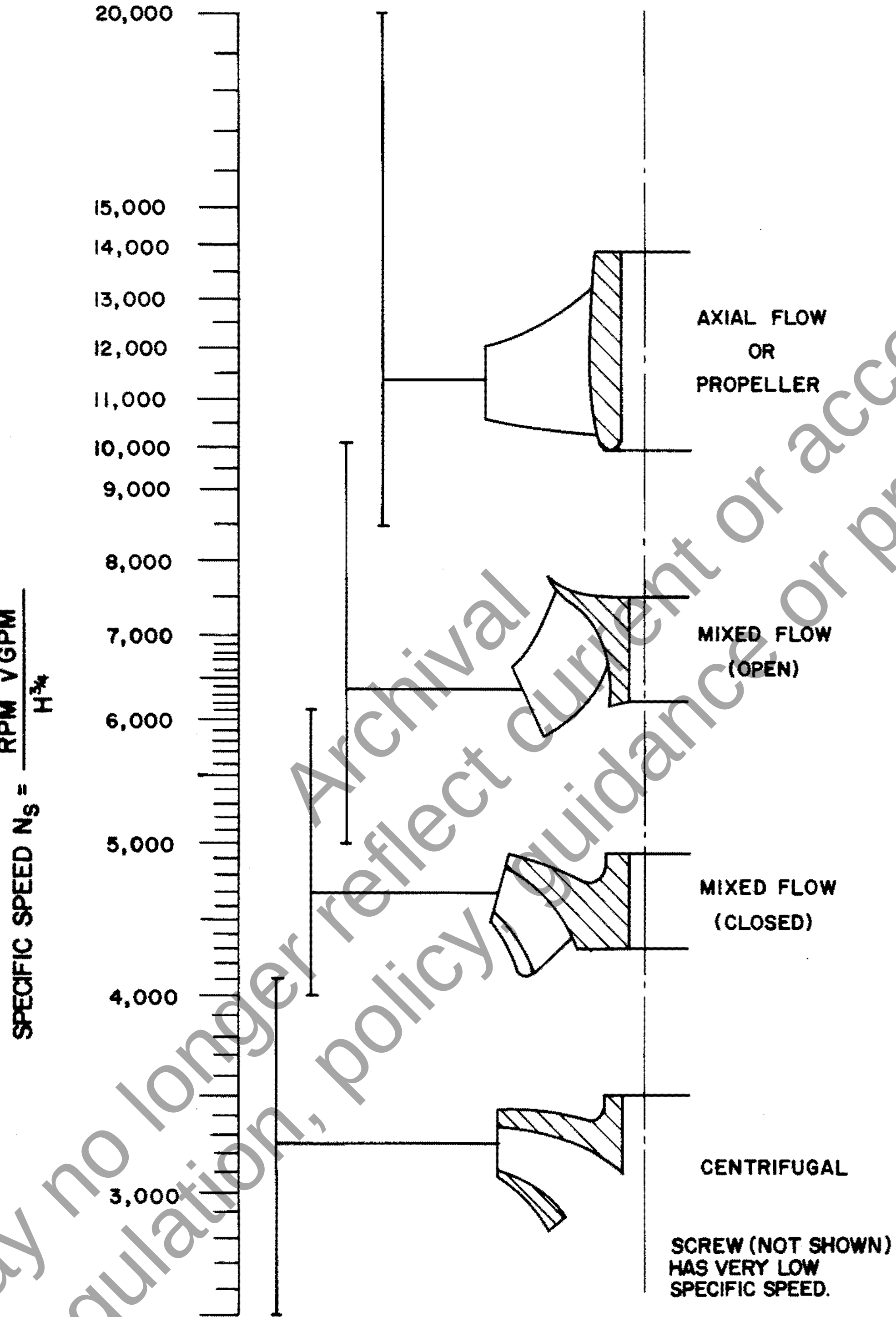


FIGURE 9-2 SPECIFIC PUMP SPEED VS. IMPELLER TYPES

efficiency of the pump. All stormwater pumps must operate over a range of heads. Every pump has a performance curve developed by its manufacturer. More precisely, a family of curves is shown for each pump, because any pump can be fitted with various sizes of impeller. The impeller is the rotating element which imparts energy to the water and it can be modified or "trimmed" exactly to suit performance requirements. Trimming refers to the process of machining the impeller to the proper dimensions to provide the performance required.

Superimposed on the pump performance curves are other curves showing the efficiency of the pump. If a pump were 100% efficient in imparting energy to the water, the work done would be the product of the weight of the water and the head. In fact, a stormwater pump selection with an efficiency of 75% would be about average. In some cases, efficiencies at design point of 85% or more may be achieved; in other cases, efficiencies at design point may be below 70%. With continuous pumping, the energy loss due to low efficiency is a significant cost factor. However, since stormwater pumps operate relatively infrequently, the cost penalty of less efficiency is usually not significant. Pumps need not be specified to have efficiencies in excess of 75% at design point. To do so would unnecessarily reduce competition between various manufacturers. The required horsepower is usually shown on any pump performance curve. This is used in selecting a driver, either electric motor or engine.

Because vertical pumps are the most commonly-used type for stormwater pumping, and because they can be either propellor or mixed flow, this type of pump is used as the basis for the rest of the text in this Section. However, the principles explained are applicable to all the other types of pump referred to in Section 9-1.

Vertical pumps for stormwater pumping stations for highway facilities will almost invariably be of the single-stage axial flow (propeller) type or the mixed-flow type. This is based on the assumption that individual pump capacities will be between a minimum of 1,000 and a maximum of 30,000 gallons per minute and that total dynamic heads will be between 8 and 50 feet. Pump manufacturers' curves are expressed in feet of head and discharge in gpm. Cubic feet per second is not used as a measure of pump capacity except as an interface with the collection and discharge systems.

Published pump performance curves of a well-known manufacturer are shown in Figures 9-3 through 9-6. The curves are for one pump of propeller type (16PO) and for two pumps of mixed flow type (24MS and 24LS). Two different speeds of rotation are shown for the 16PO, while the 24MS delivers greater quantity at higher head than the 24LS, with same diameter impeller and with both operating at the same speed. Reading at the "eye" (point of maximum efficiency on the curves) for the 16PO at 1,180 rpm and

FIGURE 9-3. 16" PROPELLOR PUMP AT 1180 RPM

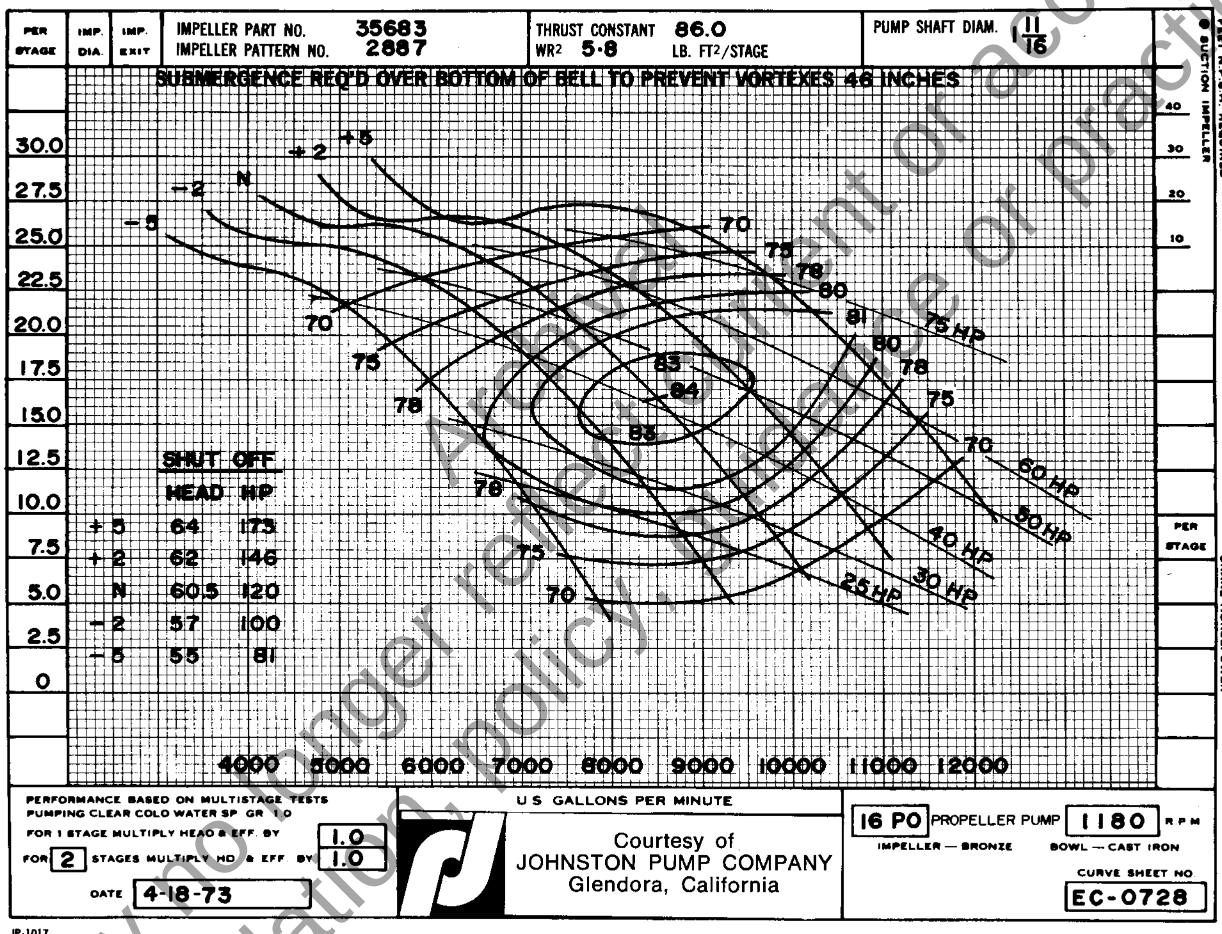
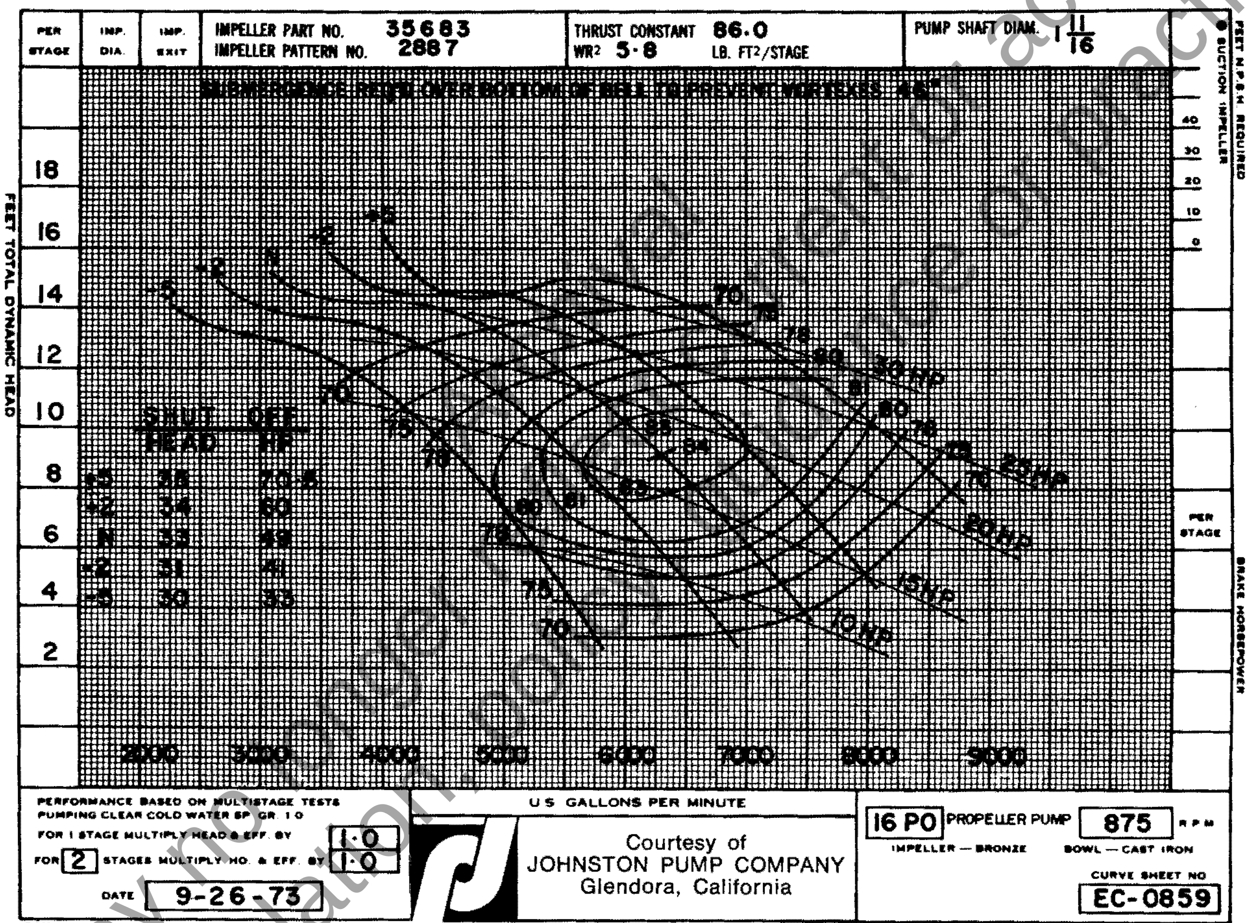


FIGURE 9-4. 16" PROPELLOR PUMP AT 875 RPM



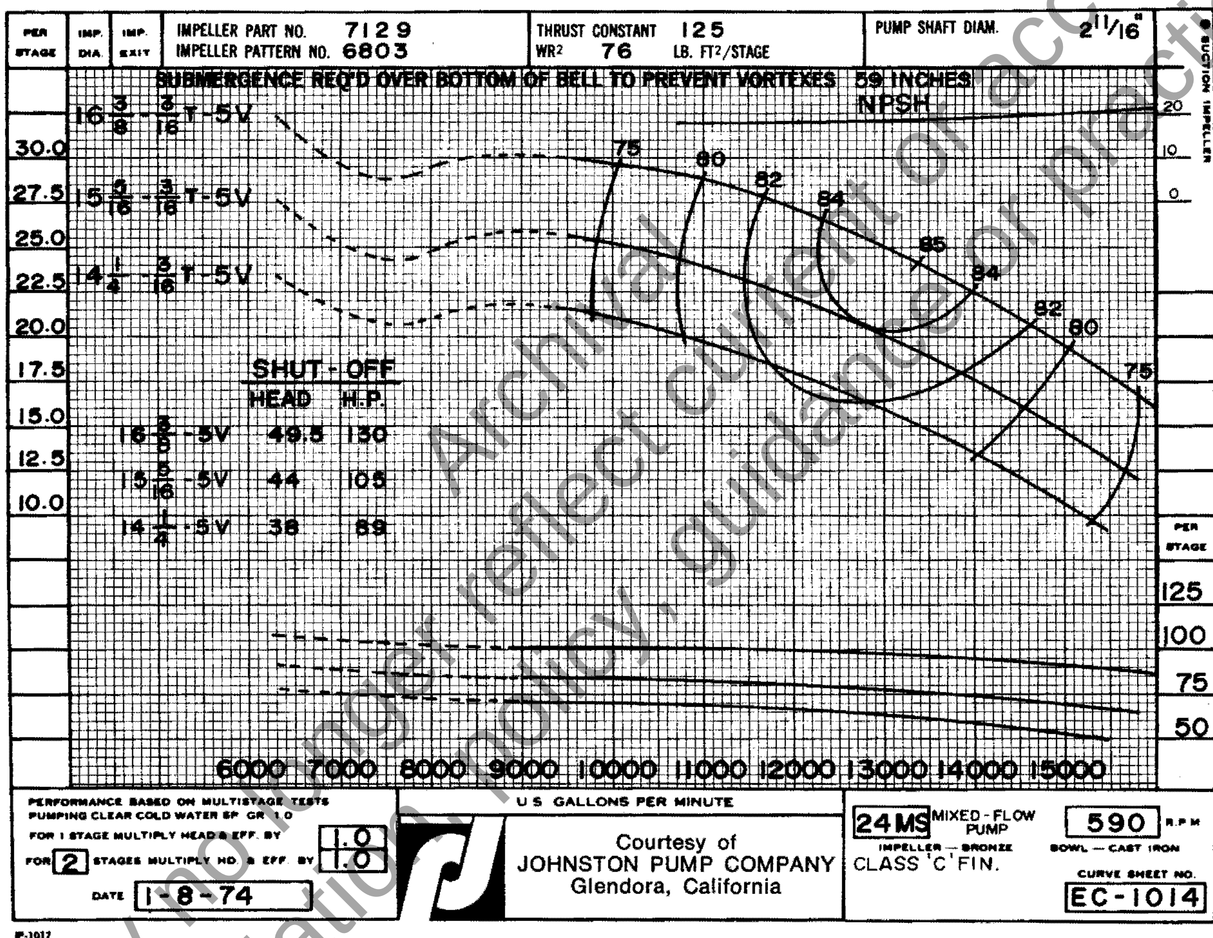
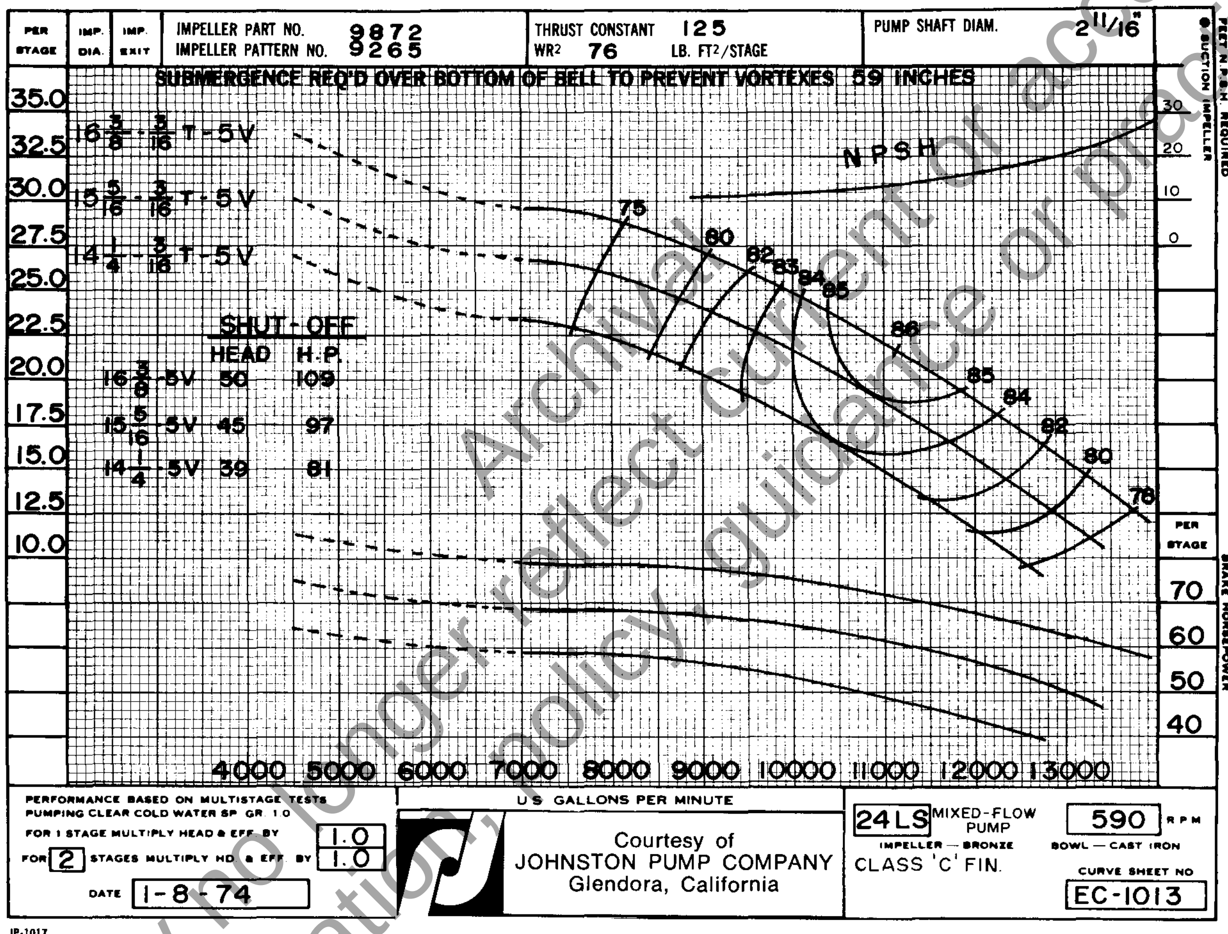


FIGURE 9-5. 24" MIXED FLOW (24 MS)

FIGURE 9-6. 24" MIXED FLOW (24 LS)



for the 24LS at 590 rpm, the specific speeds can be computed to be 13,288 and 6,225 respectively, representing mid-range of the specific speeds shown in Figure 9-2 for these types of pumps.

A comparison of the curves for the two types of impeller shows that the individual propeller pump covers a broader range of gpm and head than the mixed-flow. The mixed-flow pump delivers at a higher head than the propeller pump.

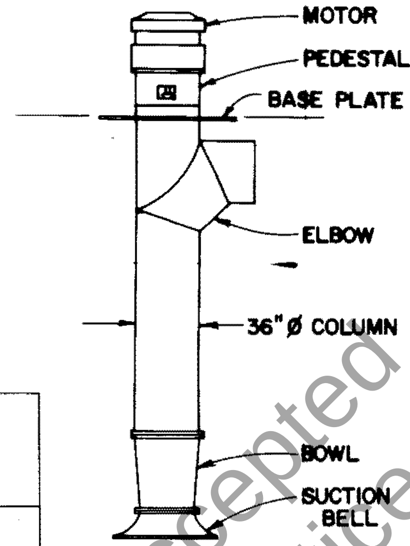
In pump selection, it is desirable that the design point be as close to the eye as possible, or else to the left of the eye rather than to the right of or above it. For a design point or condition of 8,500 gpm at 16.5 ft. TDH, the 16PO propeller pump at 1,180 rpm would be an ideal selection. For a design point of 11,000 gpm at 22.5 ft. TDH, the 24LS would not be a suitable selection. The 24MS rotating at the same speed has a curve which produces a slightly higher head and this pump would be an acceptable selection. A different impeller is used and the lower efficiency at the design point gives a correspondingly higher horsepower requirement. Again, performance should always be in the constantly rising portion of the curve. Avoid conditions where the pump is operating at a dip in its curve because its output will drop sharply and become unstable.

The effect of the Laws of Affinity can be observed by comparing the 16PO propeller pump running at different speeds, see Figures 9-3 and 9-4. When running at 875 rpm instead of 1,180, the discharge is reduced in direct proportion from 8,500 to 6,250 gpm. The head is reduced by the square, from 16.5 ft. to 9.1 ft. and the horsepower requirement by the cube, from 42 to 17.

Figures 9-3 through 9-6 show two different methods used to describe impeller size. Horsepower requirements are also shown in two ways, either by commercial motor size or by actual brake horsepower required. Net positive suction head (NPSH) requirements are also shown for the mixed flow pumps, but for practical purposes the submergence requirements shown are sufficient guide. As additional information which is sometimes needed, shut-off head and horsepower are shown on the Johnston curves. The significance of shut-off head is that if the pump was pumping against a closed valve, the head and horsepower requirement would rise to the values shown. Whereas the head and corresponding pressure would not overstress the pump elbow and piping, the motor, if not of sufficient horsepower, would be overloaded. Sometimes in stormwater pumping stations, conditions are such that pumps may develop shut-off head, and in such cases the motors or other drivers must be sized accordingly.

Proper selection of pumps requires some practice. The following examples are presented for illustration, using curves specially drawn in simplified form. Two further methods are used to describe impeller size.

CURVE NUMBER 1



TYPICAL OUTLINE OF 36" PROPELLER PUMP

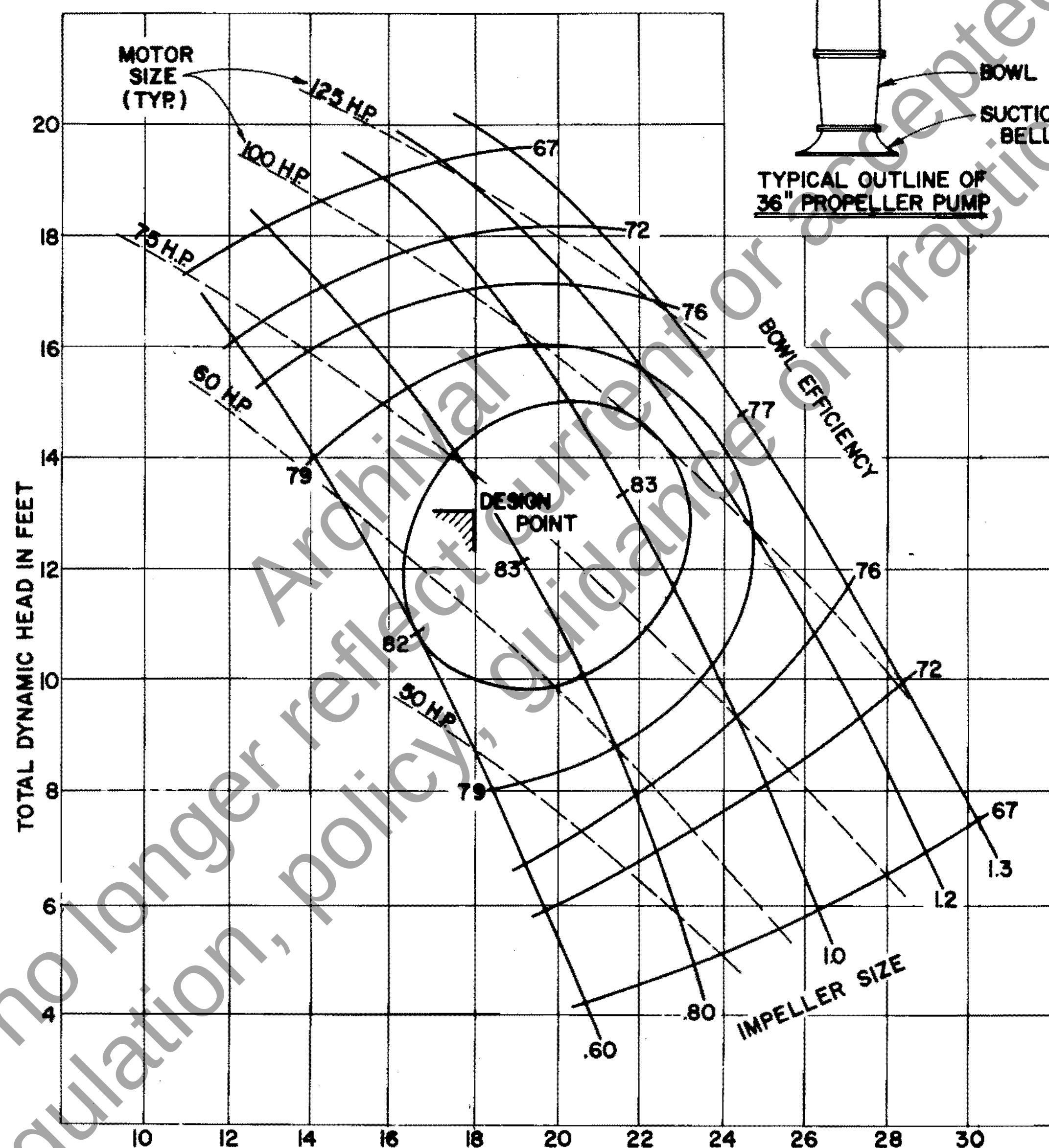


FIGURE 9-7. PERFORMANCE CURVE FOR 36 INCH PUMP ROTATING AT 590 R.P.M.

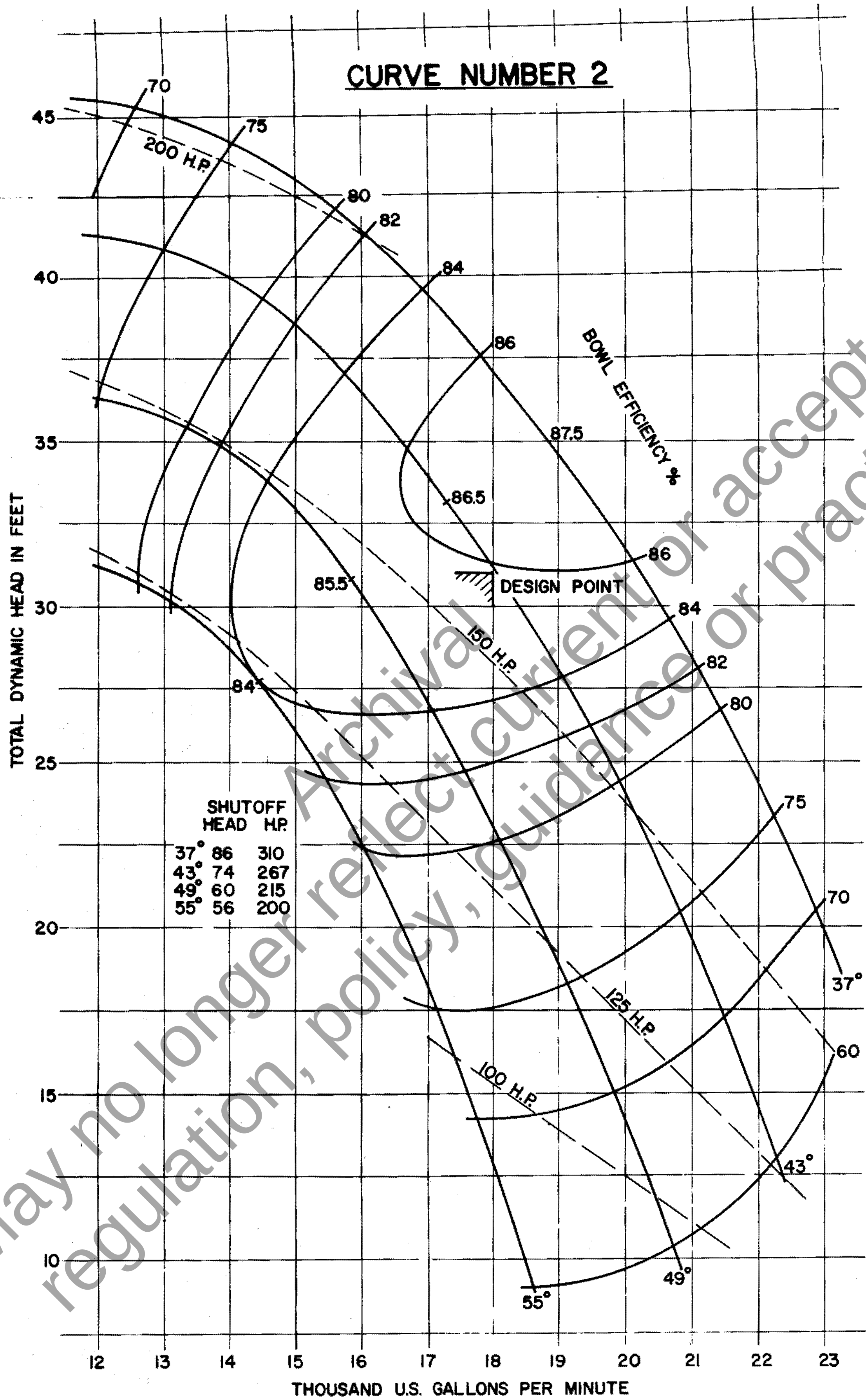


FIGURE 9-8. PERFORMANCE CURVE FOR 24 INCH MIXED FLOW PUMP ROTATING AT 700 R.P.M.

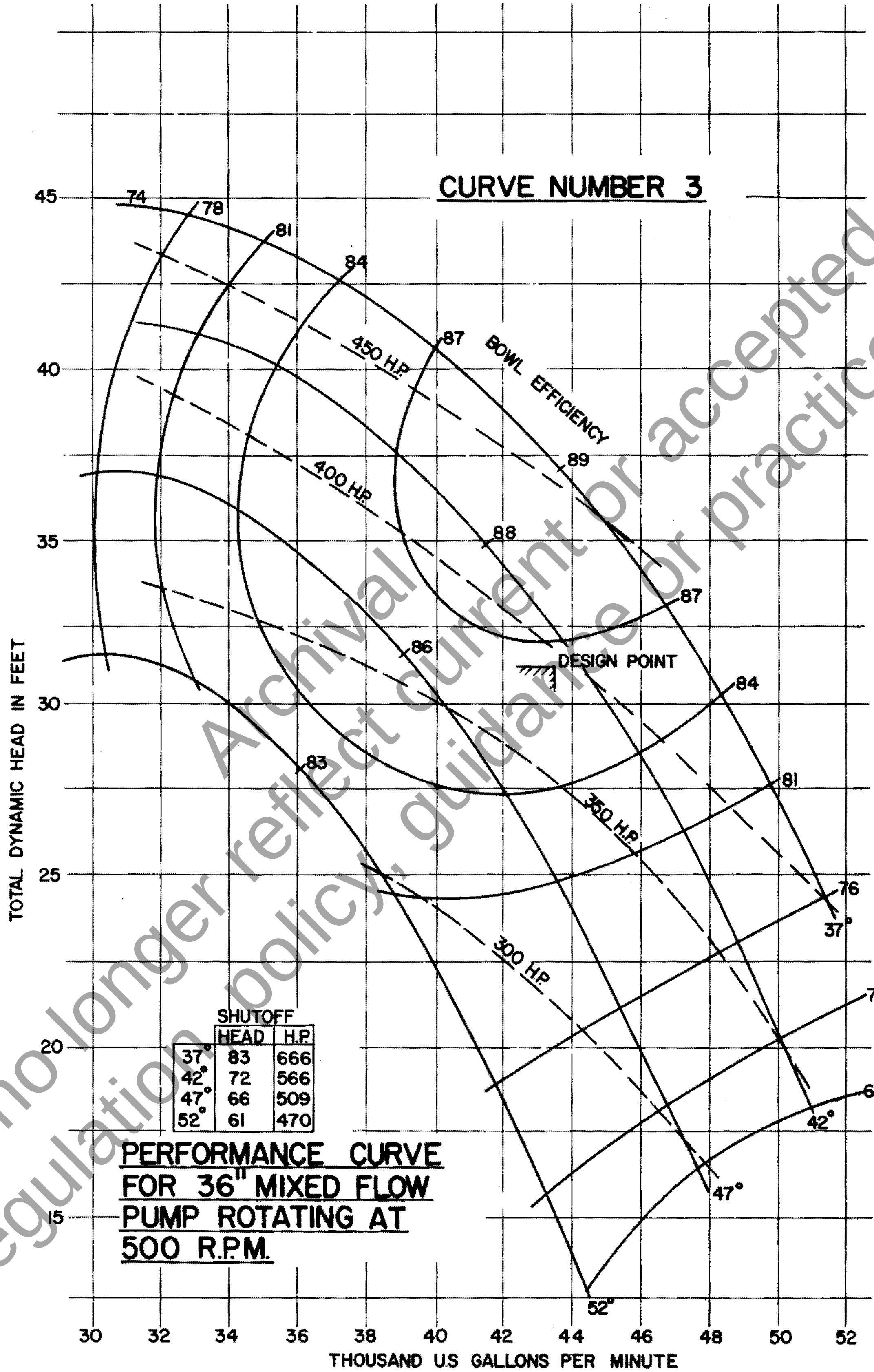

CURVE NUMBER 3
BOWL EFFICIENCY
450 H.P.
400 H.P.
350 H.P.
300 H.P.
DESIGN POINT
74
78
81
84
87
89
88
86
83
76
71
61
37°
42°
47°
52°
SHUTOFF
HEAD H.P.
37° 83 666
42° 72 566
47° 66 509
52° 61 470
PERFORMANCE CURVE FOR 36" MIXED FLOW PUMP ROTATING AT 500 R.P.M.
TOTAL DYNAMIC HEAD IN FEET
15
20
25
30
35
40
45
THOUSAND U.S. GALLONS PER MINUTE
30
32
34
36
38
40
42
44
46
48
50
52

FIGURE 9-9.

Referring to the three curves shown, Curve No. 1, Figure 9-7 is for a 36" propeller pump, Curve No. 2, Figure 9-8, is for a 24" mixed flow and Curve No. 3, Figure 9-9, is for a 36" mixed flow. Note that the column and elbow for the first and third pumps may be identical, but the bowl, shafting and motor are different. The example first compares two pumps of different sizes selected to pump the same quantity of water, but at different heads; and then compares two pumps of different sizes selected to pump different quantities of water, but at the same head. The comparisons are made using the Design Points shown on the curves.

Curve No. 1 — The 36" propeller pump rotating at 590 rpm delivers 18,000 gpm at 13.0 ft. TDH. Impeller trim is .78 and a 75 HP motor is required. Efficiency at design point is 82.5%.

Curve No. 2 — The 24" mixed flow pump rotating at 700 rpm delivers 18,000 gpm at 31.0 ft. TDH. Impeller trim is 43^{o} and a 200 HP motor is required. Efficiency at design point is 86%.

Curve No. 3 — The 36" mixed flow pump rotating at 500 rpm delivers 43,500 gpm at 31.0 ft. TDH. Impeller trim is 43^{o} and a 400 HP motor is required. Efficiency at design point is 86.5%.

Impeller trim and efficiency are interpolated between curves plotted. Motor size is always the next larger commercial size than the bare requirement read directly or by interpolation. Different manufacturers have different nomenclatures for impeller size or trim; this may be numerical or decimalized, or shown by angular degrees, or by the actual dimension of the impeller diameter, or by a series of letters. Study manufacturers' curves.

If unfamiliar with pump curves the reader should solve the following:

Curve No. 1 (36" Prop.)

(a) Find motor size and impeller trim required to deliver 14,000 gpm at 16 ft. TDH, and determine efficiency at this design point.

(b) Find motor size and impeller trim required to deliver 26,000 gpm at 8 ft. TDH and determine efficiency at this design point.

(c) With .78 impeller trim as in the example, determine discharge in gpm at 17 ft. and 6 ft. TDH, with corresponding efficiencies and motor sizes required.

Curve No. 2 (24" MF)

(a) Find motor size and impeller trim required to deliver 15,000 gpm at 40 ft. TDH and determine efficiency at this design point.

(b) Find motor size and impeller trim required to deliver 22,000 gpm at 15 ft. TDH and determine efficiency at this design point.

(c) With 43° impeller trim as in the example, determine discharge in gpm at 40 ft. and 15 ft. TDH, with corresponding efficiencies and motor sizes required.

Curve No. 3 (36" MF)

(a) Find motor size and impeller trim required to deliver 44,000 gpm at 30 ft. TDH and determine efficiency at this design point.

(b) Find motor size and impeller trim required to deliver 35,500 gpm at 35 ft. TDH and determine efficiency at this design point.

(c) With 42° impeller trim, determine discharge in gpm at 20 ft. TDH with corresponding efficiency and motor size required.

Answers:

Curve No. 1

(a) 100 HP, .70 imp., 75% efficiency.

(b) 75 HP, 1.05 imp., 70% efficiency.

(c) 13,800 gpm, at 17 ft. TDH, 100 HP, 72% efficiency.

22,500 gpm, at 6 ft. TDH, 50 HP, 67% efficiency.

) See Note Next Page

Curve No. 2

(a) 200 HP, 41° imp., 81% efficiency.

(b) 150 HP, 42° imp., 64% efficiency.

(c) 13,800 gpm, at 40 ft. TDH, 200 HP, 77.5% efficiency.

21,800 gpm, at 15 ft. TDH, 150 HP, 65.0% efficiency.

Curve No. 3

(a) 400 HP, 43° imp., 85.5% efficiency.

(b) 400 HP, 47° imp., 85.0% efficiency.

(c) 50,200 gpm, 70% efficiency, 350 HP.

Note: For Curve No. 1 (c) it could be that the range over which the pump must operate would be from low water in the pump pit (maximum TDH 17 ft.) to high water (minimum TDH 6 ft.). Although at design point a 75 HP motor would suffice, a 100 HP motor is required to pump from the low water level. This is frequently the case and more likely with propeller pumps than with mixed flow.

The designer must always specify requirements which can be satisfied by pumps readily available on the commercial market. The pumps of any given manufacturer are normally available in a range of sizes and types so that capacities and heads can be tailored to suit most conditions. However, not every manufacturer can furnish an equally suitable pump for every condition. It is necessary for the pump station designer to refer to the catalogs of a number of manufacturers in developing non-proprietary specifications.

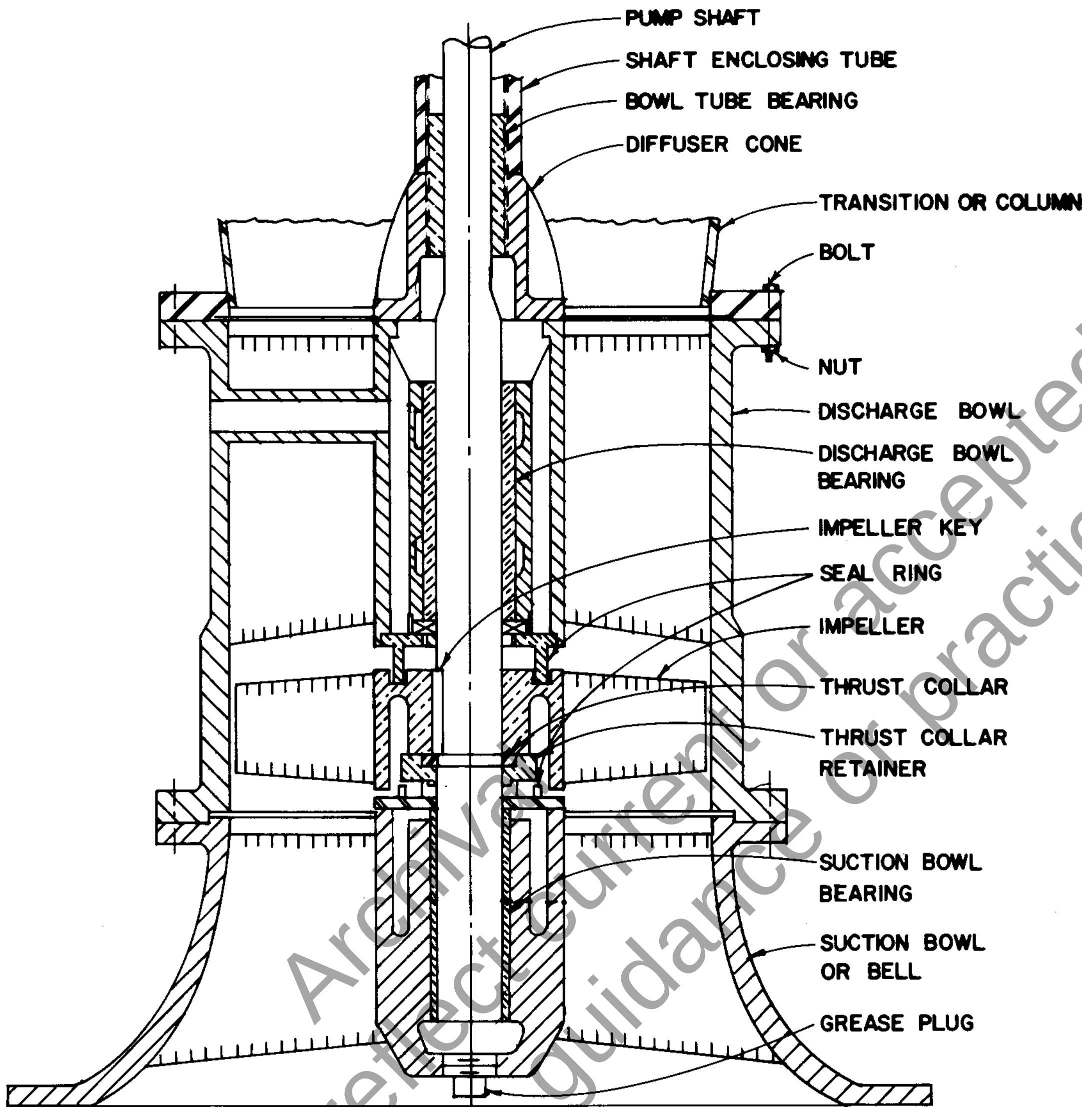
9-C. VERTICAL PUMPS - PROPELLER AND MIXED FLOW

Manufacturers normally make pumps of various material qualities and features according to their standards, but the standard products may not be entirely suitable for all conditions or in accord with recommendations made in this Section. It is necessary to specify the materials and components of pumps adequately so that deficiencies will not cause operating problems.

Discounting any provision or devices for varying the speed, the pump shaft and the impeller of a vertical pump will always rotate at the same speed as the motor, since the shaft is directly coupled to the motor. Standard electric motors rotate at a fixed speed depending on the supply voltage and the winding. Motors for vertical pumps within the range we are considering rotate at 1,760 rpm, 1,170 rpm, 875 rpm, or lesser speeds, reducing in steps to as low as 220 rpm. These numbers are sometimes quoted a little differently, e.g., 880 in lieu of 875 rpm, but this is not significant. Pumps are designed to operate at these standard motor speeds. Speeds, of course, become less and less as pump size increases, and as a general principle the lower the speed, the longer the life of the equipment. Where an engine is used as the driver, the normal engine speed will be 1,200 rpm, and the right-angle gear drive must have a suitable ratio to rotate the pump at its correct speed.

The pump assembly of vertical pumps is suspended below the base-plate by the necessary length of discharge column and elbow, with the pump bowl being adequately submerged into the liquid being pumped. An oil or grease lubrication system must be provided since the silty stormwater is not a suitable lubricant.

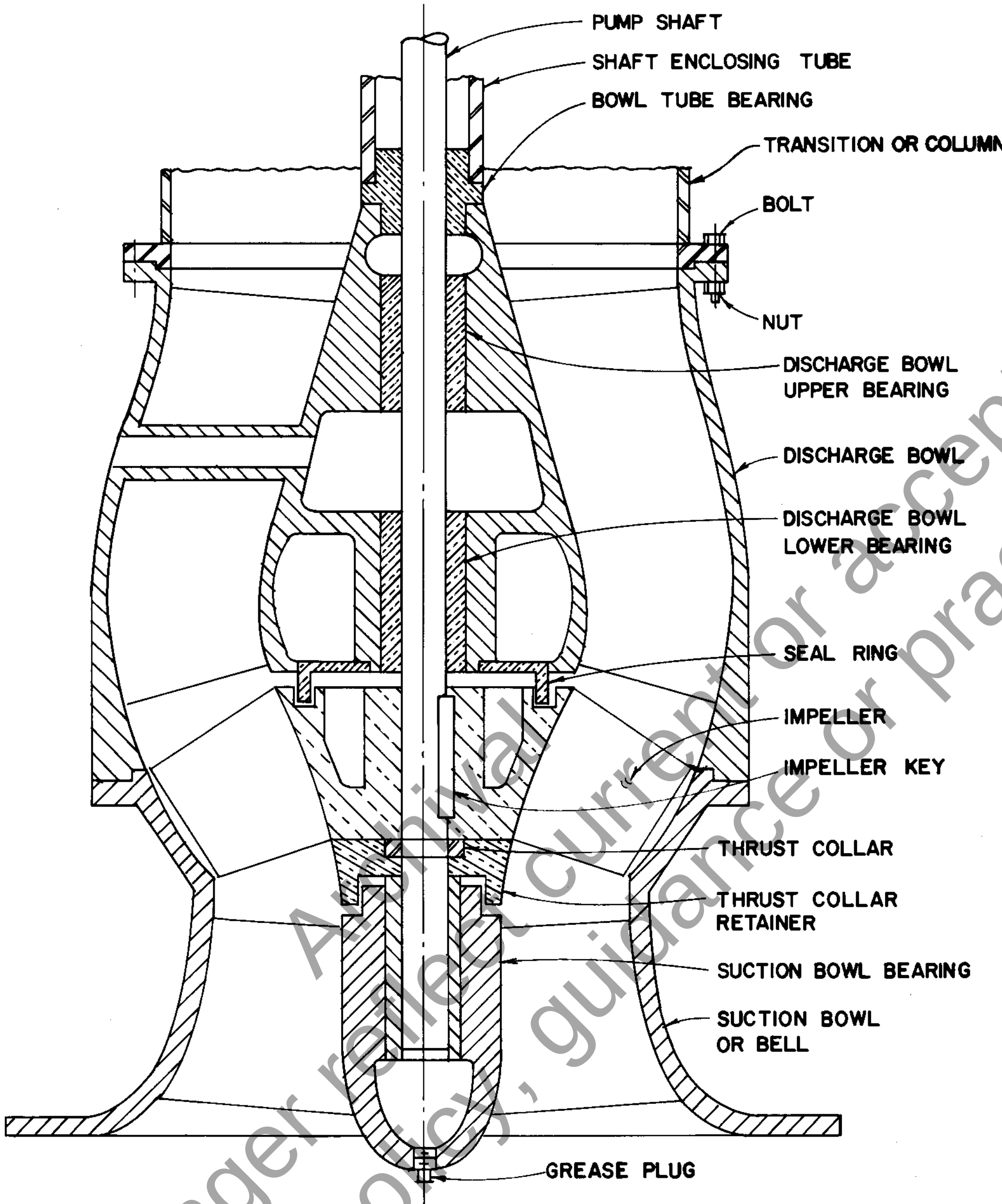
The bowl assembly is the heart of the vertical pump and consists basically of a suction bowl or bell, discharge bowl, impeller,



BILL OF MATERIALS

DESCRIPTION	MATERIAL
SUCTION BOWL	ASTM A 48, CLASS 30
DISCHARGE BOWL	ASTM A 48, CLASS 30
PUMP SHAFT	AISI TYPE 410
SHAFT ENCLOSING TUBE	ASTM A 120 PIPE OR TUBING
DISCHARGE BOWL BEARING	ASTM B 144, ALLOY 3A
THRUST COLLAR RETAINER	ASTM B 143, ALLOY 2B
SUCTION BOWL BEARING	ASTM B 144, ALLOY 3A
IMPELLER	ASTM B 143, ALLOY 2B
SUCTION MANIFOLD PLUG	STEEL
THRUST COLLAR	AISI TYPE 410
DIFFUSER CONE	ASTM A 48, CLASS 30
BOLTS	300 SERIES STAINLESS STEEL
NUTS	300 SERIES STAINLESS STEEL
TRANSITION	ASTM A 283 GRADE D
IMPELLER KEY	AISI TYPE 410
BOWL TUBE BEARING	ASTM B 143, ALLOY 2B
SEAL RING	ASTM B 144, ALLOY 3B

FIGURE 9-10. TYPICAL AXIAL - FLOW PUMP BOWL



BILL OF MATERIALS

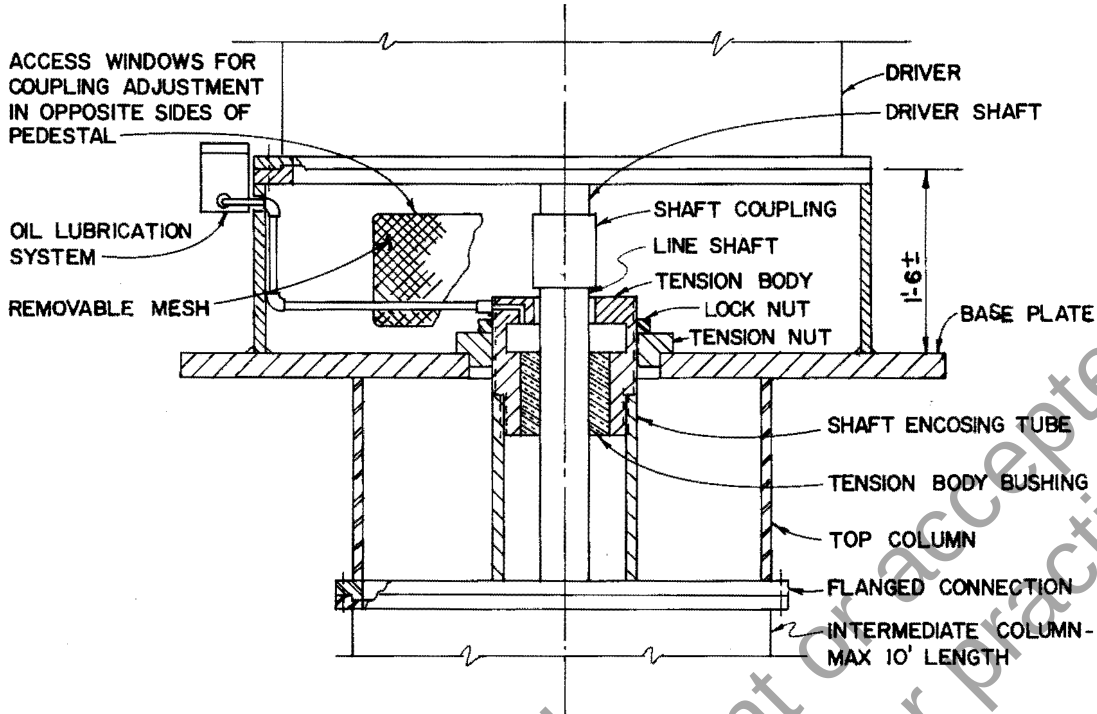
DESCRIPTION	MATERIALS
SUCTION BOWL	ASTM A 48, CLASS 30
DISCHARGE BOWL	ASTM A 48, CLASS 30
PUMP SHAFT	AISI TYPE 410
SHAFT ENCLOSING TUBE	ASTM A 120 PIPE OR TUBING
DISCH. BOWL UPPER BEARING	ASTM B 144, ALLOY 3A
DISCH. BOWL LOWER BEARING	ASTM B 144, ALLOY 3A
THRUST COLLAR RETAINER	ASTM B 143, ALLOY 2B
SUCTION BOWL BEARING	ASTM B 144, ALLOY 3A
IMPELLER	ASTM B 143, ALLOY 2B
SUCTION MANIFOLD PLUG	STEEL
THRUST COLLAR	AISI TYPE 410
BOLTS	300 SERIES STAINLESS STEEL
NUTS	300 SERIES STAINLESS STEEL
TRANSITION	ASTM A 283 GRADE D
IMPELLER KEY	AISI TYPE 410
SEAL RING	ASTM B 143, ALLOY 2B
BOWL TUBE BEARING	ASTM B 144, ALLOY 3B

FIGURE 9-11. TYPICAL MIXED-FLOW PUMP BOWL

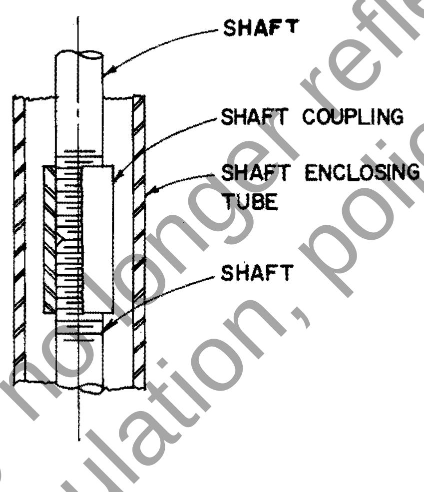
pump shaft, pump shaft bearings, and necessary parts to secure the impeller to the shaft. The suction and discharge bowls are separate units, provided with flanges accurately faced and drilled for connection to each other and to the discharge column. Figures 9-10 and 9-11 show that this applies to both axial-flow (propeller) and mixed-flow pumps. The suction bowl is designed to permit proper distribution of the liquid to the impeller and has a bell-shaped bottom designed to reduce entrance losses. All bowls must be designed to withstand not less than twice the maximum operating pressure of the pumps, when operating at the design speed. Diffuser vanes are integrally cast into the bowls above and below the impeller. The number of vanes must be sufficient to support the lower guide bearings as well as to sustain the weight of impeller and pump shaft when dismantling the pump. When oil lubrication is used, by-pass ports are provided in the discharge bowl upper guide vanes to drain excess oil from the shaft enclosing tube. The impeller must be firmly secured to the shaft by means of a key and thrust collar which should be the split type allowing the impeller to be removed from the bottom of the pump. The impeller must be balanced statically and dynamically to minimize vibration and wear, and the top of impeller hub should be equipped with a special seal ring to prevent rope, rags and other fibrous debris from wrapping around shaft above the impeller.

The pump shaft is that section of shafting which supports the impeller in the bowl assembly and extends to a point immediately above the discharge bowl bearing and connects to the line shafting. The shaft dimensions must be large enough to transmit maximum driver horsepower and must operate without vibration or distortion. The pump shaft must be accurately turned, ground and polished precision shafting. The pump bowl must have bronze bearings immediately above and below the impeller, with the lower bearing protected by a sand collar covering the locking collar. This prevents sand or grit from entering. The suction bowl bearing must be packed with waterproof grease, and a shaft seal must be provided immediately above the impeller, with the bypass ports to drain excess oil from the shaft enclosing tube provided above the seal.

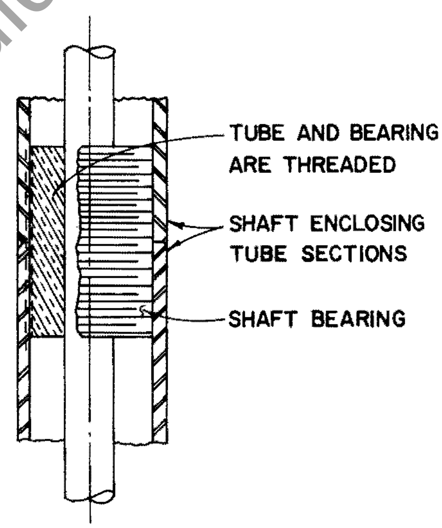
The discharge column assembly consists of the driver support pedestal, baseplate, elbow, necessary sections of column, flanges, shaft enclosing tube, enclosing tube adaptor, line shafting, line shaft couplings, line shaft bearings, and enclosing tube tension device. On occasion, as illustrated in Figures 2-9, 2-18 and 9-15, the discharge is above the floor of the pump station. In such cases, stiffening plates may be needed. Normally, the column is designed for suspension from the pump baseplate. The column, baseplate and elbow must be proportioned to safely support the bowl assembly and withstand the hydraulic pressure, dynamic forces, thrust, and any other load that it may be subjected to during transportation, erection or operation. Velocity of flow



PUMP PEDESTAL DESIGN
DIAGRAMMATIC - NOT TO SCALE



SHAFT COUPLING DETAIL



SHAFT BEARING DETAIL

FIGURE 9-12. PUMP SHAFT DETAILS

in the pump column and elbow should be limited to a maximum of 10 feet per second to avoid erosion of protective coating and unnecessary head loss and to minimize vibration.

If more than one section of column is used to connect the bowl assembly to the discharge elbow, the diameter of any intermediate section must be the same as the diameter of the discharge end of the elbow. The lowest section of column may be a tapered transition to make connection to the bowl assembly. In the normal below-baseplate configuration, the section of column above the elbow and connecting the discharge elbow to the baseplate may be less in diameter than the diameter of the elbow at the discharge end, but the thickness of the material used in that portion of the column above the elbow should be equal in thickness to the material used for the elbow.

The elbow and column may be fabricated from standard weight pipe or from steel of a corresponding thickness and should be machined between centers for perfect alignment and concentricity.

The elbows should be long sweep elbows to AWWA standards with up to three intermediate sections. Elbows may have plain ends for flexible couplings, or may be flanged for direct connection to a check valve. There need be no guide or diffusion vanes in the column or elbow with the velocity and criteria given here.

No portion of the pump assembly should be more than 10 feet in length to facilitate disassembly at the station, if this is planned, and the elbow and each of the column sections should be provided with lifting lugs or lifting eyes to facilitate the handling of these parts during removal and reinstallation. All parts except the suction umbrella should be removable through pump floor openings, and the pump column should be provided with a flanged connection between the baseplate and the discharge elbow as shown in Figure 9-1.

The vertical pump baseplate should be set in a recess in the concrete floor slab with top of the plate set flush with the finished floor and with continuous even bearing to the supporting surface. An embedded steel frame is recommended.

The electric motor or right angle gear pump drive should be mounted on a heavy fabricated steel pedestal, see Figure 9-12. Pump pedestals are essential for vertical pump installations. The pedestal is provided with diametrically opposite openings to permit access to the pump head-shaft coupling and enclosing tube tension device for adjustment, or to permit removal of the electric motor or gear drive. The pedestal should be integrally welded to the baseplate. A short section of pump column may be welded to bottom of baseplate with a flange for connection to pump extension above discharge elbow if in-station disassembly is contemplated. The pedestal should be fitted with lifting lugs of sufficient strength to support the weight of the complete pumping unit. This facilitates original installation and subsequent removal.

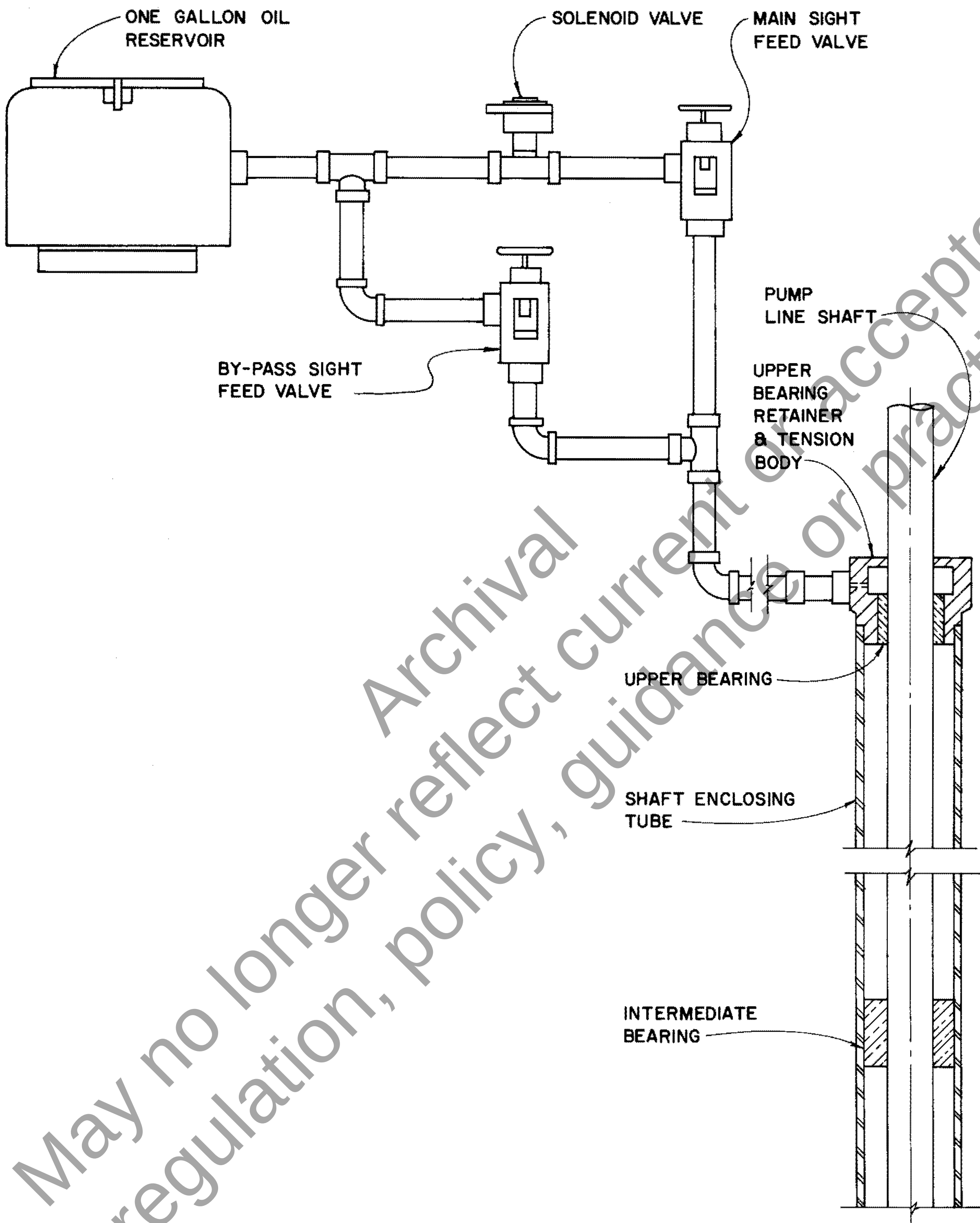
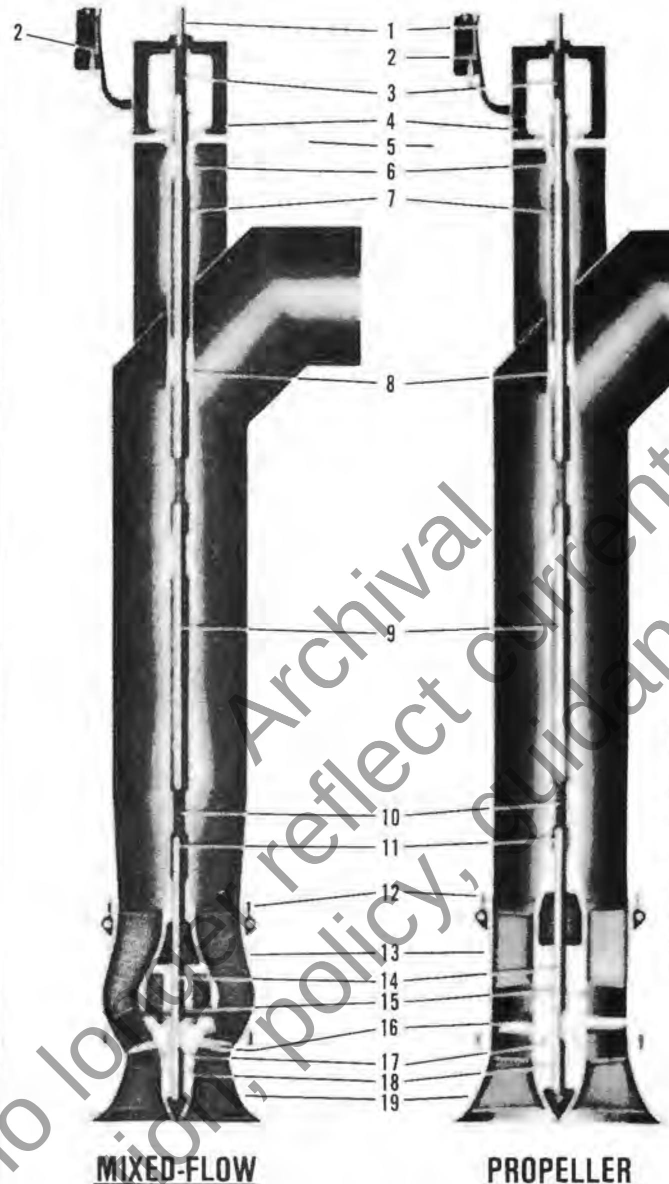


FIGURE 9-13. TYPICAL OIL LUBRICATION SYSTEM

ENCLOSED LINE SHAFT



1. Head Shaft
2. Sight-feed Lubricator
3. Head Shaft Coupling
4. Discharge Head Assembly
5. Below Surface Discharge Baseplate
6. Tubing Tension Assembly
7. Shaft Enclosing Tube
8. Line Shaft Bearing
9. Line Shaft
10. Pump Shaft Coupling
11. Pump Shaft
12. Flanged Joints
13. Cast Discharge Case
14. Discharge Bowl Bearing
15. Shaft Lip Seal (Optional)
16. Impeller/Propeller
17. Thrust Ring Retainer
18. Suction Case Bearing
19. Cast Suction Bell

VERTI-LINE VERTICAL PUMPS

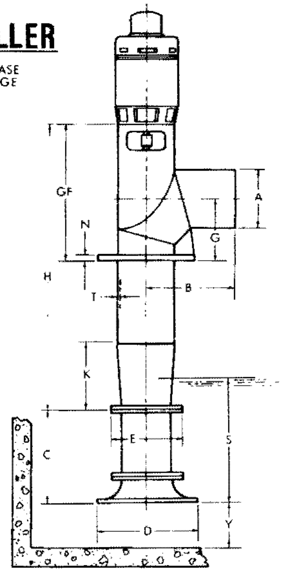
COURTESY OF AURORA PUMP • A UNIT OF GENERAL SIGNAL

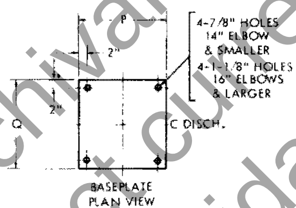
FIGURE 9-14

TYPICAL DIMENSIONS FOR VERTICAL PUMPS 8" THRU 16"

PROPELLER

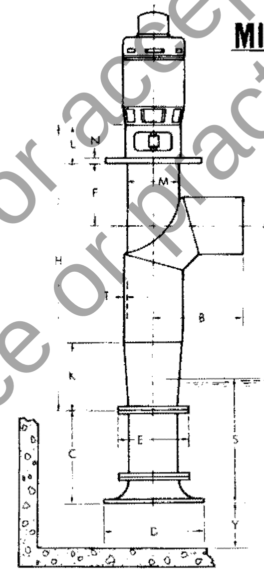
ABOVE BASE DISCHARGE





MIXED-FLOW

BELOW BASE DISCHARGE



DIMENSIONS ARE IN INCHES

MODEL NO.	A ELL O.D.	B PLAIN	B FLGD.	C ONE STAGE	C TWO STAGE	D	E	F BELOW BASE MIN.	G STD. MIN.	H BELOW BASE MIN.	H BELOW BASE STD.	GF ABOVE BASE MIN.	H ABOVE BASE MIN.	H ABOVE BASE STD.	K STD.	L	M	N	P & Q	S	T
8P8	8-5/8	14	12	13-1/4	21-3/16	14-7/8	11-3/8	10	9	34	120	25	25	120	0	12	8-5/8	3/4	18	24	1/4
10P12	12-3/4	18	16	16	26-1/4	17	13-1/2	12	13	52	120	34	44	120	10	15	12-3/4	3/4	24	26	1/4
12P12	12-3/4	18	16	19	31-1/4	18-3/4	16	12	13	42	120	34	34	120	0	15	12-3/4	3/4	24	30	1/4
14P18	18	24	20	21-3/4	35-1/2	23	17-1/4	16	18	75	120	44	64	120	20	17	18	1	30	36	1/4
16P16	16	22	18	24-1/4	39-1/2	24-3/4	19-1/4	16	16	50	120	40	40	120	0	15	16	1	30	40	1/4

COURTESY OF AURORA PUMP • A UNIT OF GENERAL SIGNAL

FIGURE 9 – 15

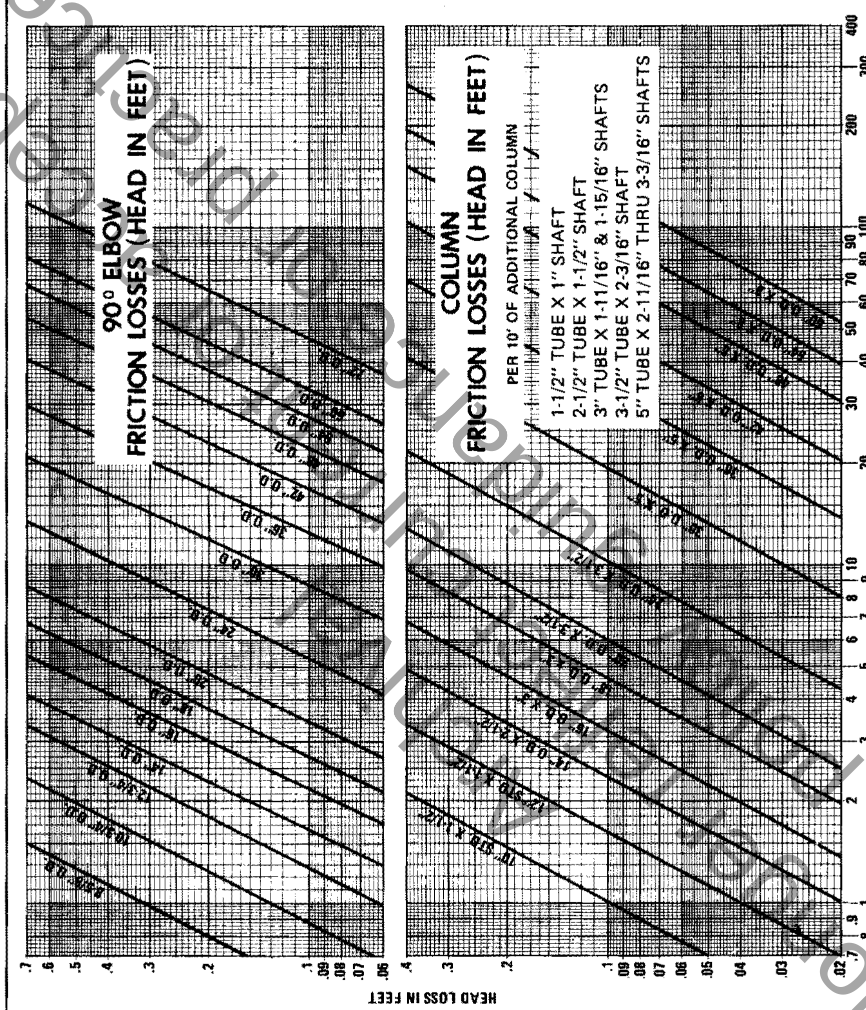
The pump drive shaft connects the motor or gear drive with the pump bowl and transmits power from one to the other. Due to the pump setting, the drive shaft may be as long as 40 feet (see Figure 2-22). However, in most cases it will be less. To remain within practical limits of size, the shaft will need intermediate bearings and these are normally provided at a spacing of 5 feet. This spacing enables the shaft diameter to be limited to levels dictated by the torque-induced shear without concern for the centrifugal (whirling) effect. The stretching of the shaft due to the force induced by the lifting of the water is also taken into account by the pump manufacturer. Drive shafts are sometimes furnished without an enclosing tube, but this is not recommended for stormwater pumping, unless grease lubrication is provided. With no enclosing tube, the intermediate bearings are supported from the sides of the pump column, and may be lubricated by the passage of the fluid being pumped. As previously stated, this is not desirable with silt-laden stormwater and a positive grease seal must be provided. Some agencies have found this grease lubrication satisfactory, while others specify a shaft enclosing tube. The tube performs the multiple functions of providing a stiff structure to support the bearings, a means of isolating the bearings from detrimental fluids being pumped, and a down-flowing conduit for the oil lubricant.

The shaft enclosing tube is designed to support the line shaft bearings and to prevent leakage of the pumped fluid into the shaft assembly. The tube may be threaded internally to receive a combination tube coupling and line shaft bearing, and may be fabricated in lengths not over five feet. The shaft enclosing tube may connect directly to the bowl assembly or may be connected by means of an adaptor or diffuser cone. The enclosing tube adaptor or diffuser cone should be cast iron or be fabricated from steel plate. Details relating to the shaft enclosing tube and bearings are also shown on Figure 9-12.

The pump, if so constructed, is unquestionably a superior piece of machinery. However, its cost-effectiveness is questionable due to the small number of annual hours of operation of a stormwater pump station and the relative ease of providing effective grease lubrication. Fresh-water flushing of bearings is also a viable alternative where there is a municipal water supply.

Calculations relating to pump drive-shaft sizing are regarded as a manufacturer's responsibility. The pump station designer should limit his responsibilities to the overall project, with appropriate assurances from others that their components meet specified requirements.

It follows that all vertical pumps must be equipped with effective lubrication systems. The recommended type is the oil system which supplies oil to the line shaft bearings. In this type, the pump shaft is totally enclosed in an oil tube which



ELBOW AND COLUMN LOSSES IN VERTICAL PUMPS

COURTESY OF AURORA PUMP • A UNIT OF GENERAL SIGNAL

FIGURE 9-16

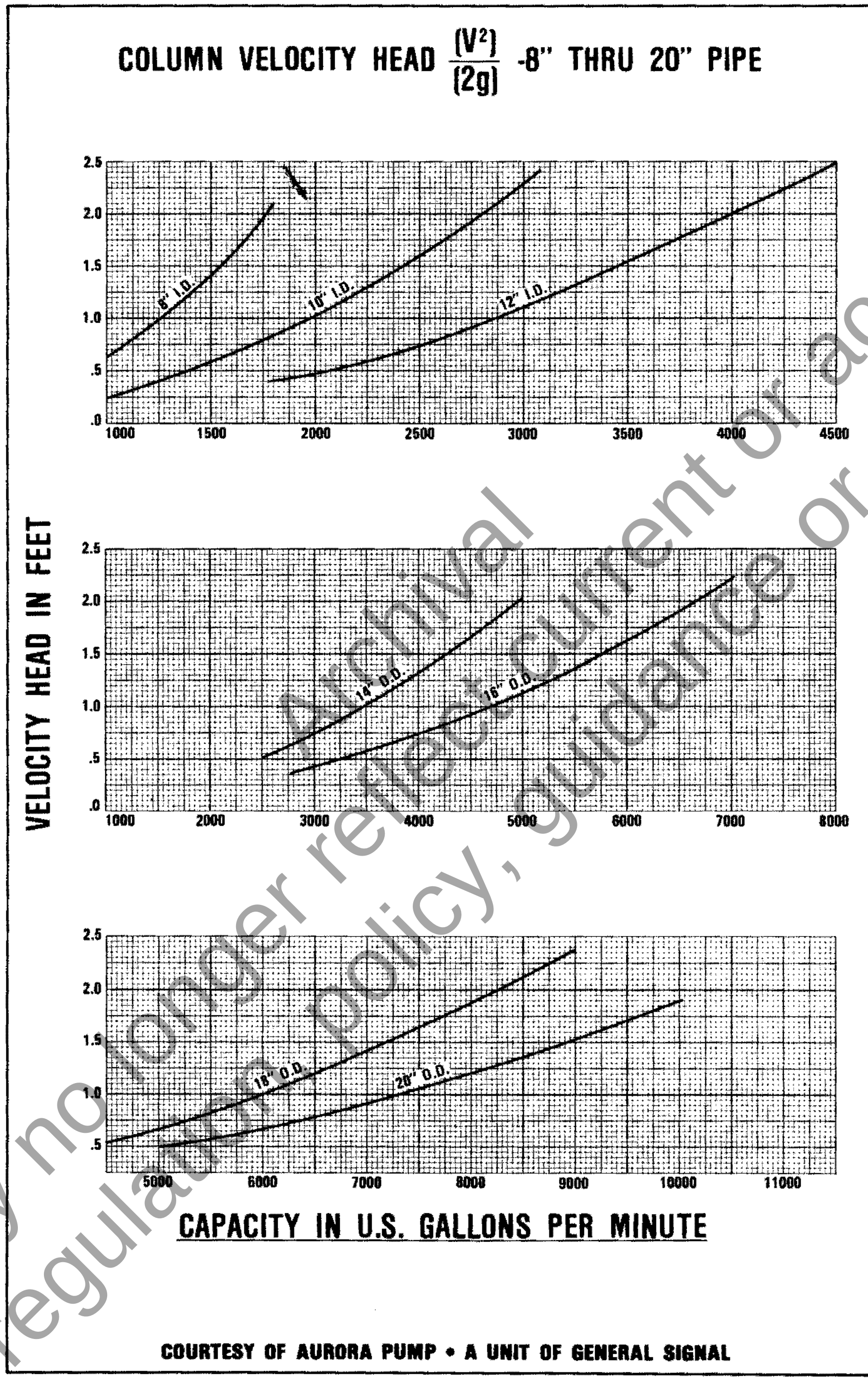
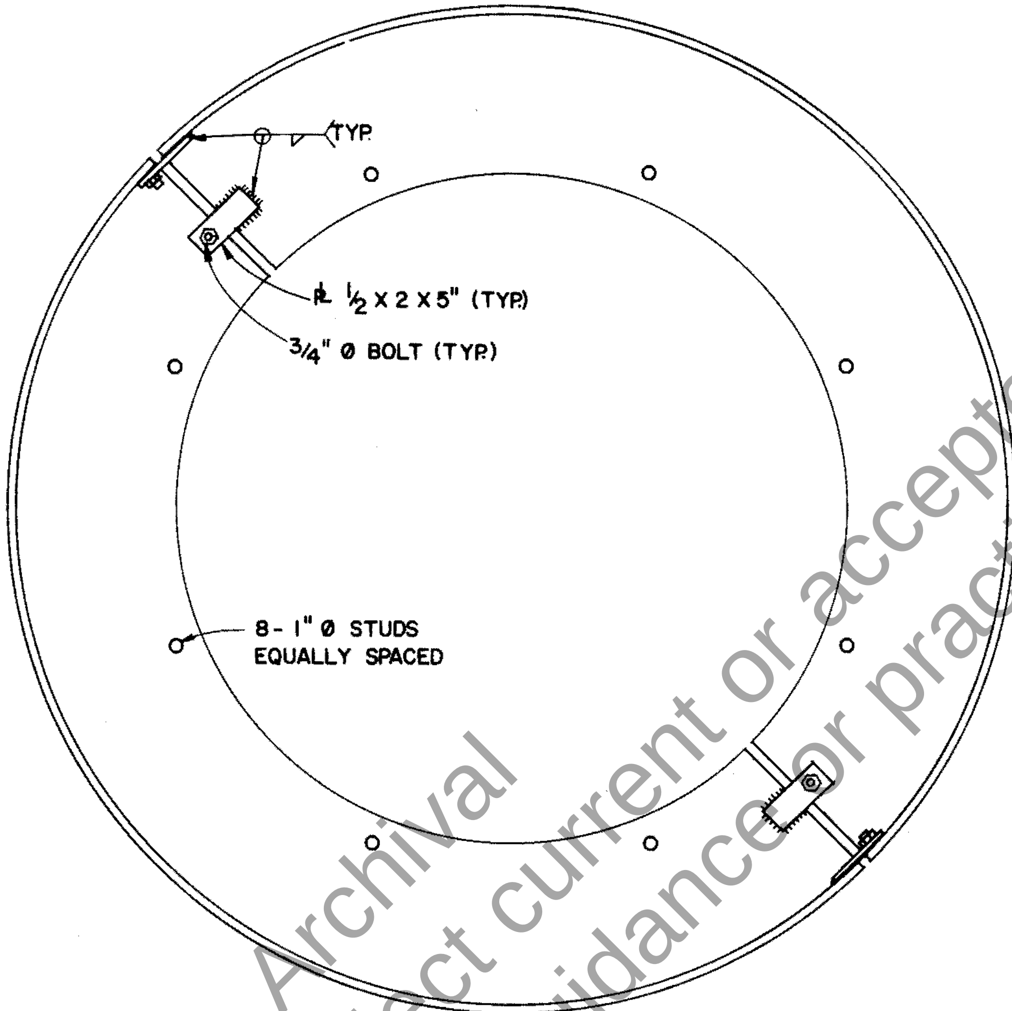
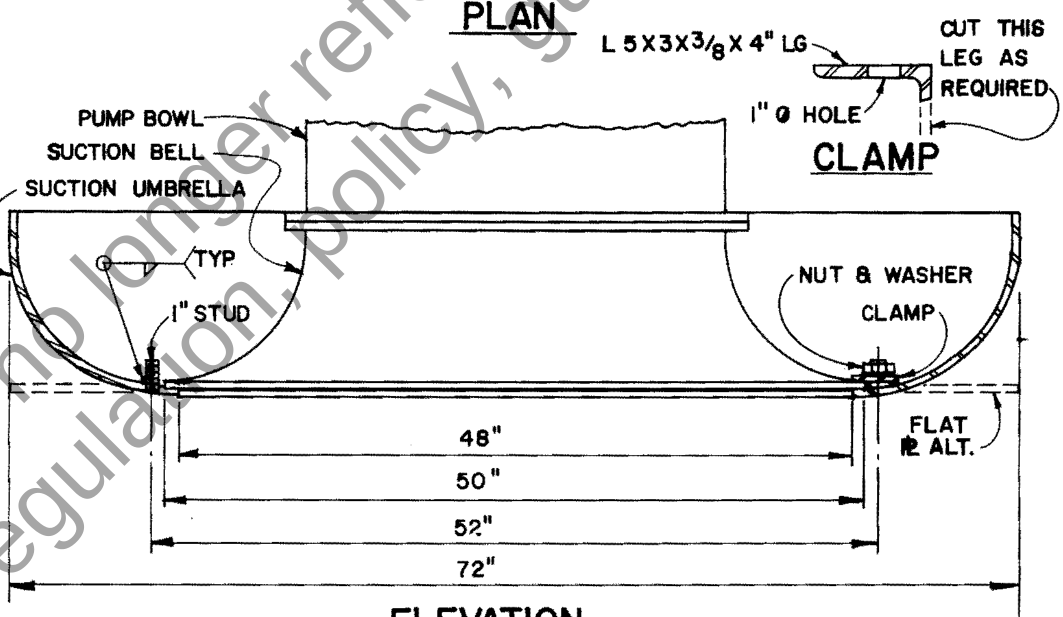

COLUMN VELOCITY HEAD $\frac{(V^2)}{(2g)}$ -8" THRU 20" PIPE
VELOCITY HEAD IN FEET
2.5
2.0
1.5
1.0
.5
.0
1000
1500
2000
2500
3000
3500
4000
4500
8" I.D.
10" I.D.
12" I.D.
2000
3000
4000
5000
6000
7000
8000
14" O.D.
16" O.D.
5000
6000
7000
8000
9000
10000
11000
18" O.D.
20" O.D.
CAPACITY IN U.S. GALLONS PER MINUTE
COURTESY OF AURORA PUMP • A UNIT OF GENERAL SIGNAL

FIGURE 9-17



PLAN



ELEVATION

FIGURE 9-18. TYPICAL SUCTION UMBRELLA

DIMENSIONS MAY CHANGE TO SUIT EQUIPMENT FURNISHED extends from the pump baseplate to the top of the pump bowl. When the pump starts a solenoid valve opens and admits oil to the line shaft from bearing to bearing by means of passing through a groove in each bearing. The rate of oil dripping is controlled by an adjustable sight-feed valve. A metal reservoir should be furnished to provide enough oil for a minimum of one month operation or as recommended by the maintenance management program for the facility.

A typical oil lubrication system is shown in Figure 9-13. It should be noted that a by-pass sight-feed valve is also provided to provide oil to the shaft bearings manually before operating the pump. This should be done regularly between periods of idleness or at planned exercise runs. Other methods of lubrication may be used such as pressure greasing of each bearing through a pressure grease system and grease lines to each bearing, or by packing the entire enclosing tube with grease.

A peculiarity in regard to the use of vertical pumps is that where the pump pit depth, and therefore the submergence, are to be held to minimum levels, then the manufacturer's standard item is incompatible. In order to hold to the above minimum, the pump must be equipped with a suction umbrella to reduce the peripheral bell velocity and, therefore, control the inflow to the pump to avoid vortexing. Note that the name umbrella refers to the shape of the appendage accessory -- actually a flat plate of equivalent diameter has proved to be equally effective. The principal consideration is that on account of its size, the single, two-or four-piece umbrella must be bolted to the underside of the pump suction bell and must be removable prior to any attempt to remove the pump from the station. Stainless steel clamps, bolts, studs or nuts may be justified. (See Figure 9-18).

Two more important factors in vertical pumps design are pump thrust and bearing life, both of which are primarily the manufacturer's responsibility. The pump station designer should only be required to specify necessary performance in discharge and head and receive assurances that the pump will perform satisfactorily for a span of years under these conditions. However, manufacturers' literature does provide the criteria on which pump thrust and bearing life are computed. The minimum life of a bearing is equal to the number of hours or years of continuous operation when 10% of all the bearings operating under identical conditions will have failed. The minimum, or as it is more commonly called, the B-10 life, is the life expectancy which is normally used in specifications. 20,000 hours is a normal standard.

Protective coating of the metal elements of the vertical pump is very important, since a large surface area of the pump is exposed to detrimental environments. Operational factors extend from continuous immersion of the pump bells in a brine solution resulting from run-off of road salt to abrasion of the column protection due to passage of silt-laden water at high velocities. Epoxy coating is recommended.

Manufacturers' catalogs always provide a wealth of information which should be closely studied. Dimensional data for a range of small pumps has been extracted from a catalog and is shown as Figure 9-15. Pump column, elbow and velocity head losses, important in calculating total dynamic head, are shown in the extracts used for Figures 9-16 and 9-17. Note that not only the numerical values, but also the presentation will vary from one manufacturer to another.

9-D. SUBMERSIBLE PUMPS

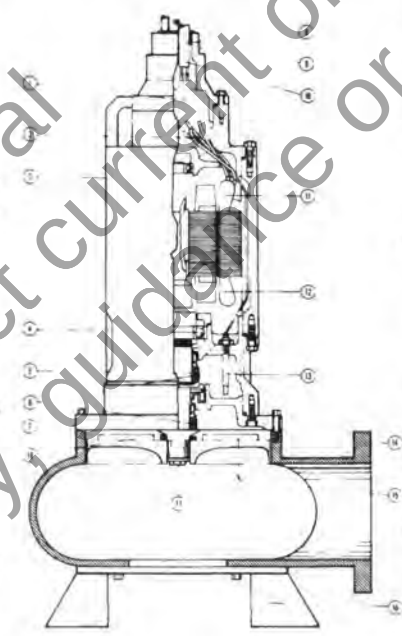
Submersible pumps are a relatively new type of pump to qualify for consideration for performing the total pumping function at a stormwater pump station in the average capacity range. This is because the physical size and role of submersible pumps has been so greatly expanded beyond their previous limitations. Previously they could serve only as sump and clean-up pumps with relatively low capacity, or be the main pumps in only the smallest stations. Future developments will include the propeller type in both horizontal and vertical configurations.

Regardless of size, submersible pumps may be manufactured in two different ways: in the first way, one manufacturer makes both motor and pump; in the second way, the pump manufacturer utilizes a proven submersible motor and couples it directly to a pump which he has manufactured. In general, the first way represents European practice, while the second represents U.S. practice. However, both types are manufactured in the U.S.

Motors vary in that the motor of European origin is air-filled, while the domestic motor is oil-filled. In either case, there is an oil seal between motor and pump which is critical, and is usually monitored to determine whether any infiltration of the pumped fluid into the motor is occurring.

Other points of difference are that one type of pump has a completely recessed impeller, out of the stream of pumped fluid, while the other has a specially shaped non-clog impeller. In principle, the latter is much as described in Section 9-E for the horizontal centrifugal pump. A difference in mounting is that one type engages a tapered metal-to-metal seating where the pump casing discharges into the discharge elbow and riser. The removal method is to slide the complete pump up guide pipes out of the pump pit. By contrast, the other type of pump has a base which enables it to sit upon the concrete floor of the sump, with a flexible discharge hose leading upwards and out of the sump. The pump can be lifted out of the sump flexing the discharge line.

Data and Assembly



1 INTEGRAL CONDUIT BOX– Leads are easily reconnectable on dual voltage motors.

2 O RING SEAL– All motor frame fits have rabbet joints with large overlap and O-ring seals.

3 SMOOTH CAST IRON BASE– Rigid, strong, resists corrosion. No ridges or pockets to collect sludge.

4 LARGE DEEP GROOVE BALL BEARING– Clamped, takes up and down thrust. Bearings are conservatively rated; prelubricated at the factory.

5 OIL CHAMBER– Sealed oil filled chamber between pump and motor provides lubrication for inner seal giving motor complete environmental protection.

6 TANDEM SEALS– High quality mechanical seals provide double protection for motor internals against contact with pumpage.

7 CLOSE COUPLED MOTOR– Impeller mounts directly on stainless steel motor shaft. Eliminates alignment problems.

8 POWER CABLE– Motor is supplied with 30 feet of multi-conductor cable with ground wire as standard. Moisture detector and thermal protection leads are in separate cable.

9 CONDUIT CONNECTION– Threaded extension is cast into top of frame to permit installation of armored covering of flexible conduit if desired.

10 SEALED MOTOR LEADS– Buna-N grommets, epoxy sealed leads and butt spliced connectors effectively seal cable connections.

11 THERMAL PROTECTION– Built-in thermal protection is standard with automatic reset.

12 LONG-LASTING INSULATION Special Class B insulation system with Class F materials is designed for long winding life.

13 MOISTURE DETECTION SYSTEM– Moisture sensing probes located in the oil seal chamber are connected above ground to warn of impending seal failure.

14 STANDARD CAST IRON 4" DISCHARGE FLANGE– (Flanged– Screwed ell optional).

15 IMPELLER– 100% recessed type. Accurately balanced with repelling vanes on back shroud to prolong seal life.

16 SUPPORTS– Heavy duty high grade steel. Four supports prevent rocking and lower center of gravity to keep pump upright. Attached with stainless steel fasteners.

17 IMPELLER ATTACHMENTS– Stainless steel screw, washer, and key for corrosion resistance.

18 IMPELLER SPACER– Stainless Steel for long life and corrosion resistance.

Patent No. 4134711

Model 4 X 12 TF **ESSCO SUBMERSIBLE PUMP** Courtesy of Engineers Sales-Service Co.

FIGURE 9-19.

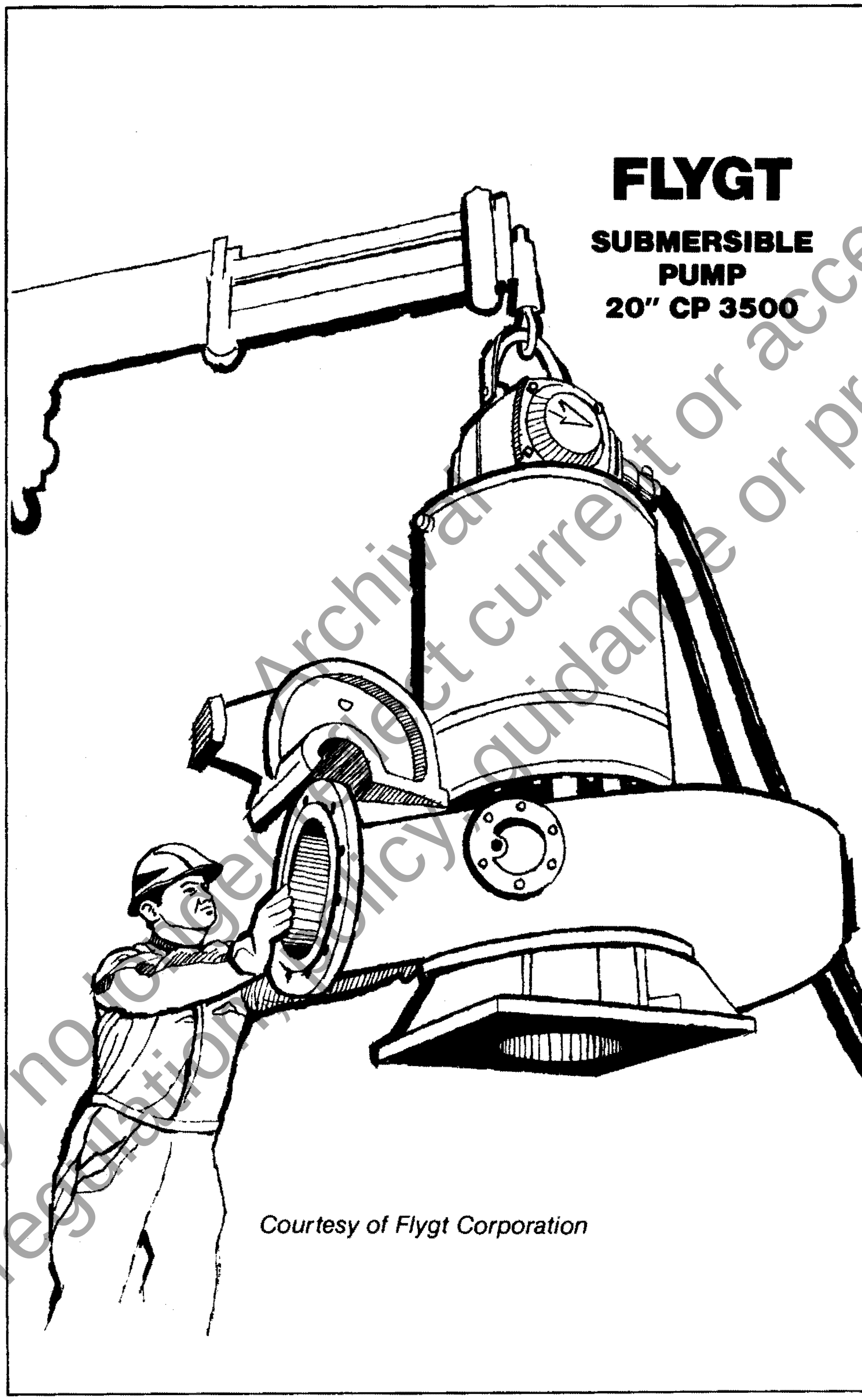
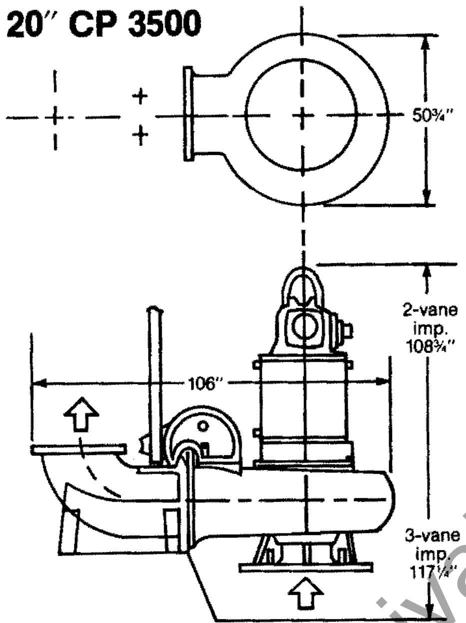
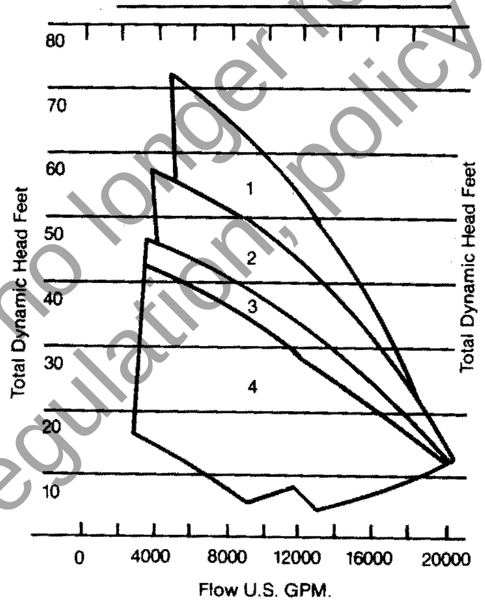

FLYGT
SUBMERSIBLE
PUMP
20" CP 3500
Courtesy of Flygt Corporation

FIGURE 9-20.

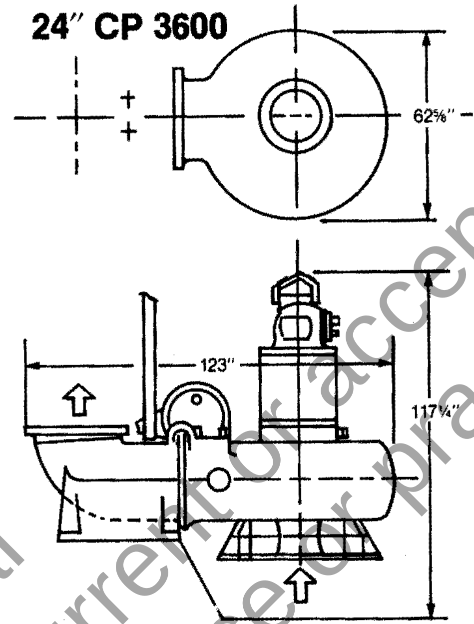
20″ CP 3500



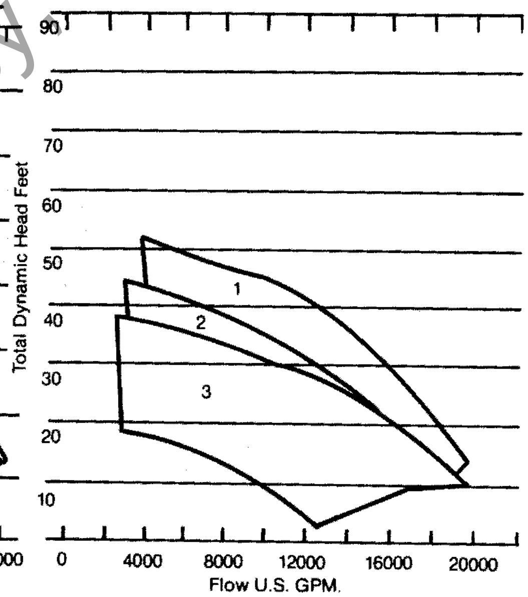
Pump		IMP.	HP.	RPM.
20″ ST'D.	1	500-810	200	880
	2	500-1010 500-1020	170	705
	3	500-1210 500-1220 500-1230	122	585
	4	500-1410 500-1420 500-1430	100	502



24″ CP 3600



Pump		IMP.	HP.	RPM.
24″ ST'D.	1	600-1020	170	705
	2	600-1220 500-1230	122	585
	3	600-1420 600-1430	100	502

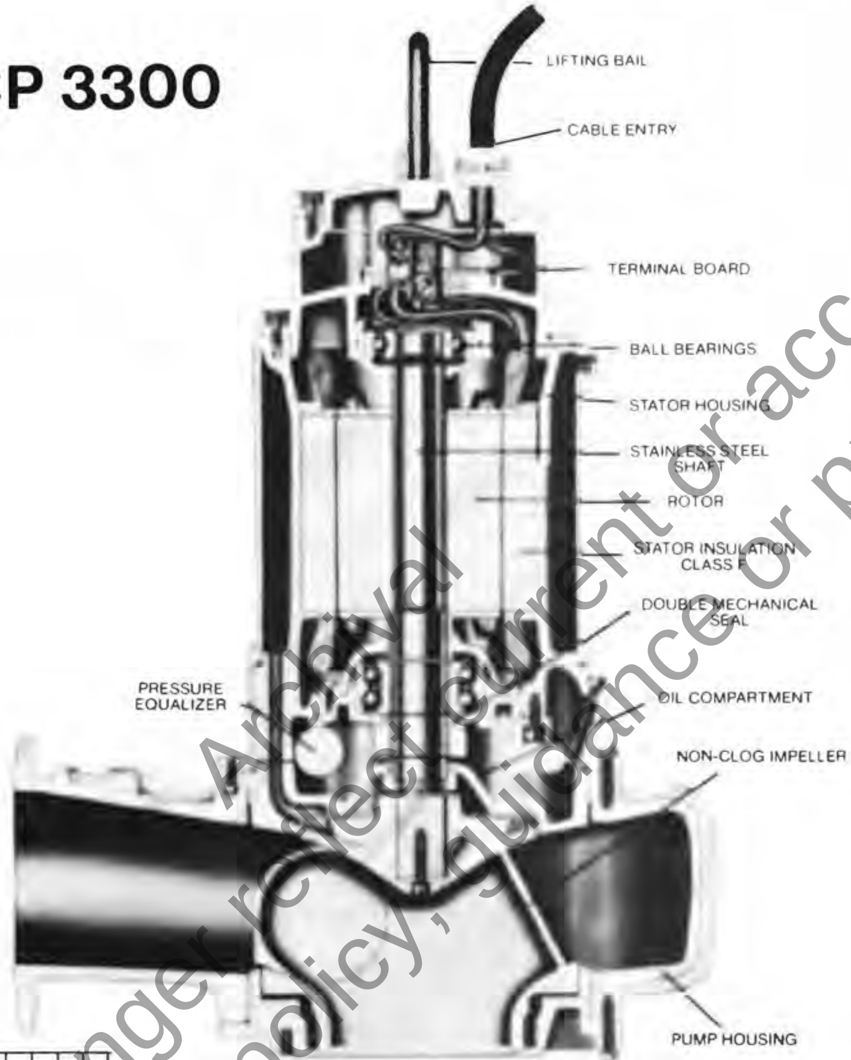


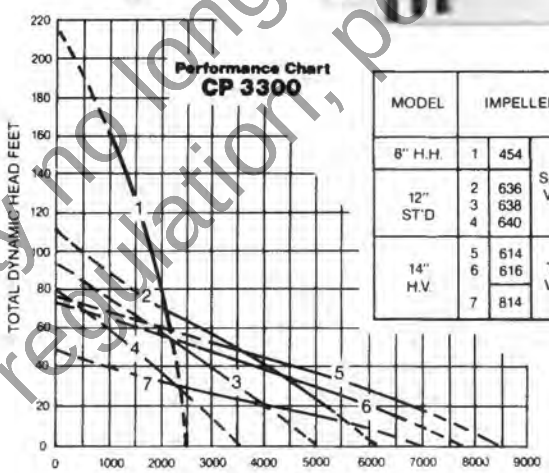
FLYGT SERIES CP

Courtesy of Flygt Corporation

FIGURE 9-21.

CP 3300





MODEL	IMPELLERS			RPM	RATED HP	RATED KW	WEIGHTS LBS. PUMP	WEIGHTS LBS. DISCH
8" H.H.	1	454	Single Vane	1770	88	70	2050	136
12" ST'D	2 3 4	636 638 640		1150	77	63	2460	370
14" H.V.	5 6	614 616	Two Vane				2620	440
	7	814		870	32	27		

Courtesy of Flygt Corporation

FIGURE 9-22.

Although intended to operate with both pump and motor completely submerged, there are occasions when the motor will not be surrounded by water, with its cooling effect. Some submersibles have the motors with the capability to run dry for extended periods without overheating or damage. Other submersibles have limited capability to run in this condition without damage, or they may be fitted with cooling sprays fed from the pump which allow the pump to pump down and break suction on every cycle so as to virtually empty the sump completely. The ability to pump dry is more important in sewage applications than in stormwater. Most manufacturers' literature on submersible pumps places more emphasis on sewage and wastewater than on stormwater applications. The designer should not misinterpret factors applicable to sewage and apply them to stormwater installations.

Figure 9-19 shows the smaller and more familiar submersible pump with the Reliance motor which is of U.S. manufacture. The Essco pump has a recessed impeller with flat back or shroud. In Chapter 14 - Construction Details, Figure 14-20 shows the flexible hose discharge connection with a call-out of all the necessary fittings. The range of these smaller pumps now extends to about 1,500 gpm at 60 feet total dynamic head. The limitation is the available motor size, and the fact that the efficiency of the recessed impeller is about 50%.

By contrast, Figure 9-20 is reproduced from a photograph of a 20" Flygt CP 3500, showing ease of handling by mobile equipment. When fitted with a Type 4 impeller and a 100 HP motor rotating at 502 rpm, this pump will deliver in the range of 10,000 gpm at 25 feet total dynamic head. These figures are interpreted from the pump performance "envelope" shown in Figure 9-21, and must be verified from manufacturers' published performance curves for each pump and impeller. A performance chart for the Flygt CP 3300 showing differing sizes of impellers is shown in Figure 9-22. Note that the pump size varies to suit high head, standard or high volume conditions.

In general, the in-flow non-clog impeller will show substantially higher efficiencies than the recessed impeller, and these are obtained and usable in stormwater pumping provided adequate provision is made for properly fluidizing the abrasive stream to which the stormwater pump is exposed. This is done by the use of an agitator spray ring, which releases jets of water and flushes away and fluidizes the blankets of grit or mud which may build up around the pump during periods of inactivity. This is particularly important with small submersible pumps used as sump or clean-up pumps.

The spray ring is controlled by a solenoid valve in the pump starting circuit, with a time-delay relay for the pump start. Then, when the pump control signals the pump to start, the spray will commence and perform its flushing action for ten to fifteen seconds before the pump starts. By this means, the pump is

FLYGT 7000 SERIES
PROPELLER PUMP

FLYGT

Courtesy of Flygt Corporation

FIGURE 9-23.

protected from the harmful effect of grits and sands entering the pump without sufficient dilution by water. Where large submersible pumps are used (see Chapter 6 - Wet Pit Design) the flushing action of the water makes such precautions unnecessary.

A final illustration is the propeller-type vertical submersible shown in Figure 9-23. This pump is becoming available in various sizes and horsepowers to compete directly with the conventional vertical pump.

A specification for a submersible pump will be found in Appendix D - Specifications. However, certain features such as the recessed impeller are required in the referenced specification, which should be used as a guide only, and should be adapted as necessary to suit the judgment of the designer.

9-E. HORIZONTAL CENTRIFUGAL NON-CLOG PUMPS

This type of pump is a particular configuration of the non-clog dry-pit pump which has been found suitable for use in small stormwater pump stations. Refer to Figures 2-1, 7-1 and 7-2. The origin and principal use of this pump is to pump sewage; therefore, capacities in gpm are limited, but the available total head exceeds 250 feet for some models. The non-clog feature evolved from the necessity of passing solids when pumping sewage, and this has now been successfully utilized in pumping silt-laden stormwaters. An effective capability for settling out solids in the storage box has been provided, with a consequent reduction in the solids passing through the pump. Less wear on the pump should result.

Pumps of this type are furnished with motors in various speeds from 1,750 rpm down. Consistent with other types of pump, the higher speeds are more applicable to smaller pumps or higher heads.

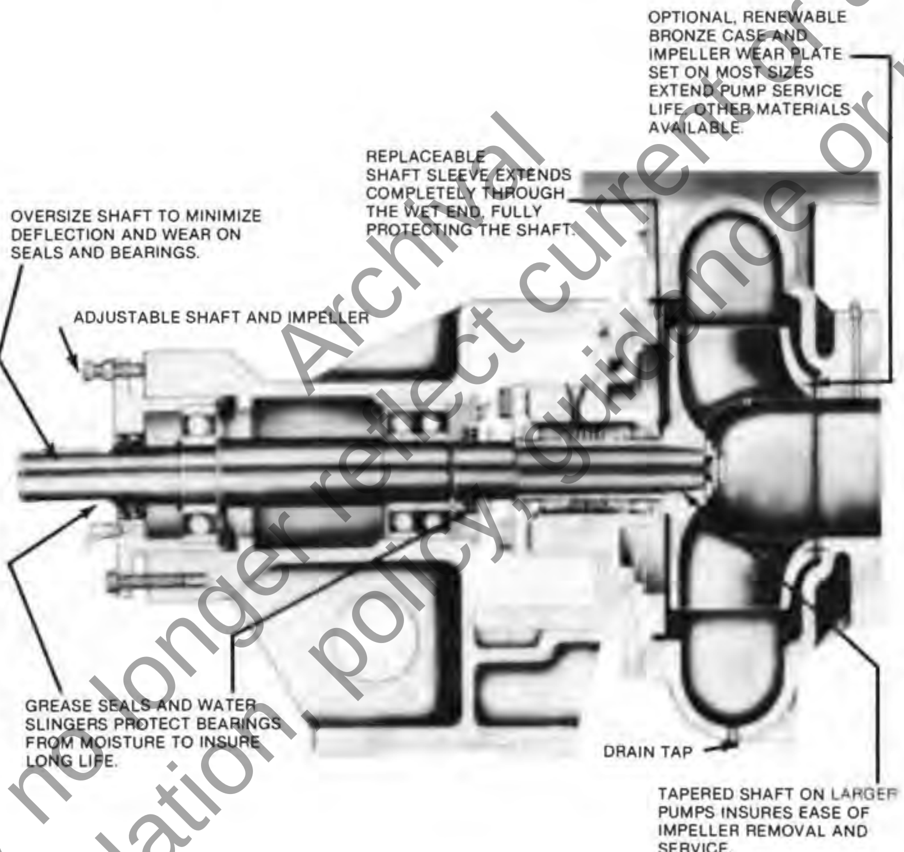
When there is more need for quantity than head, the slower speed pump is more suitable. Pumps with six-inch to twelve-inch diameter suction and six-inch to ten-inch diameter discharge have been utilized, which with motors wound for 1,150 or 870 rpm deliver about 1,500 to 5,000 gpm at forty feet total dynamic head.

Non-clog pumps are fitted with two-port closed impellers as standard. These have two water passages and contoured leading edges for optimum clog-free operation, the solids passing through the impeller. As an alternate, vortex impellers can be furnished which rotate clear of the water flow. The vortex action does not require solids to actually pass through the impeller and this type is sometimes offered as the best solution to extreme problems with the pumping of fluids containing waste and grit.

Neither type of impeller is very efficient, the two-port rating about 70% average, and the vortex type rating 50% or less. However, reliability of equipment is far more important than

Horizontal Type NCH
Centrifugal Non-Clog
Pump

Cast Iron
Base Plate



Typical Horizontal Centrifugal Pump Features

Courtesy of PACO PUMPS

FIGURE 9-24.

Horizontal Centrifugal Pump Components

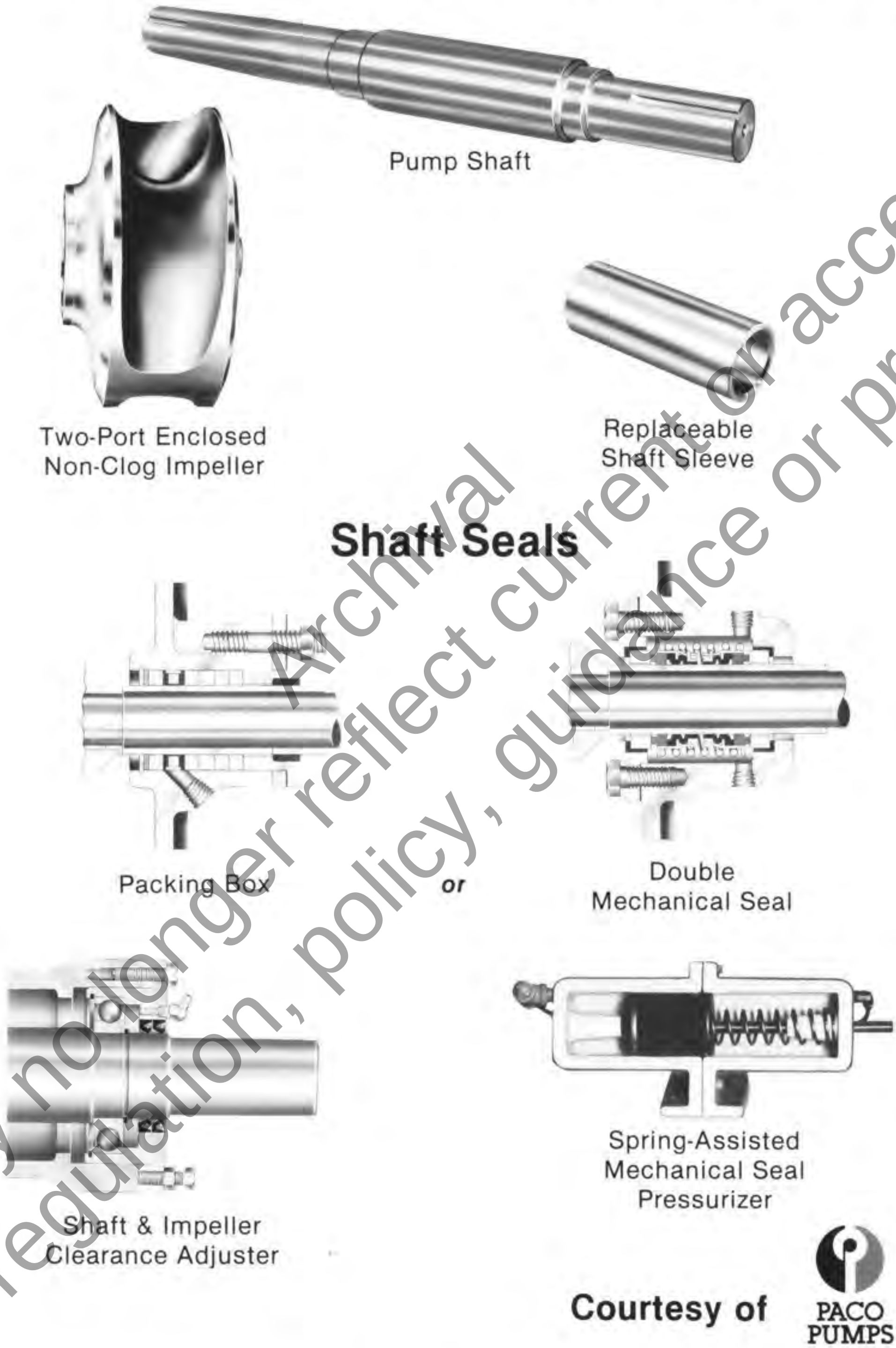


FIGURE 9-25.

efficiency. In this regard, the dry-pit station, storage box combination with the horizontal centrifugal non-clog pump, represents mechanical and electrical simplicity with high reliability.

Figure 9-24 illustrates a typical horizontal centrifugal non-clog pump. The motor is directly coupled by flexible coupling to the pump, and both are mounted on a fabricated steel or cast-iron base which provides an integral drip rim and drain connection. Any dripping from the pump seal then drains away freely. The pump casing can be plainly identified in the figure. It is cast from high-grade gray iron Class 30 and should be complete with suction and discharge gauge taps and drain taps. It should also be provided with a contoured hand-size clean-out, to allow inspection at any time and removal of debris. Highway debris of the floating type may find its way through the gratings or trash bars and lodge in the impeller of the pump. The hand-hole will permit removal of the obstruction without dismantling the complete pump. Although the discharge can be furnished in other positions, the vertically upward position is required for the dry-pit station, as illustrated.

The pump must have a seal where the rotating shaft enters the casing. A mechanical seal should be specified for the most severe service, but in stormwater applications, a stuffing box has been found satisfactory. See Figure 9-25. The grease and water slinger seals which protect the bearings at each end of the bearing frame are also shown, together with an illustration of the two-port impeller.

By comparison with the vertical pump, the horizontal centrifugal non-clog pump is a relatively simple piece of machinery to select and specify. Reference to manufacturers' literature will amplify the outline given here. An effective specification follows, which may be used verbatim, merely requiring insertion of the number of pumps and their required performance.

<u>Pumps for Dry Pit Service</u>

<u>General</u>

Pumps for dry pit service shall be single-stage, horizontal shaft, nonclog, end inlet, top discharge, centrifugal type. The pumps shall have volute casings with flanged suction and discharge. ..... pumps shall be furnished having a capacity of ..... U.S. gpm at a total head of ..... feet, and a secondary capacity of ..... U.S. gpm at a total head of ..... feet. Shut-off head shall not exceed ..... feet. Motor horsepower shall be not less than ..... HP and speed shall be ..... rpm.

<u>Casings</u>

The volute casing shall be a substantial casting to withstand the abrasive action of sand and other foreign matter contained in the stormwaters, and shall be equipped with a hand-hole or access to the suction side of the impeller.

Solid casing pumps shall be built so that the shaft, impeller and bearings may be removed by unbolting the backhead. Horizontal split casing pumps shall be split on the horizontal axis.

Each casing shall be provided with eyebolts or lugs for lifting and handling with the shaft in a horizontal position. Suitable feet and sole plates with anchor bolts or baseplates shall be provided for each pump. The feet and sole plates for the pump shall be designed to support the entire weight of the equipment on the foundation without strain on the suction or discharge flanges. Suction and discharge nozzles shall be flanged with drilling and dimensions meeting the requirements of ANSI B16.1, Class 125.

Impellers

Impellers shall be of the enclosed type, bronze, dynamically balanced, and designed to prevent clogging and to pass trash and stringy material in the stormwaters. Impeller vanes shall have well rounded entrances, finished all over, and all water passages shall have smooth contours free from sharp edges. The impeller shall be secured to the shaft by a key, and shall be held in place by an impeller nut. After the impeller nut is tightened, it shall be held in place by an ample sized set screw in a tapped hole, and embedded at least 3/8" into the impeller or the pump shaft. It is the intent to secure the impeller to the shaft in such a manner that the impeller cannot become loosened due to torque resulting from rotation in either direction. The nut shall be recessed into the impeller hub and shaped to provide smooth flow at the eye of the impeller. The arrangement, however, shall provide for easy removal of the impeller.

Shafting Assembly

The pump shaft shall be made of AISI type 416 stainless steel, ground and polished, and key seated for mounting of the impeller and coupling between motor and pump. The shaft shall have a replaceable stainless steel shaft sleeve with a ceramic coating (600 Brinell) where it passes through the stuffing box.

The pump shaft shall be of sufficient diameter to carry the maximum load imposed, and to assure rigid support of the impeller and to prevent excessive vibration at the operating speed.

Bearings

Each pumping unit shall be provided with guide bearings of the anti-friction ball or roller type of ample size to carry the radial loads, and a thrust bearing at the coupling end of the frame. Bearings shall be oil or grease lubricated and shall be entirely independent of the casing and stuffing boxes and shall have sufficient space to allow packing of the stuffing boxes without disturbing the bearings. All bearings shall be made to limit gauges to assure interchangeability of like parts. All removable bearing housing supports, or brackets affecting alignment shall be shoulder fitted and provided with adequate dowel pins. Holes with grease relief fittings or brass plugs shall be furnished to facilitate greasing. The relief holes shall be readily visible and accessible.

All bearings shall be accessible and be designed for convenient repair or replacement, and shall have a B-10 life of 50,000 hours.

Lubrication

Anti-friction bearings shall be either oil or grease lubricated. If grease lubricated, provision shall be made to maintain a reserve of grease to assure positive lubrication.

Each bearing shall be individually piped to a fitting conveniently located.

If oil lubricated, a reservoir system or other approved method shall be used. All bearings shall be provided with oil reservoirs to insure a constant supply of clean oil and with suitable gauges to give visual indication that an adequate supply of lubricant is available and is being supplied to the bearings.

Stuffing Boxes

Each pump shall be provided with a stuffing box to exclude air from the casing and to reduce water leakage to a minimum. Each stuffing box shall be provided with a water seal and bronze split type gland designed to facilitate adjustment and repacking. Stuffing boxes shall be properly packed with suitable packing material.

General Construction Features

The pump shall be built so the shaft, impeller and bearings may be removed by unbolting the back head and not disturbing the piping.

A spacer coupling shall allow the removal of the pump without disconnecting the motor. The pump shall have axial external impeller adjustment to adjust the case impeller clearance without disassembling the unit and shall not depend on shims or spacers.

Wearing Rings

Removable wearing rings shall be installed at the inlet side of the impeller and at the casing of the pumps. Wearing rings shall be made of series 400 stainless steel. The Brinell hardness shall not be less than 300 for the casing rings and 350 for the impeller rings. Wearing rings shall be secured in a manner to prevent loosening in normal operation or by reverse pump rotation. Wearing ring clearances shall be not less than 1/1000 of an inch per (1) one inch of wearing ring diameter. The casing ring shall be drilled and tapped to allow flushing from an external source. Replaceable wearing plates meeting the requirements of the above specification may be furnished instead of wearing rings.

Pump and Motor Base

The base for each main pump and motor shall be of cast iron or welded steel construction and of such rigidity as to keep the pump and motor in alignment permanently. The base shall be furnished by the manufacturer of the pump and the pump and motor assembled thereon and aligned by him. The units shall be connected with a flexible coupling of a type recommended by the pump manufacturer. The coupling shall be equipped with a guard that meets OSHA requirements to prevent accidental contact.

Installation

The pumping unit shall be set in place on levelling devices. All suction and discharge piping shall be in place and all flange bolts tightened. The nuts of expansion type anchor bolts shall be tightened against the base. The space under the base shall be packed with non-shrink grout and the void within the base shall be completely filled with non-shrink concrete and the anchor bolts retightened.

Testing and Guarantees

Any requirements considered necessary for performing testing, guarantees or the like should be added to suit the specifying agency.

Protective Coating

The required standard of protective coating must also be specified.

9-F. SCREW PUMPS

The principle of pumping water with a screw pump has been known since its invention by the Greek mathematician, Archimedes, in the third century, B.C. After the piston pump was developed in the nineteenth century, and later the centrifugal pump, the screw pump was considered obsolete because of its lower head capacities.

Since 1950, the screw pump has been redeveloped because it offers many advantages over centrifugal pumps. Screw pumps are non-clogging, require no pre-screening and pass any debris as large as the gap between the screw flights. They operate at slow speeds and require only minimum repair and maintenance. They are highly efficient over most of their operating capacity and pump from zero to full capacity according to inflow to the station. Twenty feet of lift to a free discharge is readily obtained and this range will be found suitable for many highway pumping requirements. Pumps are manufactured with one, two or three flights, the greater number of flights increasing the capacity, but reducing the head. Several angles of inclination are available, but the 30° slope is most applicable for highway use. For economy and reliability, two or more screw pumps are usually installed in a given pump station.

Figure 9-26 shows the general arrangement and principal parts of the three-flight pump. Figure 9-27 shows a tabulation of pump characteristics and typical performance curves. Hydraulic and construction details for screw pumps are shown in Figure 6-9, Chapter 6. - Wet Pit Design.

The following general description of screw pump components and features will be found suitable as a guide for the writing of a specification, the number of pumps and required head and capacity being stated as necessary. Although electric motors are normally used for screw pumps, gas engines driving through reduction gears have been utilized.

Screw Pump Components and Features

Lower Bearing

The lower bearing is a grease lubricated sleeve bearing that is totally enclosed, hermetically sealed, and automatically lubricated. Radial forces are absorbed by the lower bearing, which is fitted into a fabricated housing of special design. A mechanical lip seal keeps water from the bearing. An automatic grease pump lubricator driven by a 1/3 HP motor feeds grease to the bearing housing during operation. The shape of the bearing housing assures an even flow of lubricant.

NO.	PART NAME		
1.	GEARED MOTOR	7.	UPPER SHAFT
2.	FLEXIBLE COUPLING	8.	LOWER SHAFT
3.	UPPER BEARING	9.	SCREW SHAFT
4.	LOWER BEARING	10.	SCREW BLADE
5.	UPPER BEARING STAND	11.	SHAFT COUPLING COVER
6.	LOWER BEARING STAND		

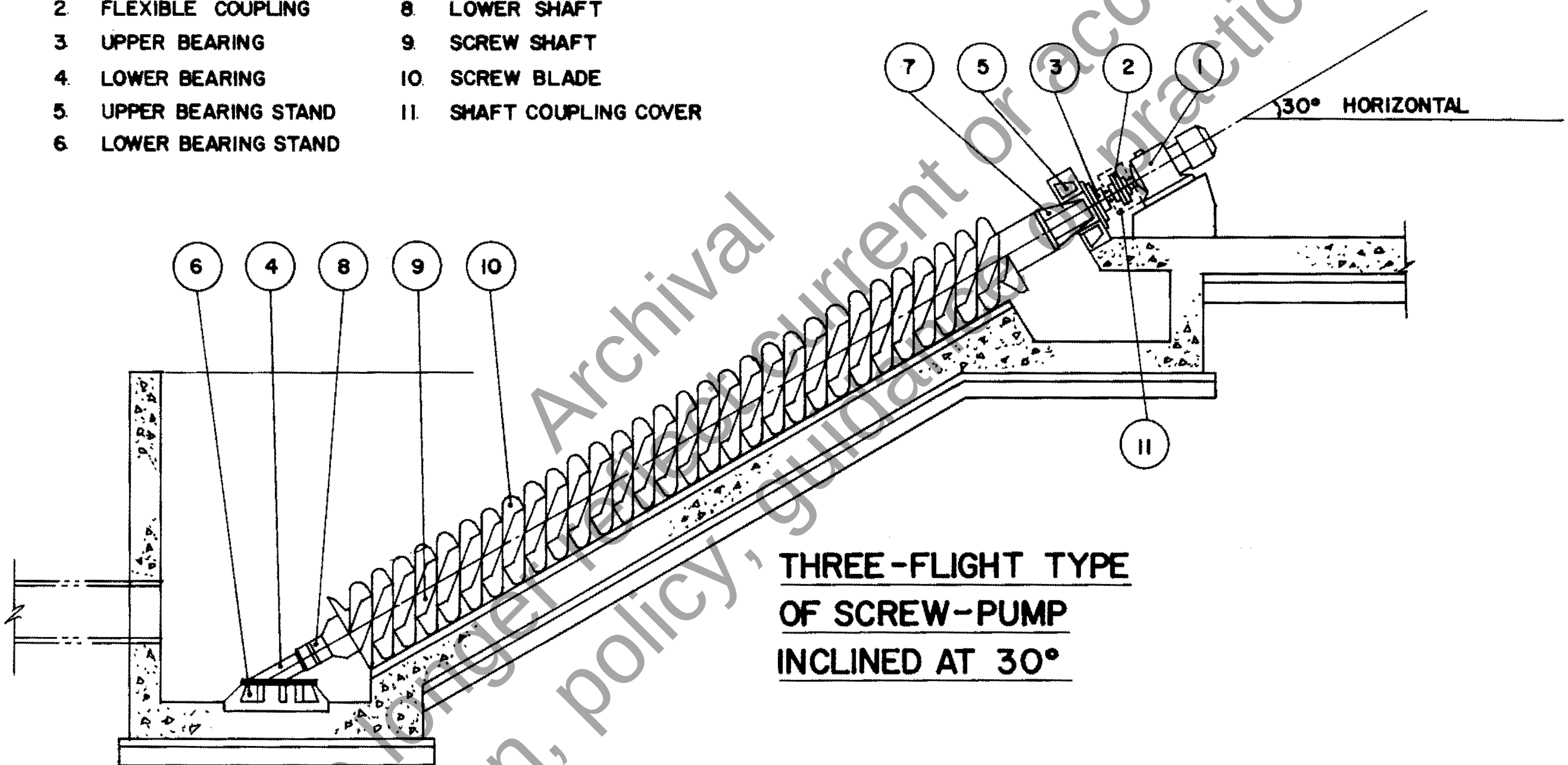
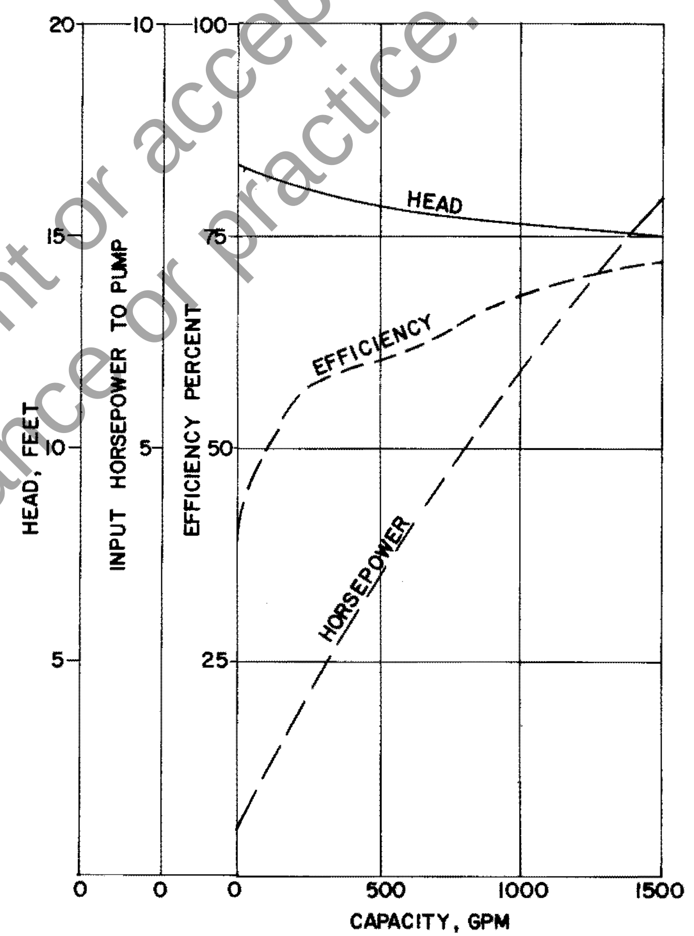


FIGURE 9-26. GENERAL ARRANGEMENT

GALLONS PER MINUTE	SCREW DIAMETER, INCHES					MOTOR HORSEPOWER				
	HEAD, FEET					HEAD, FEET				
	5	10	15	20	25	5	10	15	20	25
160	12	12	16	..	..	3/4	1	1 1/2	...	...
300	16	16	16	..	..	1	2	3	...	...
500	20	20	20	..	..	2	3	5	...	...
800	24	24	24	..	..	3	5	7 1/2	...	...
1200	24	24	30	30	..	3	7 1/2	10	15	...
1800	30	30	30	36	..	5	10	15	15	...
2100	36	36	36	36	..	5	10	15	20	...
3000	36	36	36	..	..	7 1/2	15	20	...	...
4200	42	42	42	42	..	10	20	25	40	...
5400	48	48	48	48	54	15	25	40	50	60
7000	54	54	54	54	60	20	30	50	60	75
9000	60	60	..	..	..	25	40	...	...	...
11000	60	60	60	60	..	25	50	60	100	...
14000	72	72	..	..	..	40	60	...	...	...
16000	72	72	72	72	72	40	75	100	125	150
22000	84	84	84	84	84	50	100	125	200	200
28000	96	96	96	96	96	60	125	200	250	300

SCREW PUMP CHARACTERISTICS
30° INCLINATION



PERFORMANCE CURVES FOR 30-INCH SCREW PUMP LIFTING WATER AT 1500 GPM THROUGH 15 FT. HEAD AT CONSTANT SPEED-FREE DISCHARGE

FIGURE 9-27.

The sleeve bearing compensates for changes in overall length of the screw caused by temperature changes. A shield shall be provided in front of the bearing in the influent chamber to prevent floating debris from winding around the shaft.

Upper Bearing

The upper bearing carries the weight of the screw and water and absorbs the thrust of the pumping action. It is a dual bearing fitted into a special split housing. The split housing permits easy access of the two bearings. A thrust bearing absorbs the thrust from the pump; a radial bearing absorbs radial loads. The housing is double sealed to protect the bearing from foreign materials.

Drive

The screw pumps shall be motor-driven through a double reduction helical gear reducer and flexible coupling or shaft mounted reducer. The gear reducer steps down motor speed to screw speed and is connected to the motor by V-belts. Loading is low because the screw is empty while starting. Backstops are required on all units to prevent reverse rotation if the screw is shut down. All screws should be furnished with backstops as standard equipment. Neither a variable speed drive nor complex electrical controls are needed. Automatic operation can be arranged with electrodes or pneumatic water level controls.

Screw

The spiral screw consists of a hollow revolving steel tube to which is mounted helically shaped flighting made of steel and continuously welded on both sides to the tube. For varying operating requirements, the screw can be designed for 1, 2 or 3 flights. End plates should be welded to the tube ends, to which the bottom and upper end bearing stub shafts are bolted. Screw length is limited by deflection. All screw pump parts coming into contact with the waters should be sand blasted and sprayed with a special corrosion-resistant coating. A steel deflector plate mounted on the screwtrough should curve around the upper section of the screw to prevent spills as the screw rotates.

Safety

The screw should revolve in an open trough (part of which is located in a pit), and every precaution should be taken to prevent personnel from entering the pumping area. The pit should be covered with grating, and handrails should be installed between the trough and the service stairs, all as shown on plans. The control equipment for the drive motor should be interlocked so that the screw cannot be started accidentally.

9-G. ANGLEFLOW PUMPS - VERTICAL TYPE

This type of pump is illustrated in Figures 2-5, 2-6, 9-28 and 9-29. The first two of the figures show a typical arrangement with the pumps taking suction from the wet-well through elbows and piping to the bottom flange of the casing. The vertical drive shafts to the motors will also be observed. The second two figures show details of pump construction and are extracts from a manufacturer's catalog. Note that these pumps are available in a wide range of sizes and capacities. They can also deliver at high heads. There is great similarity between this pump and the horizontal non-clog centrifugal.

Typical specification data is included as Figure 9-30 continued with Figure 9-31 to show alternate materials which are available for impellers and other parts.

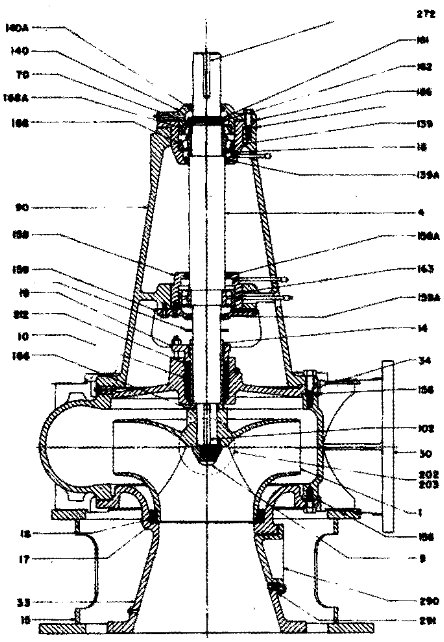
This type of pump is sometimes mounted on a cast-iron base which incorporates a suction elbow turning from horizontal to vertical. Also the motor is sometimes mounted on top of another metal support frame attached to the top of the pump. This eliminates the long vertical shaft as shown in Figure 2-5.

Some manufacturers refer to this type of pump as a sewage pump. It is of the non-clog type and depending on size can pass spheres up to six inches in diameter. This may be of value where trash screening is inadequate.

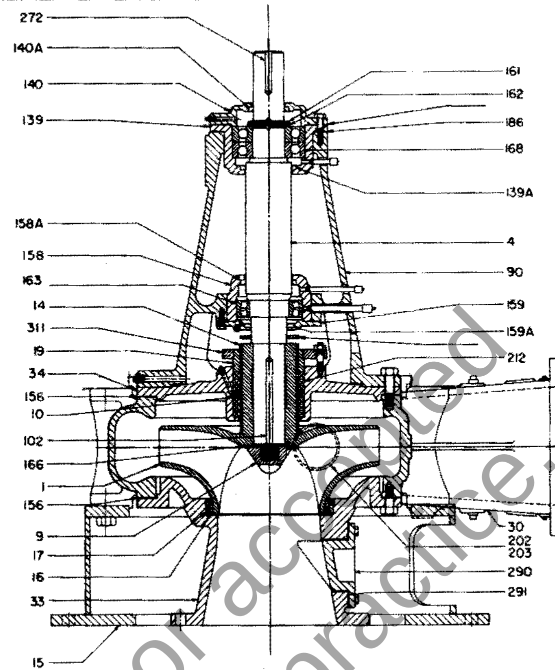
An advantage claimed for this type of pump is the small floor area required to accommodate it. For the small dry-pit station illustrated in Figure 2-1 and elsewhere this type of pump could be considered, mounted vertically. A disadvantage would be the two additional elbows required, one in the suction and one in the discharge compared with the piping arrangement shown in Figure 2-1.

When this type of pump is being considered the catalogs of several different manufacturers should be studied in order that the various features of the pump are fully understood. From the data herein and from the catalogs an adequate specification can then be developed.

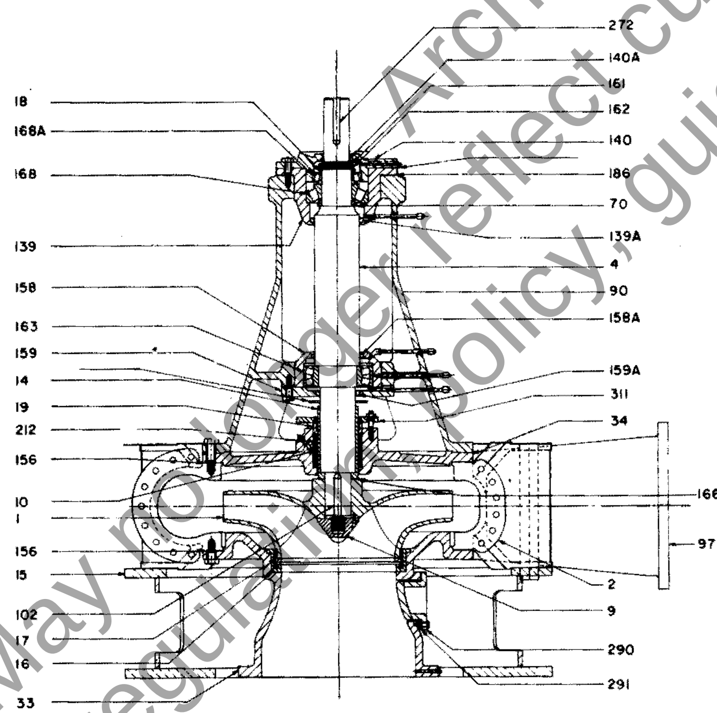
* * * * * * * * * * *



5712 - 14", 20" AND 24"



5713 - 14"



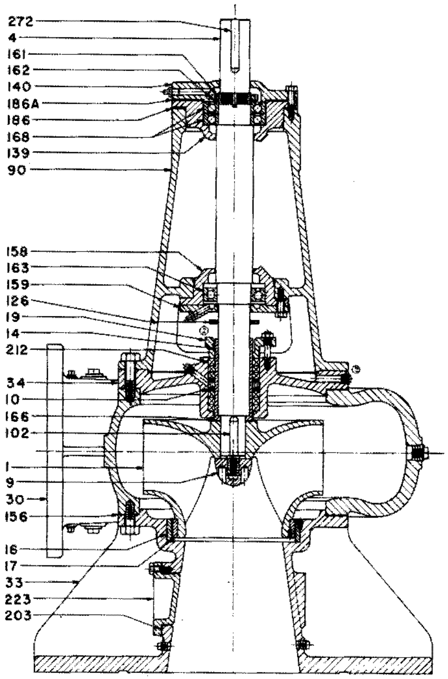
5712 - 36"
5713 - 24" AND 30"

REF. NO.	DESCRIPTION
1	IMPELLER
4	SHAFT
9	NUT, IMPELLER
10	RING, WATER SEAL
14	SLEEVE, SHAFT
16	WEAR RING, CASING
17	WEAR RING, IMPELLER
18	COLLAR, BEARING
19	GLAND HALF
30	VOLUTE
33	FRONTHEAD
34	BACKHEAD
70	COLLAR, SHAFT
90	FRAME
102	KEY, IMPELLER
126	DEFLECTOR
139	HOUSING, BEARING OUTER
139A	LIP SEAL
140	COVER, OUTER BEARING HOUSING
140A	LIP SEAL
156	GASKET, VOLUTE
158	HOUSING, BEARING INNER
158A	LIP SEAL
159	COVER, INNER BEARING HOUSING
159A	LIP SEAL
161	LOCKNUT, BEARING
162	LOCKWASHER, BEARING
163	BEARING, INNER
166	GASKET
168	BEARING, OUTER
168A	BEARING, OUTER
186	SHIM
186A	SHIM, BEARING OUTER
202	COVER, VOLUTE HAND HOLE
203	GASKET, HAND HOLE COVER
212	PACKING
219	CLIP, GLAND
223	COVER, SUCTION HAND HOLE
272	KEY, COUPLING
290	COVER, SUCTION HAND HOLE
291	GASKET, SUCTION HAND HOLE
311	GLAND RING

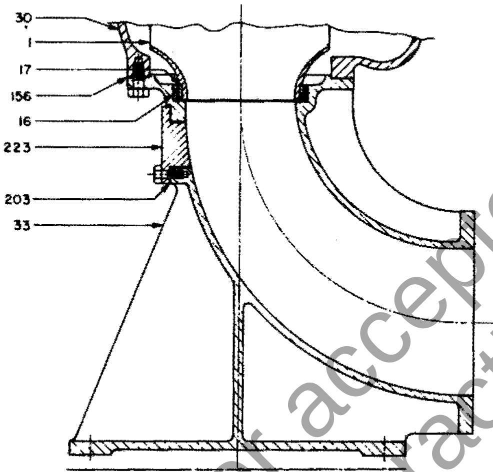
VERTICAL DRY-PIT ANGLEFLOW PUMPS
CROSS-SECTION AND PARTS

COURTESY OF
FAIRBANKS MORSE PUMPS

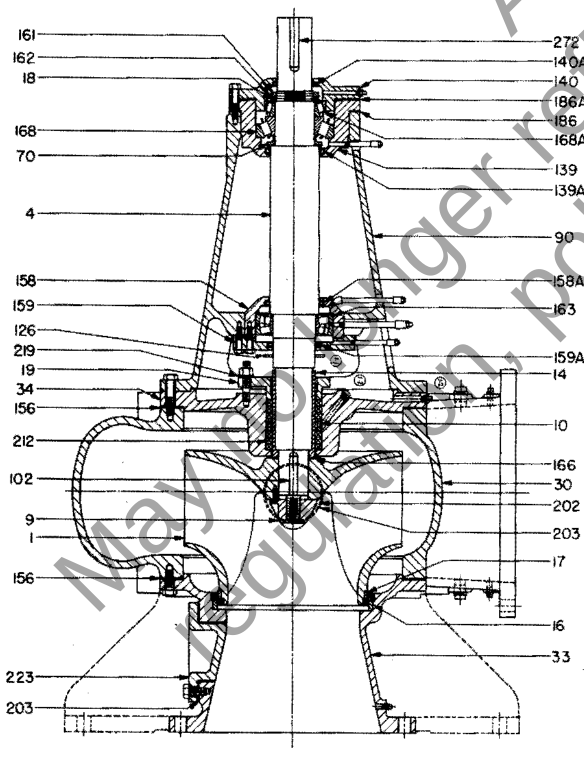
FIGURE 9-28.



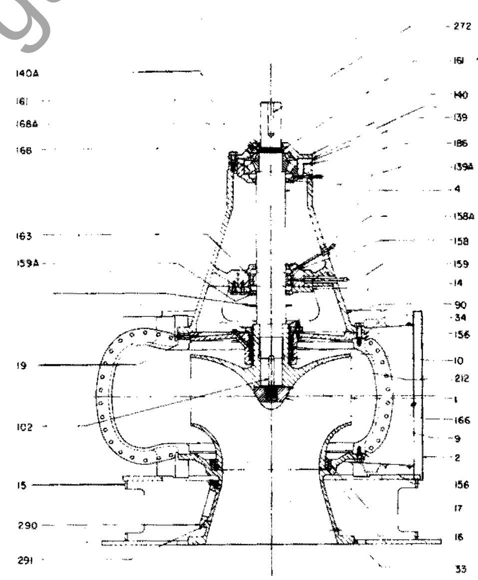
5711 - 8" THROUGH 16"



COMBINATION BASE - ELBOW
5711 - 12", 14" AND 16"



5711 - 18" THROUGH 36"



5711 - 42"

FIGURE 9-29. VERTICAL DRY-PIT ANGLEFLOW PUMPS CROSS-SECTION AND PARTS

COURTESY OF FAIRBANKS MORSE PUMPS

VERTICAL ANGLEFLOW PUMPS
TYPICAL SPECIFICATIONS

GENERAL

Contractor shall furnish and install a quantity of _____ Fairbanks Morse _____" x _____" Model 571 _____vertical dry pit angleflow pumping units. Pumps are to be connected to drivers by (flexible) (solid) shafting with guide bearings as required. Drivers shall be mounted on heavy duty ring bases which provide access to the motor shaft coupling.

CONDITIONS OF OPERATION

Each pump shall be capable of providing the following hydraulic conditions:
Design Condition of _____ GPM, _____'TH _____ % Efficiency, at _____ RPM.
Secondary Point: _____ GPM, _____'TH.
Maximum shutoff head shall be _____ 'TH.
Net Positive Suction Head Available (NPSH-A) at center of pump impeller is _____' at _____ GPM.
Liquid is _____ with a maximum temperature of _____ ^{0}F.

PUMP COMPONENT CONSTRUCTION

Each pump shall be constructed as follows:

IMPELLER

Impeller shall be _____ vane, enclosed, single suction, non-clogging type designed to pass a minimum sphere size of _____ ". Wiper vanes on the impeller back shroud are not allowed. The impeller is to be dynamically balanced and secured to a straight fit on the shaft by means of a key and locknut with setscrew.

VOLUTE

Volute is to be one-piece cast (30" and up, split) with side flanged tangential discharge. Discharge flange shall be rated 125# per A.N.S.I. standards. Volute design to permit front or back impeller removal and be capable of rotation in 45^{0} increments to accommodate piping orientation independent of the base location. Diffusion vanes are not permitted. A volute handhole for inspection and cleanout at the impeller is required. Nominal casing thickness is to be _____ ". Casing shall be hydrostatically tested to two times the design head or 1.5 times the shutoff, whichever is greater.

FRONTHEAD AND BASE

Units 36" and smaller shall have the base cast integrally with the fronthead. (NOTE: Integrally cast base, fronthead and suction elbow is available in 12", 14" and 16" sizes.) Suction flange shall be rated 125# per A.N.S.I. standards. Fronthead shall incorporate a handhole for inspection and a _____" flanged suction.

BACKHEAD

Backhead shall be provided with an integrally cast stuffing box. The stuffing box is to accommodate a minimum of _____ rings of packing and a seal cage. A split gland shall be furnished. Provisions are to be made for draining stuffing box leakage.

FITS

Volute, suction, backhead, and frame shall be manufacutured with concentric shoulder fits to assure accurate alignment.

SHAFT

Shaft shall be made from high quality steel, of sufficient diameter to carry the maximum load imposed and to prevent vibration and fatigue. Shaft is to be accurately machined along its entire length. A renewable straight or hooked type shaft sleeve, positive adhesive sealed, shall protect the shaft through the stuffing box area.

WEARING RINGS

Annular type removable wearing rings are to be provided on both the impeller and suction head. They shall be made to withstand abrasion, and provide a seal between the impeller and suction head for reduction of recirculation. The impeller wear ring shall be approximately 50 Brinell softer than the suction head ring.

FRAME

Frame shall be of rugged design, completely enclosing the shaft between bearings. Bearing supports are to be of heavy duty construction and line bored for accurate and permanent bearing alignment. Bearing housings shall be dust proof incorporating lip seal in contact with the pump shaft for units 18" and larger. Provisions for external impeller adjustment shall be provided.

COURTESY OF
FAIRBANKS MORSE PUMPS

FIGURE 9-30.

BEARINGS

Size 8" Thru 16": Radial (inboard) bearing shall be grease lubricated single row, deep grooved - ball type. Thrust (outboard) bearing shall be grease lubricated, angular contact, duplex mounted ball bearings. Bearings to be designed for a minimum B10 life of _____ hours in accordance with AFBMA.

Size 18" Thru 54": Radial (inboard) bearing shall be grease lubricated spherical roller type, self-aligning. Thrust (outboard) bearing shall be grease lubricated, tapered roller. Bearings to be designed for a minimum B10 life of _____hours in accordance with AFBMA.

PUMP MATERIALS OF CONSTRUCTION

Pump components shall be made from the materials as shown on the material specification page.

REF. NO.	DESCRIPTION	MATERIAL	SPECIFICATION
219	CLIP, GLAND	BRASS	COMMERCIAL
223	COVER, SUCTION HANDHOLE	CAST IRON	A48, CLASS 30
272	KEY, COUPLING	STEEL	AISI 1018
290	COVER,SUCTION HANDHOLE	CAST IRON	A48, CLASS 30
291	GASKET, HANDHOLE COVER	RUBBER	–
311	GLAND RING	BRONZE	B145 (836)
	BOLT, VOLUTE	STEEL	SAE BOLT STEEL
	NUT, GLAND	BRASS	COMMERCIAL
	BOLT, GLAND	BRASS	COMMERCIAL
	OPTIONS		
1	IMPELLER	BRONZE	B145 (836)
4	SHAFT	MOLYBDENUM STEEL	A332-C4140
14	SLEEVE, SHAFT	STAINLESS STEEL	A296 GR CA-40 (4)
16	WEAR RING, FRONTHEAD	STAINLESS STEEL	A296 GR CA-40 (5)
17	WEAR RING, IMPELLER	STAINLESS STEEL	A296 GR CA15 (2)
19	GLAND, HALF	BRONZE	B145 (836)

NOTES:
1. ALL MATERIAL SPECIFICATIONS ARE ASTM UNLESS OTHERWISE NOTED, AND ARE FOR DESCRIPTION OF CHEMISTRY ONLY.
2. 300 TO 350 BRINELL HARDNESS
3. 193 TO 223 BRINELL HARDNESS
4. 400 TO 450 BRINELL HARDNESS
5. 450 TO 484 BRINELL HARDNESS

VERTICAL ANGLEFLOW PUMPS
TYPICAL SPECIFICATIONS

COURTESY OF
FAIRBANKS MORSE PUMPS

FIGURE 9-31.

CHAPTER 10. ELECTRIC MOTORS FOR STORMWATER PUMPS

10A. GENERAL

The purpose of this Chapter is to familiarize the pump station designer with electric motors sufficiently to ensure that requirements can be understood and properly specified. Three types of motor need to be considered. These are the vertical, horizontal and submersible types.

It is not necessary to consider direct current (D.C.) motors because electricity supply in the United States is virtually all alternating current (A.C.). This is transmitted from generating stations at high voltages, stepped down by transformers to lower voltages suitable for power supply to large motors and to even lower voltages suitable for small motors and domestic appliances and lighting. The supply is 60 cycle frequency, or hertz.

In order to increase efficiency, power is generated in separate circuits or phases. These are interconnected to produce a polyphase supply with desirable system characteristics. Interconnection into a three-phase system is used the most extensively and is the only system necessary of consideration here. Conventional three-phase 480 v. A.C. supply may utilize three or four-wire service. The matter of supply voltage and three or four-wire service is dealt with in greater detail in Chapter 12 - Electrical Systems and Controls.

Domestic lighting and power in the United States is alternating current (A.C.) transformed for safety to only 110 to 120 volts, and only a single phase is used. Most appliances are manufactured for this voltage range. Some domestic appliances require from 208 to 240 volts, which can be delivered either single phase, or three-phase. However, because of limitations on the combination of voltage and current, only motors of very low horsepower can be operated at these low voltages. For the motor horsepower range required for stormwater pumps, three-phase alternating current at or about 480 volts is necessary. Sometimes where larger motors are used, the supply voltage may be higher.

The speed at which a motor will run depends on the supply voltage and the style of the stator windings. The speed is determined by design and manufacture and is not usually variable. The power in watts needed to operate a motor is a combination of voltage (intensity or pressure) and amperes (flow or current). Larger motors need a combination of more voltage and amperes, but there is a practical limit on the amperage or current due to the physical size of the copper conductors. Therefore, a higher voltage is necessary for larger motors.

For motors below 5 horsepower, single-phase A.C. service at 120 volts or three-phase service at 208 v. or 240 v. is approprate, but three-phase service at higher voltage is preferred, especially where there are larger motors at the same location. For motors between 5 and 400 horsepower, three-phase A.C. service at 480 volts is appropriate. Few motors over 5 HP are manufactured for other than three-phase service at 480 v. and this may be regarded as standard for stormwater pump stations. For motor horsepowers in excess of 400 horsepower, three phase A.C. service at 2,300 v. or 4,160 v. is appropriate. Several pump stations illustrated in Chapter 2. - Review of Current Practice, have motors operating at 2,300 volts.

Electric motor construction is frequently described by the type of winding employed to create the magnetic field and rotational effect. Types include synchronous, wound-rotor induction and squirrel-cage induction. The following text deals only with squirrel-cage induction motors, since this type of motor is the most suitable for stormwater pumping, and is invariably used. Squirrel-cage induction motor windings may be arranged in various different patterns so that different speeds result at the same input frequency. Dual-speed or variable-speed motors have little or no place in stormwater pumping; therefore, they are not discussed. Because of necessary details of construction, the vertical pump motor is far more expensive than a horizontal motor of the same horsepower. Usually, the cost of the vertical motor exceeds that of the pump. Similarly the submersible motor would be the most expensive part of the entire submersible pump.

How motors are started is important. Depending on connected load, system capacity and other factors, the utility may permit motors to be started "across-the-line", that is, by being directly exposed to the line voltage when stationary. This is the most economical since it avoids the use of an expensive starter. The alternative to across-the-line starting is known as reduced inrush starting in which the starter acts to reduce the voltage at the time of starting and increases it over a short period of time to the actual line voltage. The serving utility has to approve across-the-line starting installations on an individual basis and, where not compatible with the system capabilities, the serving utility will not approve and reduced inrush starting must be used.

Motors are manufactured in accordance with NEMA (National Electrical Manufacturers Association) Standards. ANSI (American National Standards Institute) and IEEE (Institute of Electrical and Electronic Engineers) also have standards. Testing of motors is performed in accordance with standards developed by the IEEE.

With motors, as with pumps, the pump station designer must place reliance and responsibility on the manufacturer.

10-B. PERFORMANCE AND CHARACTERISTICS

Motors are manufactured in standard horsepowers, stated in round numbers which increase by 5, 10, 15, 25 and 50 HP intervals as sizes increase. An exception is a certain make of submersible pump where an irregular progression of motor sizes prevails to over 100 HP, tailoriing the motor exactly to the maximum impeller input HP required. Only three-phase induction motors need be considered. They have good dependability, simplicity of design and are relatively low in cost. Induction motors have two mechanical members, one stationary and one rotating. The members are normally separated by a small air gap, but this is oil-filled in some submersible motors. On the stationary member or stator, a primary three-phase insulated winding connected to the main electric-power lines sets up a synchronously rotating magnetic field in the air gap. The rotating field induces currents in the rotor or secondary winding, provided the rotor runs slower than the synchronous speed. Thus, torque is developed to turn the rotor and drive its connected load. The amount by which the rotor runs slower than the synchronous speed is known as rotor slip, and is expessed as a percentage of synchronous speed. Slip is greater at full load than at no-load.

The squirrel-cage induction motor gets its name from the rotor, built similar to a squirrel-cage running wheel. The secondary winding is embedded in slots near the periphery of the rotor. The winding consists of uninsulated slot-embedded copper, copper alloy, or other suitable bar or rod materials. The starting torque, current and full-load speed are fixed, depending on the manner in which the cage-type rotor is built.

Motor performance data gives the properties associated with the motor design and load requirements. Motor performance must suit the requirements of the drive to assure economical and successful operation.

Every motor carries a nameplate marked with the following minimum information:

Manufacturer's name and motor serial number;
Horsepower output, (H.P.);
Supply voltage, (v);
Cycle frequency or hertz (usually 60 hz.);
Number of phases (usually 3 ø);
Current in amperes (amps) at rated load (horsepower output);
RPM at rated load;
Service Factor;
Temperature rise; and
Type of enclosure.

All performance data is based on supply voltage and frequency values stated on the motor nameplate, unless otherwise specified.

The service factor is a multiplier which when applied to the nameplate horsepower rating indicates the maximum permissible loading on the motor without being harmful. A common service factor is 1.15, and this is recommended for pump motors.

The allowable temperature rise depends upon the class of insulation. The nameplate shows the allowable temperature rise when measured by thermometer applied to the surface of the hottest accessible part. Temperature measurements made in this manner should not exceed the nameplate value, plus a standard ambient temperature of 40°C. The standard ambient temperature is warmer than usual room temperature, to provide for satisfactory operation under warmer than normal conditions. Overheating and damage to the insulation of the windings is the principal cause of motor failure.

The efficiency or power factor of a motor is an important consideration. When a motor is connected in a circuit and running, the voltage and current may be out of phase, so that the product of volts and amperes, called volt-amperes or apparent power will be greater than the watts consumed by the circuit. The ratio of actual watts consumed by a circuit to the volt amperes of apparent power of that circuit is called the power factor. Using the terms kilowatt (kw) for units of 1,000 watts input and kilovolt-ampere (kva) for output, the power factor of a motor is the ratio of the kilowatt (kw) input to the kilovolt-ampere (kva) output, expressed as a number usually between 0.8 and 1.0. Power factor for squirrel-cage motors usually is highest at rated load and drops off with decrease in load. As high a power factor as possible is desired because this is one of the items considered by the serving utility in determining its billing to the user. There is a cost penalty for low power factor. Capacitors are sometimes used in a circuit to improve power factor.

Full-load torque is the torque necessary to produce rated horsepower at full load speed. The horsepower multiplied by 5,252 and divided by the full-load rpm gives the full load torque in foot-pounds. Locked-rotor torque (static torque) is the minimum torque the motor will develop at rest for all angular positions of the motor with rated voltage and frequency applied. Pull-up torque is the minimum torque developed by a motor during the acceleration period from rest to the speed at which breakdown torque occurs. Breakdown torque is the maximum torque a motor will develop at rated voltage and frequency without an abrupt drop in speed. See torque curves for NEMA Design B in Figure 10-1.

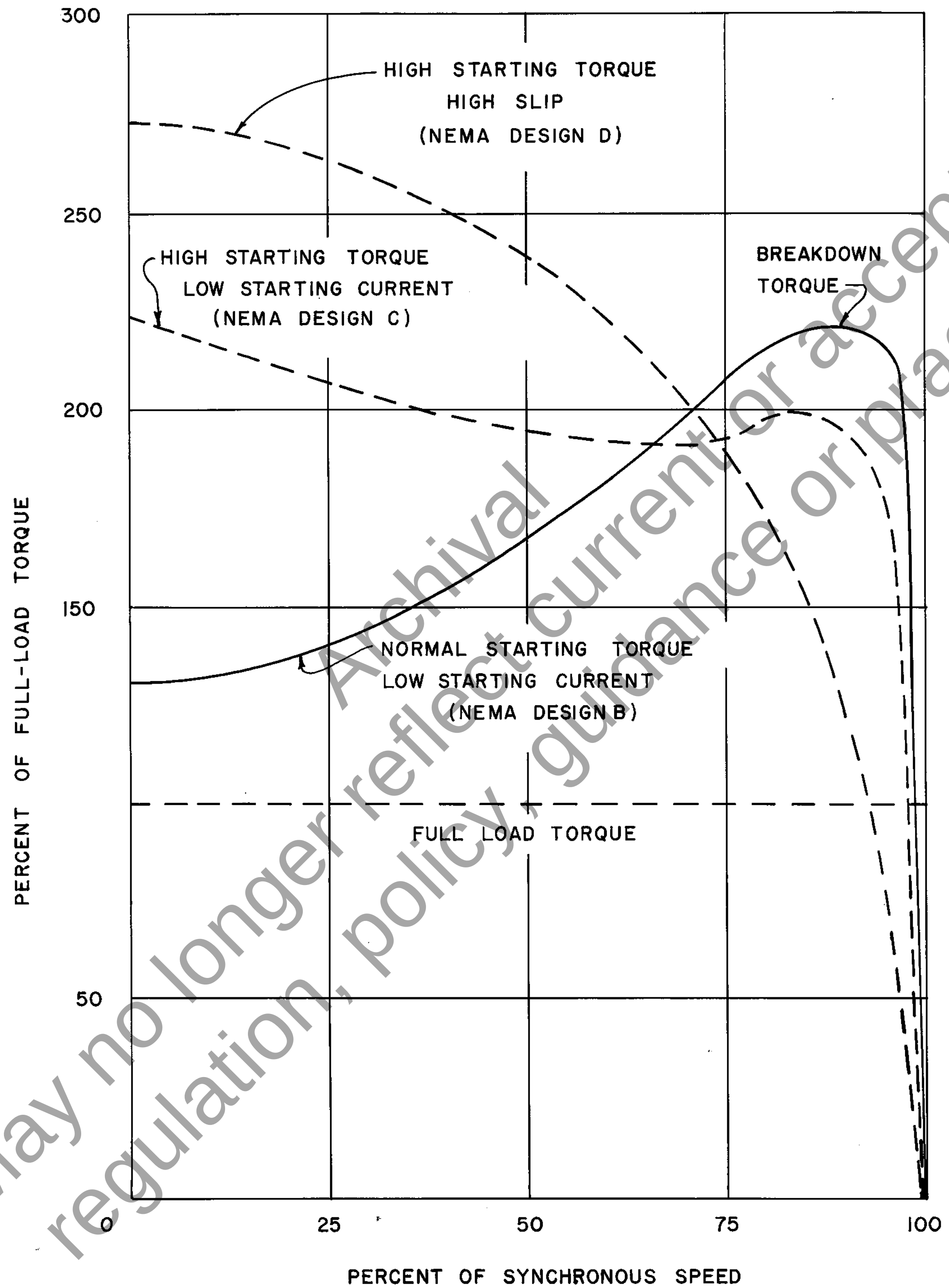


FIGURE 10-1. TYPICAL TORQUE CURVES FOR NEMA DESIGN B, C, & D SQUIRREL-CAGE INDUCTION MOTORS

Locked rotor current is the steady-state motor current taken from the line with the rotor locked at rated voltage and frequency. Locked-rotor current at full rated voltage should be kept low, consistent with required locked-rotor torque and breakdown torque, to minimize supply-voltage dip and large KVA demand. Locked-rotor current may be specified in amperes, as percentage of full-load current or by means of a code letter.

Motor application data for centrifugal pumps must be accurately defined because pump characteristics vary widely, but the responsibility of matching motor and pump is that of the pump manufacturer, not the pump station designer.

The electrical design classification for a standard squirrel-cage induction motor with normal starting torques and normal starting currents is generally identified as NEMA Design B. This design is ideal for typical pump loads. It has high full-load speed, high efficiency, standard starting torques and relatively low starting current.

Starting torque requirements of centrifugal pumps are quite moderate. 10 to 20 per cent of full-load torque will usually start these pumps from rest. Refer to Torque Curves, Figure 10-1. One exception is low-speed vertical pumps. They have high thrust loading and may require 40 per cent starting torque.

Normal starting torques range from 60 to over 100 per cent of full-load torque, depending on horsepower and speed. As horsepower rating increases for a given speed, the starting torque tends to decrease. Breakdown torque is between 175 and 200 per cent of full-load torque and occurs at approximately 92 per cent of full normal speed. Normal starting current is approximately 550 to 700 per cent of full-load current. Motor slip is low in a NEMA Design B, approximately 0.1 to 2.5 per cent from no load to full load. Deficiencies in motor torque during starting must be considered when voltage or frequency deviations are anticipated. Torque varies as the square of the voltage and inversely as the square of the frequency. Thus, if voltage is raised 10 per cent, torque increases 21 per cent, or if frequency is lowered 5 per cent, torque is raised 11 per cent.

Service conditions should be included in the motor specifications, especially those that may deviate from normal or standard, such as unusual voltage variations, ambient temperature above 40°C or below 10°C, and operation above 3,300 ft. elevation. Increase in supply voltage will increase the synchronous speed of a motor. Squirrel-cage motors will withstand about 20 per cent overspeed of their synchronous speed without mechanical damage. Thermally, the motor capacity is increased about one per cent for each degree the ambient is below 40°C and decreased for the same amount for each degree it is above this value.

10-C. INSULATION

The electrical-insulation of an electric motor is one of its most important components. While the insulation is often considered a non-wearing part, thus non-aging, it is probably the part of a motor most easily damaged during handling or maintenance and the most susceptible to degradation from normal and abnormal operating conditions and from environmental conditions. Use of insulation with high dielectric-strength is the most important, especially in motors operating at 460 volts and above. Insulation in motors large enough to drive stormwater pumps is expected to be serviceable for upward of 20 years with minimal maintenance. To project long life is exceedingly difficult, primarily because of the inability to anticipate and control damage due to the corona activity and the effect of heat.

NEMA design standards provide for a number of classes of insulation, depending on size and service of motor. These classes specify the hot-spot temperature which the insulation can resist without damage as follows:

Class	A	Hot-Spot	Temperature		105°C
"	B	"	"	"	130°C
"	F	"	"	"	155°C
"	H	"	"	"	180°C

Usually, large motors are Class B insulated, with a trend to Class F. A motor may not require a high hot-spot rating. However, an insulating system that can operate at higher temperatures will provide greater reliability for a longer time because it can more effectively withstand the damaging heat of short-time overloads.

Since starting current is from five to seven times the full-load operating current, each start temporarily overheats the motor insulation, and the life of the motor is reduced by the number of starts. Normal motor overload protective relays will not protect a motor against damage from too frequent successive starts, so it is necessary to limit the number of starts over a given period of time. NEMA design standards state that large motors should be capable of withstanding two successive starts from ambient temperature and one start from rated operating temperature during each hour, providing the design load conditions are not exceeded. If the motor can come up to speed with little or no load, the heating effect is much less.

In unattended pump stations, it would be possible to have a malfunction in the water level controls which would cause cycling of the motor on and off without tripping the motor overload relays, thus causing damage to the motor windings. To prevent the motor from exceeding the thermal limits, it is advisable to provide a restart permissive timer in the automatic control circuit to ensure a sufficient cooling-off period between starts. The timer should be connected so that starts will not be prevented after a sufficient running period. Also, the timer should function to prevent re-starting while the pump is back-spinning from reverse flow.

10-D. BEARINGS

Motor bearings, plain or antifriction, support and control the motion of a rotating shaft while consuming a minimum of power. Plain bearings are either sleeve or thrust types that depend on a lubricating film to reduce friction between the shaft and the bearing. When properly designed and lubricated, plain bearings develop oil films which have tremendous load-carrying capabilities. Antifriction bearings operate on the principal of rolling contact between elastic circular bodies. The resistance of this rolling action is quite low. At low speeds, ball and roller bearings develop so little resistance through rolling that they are superior to plain bearings. Individual antifriction bearings can support, at the same time, both radial and thrust loads in varying degrees -- a characteristic not typical of plain bearings. Antifriction bearings require only small amounts of lubrication and they are relatively insensitive to viscosity changes. When too much grease is used, the turning action of the rolling element produces excessive fluid friction, thus overheating.

The life of ball or roller bearings depends on fatigue strength of the material and decreases as speed and load increases. Labyrinth and rotating seals and other mechanical and chemical devices help protect against unfavorable environmental conditions, such as vibration, poor fits, corrosion or abrasive dirt. Normally standard horizontal motors up through 125 horsepower, 1800 rpm, are furnished with radial deep-groove ball bearings which permit the motor to be mounted in any position, including vertical, providing the downward thrust on the shaft is less than the weight of the motor. Bearings in vertical motors require special considerations. Both ball and roller, as well as sliding element-type, are used to carry the weight of the motor rotating element and in some cases the weight of the pump shaft and impeller. Data on Page 9-29 explain bearing life criteria.

10-E. ENCLOSURES

Motor enclosures, or types of frame design, may be open, totally enclosed, or submersible.

Open-type motors have ventilating openings to permit the unrestricted passage of air over the windings, and are of three types: protected motors which have each opening limited in size and shape, generally not to exceed one-half square inch; drip-proof motors which are constructed so that drops of liquid or solid particles which fall at an angle of 15 degrees from the vertical are prevented from entering; and splashproof motors which have openings so protected that drops of liquid impinging at an angle not greater than 100 degrees from vertical cannot enter the motor directly.

Totally-enclosed motors prevent the exchange of air between the inside and outside of the motor, but are not completely airtight. These also are of three types: Nonventilated (TENV) motors which have no provisions for external cooling other than fins or radiating surfaces on the frame; fan-cooled (TEFC) motors which have integral fans for external cooling of enclosing parts; and explosion-proof (TEXP) motors which can withstand explosion of vapor within the motor and prevent the ignition of gas vapor outside the motor by this explosion.

Submersible motors are designed in one of several special fashions for operation while totally submerged in water having a temperature not exceeding 25^{o}C.

Most motors in pump stations are air cooled and of the open-type, either forced or self-ventilated. The manufacturer, in conforming to NEMA Standards, will make provision for passage of sufficient air to cool the motor.

The motor stator frame should be of steel or normalized cast iron, accurately machined and drilled to receive the end brackets and bearing supports. The motor should be balanced after assembly to an overall vibration amplitude peak-to-peak of not more than .001 inches.

All vertical motors of one hundred horsepower and over should have the thrust bearing and lower guide bearing oil lubricated, with visible means for checking oil level and quality. Motors below one hundred horsepower may be grease lubricated, but the system must provide for flushing out and replacing old grease.

Enclosures for motors will be found to vary in physical shape and appearance. A comparison of Figures 10-3 through 10-5 will show the variation for horizontal motors of different manufacture. As motors increase to the very large size, they will assume a more rectangular shape, due to ventilation requirements. Figures 10-2, 10-6 and 10-11 will make this clear.

Operating conditions at many pump stations will subject electric motors to a prevailing dampness, and possibly extremely low ambient temperatures. If so, space heaters should be used in open-type motors to prevent condensation of moisture on cores, windings and wiring while the equipment is not in use.

Heater units of strip-type are located in the bottom of the motor enclosure so convention currents carry the heat upward. It is usually desirable to turn the heaters on with a normally closed contact on the motor starter. A pilot light should be used to indicate that the heater is energized. The heater elements should be located so that they can be replaced without dismantling the motor.

Another precaution with open-type motors is the provision of rodent screens. Varnish on the winding insulation is attractive to rodents.

The usual voltage of heaters is 240 v., and a separate junction box may be provided to allow for easy connection, as shown in Figure 10-2. The heater elements must always be insulated electrically from the motor frame. The power requirements can be estimated roughly as 0.5 to 1.0 kilowatts per 1,000 horsepower.

Motor noise is more noticeable with open-type motors than totally-enclosed. It is impossible to eliminate noise completely. Housing in a concrete or masonry structure is probably the most effective means of reducing it. Procedures for determining motor noise is described in IEEE Standard #85 Test Procedure.

10-F. STARTING

The starting of an electric motor from rest usually requires relatively expensive accessory equipment. It is rarely a simple matter of wiring through a three-pole switch to the motor, which is known as full-voltage or across-the-line starting. Motor starting characteristics must be compatible with the electrical utility distribution system and with the requirements of the motor application. 100 h.p. is often the limit for across-the-line.

The two methods of starting squirrel-cage induction motors are either full-voltage, across the line, which is the most economical and simplest method, or reduced inrush starting which can be effected in a number of ways with additional wiring and equipment. This extra gear may cost more than the motor itself.

Using across-the-line starting the motor current will be many times the rated full-load current and the power factor will be low during starting. The approximate ratio of starting inrush current to full-load current is 6.25:1. This puts a high-current surge on the electrical distribution system until the motor has accelerated to rated speed. Most utility companies have definite restrictions on permissible starting current (sometimes referred to as locked-rotor KVA). This is because in some locations the resulting dip in line voltage due to starting inrush would produce objectionable light flicker or other disturbances.

FIGURE 10-2

Very large (700 HP) vertical motor mounted on above-floor discharge vertical pump, I-696 Station.

Detroit, Michigan

(See Figure 2-14)

FIGURE 10-3

Horizontal Motor (25 HP) driving non-clog centrifugal pump in dry-pit station.

Los Angeles, CA

(See Figure 2-1)

FIGURE 10-4

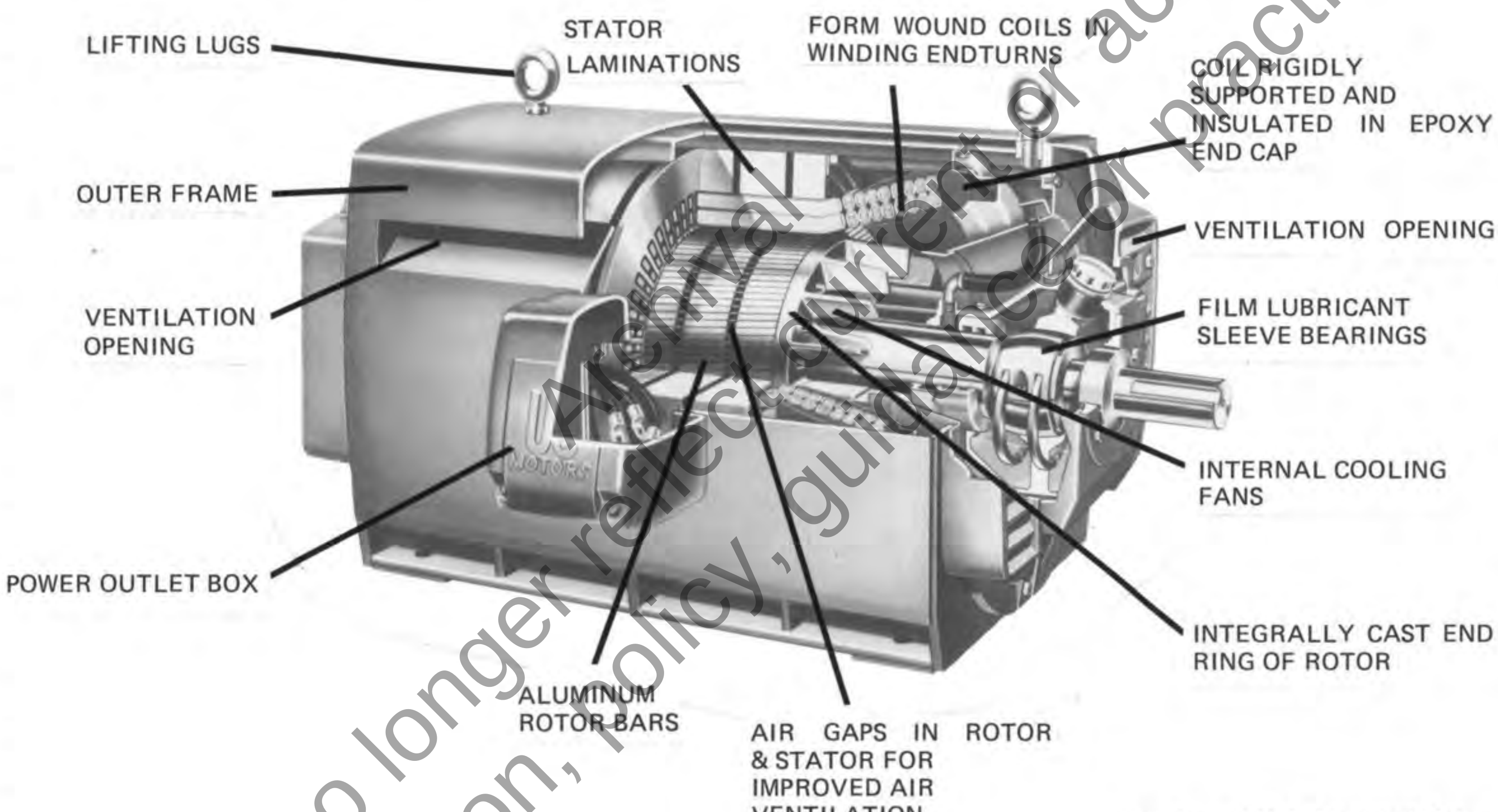
Typical Horizontal Motor (25 HP) for non-clog horizontal pump in dry-pit station.

Los Angeles, CA

(See Figures 3-1 and 3-2)

FIGURE 10-5

View of same pump station equipped with two 25 HP and one 10 HP motors.



Courtesy of U. S. Electrical Motors

FIGURE 10-6. TYPICAL LARGE HORIZONTAL MOTOR

Reduced inrush starting is of various types and may be effected by step-switching the motor starter winding, such as with part-winding and wye-delta starting, or by voltage reduction as in reactor, resistor and auto-transformer starting. The various types of starting are illustrated in Figure 10-7.

Closed transition starting is now practically a standard requirement. This means a method of starting that will not open the circuit between the motor and line during starting. The starting methods in the tabulation below are all closed transition. A brief explanation of the types follows:

Characteristics of Types of Starting
In Per cent of Rated Starting Values

	Motor Voltage	Motor Current	Line Current	Torque	Torque Per KVA
Full Voltage	100	100	100	100	100
Part-Winding			High Speed		
	100	70	70*	50*	72
			Low Speed		
	100	55	55*	50*	90

*Figures above are for 2-step part-winding starting and are approximate. Actual values will vary with the motor design application.

	Motor Voltage	Motor Current	Line Current	Torque	Torque Per KVA
Reactor or Resistor	80	80	80	64	80
	65	65	65	42	65
	50	50	50	25	50
Auto-Transformer	80	80	64	64	100
	65	65	42	42	100
	50	50	25	25	100
Wye-Delta	100	33	33	33	100

Full voltage starting gives the highest starting torque efficiency -- that is, the highest torque per starting KVA. Full voltage starting should always be used unless power system disturbance makes reduced current inrush necessary, or torque increments are required in starting. See Figure 13-1 also.

Part-winding starting is effected by connecting the sectionalized, parallel stator windings to the line in two or more steps. This type of starting requires no auxiliary current reducing device and uses simple switching. If the motor can be designed for

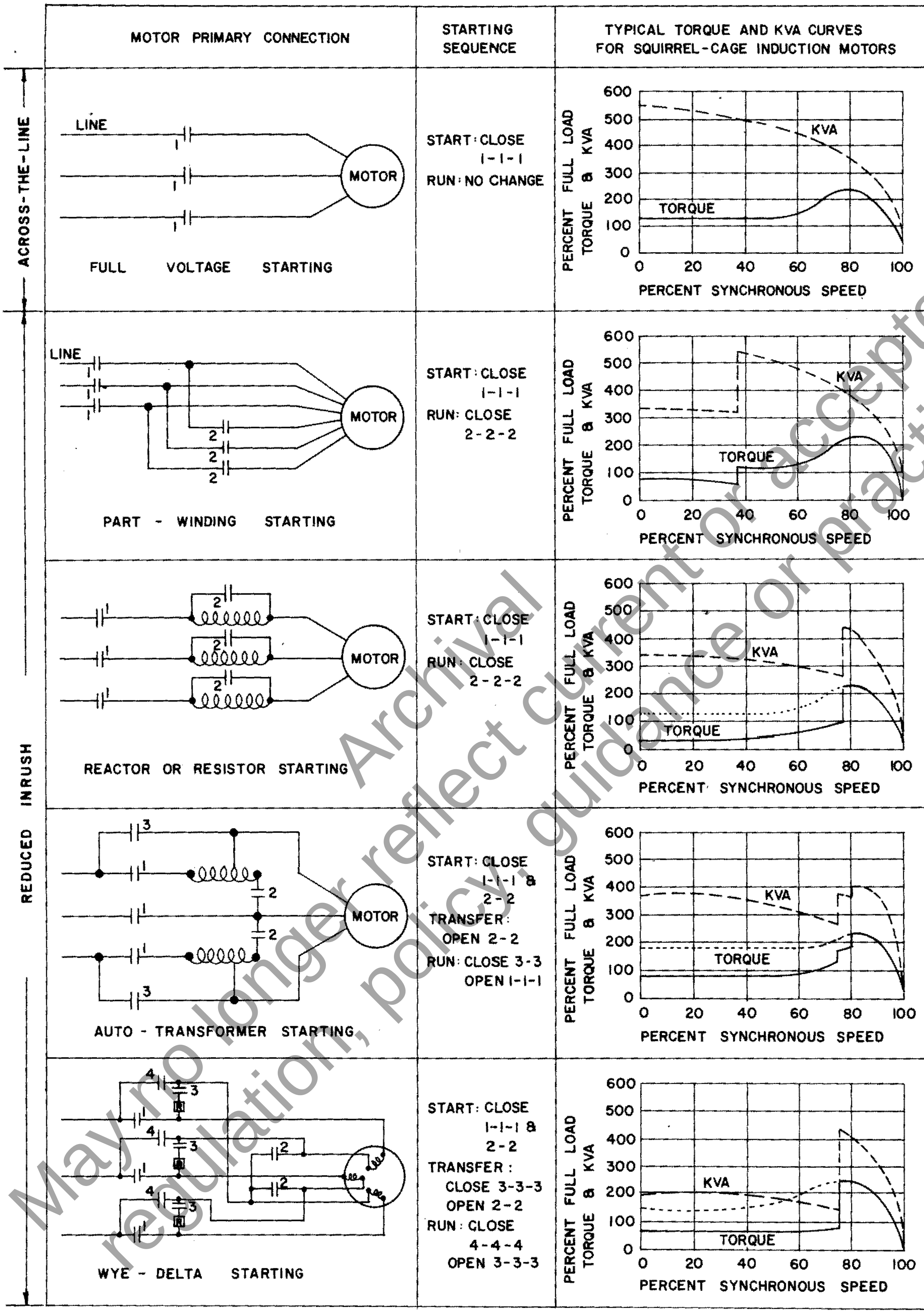


FIGURE 10-7. TYPES OF STARTING

part-winding starting, resultant starting torque and reduced in-rush possibilities may meet the requirement of the load and system at least possible expense.

Reactor or resistor starting requires inserting an impedance (reactor) or resistance (resistors) in the circuit during motor starting. Torque per KVA is lower than with auto-transformer starting. For increment starting, more than two resistance steps may be used.

Auto-transformer starting requires the use of an auto-transformer to reduce voltage to the motor. Addition of switches in the auto-transformer interconnection provides closed transition in transfer to full voltage. Ratio of starting torque to starting KVA is highest with this type of starting.

Wye-delta starting results from switching the windings on a motor designed for wye-delta connection, and provides closed transition by use of a small resistor inserted during transfer. When wye connected, winding voltage is 58% rated value.

Any reduction in starting KVA will be accompanied by at least an equal reduction in break-away torque and accelerating torque. Therefore, requirements of the driven equipment must be compatible with the starting method utilized.

10-G. TESTING

All motors are tested by their manufacturers. The designer may specify that test results be certified and furnished as part of the shop-drawing procedure, showing compliance with NEMA and other specifications.

Test procedures should be made in accordance with IEEE Procedure 112A, and motor tests may be routine or complete.

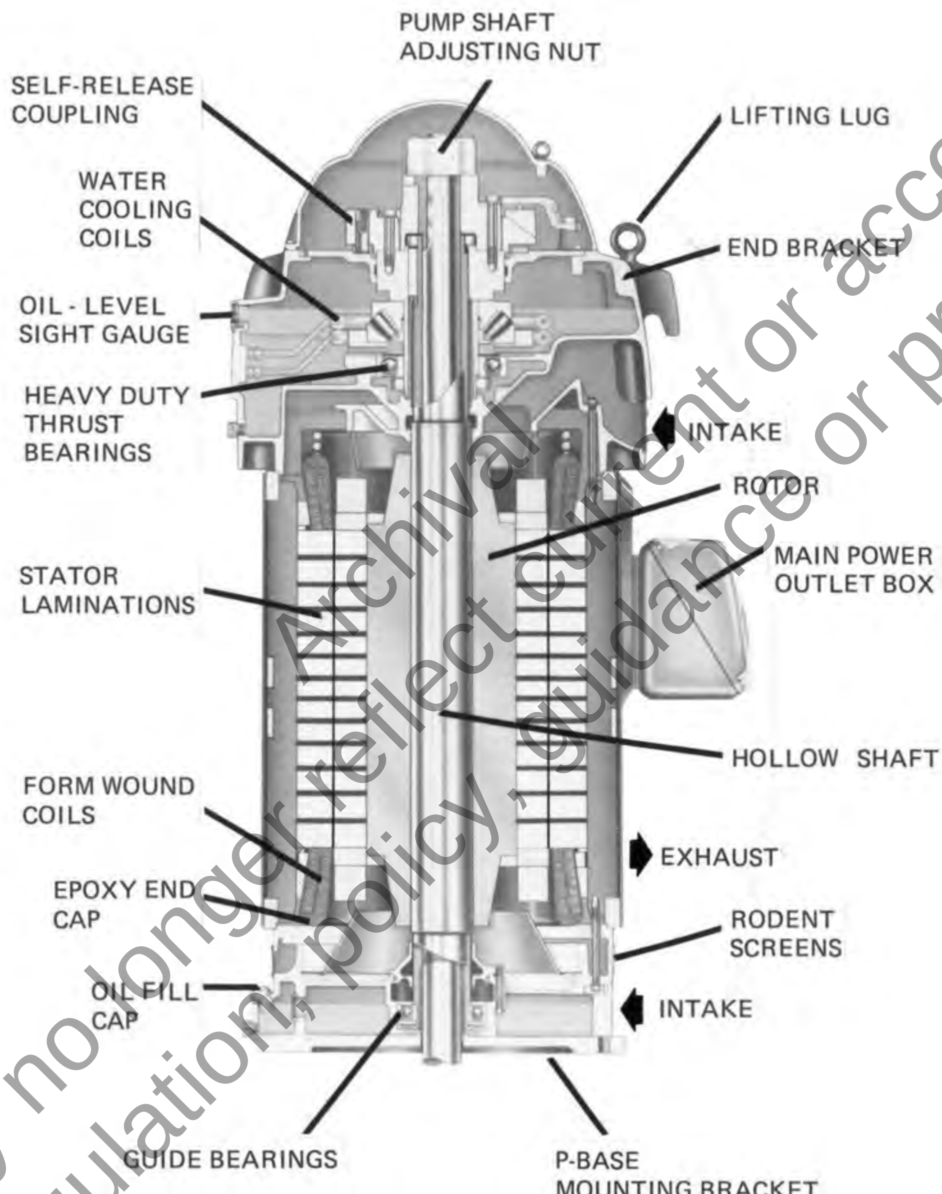
The routine (or commercial) test consists of:

a. Measurement of winding resistance;
b. No-load readings of current and speed at normal voltage and frequency; and
c. High-potential test for motor insulation.

Each motor intended for use in a pump station should be required to be subjected to commercial test and be accompanied by a complete test report of a duplicate motor in accordance with NEMA test standards. The commercial test report should be submitted to and approved by the pump station designer before the motor is shipped to the pump company for laboratory testing of the pump.

The complete test includes routine test as above: full-load temperature rise, speed, efficiency and power-factor, torque values for locked-rotor, pull-up, breakdown and full-load speed; noise rating; and vibration at no load and full-load.

TYPICAL LARGE VERTICAL MOTOR



Courtesy of U. S. Electrical Motors

FIGURE 10-8.

10-H. SUMMARY

Vertical motors are electrically similar to horizontal motors and are primarily designed for driving vertical pumps. To provide greater torque capability at less weight, the hollow shaft has been adopted as standard. It also allows adjustment of the pump shafting at the top of the motor, where it is easily accessible instead of a hard-to-reach and expensive adjustable flanged coupling in the pump pedestal.

Vertical motors are frequently mounted on the pump head. However, in stormwater pump stations with vertical pumps, the motor should be mounted on a pedestal above the pump baseplate. Refer to Figure 9-12 in Chapter 9. In addition to standard motor requirements, vertical motors are classified primarily by their capacity to carry external axial thrust. The vertical motor bearing system is usually designed to carry the weight of the motor rotor, the dead weight of the rotating pump parts and the hydraulic thrust produced by the pump. Pumps generally develop downthrust at their operating design point, but can and do at various points on their operating curve produce a momentary or continous upthrust condition. The possibility of exceeding this capability, however, makes it imperative that a complete description of all thrust conditions which might be encountered in the operation of the pump be considered to assure a bearing arrangement suitable for the application.

Figure 10-8 is a cut-away section of a large vertical motor as manufactured by U.S. Motors. The heavy-duty thrust bearing near the top of the motor and the provision of cooling water to this vital motor element can be seen. This motor does not have a non-reverse ratchet. Figure 10-9 is a photograph of the identical make of motor mounted on top of a combination gear drive. Differences in configuration will be noted compared with the motors of another manufacturer shown in Figure 10-10.

Horizontal motors are designed to operate with the shaft in a horizontal position. The best overall efficiency of a drive system is obtained when the motor is positioned as close to the pump as possible. Most horizontal motors are supplied with foot for mounting to a base. See Figure 9-24. If a motor designed for horizontal use were to be mounted vertically, special consideration of the bearing arrangement and lubrication would be required. Typical horizontal motor applications are shown in Figures 10-3 through 10-5, and a very large motor is shown in Figure 10-6. Most submersible motors are filled with highly refined transformer oil which serves to lubricate the bearings, insulate electrical parts and dissipate heat. Spring-loaded rotary shaft seals are used. Submersible air-filled motors are also produced. Reference to Figures 9-19 and 9-22 will show details of construction.

* * * * * * * * * * *

FIGURE 10-9

Large Vertical Pump (U.S. Motors, 200 HP) mounted on combination gear drive.

U.S. 59, Texas

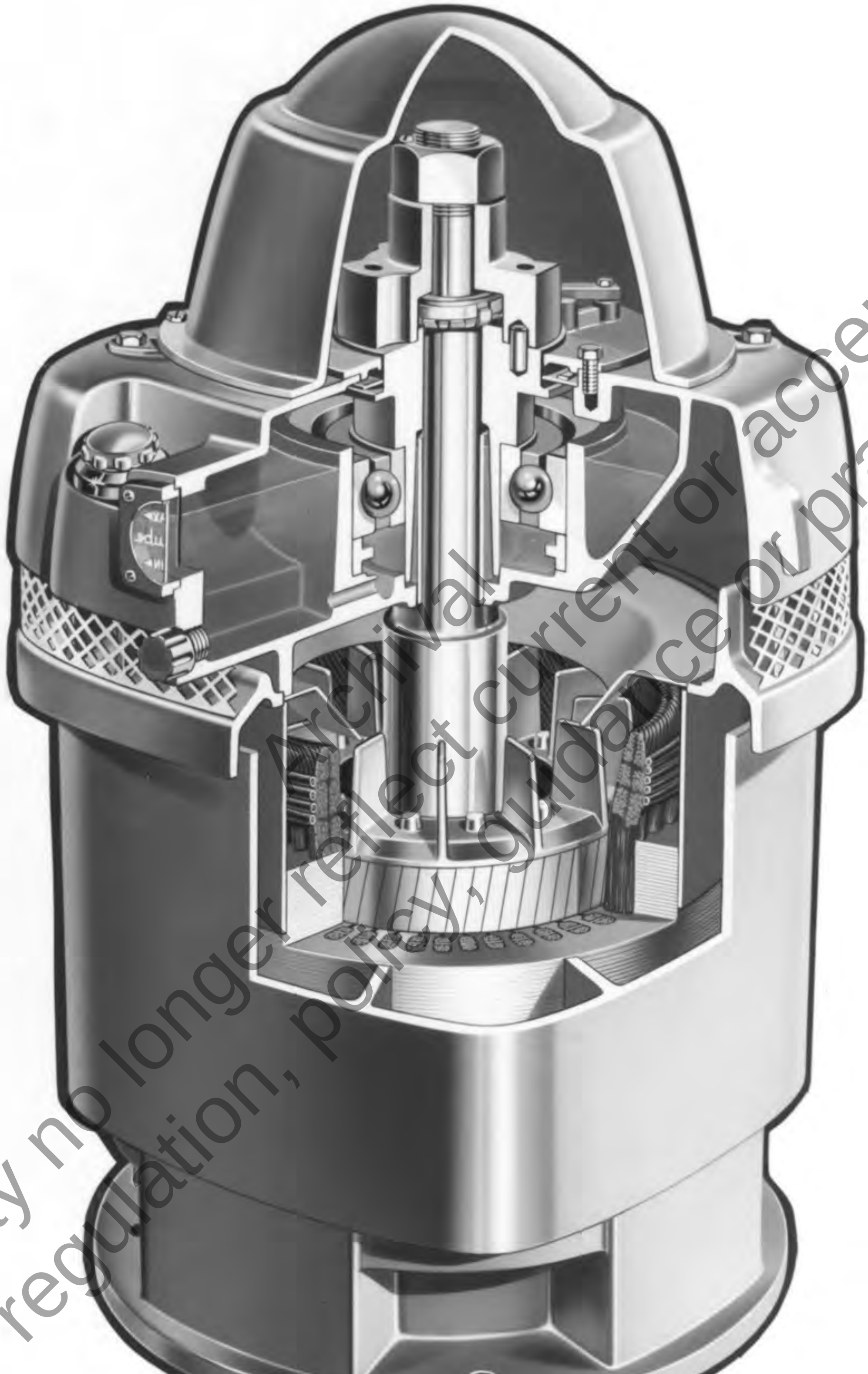
(See Figure 2-15)

FIGURE 10-10

Vertical Motors (General Electric, 20 HP) mounted on above-floor discharge vertical pumps.

Detroit, Michigan

(See Figure 2-8)



Courtesy of U.S. Electrical Motors

FIGURE 10-11. VERY LARGE VERTICAL MOTOR

CHAPTER 11. ENGINES AND ACCESSORIES

11-A. GENERAL

Internal combustion engines are used extensively as drivers for vertical pumps. Occasionally they may be used to drive screw or angleflow pumps. The primary factor in selecting an engine for any pumping application is that it be suitably sized to avoid overloading when continuously producing sufficient brake-horsepower, which is the measurable horsepower of the engine at the output shaft available for driving the pump. Engines may also drive electric generators at pump stations, usually on a stand-by or emergency basis. See Chapter 13. - Emergency Generators.

The engine fuel may be gasoline, natural gas, diesel, or liquefied petroleum gas (LPG). Most smaller engines are able to use gasoline, natural gas or LPG interchangeably. These engines run at speeds up to 2,400 revolutions per minute, and the largest models in this range are rated at a maximum of about 110 brake-horsepower. They are sometimes referred to as automotive type due to their oil pan being of the type used in automotive applications.

Automotive type engines may have sufficient horsepower to drive smaller stormwater pumps, but a larger stationary type of engine is usually required. These have a base type oil pan giving better access to crankshaft and bearings. As the engine size increases, the revolutions per minute decrease, 1,200 rpm being the conventional maximum speed of larger engines used for pumping applications. Natural gas and LPG are the predominating fuels for these larger engines. Four-cycle engines only are discussed.

Diesel engines of four-cycle type are usually available in the same sizes or cylinder displacements as the gas engines. However, for pumping applications, natural gas engines are preferred over diesel engines for several reasons; mainly, they are more economical to operate, require less maintenance, and start more reliably when unattended. Therefore, the discussion which follows refers principally to engines fueled by natural gas, including LPG as an alternate.

Engines require a drive shaft and some form of gear drive to transmit power from the horizontal crankshaft to the vertical or inclined pump shaft. These items are described as accessories and discussed appropriately.

SMALL ENGINES

VRG310U Inline
6 Cylinder Gasoline
Open Power Unit with
Optional Accessories

PRINCIPAL ENGINE DATA	MODEL VRG155U		MODEL VRG232U		MODEL VRG265U		MODEL VRG283U		MODEL VRG310U	
	Gasoline	Nat. Gas	Gasoline	Nat. Gas	Gasoline	Nat. Gas	Gasoline	Nat. Gas	Gasoline	Nat. Gas
Max. H.P.* @ Indicated RPM	42 @ 2200	32 @ 2200	60 @ 2200	51 @ 2200	85 @ 2200	67 @ 2200	108 @ 2400	84 @ 2400	112 @ 2400	88 @ 2400
Max. Torque* @ Indicated RPM	118 @ 1200	101 @ 1200	175 @ 1200	142 @ 1200	223 @ 1200	179 @ 1200	253 @ 1600	201 @ 1800	272 @ 1600	214 @ 1400
Bore and Stroke	3.625 x 3.75 (92 mm x 95 mm)		3.625 x 3.75 (92 mm x 95 mm)		3.75 x 4.0 (95 mm x 102 mm)		3.875 x 4.0 (98 mm x 102 mm)		3.875 x 4.375 (98 mm x 111 mm)	
Number of Cylinders	4		6		6		6		6	
Displacement	155 Cu. In. (2.54 liters)		232 Cu. In. (3.8 liters)		265 Cu. In. (4.3 liters)		283 Cu. In. (4.6 liters)		310 Cu. In. (5.1 liters)	
Number of Main Bearings	3		4		4		7		7	
Lube Oil System, Capacity With Filter	6.0 Quarts (5.7 liters)		7.0 Quarts (6.6 liters)		10.0 Quarts (9.5 liters)		10.0 Quarts (9.5 liters)		10.0 Quarts (9.5 liters)	
Jacket Water System, Capacity	20.0 Quarts (18.9 liters)		23.0 Quarts (21.7 liters)		23.0 Quarts (21.7 liters)		24.0 Quarts (22.7 liters)		24.0 Quarts (22.7 liters)	
Weight, Dry, Approx. w/o PTO	720 lb. (327 kg)		1060 lb. (482 kg)		1130 lb. (514 kg)		1190 lb. (541 kg)		1210 lb. (550 kg)	

*Horsepower and Torque ratings corrected to 29.92 in. (760 mm) Hg. and 60° F (16° C).

Courtesy of Waukesha Engine Division

FIGURE 11-1

11-B. ENGINE TYPES AND SIZES

There is a very small number of manufacturers of natural gas engines of the sizes usually required. As a result, manufacturers' illustrations in this Chapter are limited to two firms only. Drawings and photographs of actual installations supplement the manufacturers' data.

A range of small engines of the so-called automotive type is the VR series manufactured by Waukesha Engine Division of Dresser Industries, Inc. These range from the smallest engine with a maximum rating of 32 bhp, to the largest engine of the series with a maximum rating of 88 bhp, using natural gas. The same engines running on gasoline will develop about one-third more power. Figure 11-1 is an illustration of the Waukesha VR series showing the principal engine data. Note that maximum horsepowers quoted are peak figures which must be reduced for either intermittent or continuous service. Ratings are corrected to standard barometric and temperature conditions. Torque, another important measure of output is also stated. Note that maximum torque is at much less rpm than maximum bhp.

With Waukesha engines, the model number of the engine refers to its displacement in cubic inches. Thus, the smallest engines numbered by model from 155 to 310 have displacements ranging from 155 to 310 cubic inches.

The next model illustrated and referenced is the Waukesha F1197, with 6 cylinders and 1,197 cubic inch (19.61 liters) displacement. Figure 11-2 shows performance for this engine with various fuels and compression ratios. Note maximum, intermittent and continuous bhp ratings, and corresponding torque values.

A further step larger is the Waukesha F1905 series engine, another 6-cylinder model made by this manufacturer. Catalog information included is Specifications and Optional Accessories, Figure 11-3 and Dimensions for Model F1905GU with Power Ratings, Figure 11-4. Some of optional accessories, such as the radiator fan, slightly reduce the power available from the engine. A selection of accessories is essential to the proper functioning of the engine, however. Figures 11-5 and 11-6 show two F1905 engines being installed.

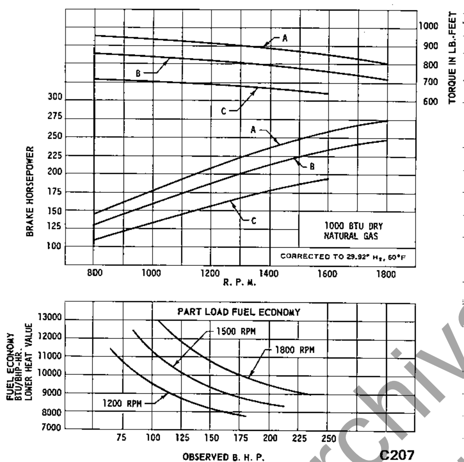
Other models increasing in size are 6-cylinder in-line or V-8 configurations, but the V-12 arrangement is used for Waukesha Model L3711 and larger engines. The L3711 is rated at a maximum brake-horsepower of 648 at 1,200 rpm. With accessories and at continuous rating the output is approximately 454 brake-horsepower. This could be considered to be largest engine likely to be used for pump station applications.

PERFORMANCE CURVES FOR WAUKESHA MODEL F1197GU

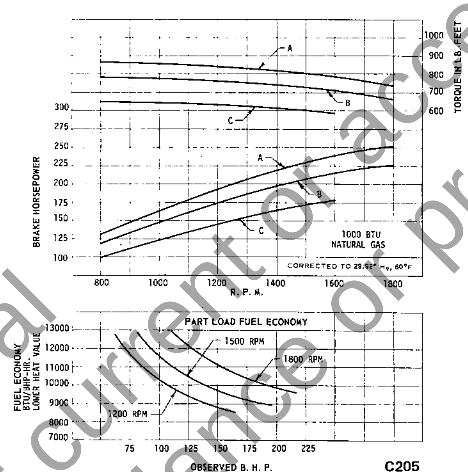
Curve A: Maximum Rating of Engine with Accessories
Curve B: Intermittent Rating of Engine with Accessories
Curve C: Continuous Rating of Engine with Accessories

All ratings corrected to 29.92 in. (760 mm) Hg. and 60° F (16° C).

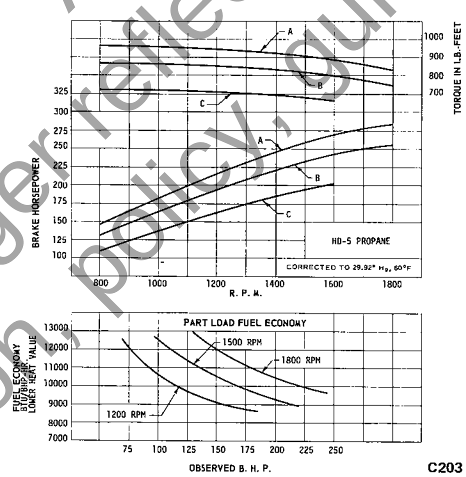
Model F1197GU Power Unit
Naturally Aspirated
9:1 Compression Ratio – 1000 BTU Dry Natural Gas



Model F1197GU Power Unit
Naturally Aspirated
7:1 Compression Ratio – 1000 BTU Natural Gas



Model F1197GU Power Unit
Naturally Aspirated
7:1 Compression Ratio – HD-5 Propane



Courtesy of Waukesha Engine Division

FIGURE 11-2

SPECIFICATIONS FOR WAUKESHA MODEL F1905GU

Engine — Inline 6, overhead valve, 4-cycle gas engine.

Air Cleaner — One dry type.

Cooling System — Gear driven water circulating pump. 170° F (77° C) thermostats, bypass type.

Connecting Rod — Steel forging, angle split for easy removal through cylinder liner. Rifle drilled for full piston pin lubrication and piston crown cooling.

Crankcase — Rigid one piece ferrous alloy casting with integral cylinder frame. Deep section main bearing caps.

Crankshaft — A multi-plane forging of high alloy steel, with precision ground and hardened main bearing and crankpin journals. Dynamically balanced. Generous overlap of main bearing and crankpin journals for increased crankshaft stiffness. Seven (7) large diameter main bearings.

Cylinder Head — High strength deep section casting. Alloy steel intake valves and valve seat inserts. Stellite faced exhaust valves and solid stellite valve seat inserts. Valve guides of alloy iron. Forged steel rocker arms.

Cylinder Liner — Removable precision honed wet cylinder liners.

Engine Rotation — Counterclockwise when facing flywheel.

Exhaust System — Water cooled exhaust manifold.

Flywheel and Ring Gear — Flywheel machined for TD 2 plate 18" (457 mm) clutch, adapter ring included.

Flywheel Housing — SAE No. 00.

Fuel System — Carburetor, natural gas, 2.5" (63.5 mm) downdraft, gas pressure test gauge.

Governor — Built-in centrifugal type.

Ignition — Low tension fixed spark magneto and cables. One coil and one spark plug per cylinder.

Instrument Panel — Engine mounted including ignition switch, water temperature, oil pressure, and vacuum gauges.

Lubrication — Full pressure system with high capacity gear type pump. Externally adjustable relief valve for accurate pressure control. Full flow oil filters.

Oil Cooler — High capacity shell and tube type.

Oil Pan — Base type with access openings to permit inspection, maintenance and removal of connecting rod bearings and main bearings.

Pistons — Heavy section contour ground aluminum alloy pistons. Floating piston pins.

Safety Controls — Low oil pressure, high water temperature. Manual reset type.

OPTIONAL ACCESSORIES

(Available as original equipment when specified)

Controls — Woodward Hydraulic Governors. Solenoid fuel shut-off. Waukesha Engomatic® Control System. Tachometer drive overspeed shut-down.

Cooling — Radiator, heat exchanger, ebullient cooling.

Electrical — 24 volt 40 or 45 amp., 32 volt 45 amp. alternator.

Elements — Lubricating oil, for high sulphur fuel applications.

Filter — Sweet or sour natural gas, sewage gas, not mounted.

Flywheel and Ring Gear — Available for other applications.

Ignition — Low tension radio shielded and/or low fire hazard magneto, coils and cables, low tension solid state, and C.S.A. approved system.

Instruments — Ammeter, tachometer, hourmeter.

Pistons — Natural gas, high ratio.

Power Take-Off — Heavy duty. Stub shaft for direct drive. Flexible coupling.

Starting — Air, 24 or 32 volt electric, hydraulic, line voltage.

Courtesy of Waukesha Engine Division

FIGURE II-3

DIMENSIONS FOR WAUKESHA MODEL F1905GU

M = MAXIMUM I = INTERMITTENT C = CONTINUOUS

MODEL	MAX. TORQUE @ RPM (LB. FT.)	BRAKE HORSEPOWER AT SPEEDS INDICATED																											CURVE NO.
		400			500			600			700			800			900			1000			1100			1200			
		M	I	C	M	I	C	M	I	C	M	I	C	M	I	C	M	I	C	M	I	C	M	I	C	M	I	C	
NATURAL GAS WITHOUT ACCESSORIES																													
F1905G†	1576-400	120	108	90	149	134	112	177	159	133	203	182	152	229	206	172	253	228	190	277	249	208	299	269	224	318	286	239	C222
F1905G	1536-400	117	105	88	146	131	109	174	157	130	199	179	149	224	202	168	248	223	186	270	243	203	291	262	218	310	279	233	C220
NATURAL GAS WITH ACCESSORIES																													
F1905GU†	1523-400	116	104	87	145	134	109	172	155	129	198	178	148	223	201	167	246	221	184	269	242	202	288	259	216	302	272	226	C223
F1905GU	1492-500	113	102	85	142	128	106	169	152	127	194	175	145	218	196	163	241	217	181	262	236	196	280	252	210	292	265	220	C221
HD-5 PROPANE WITHOUT ACCESSORIES																													
F1905G	1576-400	120	108	90	149	134	112	177	159	133	203	183	152	229	206	172	255	230	191	279	251	209	300	270	225	320	288	240	C224
HD-5 PROPANE WITH ACCESSORIES																													
F1905GU	1523-400	116	104	87	145	131	109	172	155	129	198	178	148	223	201	167	248	223	186	271	244	203	289	260	217	304	274	228	C225

Ratings are corrected to sea level barometric pressure of 29.92" (760 mm) Hg. and standard temperature of 60° F (16° C).
†High Ratio Pistons for Best Fuel Economy. 10:1 Compressio Ratio. Use Dry Gas having a High Methane Content.
Performance Curve Supplied on Request.
Ratings are based on availability of 1000 BTU LHV gas. For natural gas having less than 1000 BTU LHV, see chart S3955 for percentage loss of horsepower.
For sewage gas ratings consult Waukesha Engine Division.
Ratings available for HD-5 propane depend on operating conditions and approval by Waukesha Engine Division.

RATING STANDARDS

MAXIMUM RATING

- The maximum power capability of a naturally aspirated engine, which is inherently limited in power output by design, temperature, and barometric pressure.
- The maximum power rating of a turbocharged engine.
- This rating can be demonstrated within 5% at the factory under standard conditions of atmospheric pressure and temperature. Engine should not be applied at this rating.

INTERMITTENT RATING

- The highest load and speed which can be applied under specific conditions of varying load and/or speed.

CONTINUOUS RATING

- The load and speed which can be applied without interruption except for normal maintenance.

SPECIAL RATINGS: All published ratings of the Waukesha Engine Division are a general guide for a broad range of applications. Other ratings based on specific load applications and economic requirements are available upon receipt at the factory of detailed information.

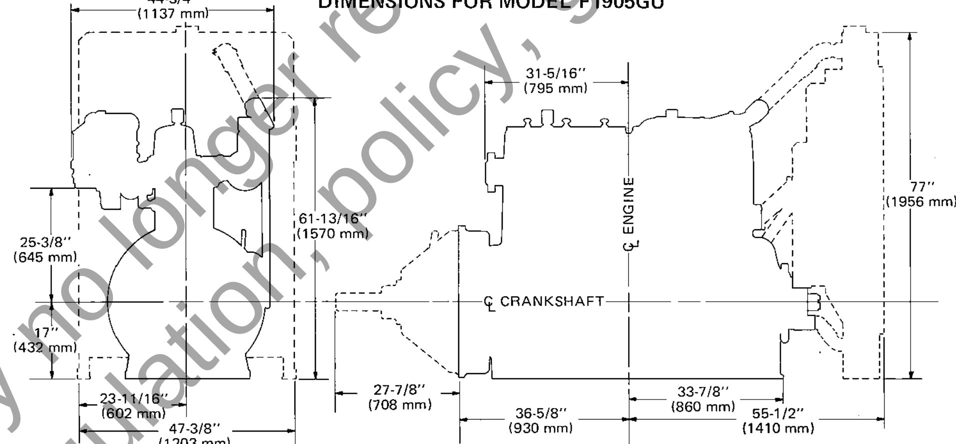
DEDUCTIONS FOR ALTITUDE AND TEMPERATURE*

Type of Engine	RATING		
	Maximum	Intermittent	Continuous
Naturally Aspirated	3% for each 1000' above sea level	3% for each 1000' above 1000' altitude	3% for each 1000' above 2000' altitude
	1% for each 10° F over 60° F	1% for each 10° F over 80° F	1% for each 10° F over 100° F

*No greater correction factor than 1.000 can be used in determining the specific rating.

The manufacturer reserves the right to change or modify without notice, the design, equipment specifications or ratings as herein set forth without incurring any obligation either with respect to engines previously sold or in the process of construction except where otherwise specifically guaranteed by the manufacturer.

DIMENSIONS FOR MODEL F1905GU



Solid line designates engine. Dashed outline indicates radiator, clutch, and Power Take Off.

Components and accessory locations and dimensions may vary with service and installation requirements. Dimensions not guaranteed. Detailed print available for layout work; C-7116 or C-7123.

Courtesy of Waukesha Engine Division

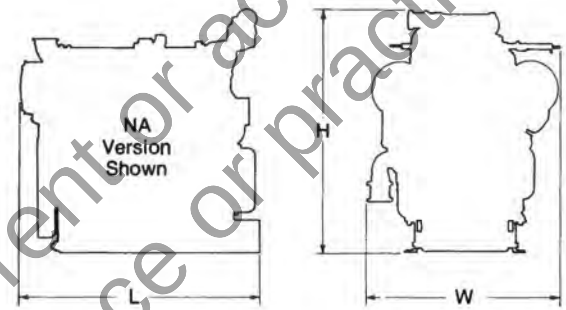
FIGURE II-4

FIGURE 11-5
Installation of F1905 GU engine at Westside Pump Station, Long Beach, CA.

FIGURE 11-6
Opposite side of engine showing provision for dual fuel supply, natural gas or LPG.

G379 NATURAL GAS ENGINE

NA VERSION SHOWN



	L		H		W	
	in	mm	in	mm	in	mm
G379 TA	83.5	(2120)	75.4	(1915)	63.5	(1612)
G379 NA	74.1	(1881)	75.1	(1909)	60.1	(1527)

V8 4-STROKE CYCLE	TURBOCHARGED-AFTERCOOLED & NATURALLY ASPIRATED
BORE — in (mm)	6.25 (159)
STROKE — in (mm)	8.00 (203)
DISPLACEMENT — cu in (liter)	1,964 (32.2)
ROTATION (from flywheel end)	Counterclockwise
COMPRESSION RATIOS	10:1 or 7:1
WEIGHT, Net Dry (approximate) — lb (kg)	
Turbocharged-Aftercooled	8,950 (4059)
Naturally Aspirated	8,350 (3787)

COURTESY OF CATERPILLAR TRACTOR CO.

FIGURE II-8

G379 NATURAL GAS ENGINE

TURBOCHARGED-AFTERCOOLED

High Compression Ratio			Fuel Consumption			
			100 percent load	75 percent load	50 percent load	25 percent load
Rated rpm	Continuous bhp w/o Fan	kW	ft^3/h (m^3/h)	ft^3/h (m^3/h)	ft^3/h (m^3/h)	ft^3/h (m^3/h)
1200	465	345	3880 (110)	3030 (85)	2250 (65)	1630 (45)
1000	400	300	3200 (90)	2570 (75)	1900 (55)	1170 (35)
900	360	270	2870 (60)	2250 (65)	1670 (45)	950 (25)

TURBOCHARGED-AFTERCOOLED

Low Compression Ratio			Fuel Consumption			
			100 percent load	75 percent load	50 percent load	25 percent load
Rated rpm	Continuous bhp w/o Fan	kW	ft^3/h (m^3/h)	ft^3/h (m^3/h)	ft^3/h (m^3/h)	ft^3/h (m^3/h)
1200	415	310	3650 (105)	2920 (85)	2080 (60)	1410 (40)
1000	365	270	3190 (90)	2510 (70)	1870 (55)	1180 (35)
900	325	240	2840 (80)	2210 (60)	1620 (45)	1040 (30)

NATURALLY ASPIRATED

High Compression Ratio			Fuel Consumption			
			100 percent load	75 percent load	50 percent load	25 percent load
Rated rpm	Continuous bhp w/o Fan	kW	ft^3/h (m^3/h)	ft^3/h (m^3/h)	ft^3/h (m^3/h)	ft^3/h (m^3/h)
1200	330	245	2810 (80)	2230 (65)	1700 (50)	1140 (30)
1000	275	205	2310 (65)	1800 (50)	1350 (40)	920 (25)
900	245	185	1980 (55)	1540 (45)	1150 (35)	780 (20)

NATURALLY ASPIRATED

Low Compression Ratio			Fuel Consumption			
			100 percent load	75 percent load	50 percent load	25 percent load
Rated rpm	Continuous bhp w/o Fan	kW	ft^3/h (m^3/h)	ft^3/h (m^3/h)	ft^3/h (m^3/h)	ft^3/h (m^3/h)
1200	300	225	2850 (80)	2260 (65)	1920 (55)	1160 (35)
1000	245	185	2300 (65)	1800 (50)	1320 (35)	810 (25)
900	215	160	1950 (55)	1530 (45)	1130 (30)	690 (20)

The International System of Units (SI) is used in this publication.

RATING DEFINITIONS

Continuous is the horsepower and speed capability of the engine which can be used without interruption or load cycling.

RATING CONDITIONS

High compression ratio turbocharged-aftercooled engines require 90°F (32°C) or lower water temperature to the aftercoolers.

Low compression ratio turbocharged-aftercooled engines require 130°F (54°C) or lower water temperature to the aftercoolers.

Fuel consumption is based on gas having an LHV of 905 Btu/cu ft (33.74 kJ/ liter).

Performance and ratings are based on SAE J816 standard conditions of 29.38 in Hg (99.2 kPa) and 85°F (30°C). Ratings also apply at DIN 6270 standard conditions of 97.8 kPa (28.97 in Hg) and 20°C (68°F) and API 7B-11C standard conditions of 60°F (16°C) at 29.92 in Hg (101.3 kPa).

Turbocharged-aftercooled engine ratings are applicable to at least 2,500 feet (760 m) elevation and 85°F (30°C) temperature without derating.

A naturally aspirated engine will derate approximately 3% per 1,000 ft (305 m) in altitudes over 500 ft (152 m).

Deration is recommended for compressors, pumps, and similar applications for variations in altitude, temperature, and gas composition.

COURTESY OF CATERPILLAR TRACTOR CO.

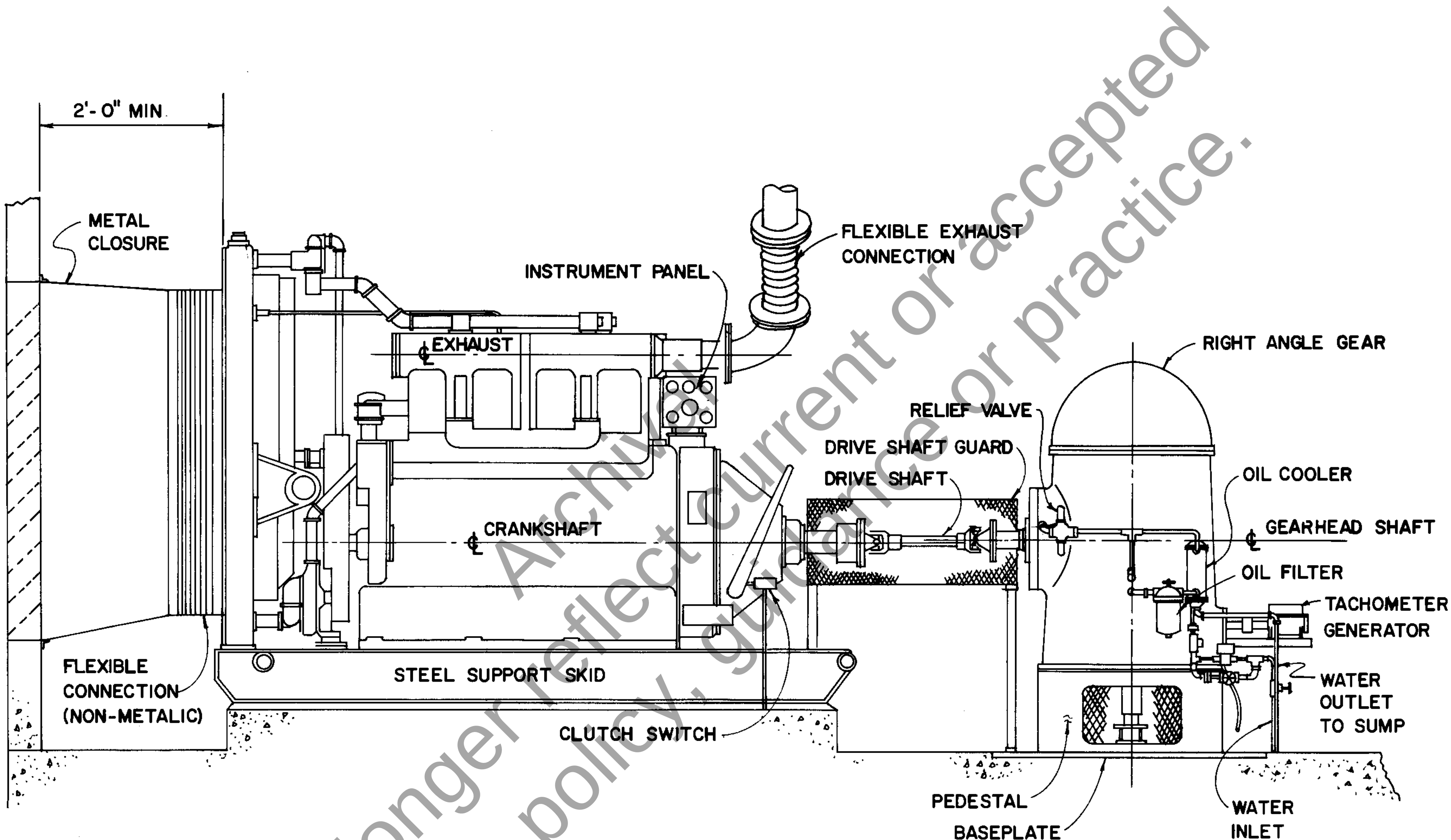


FIGURE 11-9 . TYPICAL ENGINE INSTALLATION

FIGURE 11-10

Engine installation with Combination Gear Drive.

Houston, TX

FIGURE 11-11

Combination Gear Drive with accessories at above pump station.

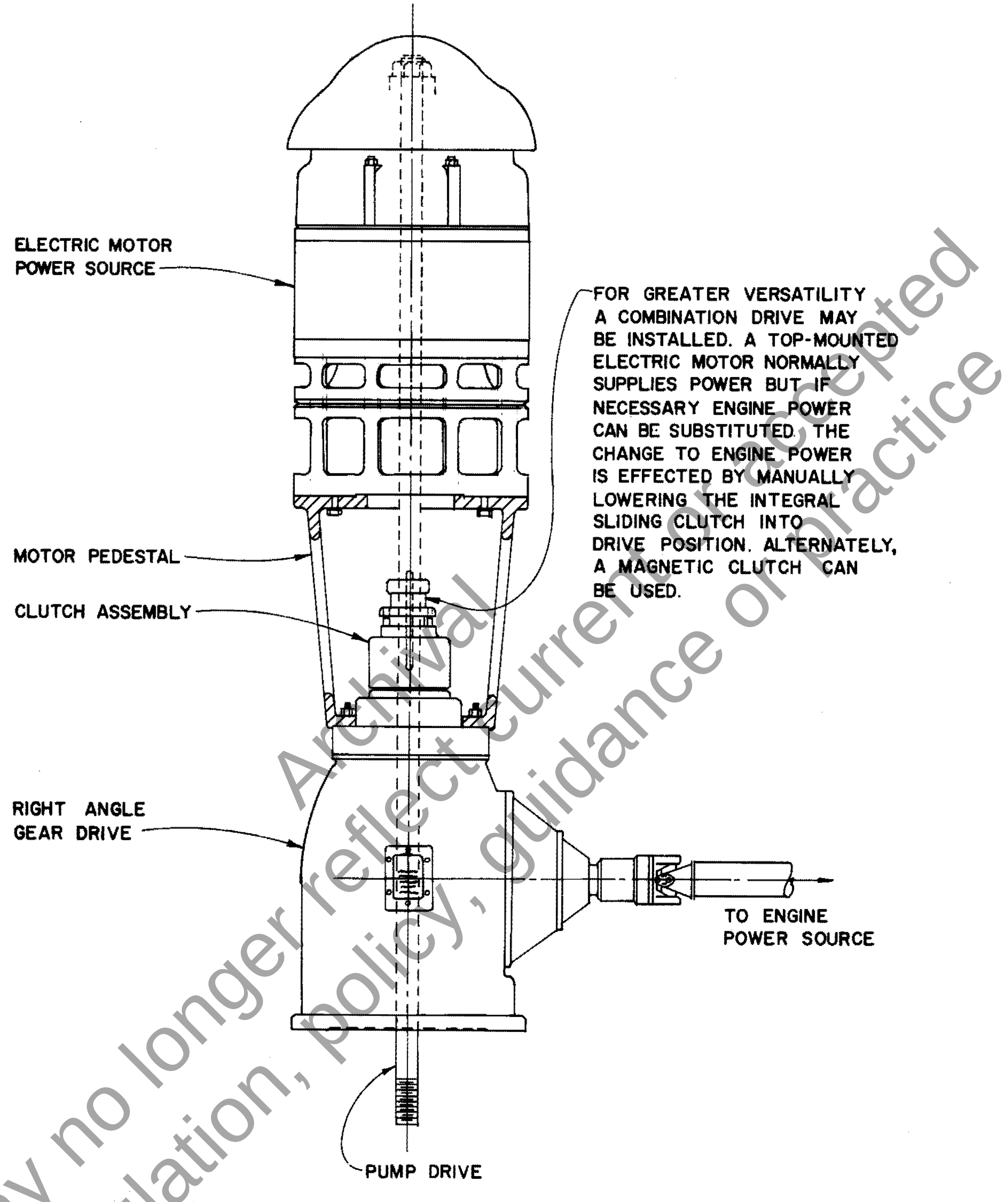


FIGURE 11-12. COMBINATION DRIVE

An extensive range of engines is also made by Caterpillar Tractor Co. Figures 11-7 and 11-8 are data sheets showing the G379 natural gas engine which is a V-8 with 1964 cubic inch displacement.

11-C. COOLING SYSTEMS

Every engine needs a cooling system, and the radiator and fan as normally used for automobiles is generally used for stationary installations. The coolant is water unless weather conditions would require anti-freeze. There is sometimes some objection to fan noise, especially in residential areas. In such a case, it is usual to employ a heat exchanger, whereby the hot jacket water enters one side of the exchanger and the cold stormwater the other. The jacket water heat is transferred to the stormwater and wasted. Sometimes a circulating pump is required with the heat exchanger, but Figure 2-20 shows how the pumped stormwater discharge is utilized, draining back into the pump pit. A piped water supply can also be used. Fans or pumps are accessories which rob the engine of a small amount of its power. In stormwater pump station design, there is rarely and economic opportunity to use the waste heat from an engine.

11-D. ACCESSORIES.

The whole array of engine and accessories, drive shaft and right-angle gear drive for the pump is illustrated in Figure 11-9. The engine assembly with combination gear drive is illustrated in Figure 11-10, while the combination gear drive is shown in Figure 11-11. The latter figure can be compared with Figure 10-9 which shows the electric motor surmounting the identical combination gear drive.

11-E. PERFORMANCE CRITERIA AND SPECIFICATIONS

Note that manufacturers may state maximum, intermittent and continuous brake-horsepower ratings for their engines. For verification, the brake-horsepower of each engine is customarily determined by a dynamometer test at the factory and is shown on test curves submitted for approval to the customer or in this case to the pump station designer. Gas engines driving stormwater pumps will have a very long life if their continuous load is held at or below the manufacturer's continuous rating. The actual brake-horsepower required for the pumping installation must be computed as the summation of the maximum horsepower input required by the pump, plus 5 per cent for right angle gear losses.

The continuous rating of the engine selected must be equal to or greater than the summation described above for a conservative selection.

Remember that the horsepower required by a pump at its design point is usually less than the maximum horsepower required when water is at low level, with the latter usually being an intermittent rather than a continuous condition. Considering the short duration of most pumping cycles, a satisfactory rule is that an engine should not be loaded at any point in its operation above 80 per cent of the maximum rated brake-horsepower of the engine with fan and radiator. Some agencies are more conservative and consider 70 per cent of the maximum rating as the permissible loading, due to their interpretations of the effects of service requirements which include a possible increase in the specific gravity of the water due to sand or debris in suspension, and a reduction in the efficiency of the driven pump due to impeller wear, improper shaft alignment, bearing wear, or the like. Wear and tear and reduction of power output of engines over the years will depend on the quality of maintenance service. Sometimes vibration peculiarities may develop requiring a speed reduction or other remedial action, but this is not usual.

In addition to limitations on the percentage of maximum rated bhp for continuous operation, it is possible to specify minimum displacement and torque, maximum rpm, BMEP and piston speed, materials of construction, but care must be taken or over-restrictive specifications will result. Various terms commonly used in the internal combustion engine industry are now explained to clarify the foregoing.

Displacement, the total number of cubic inches in all the cylinders of an engine, is one of the best descriptions of size of an engine because it refers to physical dimensions which are not subject to the many varied horsepower interpretations and speed considerations.

The torque is the "twisting effort" of the engine output shaft, expressed in pounds-feet. The final torque to the driven pump is increased or decreased by the right angle reduction gears of speed increasers, but the horsepower remains the same. Torque becomes important in engine installations when evaluating the integrity of transmission equipment such as shafts and flexible couplings. Torque in pounds-feet is given by multiplying the factor 5252 by the bhp and dividing by the rpm. In pumping applications, torque is not usually a controlling factor.

For larger engines, the manufacturers' standards limit maximum speed to 1,200 rpm since speeds in excess of this might be harmful, because in general, at higher rpm the rotating parts of the engine would be critical with respect to balance, vibrational analysis, alignment, and general maintenance.

The measure of loading of an engine is described as brake mean effective pressure, (BMEP) expressed in pounds per square inch, (psi). BMEP for an engine operating at given rpm is the product of an equation including the bhp developed, the displacement and a numerical factor. BMEP, although meaning average cylinder pressure to give resultant torque at flywheel, is a purely artificial figure and merely a means of comparison.

The equation for calculation of BMEP for a four-cycle engine is:

$$\text{BMEP} = \frac{792{,}000 \times \text{bhp}}{\text{rpm} \times \text{displacement}}$$

Applying this formula to the Model F1905GU, fueled by natural gas and with accessories, operating at 1,200 rpm (Figure 11-4) we find:

$$\frac{792{,}000 \times 220}{1{,}200 \times 1{,}905} = 76.2 \text{ BMEP at continuous rating}$$

At intermittent rating of 265 bhp, the BMEP is 91.8 and at maximum rating of 292 bhp, the BMEP is 101.2.

$$\frac{\text{Continuous bhp}}{\text{Maximum bhp}} = \frac{220}{292} = 75.3 \text{ per cent}$$

78 psi maximum BMEP is a very conservative rating which usually results in a continuous loading about 75 per cent of the maximum bhp available. Some agencies have adopted this very conservative criterion, but manufacturers usually recommend higher loadings.

If the Caterpillar G379 is considered (See Figures 11-7 and 11-8) when naturally aspirated with low compression ratio, the BMEP at 1,200 rpm is 100.8. When turbo-charged and after-cooled with high compression ratio the BMEP is 156.2. Continuous bhp ratings are 300 and 465 respectively.

Piston speed (in feet per minute) is the average velocity of a piston for a given engine at a given engine speed. It can be used to compare implied wearing tendencies of unlike engines on the basis that higher piston speed leads to higher piston and liner wear and resulting higher maintenance.

Unless the smaller automotive type suffices for the application, engines should be specified as heavy duty, industrial type with overhead valves. Other features, such as exhaust valve inserts, stellite-faced valves, renewable wet-sleeve cylinder liners, crankshaft vibration damper, full pressure lubrication and other features common to heavy-duty engine design can be specified if not exclusive to one manufacturer.

Vibration caused by unbalanced vertical forces in engines can be troublesome. It is important that the magnitude and frequency of any such forces be ascertained and accounted for in the design of the necessary support structure for engines.

11-F. ENGINE STARTING AND CONTROL SYSTEMS

Most stations are unattended and engines must start automatically in response to sensing of water level, starting at a predetermined low rpm or load. After a suitable time delay the throttle is opened to its operating speed. The control panel should have a selector switch with Manual, Off, Automatic and Test positions. Operation of the entire system is described in Section 18 of Appendix D. - Specifications. Unlike most specifications, these engine specifications are quite explicit as to the reason for the requirements.

11-G. ENGINE EQUIPMENT AND AUXILIARIES

When radiator and fan are used for cooling the engine equipment usually includes thermostatically-controlled automatic louvers on the radiator. There will also be a jacket water preheater and jacket water filter-conditioner, an exhaust system and muffler, and a 24 volt starting system and control panel. Refer to Specifications for a comprehensive listing and definition of equipment and accessories. The engine itself is equipped with an instrument panel at the front of the engine, close to the fan and radiator. (See Figure 11-6.)

Adjacent to the engine but separate from it is the wall-mounted control panel with functions described in the Specifications. The control panel water level lights may also be displayed below a recording tachometer for each engine, located as convenient in the pump station. This item is specified in Section 23 of Appendix D - Specifications.

The provisions necessary for telemetering the operational status of the station to a control center are given in Section 24 of Appendix D - Specifications.

The clutch mechanism is integral with the engine and is visible in Figures 11-5 and 11-6, at the rear of the engine. A cut-away detail is shown in Figure 11-13. As in an automobile, the clutch separates the rotating engine from the driven components when the driven components are required to be at rest.

The clutch mechanism is manually engaged or disengaged. Where automatic cranking cycles are required the clutch mechanism will be set in the engaged position. After starting automatically, the engine will idle before coming up to speed to provide the necessary power for pump operation. The engine is usually selected for stormwater pumping only and is not intended to provide for any auxiliary loads. Therefore no take-offs should be permitted from the output shaft unless this has been specially provided for.

11-H. DRIVE SHAFTS

The clutch output shaft of the natural gas engine must be connected to the right angle gear input shaft with a connecting drive shaft. (See Figure 11-14.) The connecting drive shaft consists of two flexible joints and a center section which includes a shaft length adjustment feature. There are two special flanges, one for the clutch power take-off shaft at the engine, and one for the right angle gear drive input shaft.

Drive shafts for pump station service are required to have maximum reliability at all times, thus the selection standards are necessarily conservative. The major consideration in selecting a drive shaft is the transmitted torque. The manufacturer's published rating for continous duty at the maximum engine speed should be at least one and one-half times the maximum torque of the driven pump under field conditions. Transient conditions, such as the development of shutoff head at the pump must be considered in determining the maximum torque. The required bearing life is normally a minimum B-10 life of 16,000 hours. The torque ratings, joint angles, bearing life and selection data are clearly set forth in the manufacturers' catalogs.

Overall flange-to-flange length of drive shafts is not readily determined by application of simple rules related to engine speed, torque or horsepower. However, a thirty-six inch minimum length is desirable to allow for accidental or intentional misalignments and still stay within acceptable angular limits. A moderate length of shaft is recommended because a long shaft is subject to whirling and vibration. A vertical difference of about one-and-a-half inches between the centerline of the engine output shaft and the centerline of the gear input shaft would be usual for a thirty-six inch drive shaft. A necessity for the universal joints to be continuously exercised when the drive is in motion is preferred.

A suitable drive shaft guard must be provided, anchored to the floor. The upper portion of the guard should be hinged on one side and provided on the other side with a padlock hasp. The grease fittings should be accessible for lubrication service through the hinged guard. Guards must, of course, comply with OSHA (Occupational Safety and Health Act) standards.

The actual shaft selection is very simply made by consulting manufacturer's graphs and charts, a simplified reproduction of one of those of the H.S. Watson Co. is shown in Figure 11-15.

11-I. RIGHT ANGLE GEAR DRIVES

The basic requirements for a right-angled gear drive are set forth in Appendix D - Specifications, Section 17. The main features of a gear drive are shown in Figure 11-16.

A typical speed reduction would be for the engine to run at 1,200 rpm and the pump at 580 rpm. This approximates a 1:2 ratio which is the nearest available selection. Exact conformity to nominal or specified speeds of pumps and engines is seldom capable of being achieved.

The transmission of power through the gear produces a significant heating effect of the lubricating oil, and this heat is often dissipated by circulating water through cooling coils, Domestic potable water is preferred for this service, the supply being controlled by a solenoid-operated valve. See Chapter 12 - Electrical Systems and Controls. Another electro-mechanical accessory is a tachometer driven by the gear drive which enables the actual engine or pump speed to be indicated and recorded.

11-J. COMBINATION GEAR DRIVES

Sometimes it may be necessary to provide the ability to drive a vertical pump by either an engine or by an electric motor. Combination gear drives are available for this purpose, the motor being mounted axially above the pump, with the gearhead in between. The engine is mounted horizontally alongside the pump and drives the vertical pump shaft through bevel gears. A manually-controlled dog-clutch can be set to couple either the motor or the engine to the pump shaft and only the engine or the motor is operable at any time, according to the setting of the clutch. The general arrangement of a combination gear drive is shown in Figure 11-12. Also see Figures 11-11 and 10-9. It should be emphasized that the change of mode from motor to engine drive is usually effected manually. Therefore, there is no increase in dependability unless an operator is in attendance at all times while the station is operating, not usually the case with highway pump stations.

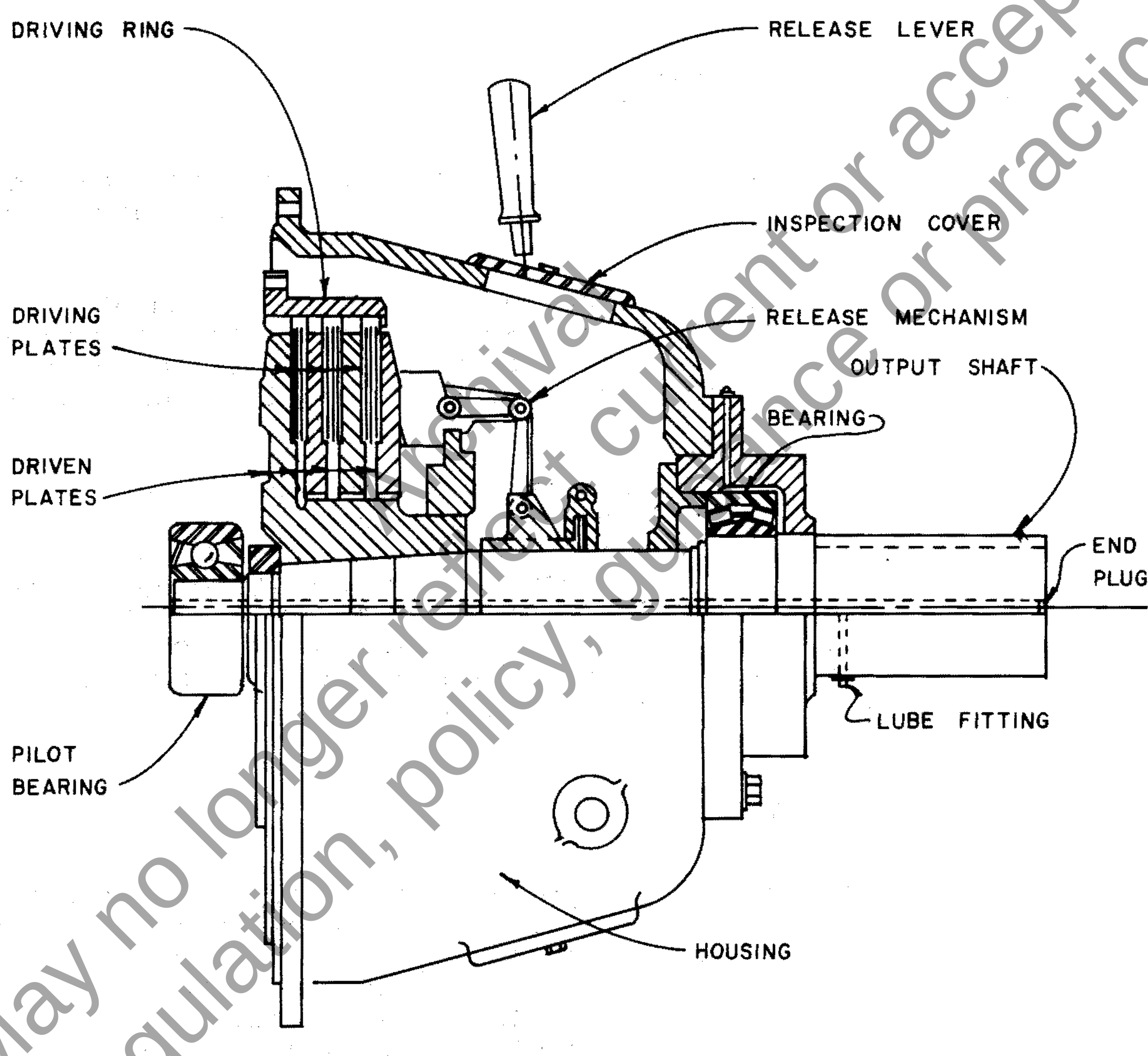


FIGURE 11-13. CLUTCH POWER TAKE-OFF

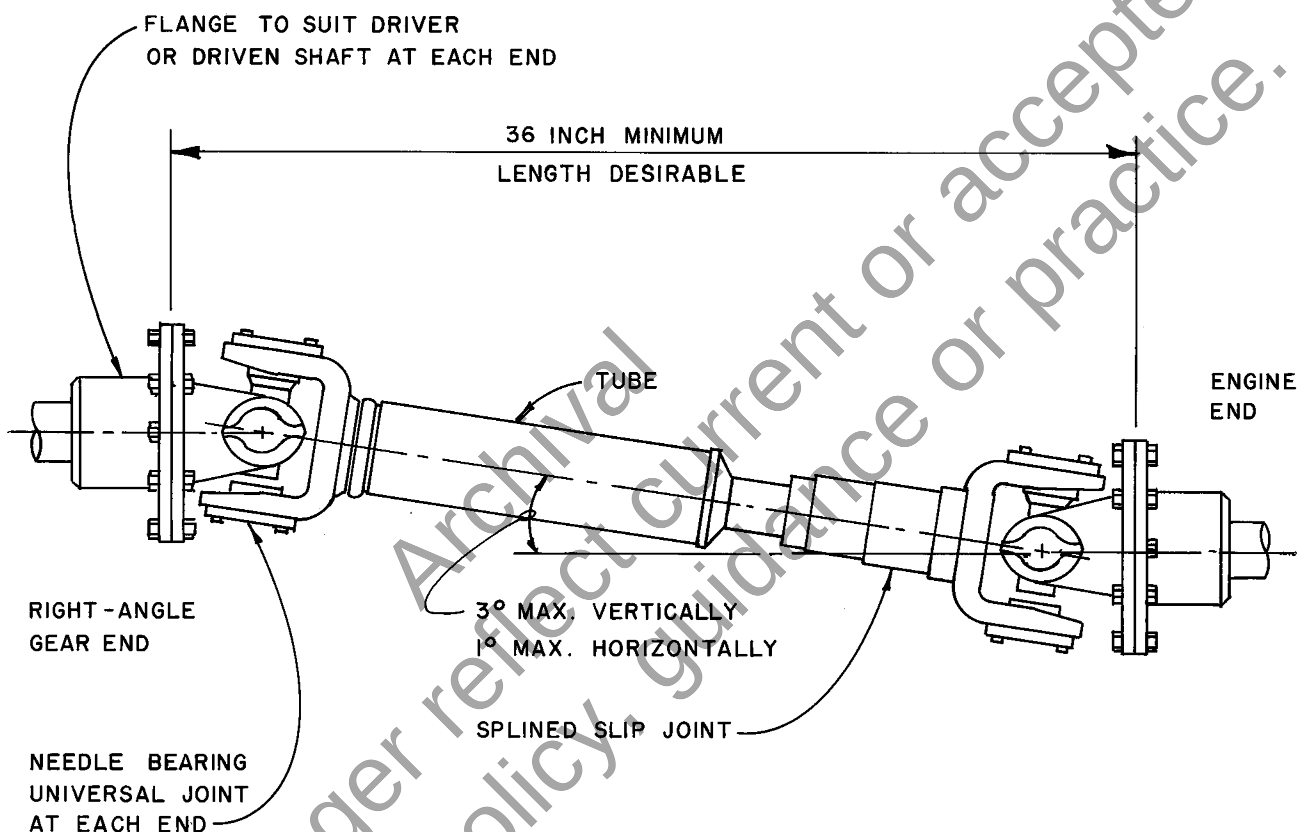


FIGURE 11-14. TYPICAL DRIVE SHAFT

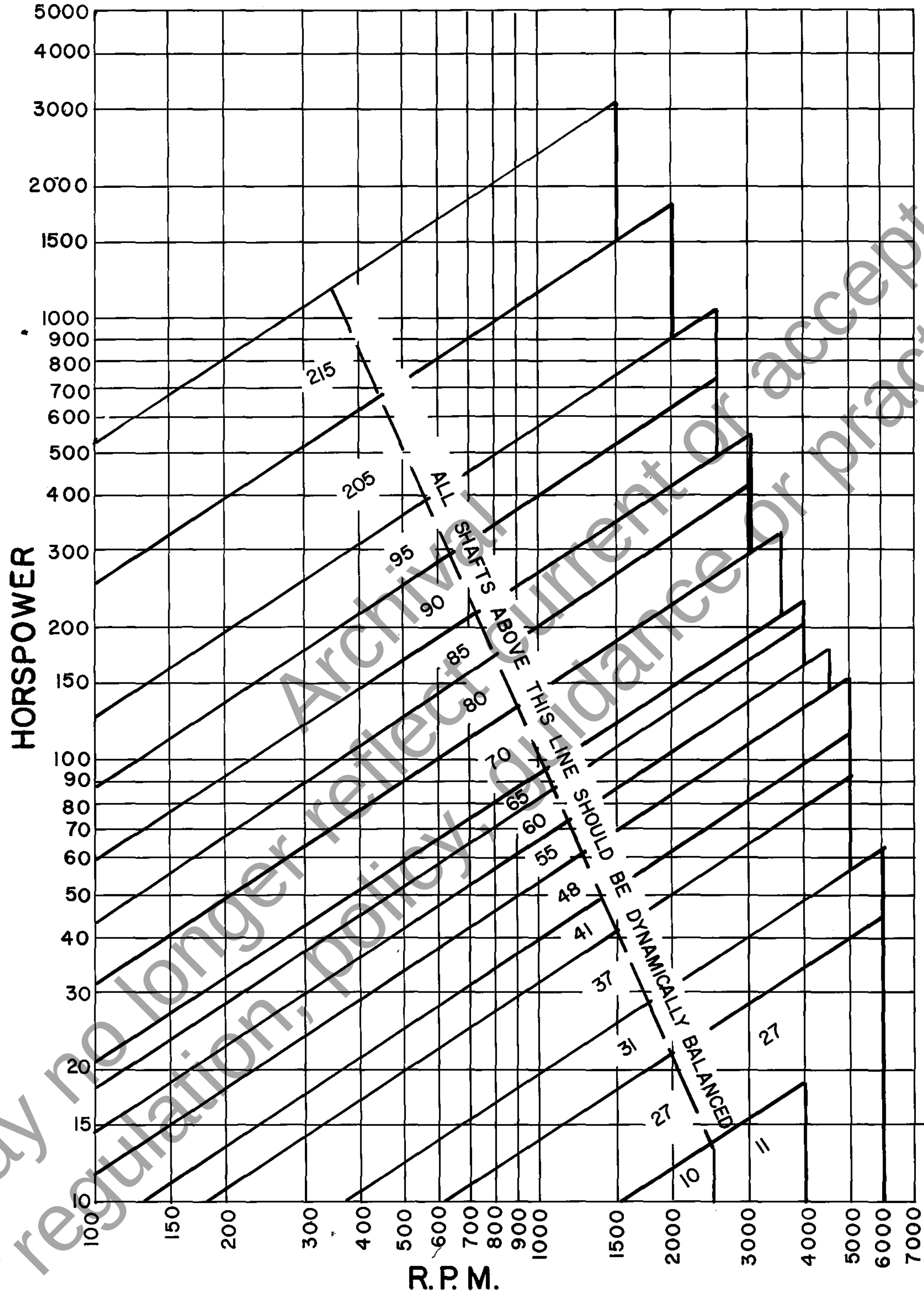


FIGURE 11-15. DRIVE-SHAFT SELECTION

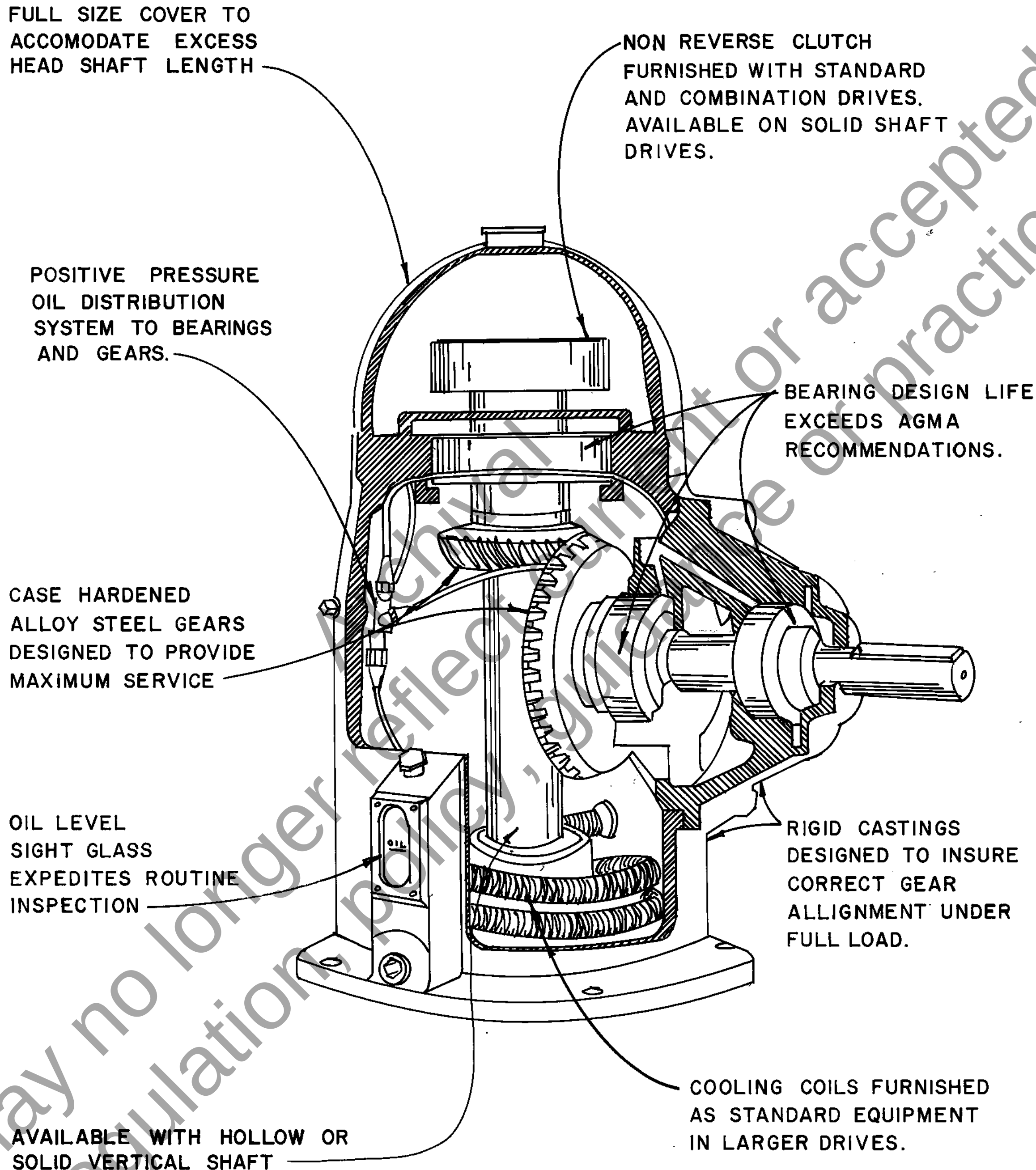


FIGURE 11-16. TYPICAL RIGHT-ANGLED GEAR DRIVE

Assuming that the equipment is set for electric motor drive, this will function normally, responding to water-level, unless there is a power outage which could cause local flooding. If the station siting is above a depressed area there would be no station damage. During a prolonged outage, if personnel could reach the station the engine or engines could be started, the clutch or clutches could be re-set and flood water could be pumped out, re-opening the highway.

If the equipment is normally set for engine drive the electric motor is redundant, except that the motor is available for use if the engine is under repair. This probably is the chief justification for the use of the combination drive. Another justification is the avoidance of stand-by charges if the engine is consistently used and no power demand is imposed by running the motor. This may be valid in existing stations where past capital costs may be ignored and only current operating costs are a consideration. However, in new stations the combination drive is difficult to justify on an economic basis.

11-K. TORSIONAL ANALYSIS

To avoid critical torsional vibrations at engine operating speed range, complete torsional analysis calculations should be performed by the engine manufacturer on each engine-driven pumping unit, before the equipment is approved for installation at the pump station. Each unit includes engine, right angle gear drive, connecting drive shaft and pump.

All components must be evaluated as a complete unit, and for this purpose the necessary mass elastic data such as moments of inertia and stiffness factors on all rotative parts of the gears and pumps must be furnished to the engine manufacturer.

11-L. RELIABILITY AND ECONOMICS

The natural gas engine is regarded as the most reliable means of driving stormwater pumps. It is not affected by electrical storms and with normal maintenance will always start automatically by sensing of water level. Dual fuel supply can be provided in the form of both piped-in natural gas and on-site storage of LPG. However, on-site storage alone is very stisfactory.

With on-site storage and battery starting, the natural gas engine assumes the reliability of the automobile or truck, in starting immediately as needed and performing with complete satfisfaction.

Some agencies have found that elaborate facilities for maintenance are not cost effective, and they avoid disassembly of engines at the stations. They rely on local dealers or service representatives to remove or replace an engine in the unlikely event that this becomes necessary.

The principal drawback to the use of engines is the high initial cost compared to electric-motor drives. Versatility of the engine to be run at different speeds, and to consequently pump greater or less quantities of water, can offset this, however. This is done at the expense of operating engines less conservatively, but perfectly safely, in the intermittent duty range for limited periods of time. Appendix E. - Energy Economics gives examples of the relative costs.

Automatic speed controls which increase engine speed as the water level rises are available. They are more suitable to smaller engines because these have a wider range of speeds.

An example using the Waukesha 1197 engine shows the various values of Q, TDH, HP, and BMEP when operating the engine at 1,000, 1,200 or 1,400 rpm. These are compared with continuous (C) and intermittent (I) ratings.

RPM	Q	TDH	BMEP	HP	C	I
1,000	24.0	18.2	52	80	133	-
1,200	50.0	14.0	66	118	157	-
1,400	62.7	16.0	81	188	178	196

The example is taken from an actual station design. The variations in the total dynamic head are in part due to the water level in the sump, but mainly due to friction in the discharge line as quantities and velocities become higher. System-head curves are needed to illustrate the matter fully. As an exercise, the reader may select hypothetical conditions and work out for himself examples of varying discharges due to change in engine speeds.

Many cost-effective pumping stations have been built utilizing the flexibility of speed modulation of gas engines. With the reliable control systems which are available and by reasonably minimizing maintenance expenses, the gas engine has an important place in stormwater pumping.

* * * * * * * * * * *

CHAPTER 12. ELECTRICAL SYSTEMS AND CONTROLS

12-A. GENERAL

This chapter provides basic information for electrical power and lighting systems for pump stations, including essential features for pump controls and engine starting. Because electrical terminology, symbols and drawings may not be readily understood, some specialized assistance may be needed. Numerous illustrations are included which the designer and the electrical specialist can adapt to their circumstances. Refer also to Appendix D - Specifications.

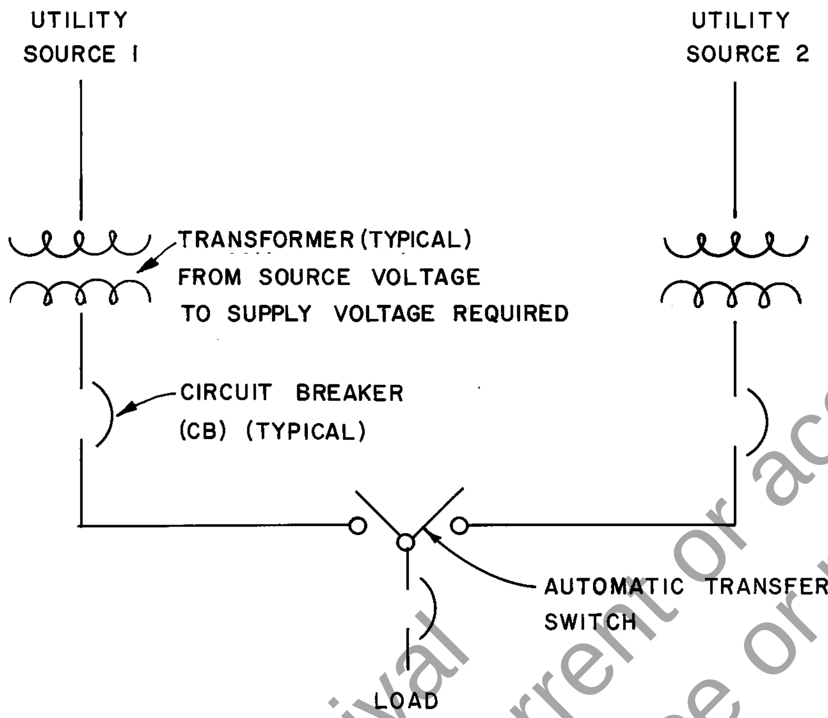
12-B. UTILITY SERVICE

Most pump stations will receive electrical service from a public utility company. The quality of service depends on how well the utility system holds a constant predetermined voltage and how free it is from interruptions. It is not reasonable to assume that perfect service can be provided by a utility company from one source. Therefore an alternate source of power is desirable. Figure 12-1 shows ways to provide pump stations with two separate services.

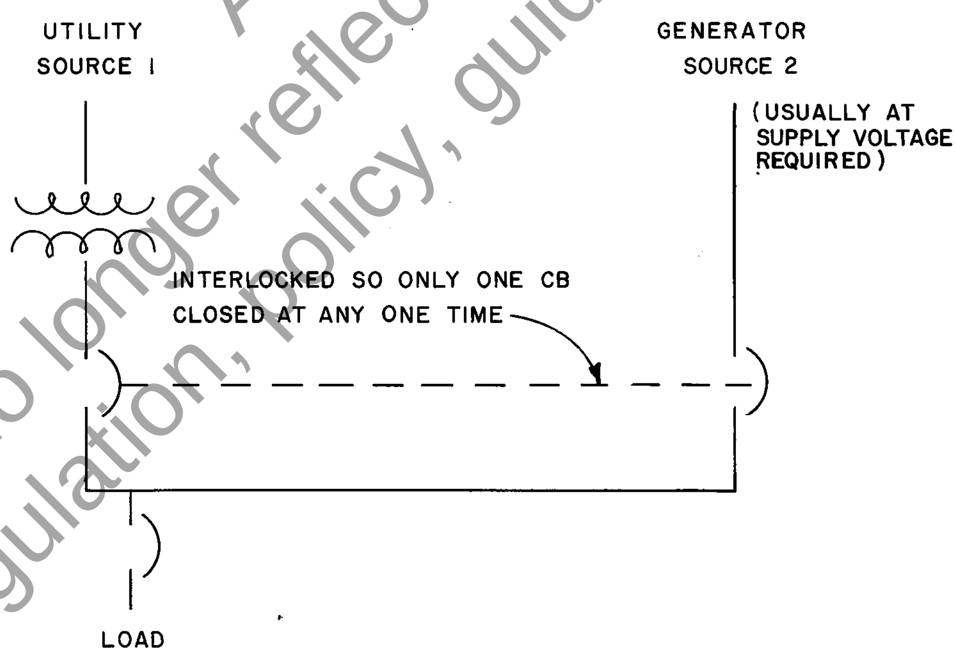
The serving utility company must always be contacted when a new service is required or a change in existing loads is contemplated. The utility company will specify their space and equipment requirements, motor starting limitations, voltage regulation, short-circuit current available, and their installation and service charges. Load data for initial and future requirements should be estimated as accurately as possible, considering demand and connected load, average usage and seasonal variation.

Utility companies have different rate schedules for different conditions. To arrive at the most economical condition, a comparison of these rates should be made. Among the factors used to establish rates are load demand, energy consumption, power factor, voltages available, primary service cost, transformer or substation ownership, fuel cost, demand interval, special demand provisions, fluctuating loads, minimum-bill stipulations, unbalanced phase charge, multiple-metering provisions and stand-by service charge. See Appendix E - Energy Economics.

Demand charges cover all generally predictable costs such as depreciation, interest and insurance. They reflect the investment required by the utility company to serve the customer's



DUAL POWER SUPPLY WITH AUTOMATIC TRANSFER



DUAL POWER SUPPLY WITH INTERLOCKING CIRCUIT BREAKERS

FIGURE 12-1

maximum power usage. The demand is usually determined by an integrating demand meter set for either 15 or 30 minute demand intervals. Energy charges include such items as cost of fuel, operating labor, and maintenance. Fuel cost affects rates more than anything else.

12-C. SUPPLY VOLTAGES AND TRANSFORMERS

The utility company will normally provide service from its nearest or most conveniently located overhead power line. Possibly some additional poles leading to the pump station will be needed, in which case the utility company will install them, at the user's expense. For a small pump station, the last pole will usually carry the transformers necessary to reduce the voltage from the level of the power line to the maximum voltage to be provided for the pump station. See Figure 12-3. The voltage of the transmission or power line may be 4,160 volts, 13,800 volts or even 15,000 volts or more (high voltage). The transformers will usually reduce these line voltages to 480 v., three phase, which is the low voltage service appropriate for the usual size of pump motors. Where larger motors of 500 hp or more are needed, the supply voltage may be higher. Refer to Chapter 10 - Electric Motors for Stormwater Pumps.

Nominal system voltages for the low voltage class are 208Y/120, 240, 480 and 480Y/277. The first and last mentioned systems are wye-connected with a fourth or neutral wire. The second and third are delta connected with three wires. See Figure 12-2 for illustration and an explanation of the advantage of the 4-wire system. From an economic standpoint there is seldom sufficient reason for selecting 208Y/120 or 240 volts instead of 480 volts. Usually the lower voltage systems would cost more because there would be more current per kilovoltampere to be carried, thus the circuit breakers, motor starters and conductor sizes would have to be increased. For the usual conditions 480Y/277, three phase, 4-wire, service is preferred. 480 v., three phase, 3-wire, is often provided. In addition to the 480Y/277 v. (or 480 v.) three-phase service for the pumps, 120-volt single-phase power will also be required for lighting and may possibly be used for very small motors where these are required to drive accessory equipment. This lower voltage is usually obtained by installing a smaller transformer in the pump station switchgear. This will step down from the 277 v. between phases of 480Y/277 three-phase, four-wire, service or from the 480 v. between phases of three-wire service. Most pumping stations will have 480 volt three-phase service only, but sometimes there is justification for providing 120 volt single-phase service also.

Instead of the transformers being pole-mounted overhead as in Figure 12-3, it may be necessary that they be pad-mounted at grade. This applies to large transformers for large loads and motors of higher (medium) voltage. Service should go underground from the pad to the station. Dual overhead service with pad-mounted transformers is illustrated in Figure 12-4.

From the transformer pole the service may go overhead directly to the pump station, but underground service is preferred both for safety and aesthetics. Underground service to a caisson-type wet-pit station is shown in Figure 12-5. The utility will generally have rules applicable to provision of conduit and cable underground from the service pole.

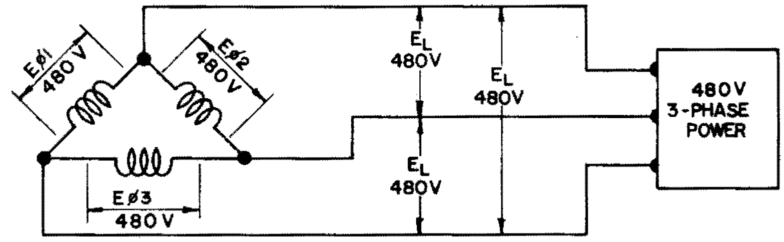
There may be cases, especially in urban areas, where the utility company will be providing service from high-voltage underground cables. In such cases, the transformers would probably be underground also, in a vault ventilated so as to dissipate heat. Transformers are almost always owned and maintained by the utility company, this cost being included in their rates. Transformer ownership by the customer would qualify for a discount when power is purchased at the line voltage available, such as 4,160 or 13,800 volts, but this is not usually a practical consideration.

12-D. STAND-BY POWER

Stand-by power should be provided for stormwater pumping stations. If the utility cannot provide two separate sources, the choice is to use engine-driven pumps or a stand-by generator. See Figure 12-1. Two utility services, when available, generally cost less than an engine-driven generator of equivalent capacity.

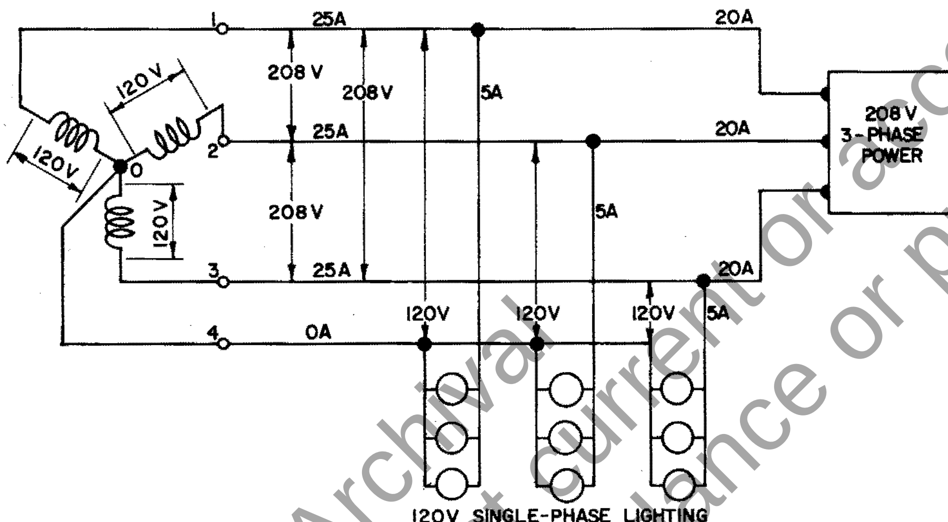
Sensing an outage and transferring the load from one utility source to another can be accomplished automatically in less than a second. Transferring to an engine-driven generator takes longer, because of the time to start and bring the engine up to operating speed. If a portable engine-driven generator is used, then considerable time may be required to transport or haul the generator to the pump station and manually transfer the incoming power switching to the generator supply. A male receptacle is generally used to make connection to the generator portable cable and female connector. A receptacle and manual transfer switch is shown in Figure 12-6.

The use of two utility services is only feasible when the local utility company can provide separate service connections over



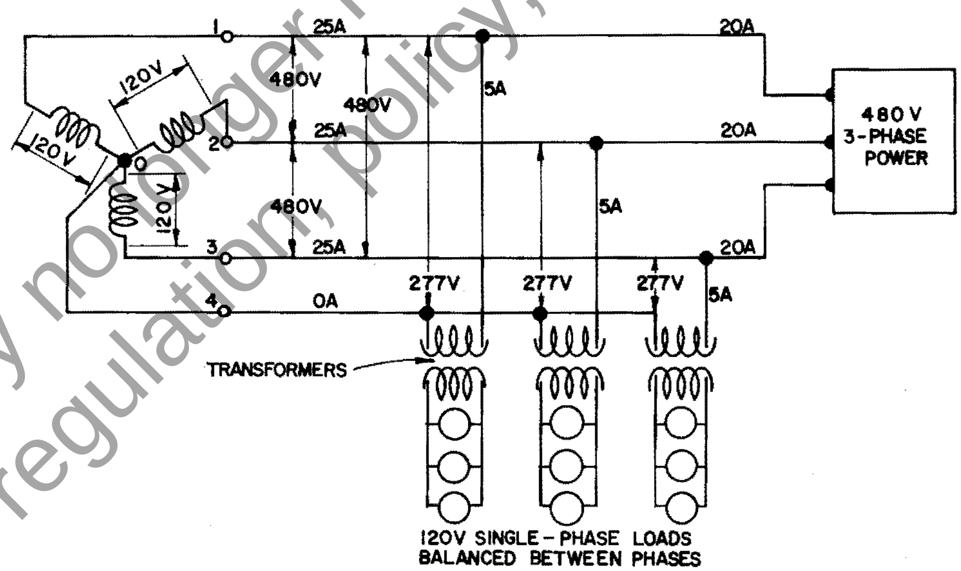
SINGLE PHASE LIGHTING NOT SHOWN

480V THREE-PHASE THREE-WIRE DELTA-CONNECTED SYSTEM



208Y/120V THREE-PHASE FOUR-WIRE WYE-CONNECTED SYSTEM

THE NEUTRAL WIRE IS USED IN ORDER TO KEEP VOLTAGE DISTRIBUTION OF THE THREE SINGLE-PHASE LOADS BALANCED WHEN THE CURRENTS IN THESE LOADS ARE UNBALANCED.



480Y/277 V THREE-PHASE FOUR-WIRE WYE-CONNECTED SYSTEM

THREE-PHASE THREE- AND FOUR-WIRE SYSTEMS

FIGURE 12-2

Single overhead service
with pole-mounted
transformers providing
480 v. three-phase four-
wire supply

FIGURE 12-3

Dual overhead service
with pad-mounted transformers

FIGURE 12-4

Underground service to externally-mounted meter with shunt-trip to main circuit breaker

FIGURE 12-5

Panel board with gutter, circuit breakers and motor starters, and with receptacle and manual transfer switch for stand-by generator

FIGURE 12-6

separate lines and from separate supply points that are not apt to have joint outages from system disturbances, storms or other hazards. Additional reliability may be obtained where the incoming services are available from different utility companies. When two sources are connected, an automatic transfer switch is usually located in the main distribution equipment. Special consideration should be given to the ability of the switch to close against high inrush currents, carry full rated current continuously from normal and secondary source, withstand fault currents without contact separation and have adequate interrupting capacity.

To avoid transferring large motors during the energized condition, the transfer switch should be provided with an accessory control that disconnects motors prior to transfer and reconnects them after transfer when the residual voltage has been substantially reduced. A time delay of 2 to 10 minutes should be provided to prevent transfer back to normal source when normal service is recovered after an outage.

12-E. SYSTEM PROTECTION

Electrical energy will normally be delivered to the station equipment safely and reliably by the utility company, but protection of the station system must provide for service irregularities or failures. This protection will minimize damage and limit the extent and duration of interruptions. The protection must isolate any affected portion of station system while maintaining normal service for the rest of the system. It must minimize the danger of short-circuit currents and may provide alternate circuits to minimize the duration and extent of outages.

System protection is the most important feature of the electrical distribution system. It must be kept simple and compatible with safety, reliability and economic considerations. Protection for the electrical system must prevent injury to personnel, prevent or minimize damage to equipment, and minimize interruption of power and the effect of the disturbance on the uninterrupted portion of the system, both in extent and duration. Important elements of system protection requiring consideration are the type of system grounding, short-circuit fault capacity, and exposure to lightning and switching surges.

The isolation of short circuits requires the application of protective equipment which will sense an abnormal current flow and remove the affected portion from the system.

The fuse is the simplest of all protective devices, performing both sensing and interrupting functions. Fuses are installed in series with the circuit and operate by the melting of a fusible link in response to the current flow through them on an inverse time-current basis. Each fuse can perform once only, since its fusible elements are destroyed in the process of interrupting the current flow. Fuses may have only the ability to interrupt short-circuit current up to their maximum rating or may also have the ability to limit the magnitude of short-circuit current by interrupting the current flow before it reaches its maximum value.

Circuit breakers are interrupting devices and must be used in conjunction with sensing devices to fulfill the detection function. Most low-voltage applications use either molded-case circuit breakers or other low-voltage circuit breakers having series sensing devices built into the equipment. After tripping, circuit breakers can be re-set.

The term "air circuit breaker" is often used in speaking of low-voltage power circuit breakers. Since the arc interruption takes place in air in both molded-case circuit breakers and low-voltage power circuit breakers, this term really applies to both types.

The ratings which apply to circuit breakers and the actual assigned numerical values reflect the mechanical, electrical, and thermal capabilities of their major components. Basic ratings are voltage, frequency, continuous current, interrupting current and short-time current (low-voltage power circuit breakers only).

When protection is being considered, the performance of a circuit breaker with respect to the connected conductors and load is of primary concern. The objective in coordinating protective devices is to make them selective in their operating with respect to each other. Normally coordination is demonstrated by plotting the time-current curves of the protective devices and making sure that no overlapping occurs between the curves of adjacent circuit breakers.

Motor protection involves consideration of motor characteristics, starting conditions, ambient conditions and driven equipment. Protection should be chosen to meet the requirements of each specific motor and its use. The following items should be considered:

(a) Motor Characteristics. These include type, speed, voltage, horsepower rating, service factor, power factor rating, type of motor enclosure, lubrication arrangement, arrangement of windings and their temperature limits, thermal capabilities of rotor and stator during starting, running and locked rotor conditions.

(b) Motor Starting Conditions. Included are full voltage or reduced voltage, voltage drop and degree of inrush during starting, repetitive starts, frequency and total number of starts.

(c) Ambient conditions. Temperature maximums and minimums, elevation above sea level, adjacent heat sources, ventilation arrangement, exposure to water and chemicals, exposure to rodent and various weather and flood conditions.

(d) Driven Equipment. Characteristics will influence chances of locked rotor, failure to reach normal speed, excessive heating during acceleration, overloading and stalling.

Motors must be protected against undervoltage, phase unbalance and overcurrent and automatic switch reclosing. Requirements include:

(e) Undervoltage. The usual reason for using undervoltage protection is to avoid excessive inrush to the total motor load on the power system following a voltage dip or when voltage returns after an interruption. Undervoltage protection will be either instantaneous or time delay type. Time delay undervoltage protection should be provided where continuity of service is important and to avoid unnecessary tripping on voltage dips. One problem with time delay undervoltage protection when used with magnetic held motor starters is that on fault currents of low magnitude, the starter contacts will open on the voltage dip and reclose into the fault current. To resolve this problem, it is best to have undervoltage protection that reinitiates the start circuit after a voltage dip condition. Another solution is to use capacitor-held main contractos to prevent instantaneous dropout.

(f) Phase Unbalance. The purpose is to prevent motor overheating damage. Motor overheating occurs when the phase voltages are unbalanced. To prevent single phasing, overcurrent protection should be provided in all three phase conductors to the motor. Phase unbalance protection should be provided in all applications where single phasing is a strong possibility due to the presence of fuses and overhead distribution lines subject to conductor breakage.

(g) Instantaneous Phase Overcurrent. The purpose is to detect phase-short circuit conditions with no intentional delay. Fast clearing of these faults limits damage at the fault, the duration of the voltage dip accompanying the fault, and the possibility of the fault spreading to fire or explosion damage.

For small squirrel cage induction motors, it is common to set the instantaneous pickup at 10 to 11 times the full load current. For large squirrel cage motors above 200 horsepower, it is recommended that the maximum symmetrical starting inrush be determined by the motor manufacturer and the instananeous pickup be set at 75 percent above this value.

(h) Time-Delay Phase Overcurrent. The purpose is to detect failure to accelerate to rated speed in normal starting interval, motor stalled condition, or low-magnitude phase fault condition.

For small motors, this overload protection scheme is relied upon to provide protection for all three of the above conditions.

(i) Automatic Reclosing or Automatic Transfer. When the supply voltage is switched off, motors initially continue to rotate and retain an internal voltage. This voltage decays with motor speed and internal flux. If system voltage is restored out of phase with a significant motor internal voltage, high inrush current can occur and damage the motor winding or produce torques damaging to the shaft, or drive coupling.

Protection is also required for conductors and switchboards and against voltage surges due to lightning.

(j) Conductor Protection. Conductor protection is based on cable ratings matched to the environment and operating conditions. Cable manufacturers specify the normal loading temperature for their products which results in 20 to 30 years normal life. High temperature is probably the most frequent cause of decreased cable life and failure, due to insulation breakdown. Protection is also required against unexpected overload and short-circuit current to safeguard personnel and equipment and to insure continuous service. Protection against overcurrent is generally achieved by means of a device sensitive to current and the length of time during which it flows. Short-circuit protective devices are sensitive to much greater currents and shorter times.

(k) Switchboard Protection. Switchboards vary in configuration from a simple gutter arrangement with circuit breakers and motor starters attached, to a more complex modular arrangement. See Figures 12-6, 12-8 and 12-22, and 12-25 to 12-27. Switchboard protection isolates faults in the power circuits. Circuit breakers and fuses are employed to disconnect the affected parts of the power system. The introduction of solid-state circuitry to perform the sensing and timing functions has provided significant improvements in the quality for low-voltage circuits and apparatus.

Overcurrent relays and trip devices must have time-delay and high-current settings to prevent opening the source circuit breakers upon the occurrence of a feeder fault.

(l) Voltage Surge Protection. A circuit or system is considered exposed to voltage surges due to lightning, if it is connected to any kind of open-line or overhead lines. Voltage surge protection is then required to protect the main switchboard and motors.

The protection is provided by lightning arresters connected, without fuses or disconnecting devices, at the incoming terminals.

As an external safety feature a shunt trip on the main circuit breaker will permit tripping the breaker from an emergency pushbutton outside the pump station in case of a fire in the station or other conditions when it is unsafe to enter. A vandal-proof lock box for the trip button is desirable. See Figure 12-5.

12-F. METERING

Metering primarily provides readouts to determine power usages. Meters are also used for testing and to indicate conditions which have occurred at the station.

(m) Kilowatt-hour meters are furnished by the utility company and their location should be exterior, accessible to the utility personnel. See Figure 12-5. Sometimes KWH meters are installed in the switchboard as shown in Figure 12-22. Demand meters are usually installed on systems.

(n) Ammeters with maximum demand needle located on the main switchboard will give a quick indication of any prolonged overload condition. The thermal type with slow response on the maximum needle will not be affected by the high in-rush motor starting currents. Individual ammeters for large motors are useful in monitoring overload conditions due to mechanical problems or phase unbalance due to motor insulation or motor branch circuit problems. See Figure 12-23.

(o) Voltmeters with minimum and maximum needle indication located on the main switchboard will give a quick indication of any voltage fluctuations since the last time the meters were reset. The low needle indicator should be the type that holds at the last voltage value before a power outage.

(p) Elapsed time meters applied to motors that are automatically controlled will totalize the total running time for that motor to permit proper division of wear where motors operate in a lead-lag sequence and the sequence is manually selected.

(q) Printers that monitor the alarm conditions and print out the time of day, sequence of alarm and nature of the alarm are valuable at remote unattended facilities.

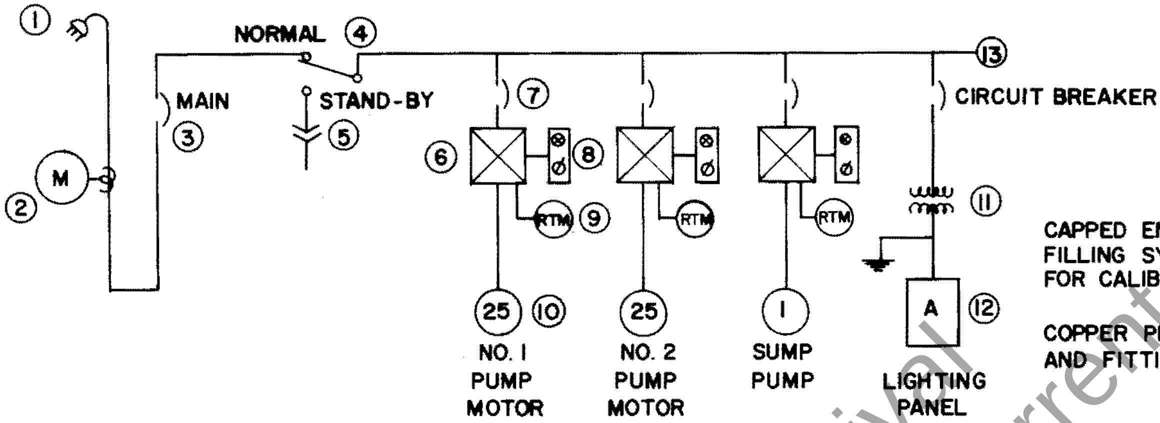
12-G. AREA CLASSIFICATION

It is not possible to determine all flammable liquids that may enter a highway stormwater pumping facility, but a hazardous area subject to explosion may easily be created.

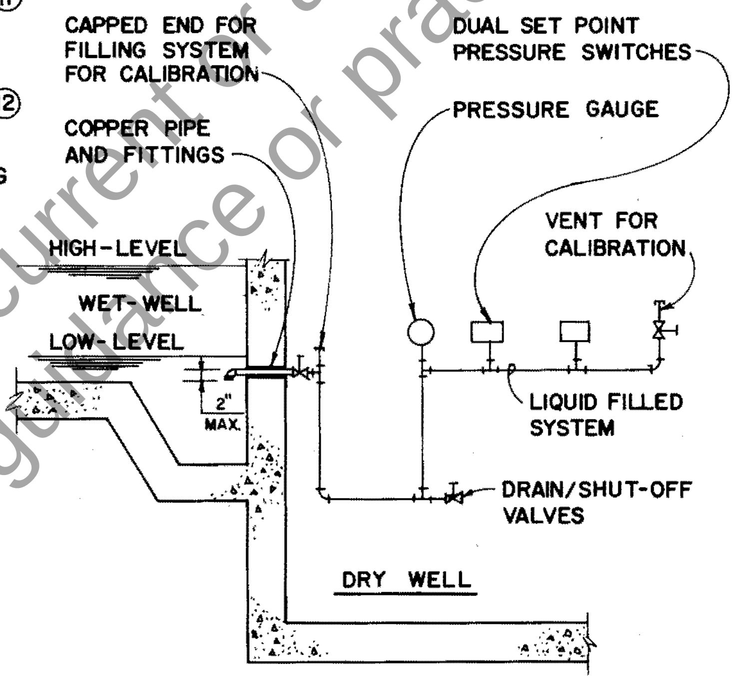
All unventilated sumps are classified as Class 1, Division 1. This would apply to all wet-well areas. Adjacent dry areas within 20 feet of any door or hatch to a Division 1 area would be considered a Division 2 area. All electrical equipment must be compatible with the classification of the area in which it is to be installed.

Positive ventilation is required in all areas which personnel must enter and such ventilation equipment must meet the area classification.

Gas detection equipment is recommended to detect explosive limits of gas vapors in the area where general purpose electrical equipment is installed.



1. UTILITY COMPANY SERVICE, USUALLY 480V 3Ø 3W
2. METERING IN ACCORDANCE WITH UTILITY CO. REQUIREMENTS
3. MAIN CIRCUIT BREAKER
4. TRANSFER SWITCH
5. MALE RECEPTACLE FOR STAND-BY POWER
6. MOTOR STARTER WITH 120V CONTROL TRANSFORMER AND THREE OVERLOAD RELAYS
7. MOTOR CIRCUIT BREAKER
8. PILOT LIGHT AND H-O-A (HAND-OFF-AUTOMATIC) SELECTOR
9. RUNNING TIME METER
10. MOTOR (SHOWING H.P.)
11. TRANSFORMER 120/240V 3Ø 3W
12. PANEL FOR LIGHTING, RECEPTACLES, CONTROL PANEL AND FAN MOTORS
13. CABLE BUS IN GUTTER



LEVEL SWITCHES

SINGLE-LINE DIAGRAM - DRY-PIT STATION

FIGURE 12-7

12-H. MATERIALS AND CODES

All electrical installations are governed by and must be in accordance with the National Electrical Code, and other local codes which may be more stringent.

The codes cover permissible materials and combinations of same, such as how many wires of what size are required for given currents, and in what size of conduit they shall be placed for protection. The standard of workmanship required for installation is also governed by Code.

For representative descriptions of requirements, refer to Appendix D - Specifications.

12-J. SYSTEM DESIGN

Following consideration and understanding of the preceding basic principles, the actual design of the electrical system for a pumping station begins with the single-line diagram. This diagram shows the source of power on one side and proceeds across a bus or bus-bar showing all the various motors, lighting panels and accessories which are attached to the bus and make up the connected load. Meters, circuit breakers, motor starters and all other devices are shown by appropriate symbols which can be identified by reference to notes, legends or schedules.

The single-line is a simplified diagram which does not show many details of the complex circuitry required to start and stop pump motors or other equipment automatically according to water-level, time, or other conditions.

The pump motors generally represent the largest and most significant components of the connected load. Lighting or other functions are only a small percentage. Where engines are utilized for the main pumps, the connected load will be far less than if motors were utilized for the whole pumping operation.

Because the requirements for a small system are less than those for a large one, the dry-pit station will be studied first. Figure 12-7 shows the single-line diagram for a typical dry-pit station. The components are set out in logical fashion and can be easily identified by reference to the legend. The bubbler control will be referred to later.

Figure 12-8 is a photograph of a dry-pit switchgear installation. It is an assembly of components on a plywood backboard, not a factory-assembled switchgear panel. In this respect, it differs slightly from Figure 12-10. The gutter containing the bus carries the numbers "480" denoting the voltage, to caution operators. Also, the generator transfer switch is stencilled "Emer. Power". A rubber floor covering is provided as insulation against dangerous electric shock. Figure 12-6 shows a similiar installation.

Figure 12-9 shows the sump pump motor starter and the disconnect switches for the main pump motors. Electrical codes require that a local disconnect be provided adjacent to the motor when the motor is not in direct view from the starter, so that there is no accident hazard during maintenance.

Schematics showing the components and functions are developed from the single-line diagram. Panel and equipment schedules follow, and layouts should then be prepared showing conduit runs and wire sizes. Detailed wiring diagrams are required for installation of the work. Written specifications are also needed to set forth the quality of materials and the standard of workmanship required. Sometimes conduit and wire sizing and the preparations of detailed wiring diagrams is delegated to the electrical contractor, to be subject to the approval of the design engineer.

Figure 12-11 shows the electrical schematics diagram for a dry-pit station. Note that no conduit or wire sizes are shown in this figure, nor in Figure 12-10. Unless this information were conveyed in other contract drawings, it could be made a contractor requirement to comply with applicable codes, to ensure that proper conduit and wire sizes were provided and installed.

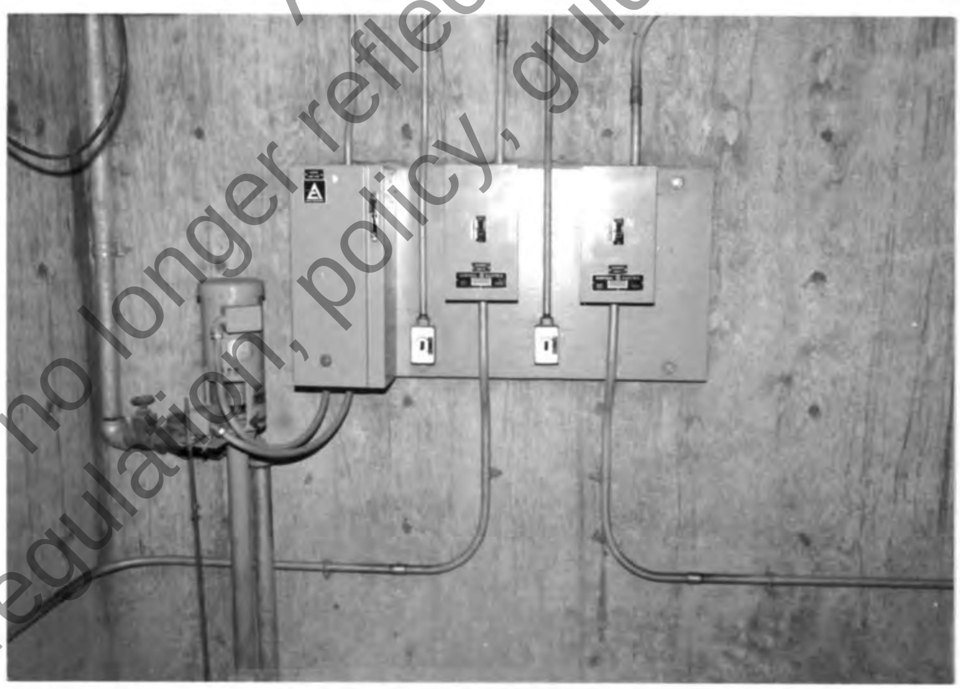
Figures 12-12 and 12-13 are single-line diagrams covering various conditions of voltage, motors and engines for wet-pit stations. The single-line often indicates circuit breaker amperage related to motor horsepower. There is no single-line in Figure 12-12 or 12-13 to relate exactly to Figures 12-14 and 12-15 but, but both power plan and lighting plan are quite specific in requirements for conduit and wire sizes. However, the conduit routing is schematic, as is usual with electical drawings.

Actual construction requires some further layout and consideration of the location of stub-ups so that these occur where they do not create personnel tripping hazards and will be acceptable to OSHA. Where conduit is intended to be embedded in concrete, it is shown differently from where it is to be surface mounted. Proper co-ordination of electrical work with the structure is always difficult and seldom achieved perfectly in accord with the intent of the pump station designer.

Figure 12-16 is supplemental to preceding Figures 12-14 and 12-15, but is typical of the way in which electrical details are conveyed. The symbol list is self-explanatory, but could be expanded to cover many other items if desired.

Circuit breakers, motor starters and gutter
on panel board for Dry-Pit Station

FIGURE 12-8



Sump pump with starter and
disconnect switches for main pumps

FIGURE 12-9

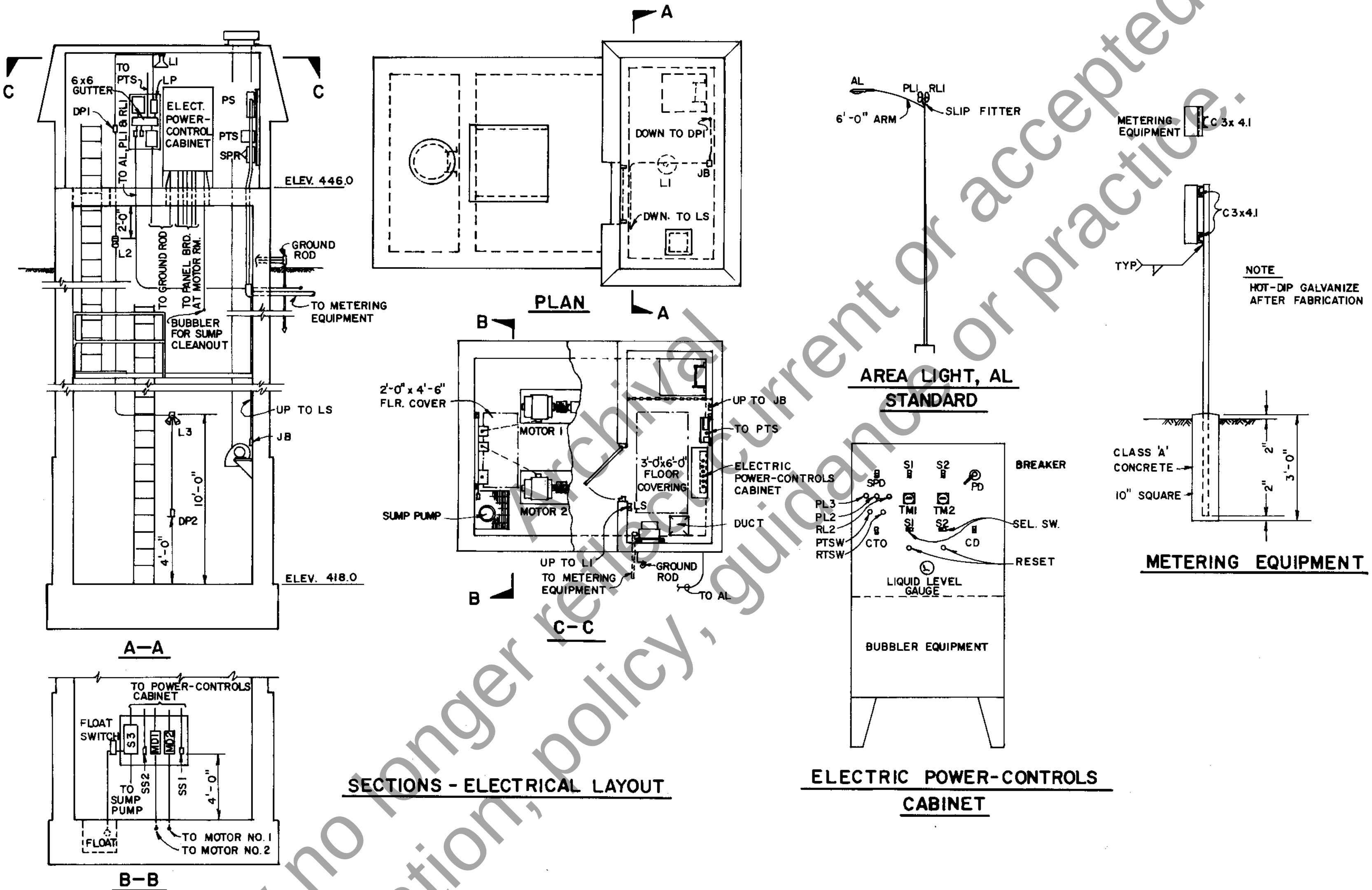
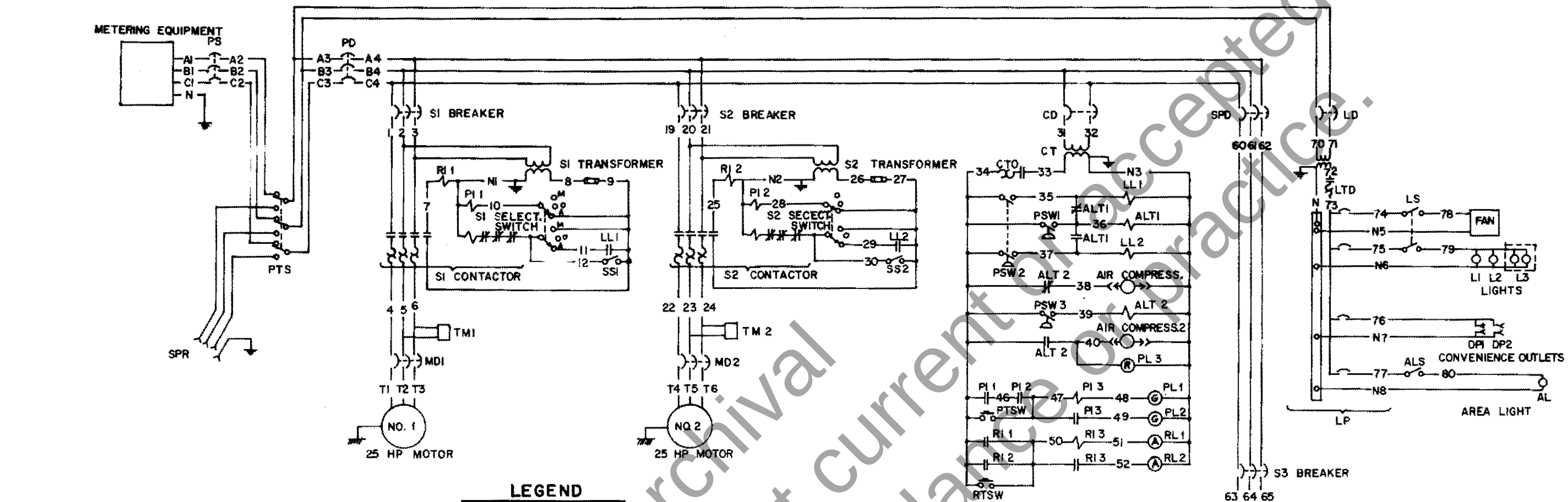


FIGURE 12-10 DRY-PIT STATION - ELECTRICAL DETAILS



PSW OPERATING POINTS

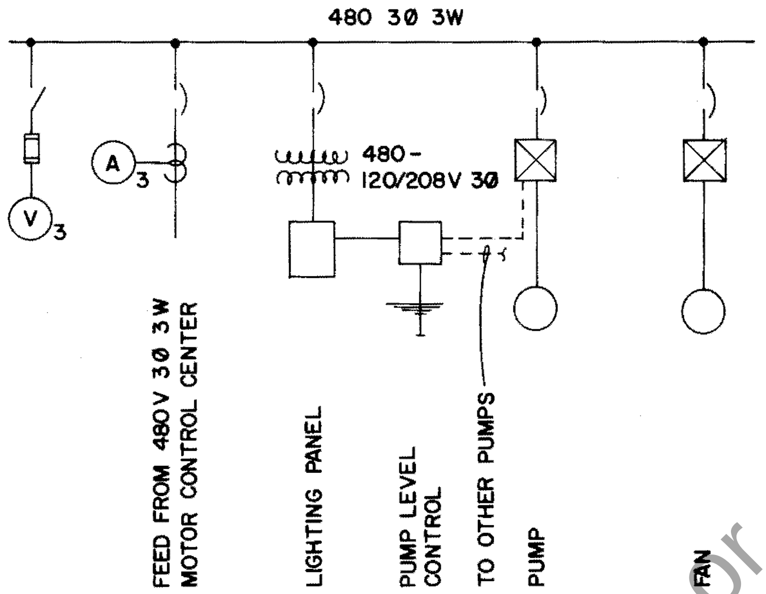
	START ELEV.	STOP ELEV.
PSW 1	423.8	420.23
PSW 2	424.1	420.34

LEGEND

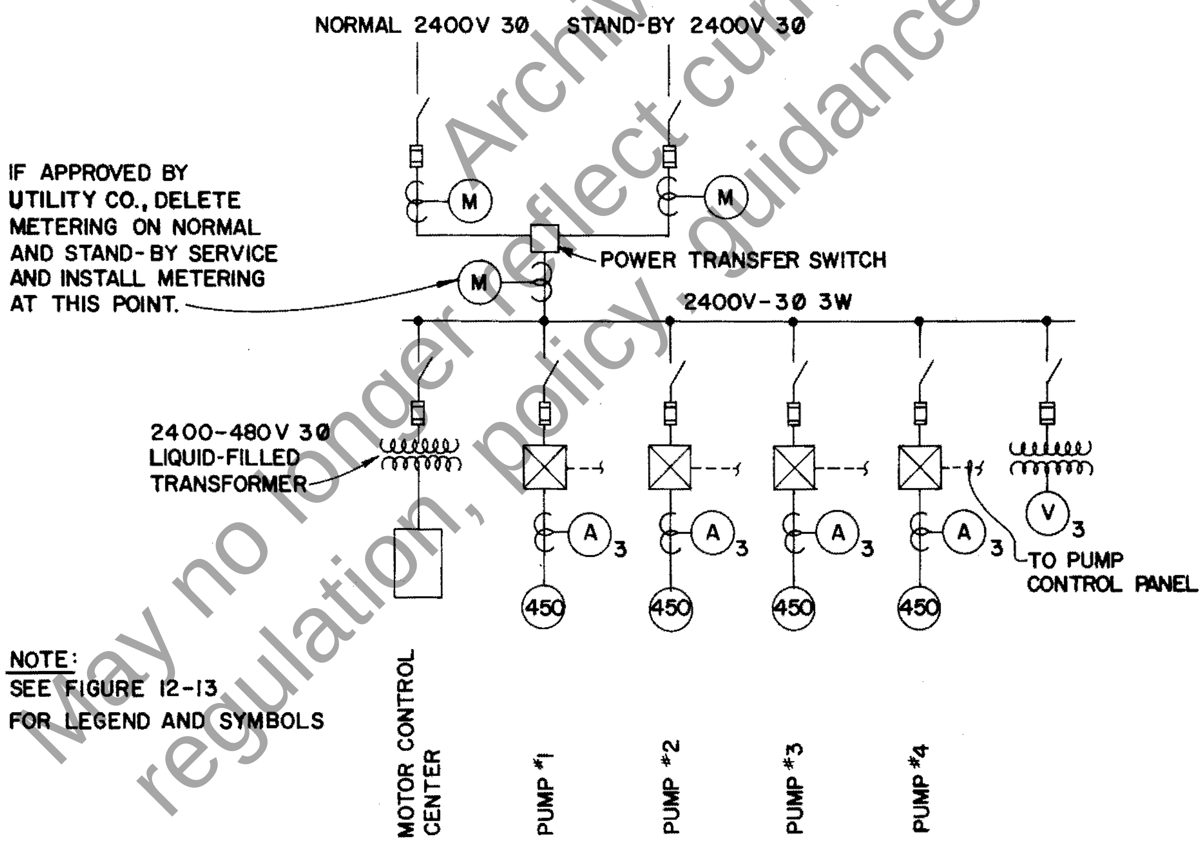
ITEM	DESCRIPTION	ITEM	DESCRIPTION
ALS	AREA LIGHT SWITCH	PD	POWER DISCONNECT
ALT	ALTERNATOR	PL	INDICATING LIGHT
CD	CONTROL DISCONNECT	PS	POWER SWITCH
CT	CONTROL TRANSFORMER	PSW	PRESSURE SWITCH
CTO	CONTROL TRANSFORMER OVERLOAD	PTS	POWER TRANSFER SWITCH
DP	DUPLEX PLUG OUTLET	PTSW	POWER TEST SWITCH
JB	JUNCTION BOX	R	RELAY
L	LIGHTS	RI	RUNNING INDICATING RELAY
LD	LIGHTS DISCONNECT	RL	INDICATING LIGHT
LL	LIQUID LEVEL RELAY	RTSW	RUN TEST SWITCH
LP	LIGHTS PANEL	S	STARTER
LS	LIGHTS & FAN SWITCH	SPD	SUMP PUMP DISCONNECT
LT	LIGHTS TRANSFORMER	SPR	STANDBY POWER RECEPTACLE
LTO	LIGHTS TRANSFORMER OVERLOAD	SS	SELECTOR SWITCH
MD	MOTOR DISCONNECT SWITCH	TM	TEST SWITCH
PI	POWER INDICATING RELAY	TSW	TEST SWITCH

ITEM	DESCRIPTION
	AIR CIRCUIT BREAKER
	CONTACT, NORMALLY OPEN
	CONTACT, NORMALLY CLOSED
	CURRENT RESPONSE ELEMENT
	ENCLOSURE BOND
	FUSE
	OPERATING COIL
	PRESSURE SWITCH, NORM. OPEN
	PUSHBUTTON SWITCH, NORM. OPEN
	PUSHBUTTON SWITCH, NORM. CLOSED
	SINGLE POLE SWITCH
	DOUBLE POLE SWITCH
	DOUBLE POLE, 3 POSITION SWITCH
	3 POLE
	2 POSITION SWITCH
	TRANSFORMER
Ⓡ	INDICATING LIGHT, RED
Ⓖ	INDICATING LIGHT, GREEN
Ⓐ	INDICATING LIGHT, AMBER

FIGURE 12-11 DRY-PIT STATION - SCHEMATIC DIAGRAM

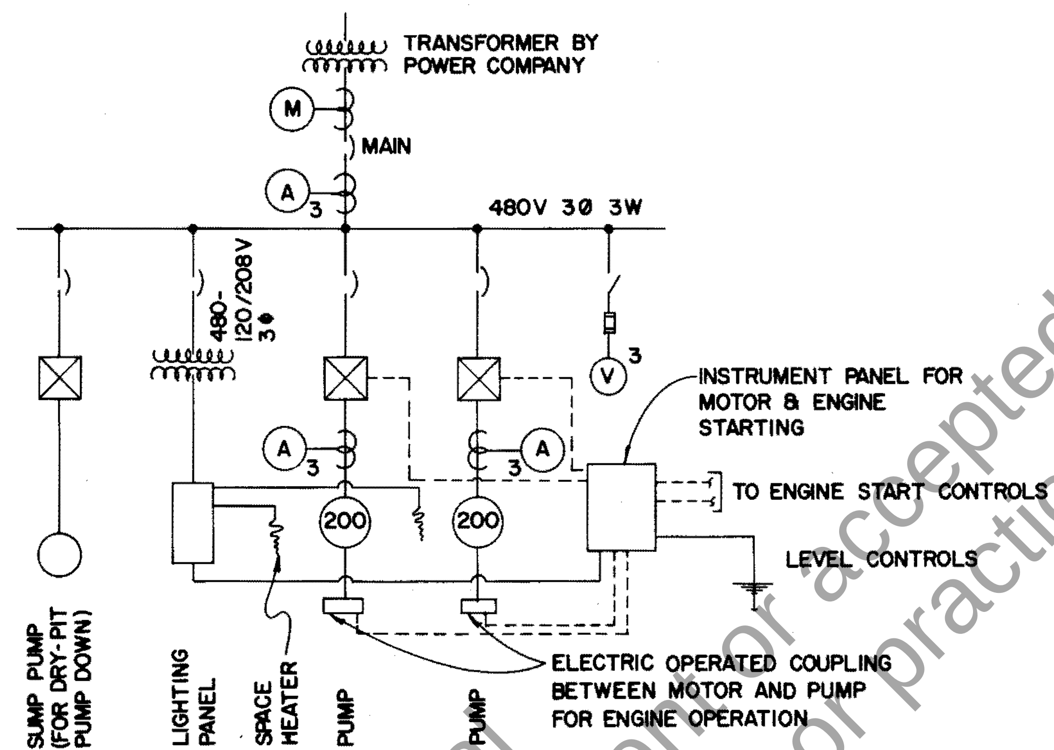


SINGLE-LINE, 480 VOLT MOTORS

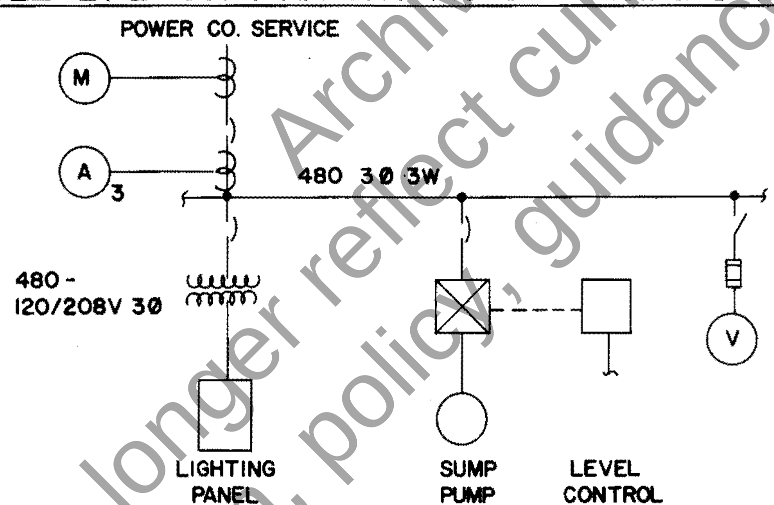


SINGLE-LINE, 2300 VOLT MOTORS

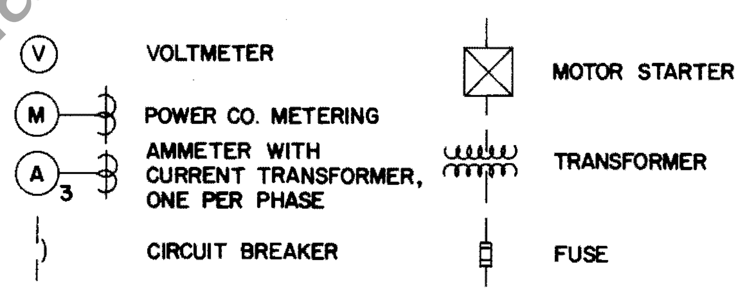
FIGURE 12-12



SINGLE-LINE COMBINATION MOTOR-ENGINE DRIVEN PUMPS

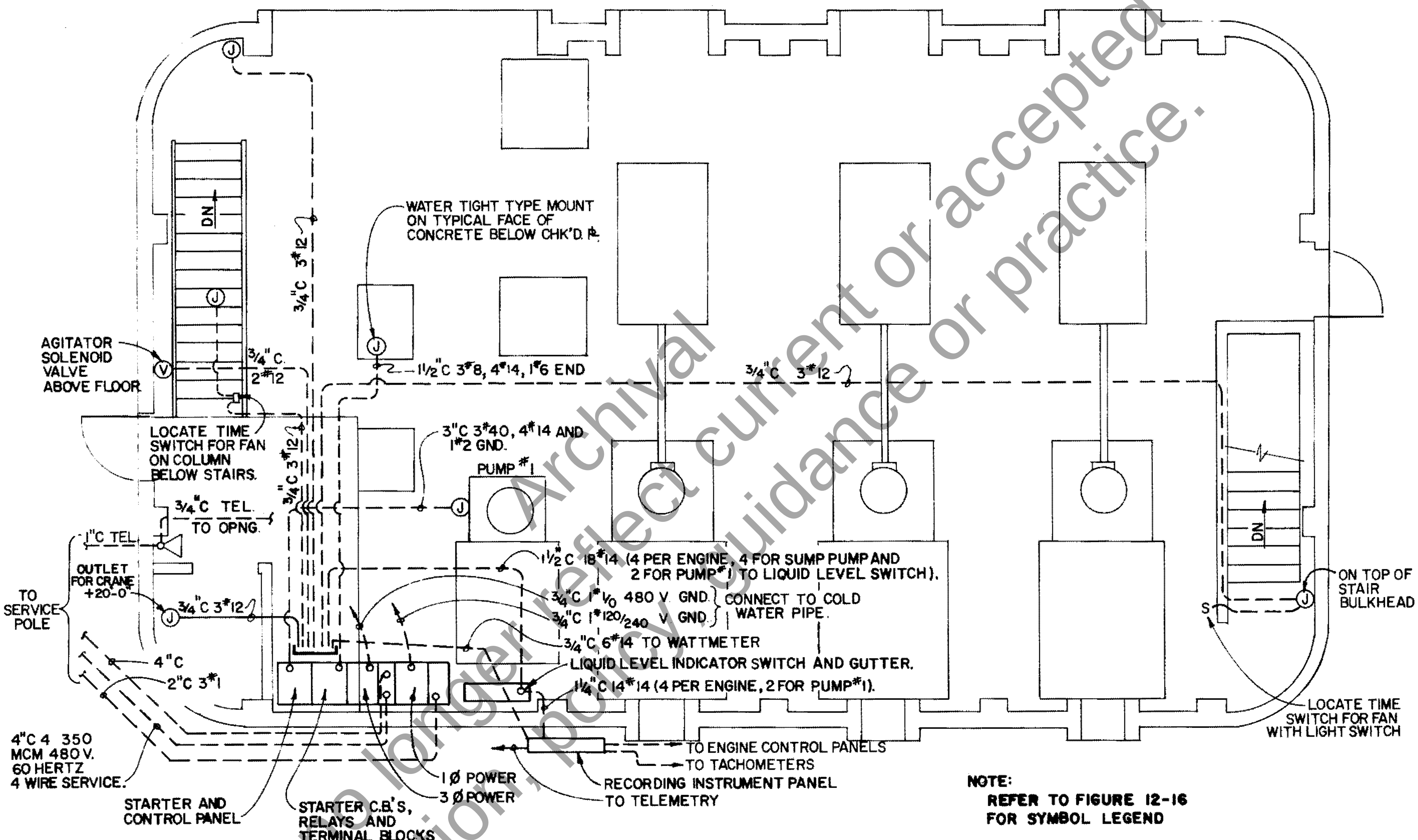


SINGLE-LINE DIAGRAM FOR ENGINE DRIVEN PUMPS



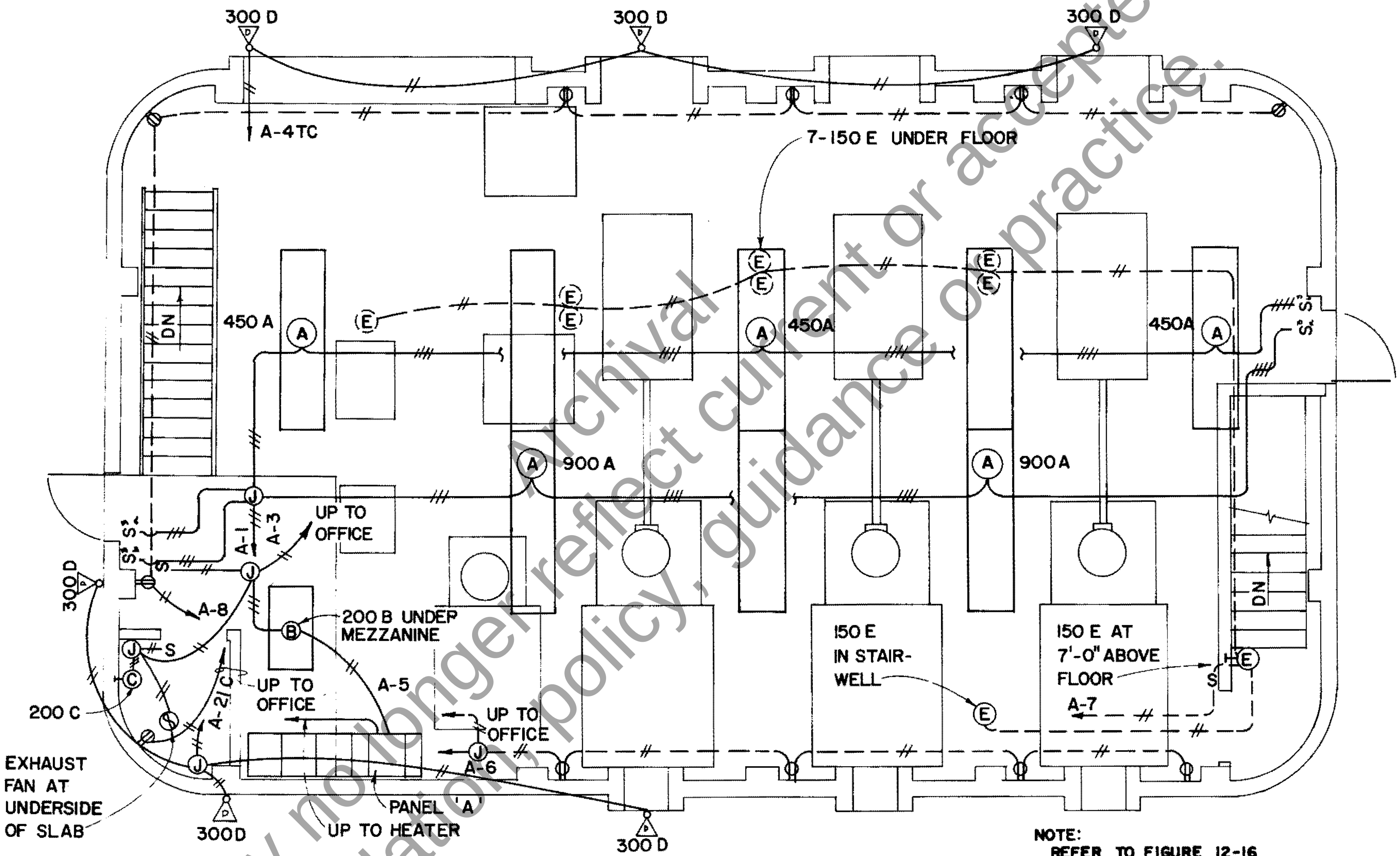
TYPICAL SYMBOLS

FIGURE 12-13



NOTE:
REFER TO FIGURE 12-16 FOR SYMBOL LEGEND

FIGURE 12-14 POWER PLAN



NOTE:
REFER TO FIGURE 12-16 FOR SYMBOL LEGEND

FIGURE 12-15 LIGHTING AND RECEPTACLE PLAN

SYMBOL LIST

	INCANDESCENT FIXTURE-CEILING MOUNTED
	INCANDESCENT FIXTURE-WALL MOUNTED
	FLOODLIGHT
	FLUORESCENT FIXTURE
S	SINGLE POLE SWITCH
S^3	THREE WAY SWITCH
	DUPLEX RECEPTACLE
	TELEPHONE OUTLET
	JUNCTION BOX
	STRIP HEATER
A-8	PANEL A CIRCUIT
	CONDUIT RUN ABOVE FLOOR
	CONDUIT RUN BELOW FLOOR
	3/4"-2#12
	3/4"-3#12
	3/4"-4#12
	3/4"-5#12
TC	TIME CLOCK
LTF	LIQUID TIGHT FLEXIBLE CONDUIT
	120 V THERMOSTAT
	EXHAUST FAN

PANEL A VOLTS 120/240 PHASE 1 WIRES 3 BUS 100A

MOUNTING SWITCHBOARD MAIN BREAKER 100 AMPS FEEDER 2"-4#1

LOAD PHASE A 6200 PHASE B 6750 PHASE C — TOTAL 12950 AMPS 54

CIRC.	BREAKER		NO. OUTLETS			LOAD WATTS			REMARKS
	AMPS	POLES	LTG.	REC.	MISC.	A	B	C	
1	20	1	4			1800			ENGINE ROOM, FLUORESCENT
2	20	1	3			900			EXTERIOR FLOODLIGHTS TC
3	20	1	4						ENGINE ROOM, FLUORESCENT
4	20	1	3						EXTERIOR FLOODLIGHTS TC
5	20	1	3		2	600			OFFICE & TOILET
6	20	1		7		1400			ENGINE ROOM, OFFICE & TOILET
7	20	1	9				1350		PUMP PIT
8	20	1		6			1200		ENGINE ROOM
9	20	2				1500			ROLL-UP DOOR
10	20	2							SPARE
11	20	—					1500		ROLL-UP DOOR
12	20	—							SPARE
13	20	1							SPARE
14	20	1							SPARE
15	20	1							SPARE
16	20	1							SPARE

PANEL SCHEDULE

FIGURE 12-16 LEGEND EXAMPLES

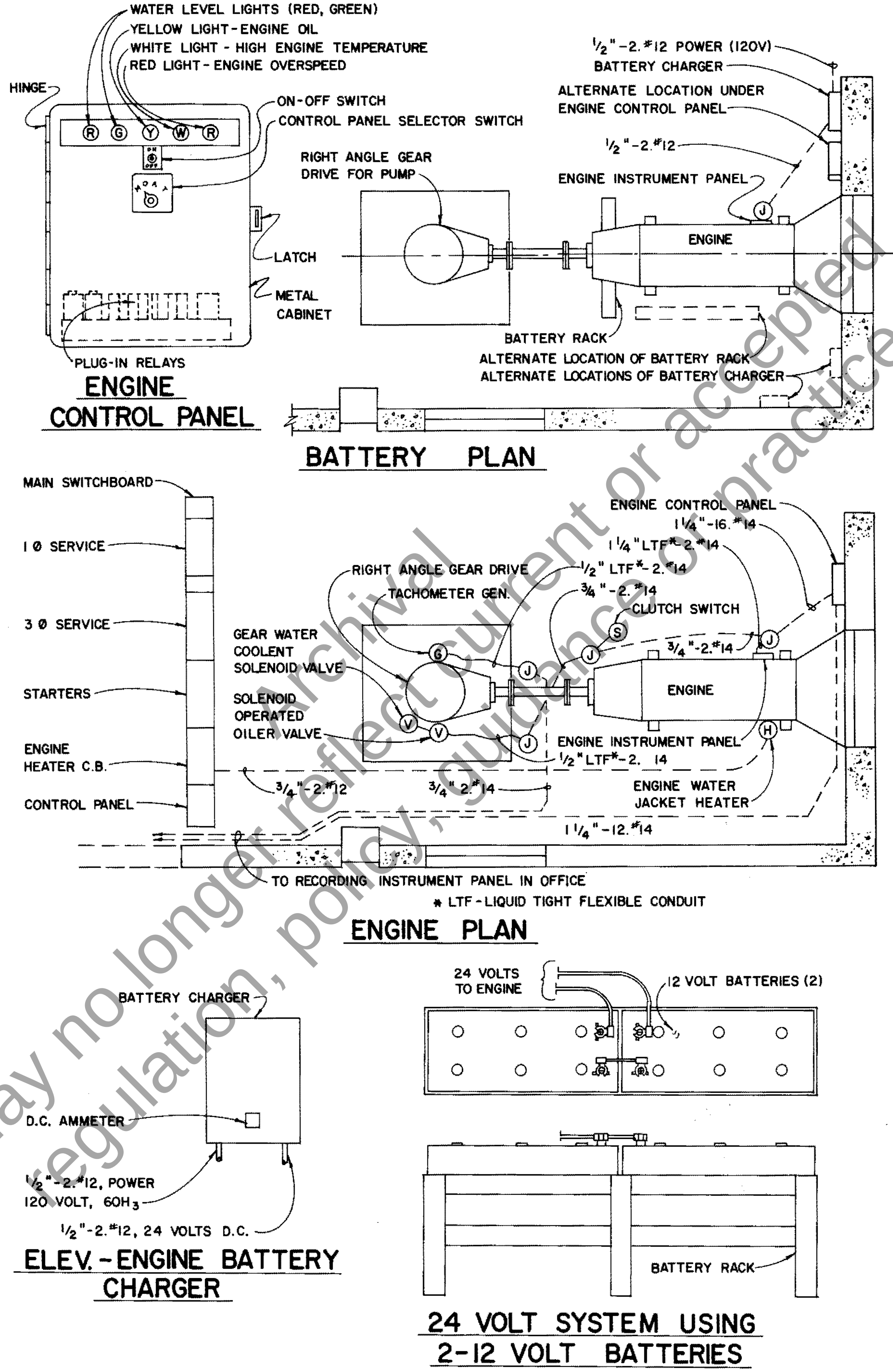


FIGURE 12-17. ENGINE STARTING

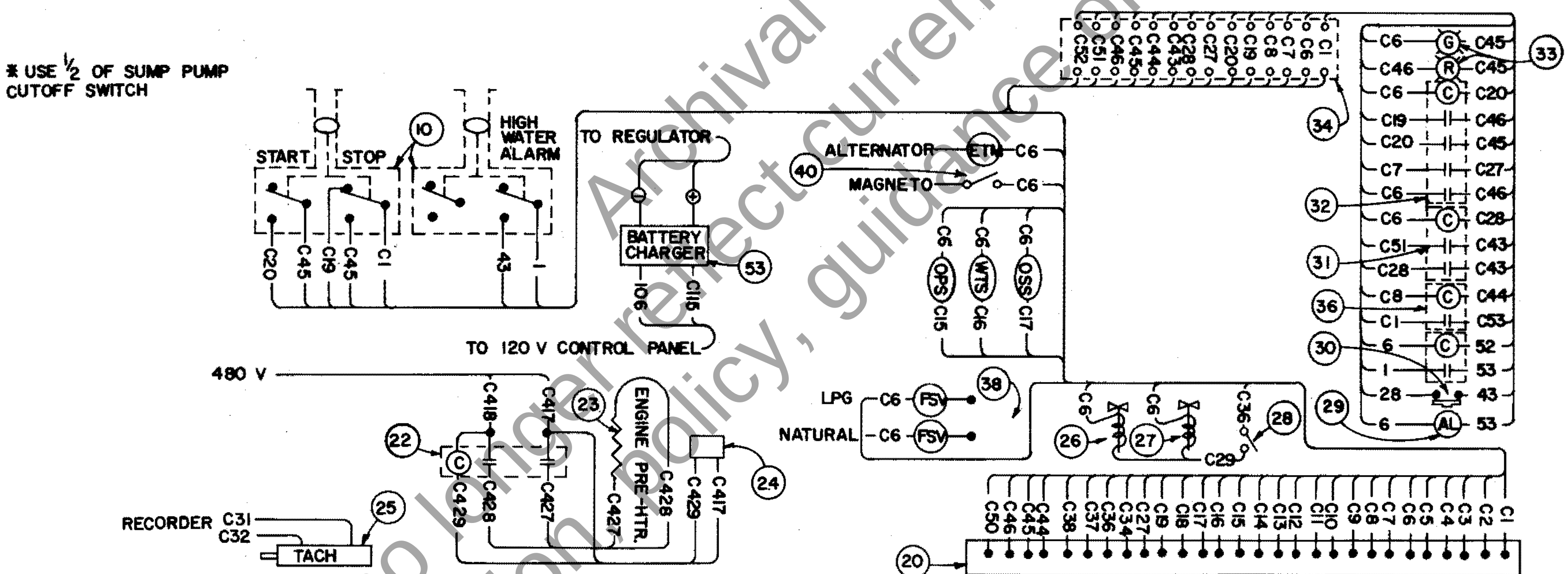


FIGURE 12-18 ENGINE CONTROL-CIRCUIT WIRING DIAGRAM

EQUIPMENT SCHEDULE

1	FUSE AND FUSE BLOCK
2	RESET TIMER - 0-20 MINUTES
3	CIRCUIT BREAKER 480 VOLT 3 POLE
4	CIRCUIT TRANSFORMER - AMMETER
5	AMMETER
6	AMBER CONTROL LIGHT AND TRANSFORMER
7	HAND-OFF-AUTOMATIC MOTOR CONTROL SWITCH (S.P.)
8	TEST SWITCH N.O.
9	MAGNETIC STARTER 480 VOLT 2 POLE
10	WATER LEVEL PRESSURE SWITCH (BARKSDALE)
11	TOTALIZING ELAPSED TIME INDICATOR 480 VOLTS
12	SOLENOID OPERATED LUBRICANT VALVE 480 VOLTS
13	TIME DELAY RELAY 120 VOLTS 2 POLE 1 N.O. AND 1 N.C. (3 MIN.)
14	RELAY 120 VAC 2 POLE 2 N.O.-G.E. MACHINE TOOL RELAY CR2810 I
15	RELAY 120 VAC 4 POLE 3 N.O. AND 1 N.C. G.E. MACHINE TOOL RELAY CR2810 I
16	RELAY 480 VAC 3 POLE 1 N.O. AND 2 N.C. G.E. MACHINE TOOL RELAY CR2810 I
17	RED AND GREEN INDICATING LIGHTS 120 VOLTS
18	CURRENT TRANSFORMER - WATTMETER
19	SOLENOID OPERATED VALVE WATER AGITATOR 120 VOLT
20	CONTROL PANEL (STANDARD DWG.# 2-ML227)
21	HAND-OFF-AUTOMATIC MOTOR CONTROL SWITCH (D.P.)
22	RELAY 480 VOLTS 2 POLE N.O. (600 VOLT CONTACTS)
23	ENGINE WATER HEATER 480 VOLTS (KIM HOTSTART)
24	THERMOSTAT 480 VOLT OPERATED
25	TACTOMETER GENERATOR
26	SOLENOID OPERATED OILER VALVE 24 VOLT D.C.
27	SOLENOID OPERATED OIL COOLANT WATER VALVE 24 VOLT D.C.
28	SWITCH, CLUTCH HANDLE OPERATED (N.O. WHEN DISENGAGED)
29	ALARM BELL 6 INCH 24 VOLT D.C.
30	SWITCH PUSHBUTTON BELL SILENCER N.O.
31	RELAY 24 VDC 2 POLE 1 N.O. AND 1 N.C. G.E. RELAY CR2811 I
32	RELAY 24 VDC 4 POLE 3 N.O. AND 1 N.C. G.E. RELAY CR2811 I
33	RED AND GREEN INDICATING LIGHTS 24 VOLTS
34	TERMINAL STRIP
35	BATTERY CHARGER (LA MARCHE MODEL A-5-10-24V)
36	RELAY 24 VDC 1 POLE N.O. (MIN. CONTACT RATING 5 AMP)
37	VERTICAL HOLLOW SHAFT MOTOR 480V 3Ø 150HP
38	FUEL TRANSFER SWITCH
39	STRIP HEATER
40	SWITCH SNAP LOADED ENGINE CUT-OFF N.C. (REMOTE)

NOTES:

1. STANDAND CIRCUITS AND WIRE NUMBERING ASSEMBLIES SHOWN ARE TYPICAL TO LOS ANGELES COUNTY FLOOD CONTROL DISTRICT PUMP STATIONS.
2. VOLTAGE CIRCUITS ARE DESIGNATED BY THE FOLLOWING METHOD:
   NUMBERS '1' THRU '99', 24 VOLT CIRCUITS
   NUMBERS '101' THRU '199', 120 VOLT CIRCUITS
   NUMBERS '201' THRU '299', 240 VOLT CIRCUITS
   NUMBERS '401' THRU '499', 408 VOLT CIRCUITS
3. PUMP AND PUMP CONTROL CIRCUITS ARE DESIGNATED THUS:
   CAPITAL LETTER 'A' - PUMP NO. 1
   CAPITAL LETTER 'B' - PUMP NO. 2
   CAPITAL LETTER 'C' - PUMP NO. 3
   CAPITAL LETTER 'D' - PUMP NO. 4
4. WIRE NUMBERING IS SHOWN THUS:
   A401 PUMP NO. 1, 480 VOLT CIRCUIT
   B402 PUMP NO. 2, 480 VOLT CIRCUIT
   C201 PUMP NO. 3, 240 VOLT CIRCUIT
   D102 PUMP NO. 4, 120 VOLT CIRCUIT
   E16 PUMP NO. 5, 24 VOLT CIRCUIT
5. WIRES CARRYING NO LETTER IN FRONT OF NUMBER ARE COMMON TO MORE THAN ONE PUMP OR CONTROL CIRCUIT. SUCH AS NO. 101 - 120 VOLT FROM CONTROL PANEL OR NO. 106 NEUTRAL OR GROUND.
6. WATER LEVEL CONTROLS SHALL BE ADJUSTABLE DUAL SNAP ACTION SWITCHES ACTIVATED BY A DIAPHRAGM PRESSURE SEALED CAPSULE OPERATED BY AIR PRESSURE.
7. FUSE AND FUSE BLOCKS TO BE DETERMINED BY CODE REQUIREMENTS.
8. MAGNETIC STARTER TO BE DETERMINED BY SIZE OF ELECTRIC MOTOR.
9. STRIP HEATER WATTAGE REQUIREMENTS, TO KEEP MOTOR WINDING AND POWER PANEL FREE OF MOISTURE.
10. ALL CIRCUIT BREAKERS SHALL BE TO CODE REQUIREMENTS.
11. ALL WIRE SIZES SHALL BE TO CODE REQUIREMENTS.
12. AMMETER RANGES SHOULD BE 40 PERCENT OVER RUNNING LOAD.
13. VOLTMETER SHALL BE 0-600 VOLTS.
14. RECORDING METER RANGES SHOULD BE 40 PERCENT OVER RUNNING LOAD.
15. CURRENT TRANSFORMER TO MATCH AMMETER AND WATTMETER RANGES.
16. TEMINAL STRIPS AS REQUIRED.
17. ENGINE WATER HEATER WATTAGE TO BE DETERMINED BY SIZE OF ENGINE.
18. PILOT LIGHTS SHALL BE TYPE S-6 CANDELABRA, SCR. BASE, INCAND. LAMP.
19. N.C. NORMALLY CLOSED SWITCH OR RELAY.
20. N.O. NORMALLY OPEN SWITCH OR RELAY.
21. O.P.S. OIL PRESSURE SWITCH.
22. F.S.V. FUEL SOLENOID VALVE.
23. C CONTACTOR OR RELAY COIL.
24. S.P.D.T. SINGLE POLE, DOUBLE THROW.
25. D.P.D.T. DOUBLE POLE, DOUBLE THROW.
26. E.T.M. ELAPSED TIME METER.
27. O.S.S. OVERSPEED SWITCH.
28. W.T.S. WATER TEMPERATURE SWITCH.

FIGURE 12-19

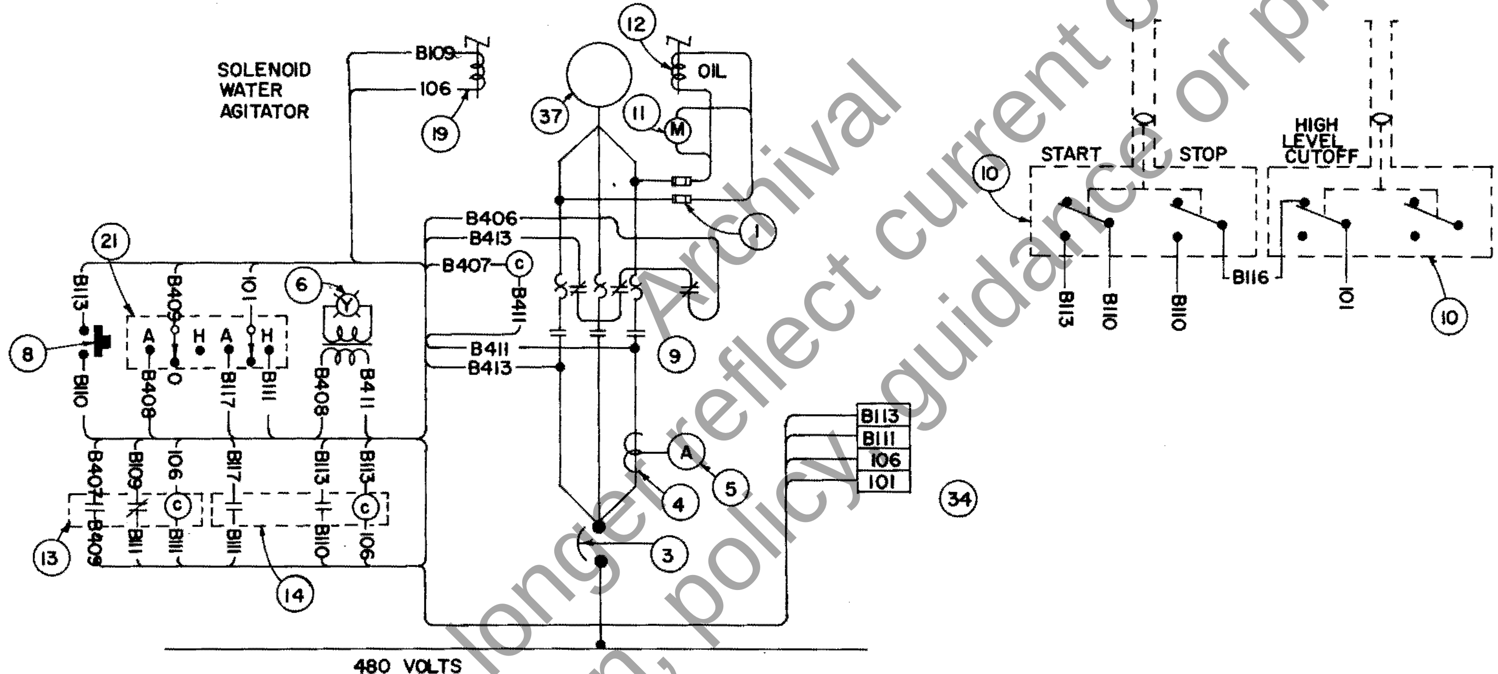


FIGURE 12-20 SUMP PUMP WITH SOLENOID AGITATOR UNIT

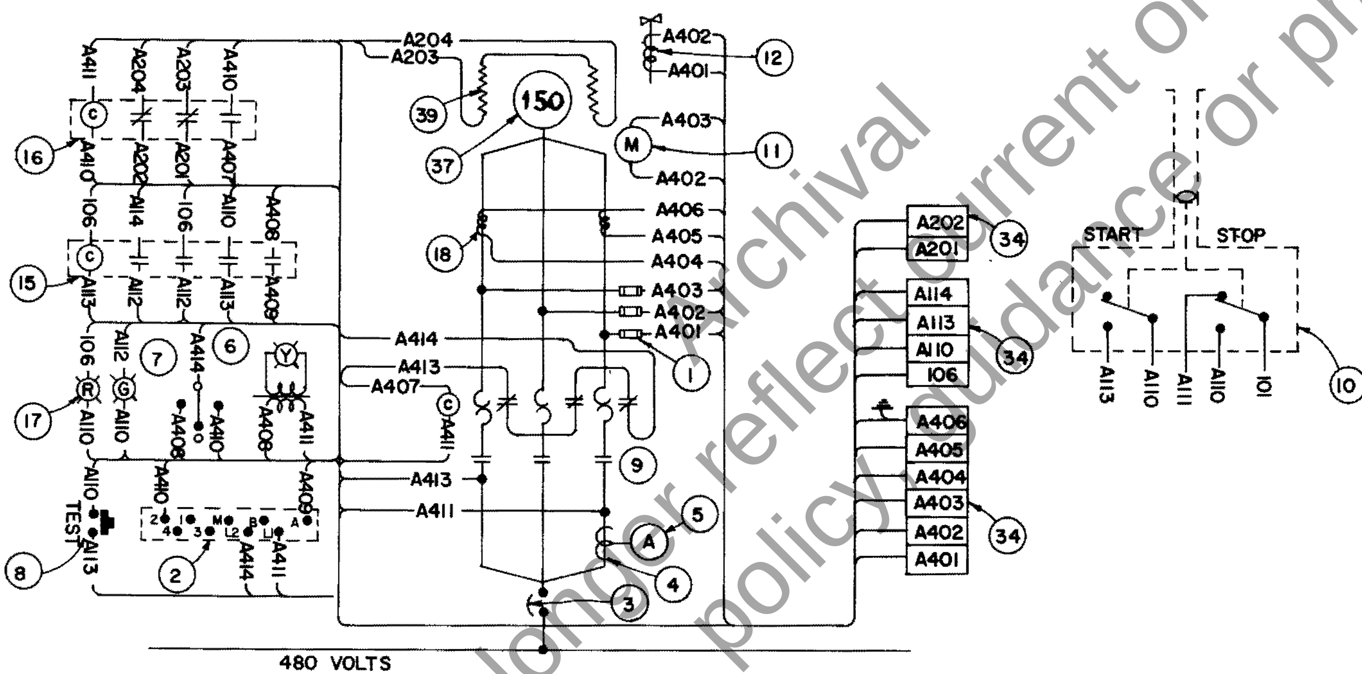


FIGURE 12-21 ELECTRIC PUMP UNIT WITH TIMER UNIT

Panel A, sometimes described as a lighting panel, shows items with 120 volt service and how the load is spread between phases. In this case, the load is easily carried by two phases and the third is not used. Circuits 9 and 11 are tied together to provide 208 volts for operating the roll-up door motor.

The use of engines with 24 volt battery starting and a 120 volt control system is a complication which needs to be carefully related to the basic 480 volt supply for pump motors. Figure 12-17 gives the basics of these requirements with further details shown in the wiring diagram, Figure 12-18. Explanatory notes relating to Figure 12-18 are shown on Figure 12-19 which applies also to the wiring diagrams for the sump pump Figure 12-20, and to the 150 HP pump, Figure 12-21. Each of the three engines at this particular station are required to start automatically in response to water level sensed by pressure switches on 120 volt circuits. Working through the engine control panels, the 24 volt batteries start the engines, each driving its pump. Meanwhile the electrically-driven pump with 480 volt motor continues to operate. See Chapter 15 - Station Layouts and Design Calculations.

Figure 12-22 shows a typical main switchboard as available from a major manufacturer. It is essentially constructed on a modular basis with both single-phase and three-phase pull-sections for underground service. Various components are set in the frame as required and empty spaces are described as fillers. Single-phase and three-phase meters are integral with the switchboard. Sometimes switchboards are referred to as panels or more appropriately as motor control centers. The motor control center with cabinet may be less costly than the panelboard because of its shop-fabrication compared with the field installation required for a panelboard. The physical size of enclosures for motor starters and some idea of the internal components will be observed from Figures 12-19 and 12-20. A minimum of three feet clearance must be allowed in front of all MCC's. Some also require rear access. Occasionally, local panel manufacturers can provide an acceptable assembly of components within lesser space requirements. This will be understood by reference back to Figure 12-10. Sufficient air space must always be allowed for heat dissipation.

A very important consideration in regard to the main switchgear is that it should be located directly in the path between the incoming power supply and the center of the electrical load. There is seldom reason to carry expensive conductors more than the minimum distance. Figure 12-14 shows how it was possible to go underground from pole to switchgear, then to the pump motor with minimum additional length of conduit and large conductors. Again, there are very stringent and specific restrictions on the number and radius of elbows in any conduit run, especially for large conductors. This has to be reviewed and properly established with the utility company at an early stage of design.

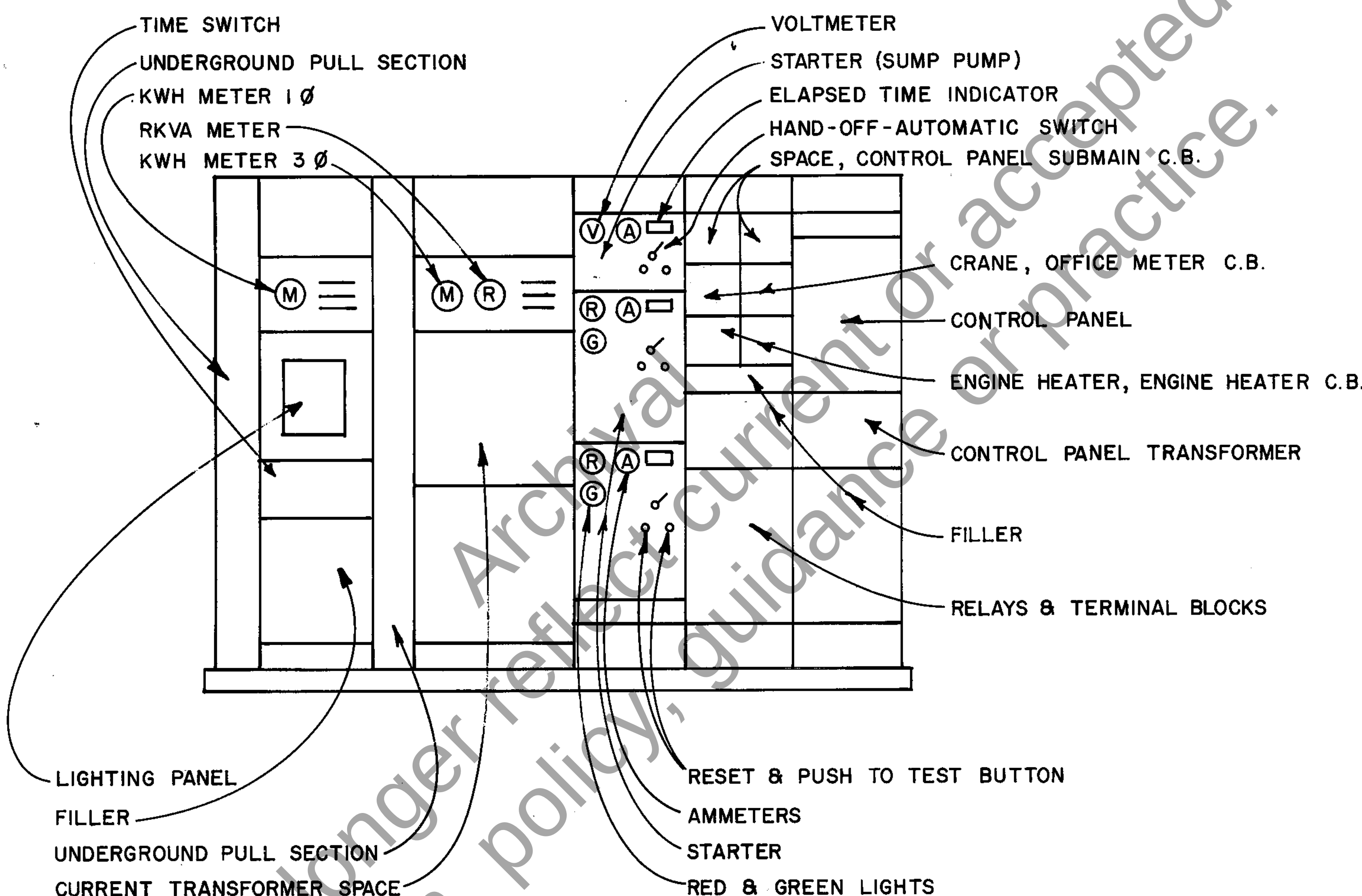


FIGURE 12-22 MAIN SWITCHBOARD LAYOUT

TYPICAL LAYOUT FOR SWITCHBOARD SERVING ONE ELECTRIC SUMP PUMP, 2 MAIN ELECTRIC PUMPS AND 2 ENGINES.

Switchgear installation for
1-150 hp pump and sump pump,
with other accessory features shown

FIGURE 12-23

Tachometer generator (cover removed)

FIGURE 12-24

Medium-voltage (2,400 v.)
motor starters, Detroit, MI

FIGURE 12-25

Motor Control Center
for 3-20 hp, 480
motors, Detroit, MI

FIGURE 12-26

See Figure 2-9 for
view of interior of
station

Main switchboard for two combination motor-engine driven pumps. Battery chargers mounted on end of switchboard

FIGURE 12-27

Level switches for Dry-Pit station

FIGURE 12-28

Figure 12-23 shows the actual construction of the switchgear shown on Figures 12-14 and 12-15. The 120 v. single-phase service and meter section were separated from the main panel. Adjacent to the 120 v. service is the telemetering cabinet and gas detection equipment, mounted above the pressure-switches for pump start and stop. Figure 12-24 shows a tachometer generator mounted behind the right-angle gear drive. The cover has been removed to show internals.

Lighting is usually a minor consideration in pump stations and formal calculations relating to foot-candles of intensity are not essential. Fluorescent fixtures are to be preferred rather than incandescent. Some exterior lighting may be needed. General details may be observed from the various figures.

12-K. PUMP ON-OFF CONTROLS

In stormwater pumping, it is usually the intent to pump out all inflows from the sump or storage box as rapidly as possible. Therefore, the control consists of starting pumps successively in response to rising water level and maintaining a pumping capacity on line greater than inflow. Various types of control switch may be used including the float switch, electrode probes, ultrasonic devices, tilting bulb with mercury switch, bubbler tube and entrapped air pressure switch. For a wet pit station, the pressure switch is recommended. This acts on the principle of rising water compressing the air in a pipe below the pressure switch so that at a given height of water and corresponding air pressure the switch is activated and the pump starts. When water drops to a given level the switch closes and the pump stops. Pump control must have enough deadband in the level switches to prevent motor re-start after the pump has stopped and water in the vertical discharge or suction pipe has drained back into the wet-well. The control circuitry for the pressure switch is shown in Figures 12-18, 12-20 and 12-21. Details are given for a main pump, a submersible pump with agitator spray ring and time-delayed start and for an engine. The corresponding schedule and notes are shown in Figure 12-19. Manufacturers' literature will show circuitry for the various other on-off controls mentioned. Some have a lead-lag feature between two or more pumps so that the first pump on, the lead pump, is alternated between all pumps to equalize wear. However, this is not an important factor in stormwater pumping. Changes in pressure switch settings to accomplish this can be done during routine maintenance.

The bubbler system has been used effectively in many stations, and is standard with the dry pit type. See Figures 12-7, 12-10 and 12-11. Access to the liquid interface is usually difficult unless the wet-well and the dry-pit have a common wall. Where the wet wall and dry pit do not have a common wall, then a bubble tube presents the best alternative. The bubble-tube is continuous 3/8" O.D. polyethyline tubing inside a galvanized one-inch conduit installed between the two structures and entering the wet well from the top and terminating in the dry pit at an elevation above the highest possible water elevation. A packaged dual air compressor system with pressure switches and level gauges is provided. The air compressors should have automatic alternators to provide alternation of air compressors each time the compressor discharges into the air receiver. The receiver should be large enough to permit bubbler system to operate for at least four hours without starting an air compressor. A rotometer provides bubble control and visual indication of air supply. By-pass valve permits periodic purging of the bubble tube to prevent clogging by trash in the wet-well. Figure 12-26 shows three non-adjustable pressure switches installed. They operate on a fixed pressure setting made at the factory. The plastic pipe is installed adjacent to the switches to test them by filling the column with water.

Tilting bulbs with mercury switches are illustrated in Figure 6-10. Each bulb is suspended by a conducting cable to the level at which the switch is to operate. Its buoyancy in water tilts the bulb and the switch makes contact. In a large wet-pit, an enclosing pipe or stilling-well subject to water level might be needed to prevent horizontal water movement from interfering with proper operation.

Electrode controls have no moving parts in the stormwater. The electrodes are suspended vertically from a fitting at the top of a non-conductive stilling-well with their lower ends positioned at the level elevations at which the control is to be actuated. From the fitting, conductors run to a controller to start and stop pumps.

12-L. SUMMARY

The information given in this chapter is general only. Any detailed electrical design, equipment selection, conduit runs, wire sizing, controls and the like should be performed by a person experienced in the subject, possibly another assisting the pump station designer. There is an important electrical inter-relationship between pumps, engines, controls, instrumentation, alarms and telemetering so that other chapters and Appendix D - Specifications should be studied as part of the electrical design.

Electrical safety must always be properly considered, with proper grounding and the avoidance of mixed-voltage hazards caused by running power, lighting, battery starting and control wiring in the same conduits. At least the minimum clear areas must always be provided in front of switchgear, and also at the rear where rear access equipment is utilized.

* * * * * * * * *

CHAPTER 13. EMERGENCY GENERATORS

13-A. GENERAL

An emergency generator can provide an alternate source of electrical power at a pump station in the event of loss of normal utility-furnished power. Because all pump stations use alternating current only such generators are considered.

The operating voltage is likely to be limited to a small selection. Utility supply at 2,400 volts or above is limited to larger motors and stations. Although generators of 4,160 Y/2,400 volt can be obtained, these are very large specialized units and are not discussed in this Manual. In the range to which the Manual applies, the choice of generator voltages is either 480 Y/277 or 208 Y/120. In all conventional installations, the utility service to a pump station will be 480 volts for motors which it is practical to run by an emergency generator. Some stations have both 480 and 120 volt services, the latter being for lighting, but it is impractical to consider generating two voltages, so the lower voltage should not be provided. A small transformer can be used instead. Again, three-phase current is invariably supplied by the utility if the voltage is 480, so only generators having 480 Y/277 volts, 3 phase, 4 wire, wye 60 Hertz out-put need to be considered.

There are numerous manufacturers of generator sets, which are available in a broad range of sizes. The size or capacity is usually expressed in KW, (Kilowatts, meaning one thousand watts of power). To convert engine horse-power to KW multiply by .746. The generator engine may be powered by natural gas, which is a convenience where a piped supply is available for a stationary installation. However a greater range of selection will apply if the engine is diesel-fueled. Propane can also be used and propane or diesel as a fuel becomes essential if the emergencey generator is to be trailer-mounted or transportable in some other fashion. Due to size and power requirements, gasoline powered generators are not likely to be applicable and are not considered.

Emergency generators may be conventional stationary installations permanently connected to the station switchgear and capable of carrying the entire load of a wet-pit pump station. Alternately, they may be of transportable type, compatible with being sized only for the lesser load of typical dry-pit stations as illustrated herein. The latter type may be intended to serve a number of stations within reasonable distance of its storage point. Certain precautions in making connections must be observed in order to safely transfer from the utility power source.

Beginning with the next section the selection of a suitable generator will be discussed with particular reference to adequate but not excessive size. Following there will be a description of motor starting characteristics and an example of the procedures necessary to ensure that proper capability is provided for the large starting loads of any motors involved. These loads are larger than the running loads.

13-B. PRINCIPLES OF GENERATOR-SET SELECTION

A generator-set is rated in kva (kilovolt-amperes) or KW (kilowatts) and its engine must have enough power to serve the peak load and must have an adequate power margin (HP-KW) to recover frequency after an abrupt load application such as starting a motor. The power rating used should be the rating established by the engine manufacturer to afford adequate engine life in the type of service to which it is being applied.

If the electrical load on the generator consists of lighting, or a number of small motors, there is little difficulty in determining requirements. However, there is a great difference between the current required to start a motor and the current required by the motor under full load. This becomes the controlling factor in selection of a generator as motor sizes increase. A numerical example of this is given later in this chapter, where four motors of two different sizes are to be started and run.

It is essential that the generator be capable of providing the necessary momentary large kva to start motors without excessive voltage dip. The skva (starting kva) of a motor can be determined from the motor code and the corresponding tabulated numerical values. See Figure 13-1. The demand can also be computed from the locked rotor current rating. When more than one motor is to be started and run, the largest motor should be started first and the others in descending order. It is not practical to provide sufficient generator capacity to start more than one motor simultaneously without overload. Provisions must be made to avoid simultaneous starts. If reduced voltage starting is incorporated in the main switchgear, its effect will be to reduce the size of generator because of the less skva required.

In Chapter 11. - Engines and Accessories, reference was made to maximum, intermittent and continuous ratings of horsepower output. In considering engines for generator sets, the method of describing the ratings may be changed to standby, prime and continuous. Unfortunately there is no uniformity in meaning given to these ratings by different manufacturers.

It is important to recognize that the emergency generator as used at a pump station will be performing emergency service as its name implies. The total electrical load of the pump station, if ever applied to the generator-set will be of short duration only. Therefore, selection and sizing of the generator should be based on its prime rating, using the meaning that prime is some intermediate figure between stand-by (intermittent) and continuous ratings. This will avoid oversizing the selection.

Excursions above the prime rating may occur during the voltage dip which accompanies motor starting. The stand-by (intermittent) rating must be sufficient to provide that margin.

13-C. MOTOR STARTING CHARACTERISTICS

It will be assumed that the pump motors are started across-the-line, since this is a more difficult conditon to be imposed upon the generator than reduced inrush starting. See Chapter 10 - Electic Motors for Stormwater Pumps, and factors in Figure 13-1.

The NEMA code letter of each motor must be determined, then the locked rotor or motor starting kva is calculated by multiplying the kva per horsepower by the horsepower of the motor, using the motor starting kva table on Figure 13-1. Code F is often applicable and an average value of 5.3 may be used. Value of skva for a 200 hp motor code is 1060 kva. The applicable formula is ska=locked rotor current x volts x 1.732/1000. For any motor, the locked rotor kva draw is the same regardless of the phase, speed, and voltage rating on the motor nameplate, provided that the motor is connected to rated (nameplate) voltage.

From a stationary condition the motor has to be accelerated to its operating rpm. The kva draw during motor acceleration is taken to be the same as the locked rotor kva determined from the tables, because the kva draw at locked rotor conditon persists until the motor has reached approximately 2/3 of rated speed. For this reason, in the following calculations, the kva draw during motor acceleration is taken to be the same as the locked rotor kva determined from the tables. During the accelerating period (up to 2/3 speed) the kva draw of the motor is much higher than the running kva draw. The kw draw during this period is also greater than the running kw draw and is approximately half the accelerating kva draw. The accelerating kw draw reaches a maximum value at about 2/3 of rated motor speed. The shaft load on the motor affects the time required to accelerate to running speed, but does not affect the kva nor kw demand during the accelerating period. As the motor accelerates from 2/3 speed to rated speed, the kva draw diminishes to the running kva which is determined by service load on the motor. From 2/3 speed to running speed, the kw demand diminishes to about 74 per cent of the running kva for small motors and 90 per cent of the running kva for large motors. When a motor is connected to an emergency

GENERATOR UNIT SELECTION CHART

60 HZ RATINGS (kW) at 0.8 P.F.					Σ OF RUNNING & STARTING KVA		
INTERMIT. RATING	PRIME RATING	CONT. RATING	CONT. R.P.M.	GENERATOR SET	10 % DIP	20 % DIP	30 % DIP
970	850	745	1200	D399 TA	575	1200	2000
845	670	665	1800	D349 TA	470	1260	1600
725	600	560	1200	D398 TA	270	620	1130
635	530	500	1800	D348 TA	280	630	1230
485	420	375	1200	D379 TA	240	500	950
560	395	390	1800	3412 TA	230	470	810
410	335	330	1800	D346 TA	216	440	740
485	320	335	1800	3412 TT	160	410	700
365	300	280	1200	D353 TA	200	400	800
430	295	300	1800	3412 T	160	410	700
355	285	270	1800	3408 TA	175	330	560
350	250	240	1800	D343 TA	175	330	560
315	235	225	1800	3408 T	175	330	560
280	210	205	1800	3406 TA	155	320	498
240	200	185	1800	3406 T	137	290	448
200	165	160	2000	3306 A	130	263	390
170	135	125	2000	3306 T	125	247	365
110	100	95	2000	3306 NA	85	165	240
125	100	95	2000	3304 T	85	165	240
75	70	65	2000	3304 NA	58	114	170

THIS TABLE IS TO BE USED AS AN EXAMPLE FOR COMPUTATIONAL EXERCISES ONLY. GENERATOR SET MODEL NUMBERS ARE TAKEN FROM CATERPILLAR TRACTOR CO. PUBLISHED LITERATURE BUT PRIME RATINGS SHOWN MAY NOT REPRESENT CURRENT MANUFACTURERS STANDARDS.

TA — TURBOCHARGED-AFTERCOOLED
T — TURBOCHARGED
TT — TWIN TURBOCHARGED
A — AFTERCOOLED
NA — NATURALLY ASPIRATED

TYPE	MULT. SKVA BY
RESISTOR, REACTOR, IMPEDANCE	
80% TAP	0.80
65% TAP	0.65
50% TAP	0.50
45% TAP	0.45
AUTOTRANSFORMER	
80% TAP	0.68
65% TAP	0.46
50% TAP	0.29
Y START, Δ RUN	0.33

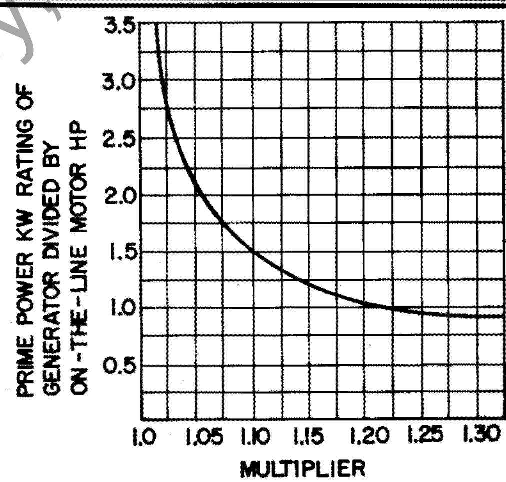
REDUCED VOLTAGE STARTING FACTORS

NEMA CODE LETTER	STARTING kVA PER HP
A	0.00 – 3.14
B	3.15 – 3.54
C	3.55 – 3.99
D	4.00 – 4.49
E	4.50 – 4.99
F	5.00 – 5.59
G	5.60 – 6.29
H	6.30 – 7.09
J	7.10 – 7.99
K	8.00 – 8.99
L	9.00 – 9.99
M	10.00 – 11.19
N	11.20 – 12.49
P	12.50 – 13.99
R	14.00 – 15.99
S	16.00 – 17.99
T	18.00 – 19.99
U	20.00 – 22.39
V	22.40 –

MOTOR STARTING kVA

HP	RUNNING KVA	RUNNING KW
1	1.22	.9
1½	1.75	1.4
2	2.3	1.8
3	3.3	2.6
5	5.4	4.4
7½	7.8	6.6
10	10.2	8.8
15	14.9	13.0
20	19.5	17.2
25	24.0	21.2
30	27.5	25.1
40	38.0	33.5
50	46.5	42.0
60	55.0	50.0
75	69.0	62.0
100	90.0	83.0
125	111.0	104.0
150	133.0	123.0
200	175.0	164.0

THREE – PHASE INDUCTION TYPE MOTORS-RUNNING KVA AND KW



PRELOAD MULTIPLIER FOR MOTORS ON THE LINE

DATA IN TABLE ABOVE ARE MOTOR LOADS AS "SEEN" BY THE GENERATOR AND INCLUDE COMPUTATIONS OF MOTOR EFFICIENCY AND POWER FACTOR.

FIGURE 13-1. EMERGENCY GENERATOR SELECTION generator which is not rated at the same voltage as the motor (for example 440 volt motor on a 480 volt generator), a correction must be made in the locked rotor kva.

Allowable voltage dip for starting a loaded motor is 20 per cent. This means that as the pump motor starts, accelerates and picks up load from the pump itself coming up to functioning condition, the generator must be able to provide the kva associated with the 20 per cent voltage dip.

13-D. COMPUTATIONS FOR GENERATOR-SET SELECTION

Assuming that the voltage of 480v and three-phase current are already established, the only basic data required to select a generator is total load served, largest motor driven with others in descending sizes, and motor code, from which is determined the kva and kw loads under locked rotor, accelerating and running conditions.

The total load to be served is easily computed from the single-line diagram for the station showing all connected loads, motor horsepowers, and lighting and other single-phase loads. The horsepower of the largest motor is special significance, because of the starting current required. Other motor sizes are to be listed in descending sequence, so that the starting current for each when added to the running currents of the larger motor or motors, produces the least total current requirement.

NEMA has standardized the running kva and kw of three-phase squirrel cage induction motors up to 200 hp and these values are tabulated in Figure 13-1. Also in Figure 13-1 is shown a Preload Multiplier for motors on the line. The total running kva of all these motors must be increased by the multiplier and added to the starting kva of the motor being started. The reason for this is that the running kva of the motors already on line will be increased somewhat due to the voltage dip when starting another motor, and this must be allowed for. Tentatively selecting a certain generator set, the sum of the running and starting kva thus produced is then compared with the kva for various percentages of dip. If less than the tabulated value for 20% dip the tentative selection is satisfactory. If the sum of the running and starting kva is more than the value for 20% another selection must be made.

The following computations are for the selection of a generator set to suit a station that has 480 volt, 3 phase, 60 hertz service, two main pumps with 200 hp motors and two smaller pumps with 100 hp motors. In addition, there is a 10 hp sump pump and a bridge crane which require approximately 15 kw of three-phase service.

All motors are NEMA Code F. There is approximately 15 kw of single-phase load consisting of lighting and miscellaneous equipment.

The kilowatt ratings of the motors are quickly calculated initially for a tentative selection of generator size. The values used are taken from the table at running kva and kw values for three-phase induction type motors in Figure 13-1.

2-200 hp motors @ 164 kw each =	328 kw
2-100 hp motors @ 82.5 kw each =	165 kw
Sump pump and bridge crane	15 kw
Lighting and other single phase loads	15 kw
Total connected load	523 kw

Allowing for starting kva considerations, Figure 13-1 shows that a Caterpillar D348 TA generator set might be suitable, since this has a prime rating of 530 kw and a stand-by rating of 630 kw.

With starting kva given detailed consideration, more extensive computations are necessary.

Motor starting sequence	First	Second	Third	Fourth
Horse-power of each motor	200	200	100	100
Full voltage across-the-line skva, using 5.3 skva/hp	1,060	1,060	530	530
Prime power kw rating Cat D348 TA	530	---	---	---
20% Dip kva	630)	) From Figure 13-1		
30% Dip kva	1230)			

Therefore without considering the second, third and fourth motors we see directly that the D348 TA is not suitable for starting a 200 hp motor across-the-line. Another selection must be made. Based on running and starting kva of 1260 read from Figure 13-1 the D349 TA should be suitable and is next tried, with the computation procedure lengthened.

Motor starting sequence	First	Second	Third	Fourth
Horsepower of each motor	200	200	100	100

Full voltage skva	1060	1060	530	530
Prime power kw rating of Cat D349 TA	670	---	---	---
Total hp of motors already started	---	200	400	500
Prime power kw/ on-the-line hp	---	670/200 3.35	670/400 1.67	670/500 1.34
Multiplier from graph	---	1.02	1.08	1.12
Running kva of motors already on the line	---	164	164 164 328	82.5 164 164 410
Running kva x Multiplier		167	354	459
Starting kva	1060	1060	530	530
Σ Running & Starting kva	1060	1227	884	989

Therefore the Cat D349 TA with 1260 kva at 20% dip is a satisfactory selection. Significantly, the continuous rating of the diesel engine driver is 890 hp. This is necessary to start and run 600 hp of large electric motors. The lighting and other loads are not significant and need not be included in the tabulation.

In a quick check it will be found that if the starting sequence is 100/200/200/100 the maximum kva is 1318 at starting the second 200 hp motor. If the sequence is 100/100/200/200 the maximum kva is 1415. This confirms the importance of starting the largest motors first to minimize voltage dip. This requirement does not necessarily conform to the normal sequence of pump starting in response to water level.

In a permanent installation the generator is connected to the station switchgear through a transfer switch which senses loss of utility power and trips to start the generator engine through its starting battery. The engine comes up to speed and the generator is ready to start the pumps. If pumps had been running at the moment of utility power outage they must be re-started in sequence, and the generator will then continue to run until power is restored. Preferably, starting occurs only if the pumps had been running.

If the pumps are connected to utility power through reduced voltage starting a smaller generator is needed. There is thus an

Trailer-mounted emergency generator
of the type used by Caltrans

Figure 13-2

Generator control panel

Figure 13-3

economic trade-off where across-the-line is possible, this being the cost of across-the-line starting and larger generator set versus reduced-voltage starting and smaller generator.

13-E. THE MOBILE GENERATOR CONCEPT

Emergency or transportable equipment to start very large motors is expensive and usually impractical. It can only be justified in unusual circumstances. On the other hand, it is feasible to provide for starting medium-size or smaller motors, especially those as installed in dry-pit stations of the California type. Caltrans has an effective program to provide this stand-by capability, each generator being trailer-mounted and garaged in a location suitable to serve a number of stations.

A generator must be compatible with the stations it serves to avoid overload, incorrect pump rotation and accidents to personnel. Figure 2-4 in Chapter 2 shows the garaging of a typical generator unit. Figure 12-6 shows a male receptacle and manual transfer switch. The wall mounted receptacle and mating female connector supplied with the generator must be polarized to prevent improper connections. The generator output connector must have the same phase-rotation as the male receptacle located at each pump station. If not checked prior to application, it is possible the motors would run backwards when the stand-by power is applied. When required to operate, the generator is brought into place adjacent to the station, the lead cables are plugged into the receptacle, the unit is started, and with the transfer switch correctly set, the motors can be restarted one at a time.

The location of the garage or storage of the towable emergency generator is very important. One method is to store it at a central maintenance yard with alternate routes available to all highway pump stations that the generator is to serve. An alternate method is to locate it at one of the pump stations it is to protect, as in Figure 2-4. Careful planning must be done to assure that the unit can be moved to any station within the area speedily. Frequently, the only highway route open to the emergency truck towing the unit is the one that is being flooded by the power outage.

Figures 12-6 and 12-8 showing station panel board can be reviewed. With all equipment in place, the procedure for transferring to stand-by power is as follows:

- Open circuit breaker on generator.
- Start engine.
- Plug-in portable cord.
- Turn manual transfer switch to stand-by.

- If ventilation equipment is required to run prior to operating pumps, open all main circuit breakers except those serving the ventilation equipment.

- Place all pump controls in "Off" position.

- Check generator control panel for proper voltage, frequency, and engine temperature.

- Close main circuit breaker at generator control panel.

- Turn control switch for largest pump motor to "manual" position.

- Start largest motor and allow it to accelerate to normal speed.

- Start other motors in sequence of descending size observing generator voltmeter. Voltage will not drop more than 20 per cent of generator rating if generator is properly sized and each motor is started and accelerated in sequence as described.

- To transfer back to normal power, follow the above procedures in reverse order. Do not restart any motor until it has come to a full stop.

Figure 13-2 shows a trailer-mounted stand-by generator of the type used by Caltrans. Figure 13-3 shows the generator control panel.

* * * * * * * * *

CHAPTER 14. CONSTRUCTION DETAILS

14-A. GENERAL

Details of construction as they relate to general types of work such as highways, bridges and buildings are assumed to be well understood. The pump station designer will be able in many cases to use details and standard specifications with which he is familiar. This chapter emphasizes conditions and requirements which are specialized and relate specifically to pump stations. Chapter 15. - Station Design Calculations and Layouts, gives a listing of 30 or more items, accessories or systems which may be found in pump stations. Some stations may have them all, some only a few, according to the need perceived.

Architectural and structural factors are first considered, followed by cranes and hoists, ventilation and plumbing, protective coatings, and some miscellaneous items such as fire protection, intrusion alarms, gas detection, instrumentation and telemetering. Appendix D - Specifications should also be studied for further details and can be used as a guide to assist the writing of specifications for a particular project.

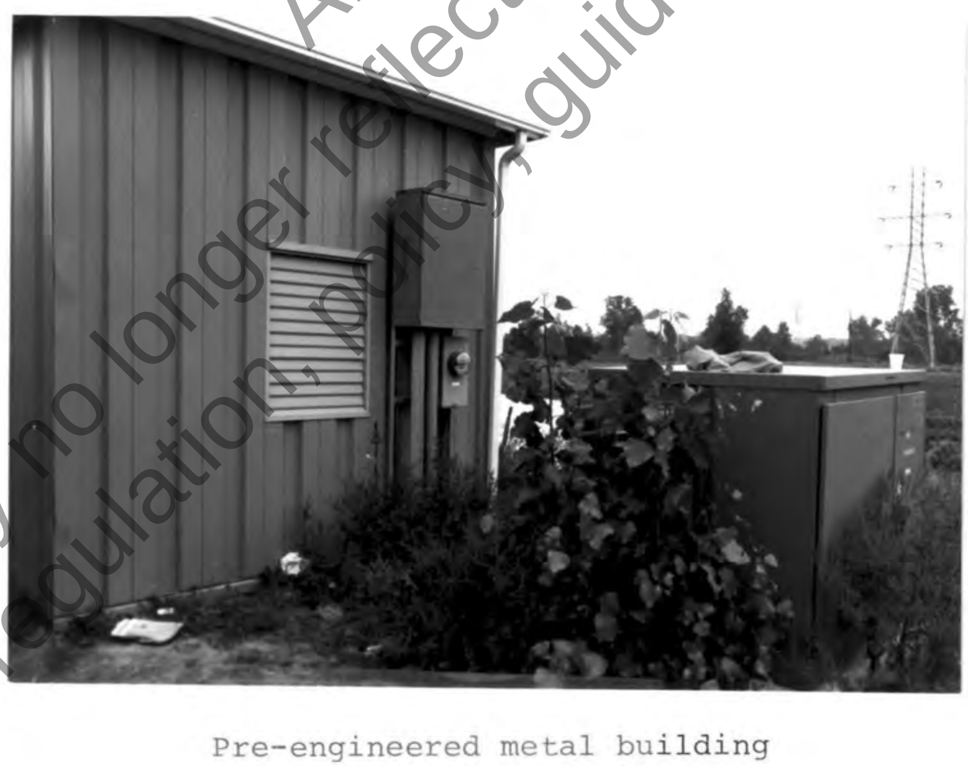
14-B. ARCHITECTURAL CONSIDERATIONS

Architecture in relation to pump stations may be narrowly defined as having to do only with the visual appearance of stations, which will vary greatly from one area to another depending on any prevailing standards of the agency, station location and other factors. Interior arrangements of space and amenity which are usually important facets of architecture will be subordinated to provisions for accommodating the necessary pumping machinery, with only the minimal space and facilities required for safe access, safe working areas and the convenience of personnel. Chapter 3. - Site Conditions, should be reviewed at this point because the text is relevant and the figures therein show increasing attention being paid to aesthetic values.

For pump station superstructures, concrete and masonry are the most widely-used materials. Figures 3-7 and 3-8 show rectangular masonry superstructures above caisson construction, and may be compared with the austere and unattractive concrete caisson superstructure shown in Figure 14-1. Wood frame and stucco shelters have had very little use and pre-engineered metal buildings as shown in Figure 14-2 have limited application. The metal superstructure is colorful and neat, usually with contrasting trim, but a

Poured concrete superstructure
for caisson-type pump station

Figure 14-1

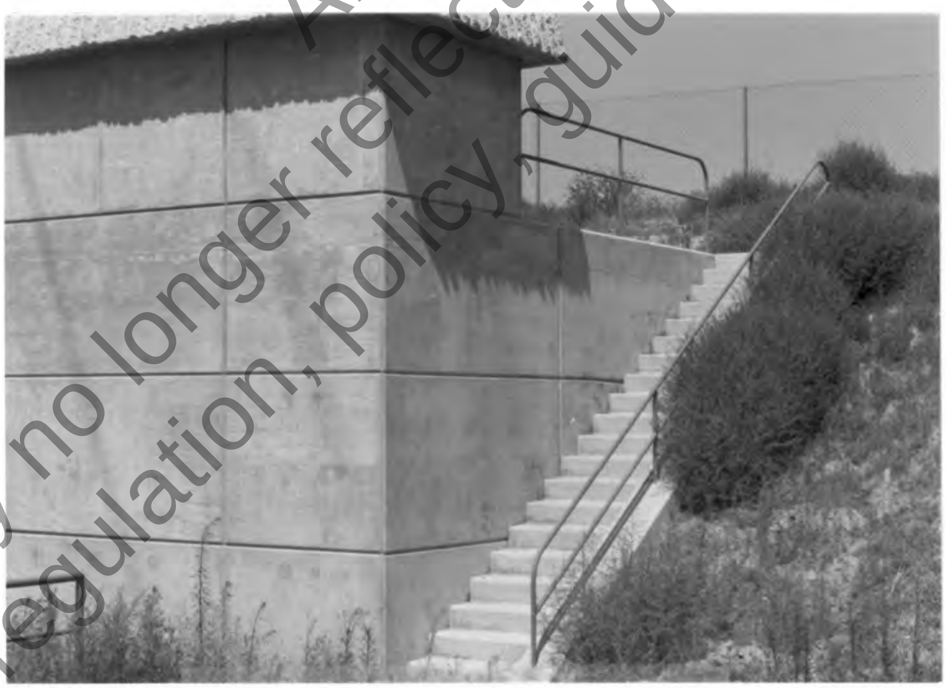


Pre-engineered metal building
for pump controls

Figure 14-2

Exposed aggregate wall panel

Figure 14-3



Architectural concrete for
dry-pit pump station

Figure 14-4

more substantial structure is usually preferred. Figures 14-3 and 14-4 show pleasing examples of work in concrete.

14-C. CHOICE OF MATERIALS

For the substructure of a pump station, the conventional choice is reinforced concrete, but the method of placement varies. Cast-in-place construction is usually used for rectangular pump pits. For caissons, concrete is normally precast either at the site or elsewhere and then sunk to required level. In the case illustrated in Figure 2-28, large-diameter precast concrete sewer pipe was used to construct the pit. Precast rectangular vaults as shown in Figures 2-26 and 2-27 have also been used for very small stations with submersible pumps. Cast-iron or pressed steel rings have been used in the past for caisson-type stations and steel vessels have been used for sewage lift stations. However, precast or cast-in-place concrete is usually the most suitable material for stormwater pump station substructures.

For pump station superstructures, poured or cast-in-place concrete is very versatile and with reasonable care some very effective results can be obtained. Some variations in treatment include the use of aggregate of various colors with light, medium or heavy sandblasting; fiberglas forms, molded to various shapes and curvatures; single-use polystyrene form liners indented to create a brick or block masonry pattern; or form linings to produce textures such as handsplit cedar or rough-sawn lumber.

In Figure 14-4, the rectangular pattern in the concrete was created by nailing square or vee strips to the forms. The simulated textured roof was created by nailing reinforcing bars to the forms. Figure 7-1 shows more detail of a similar station. Other examples where parts of the walls are exposed aggregate, or aggregate finish, are shown in Figures 2-7, 2-15 and 14-3. Precast wall panels or units rarely have a place in pump station construction due to the small size of the average station and the number of openings in the wall structure. Rock-salt finish is frequently used for flat concrete work. The salt dissolves leaving a pock-marked surface.

Masonry will usually be either brick or concrete block, although natural stone may have a place, either as a solid wall or a veneer over interior wythes of common brick or plain concrete block. A face brick of some type is usually pleasing, with or without exposed concrete columns, beams or other features. However, concrete block masonry is usually preferred over brick due to the greater variety of block type and size available.

Common precision block, devoid of ornament, tends to produce a mediocre or utilitarian appearance. On the other hand, slumped block or split face block, properly detailed, can give pleasing results. Figure 3-8 is an example of this. A pale yellow color block was used, with matching mortar. Grey block and plain mortar painted with any selected color may also be used. Split face block was used for the station illustrated in Figure 14-18. The radiused corners of the building improved the appearance with insignificant cost increase.

It is not appropriate to recommend the use of concrete for superstructures in preference to masonry, or vice versa. The proper use of either can produce very satisfactory results.

14-D. STRUCTURAL ANALYSIS

An adequately designed foundation for the pump station is essential. In particular, the need for piling and the possibility of hydrostatic uplift must always be checked. An exterior waterproofing membrane may be required to prevent groundwater infiltration.

The foundation investigation involves determination of the seismic factor in some localities. A seismic factor that is higher than usual building code values is sometimes necessary due to proximity of the station to active earthquake faults. A recently constructed station in Southern California was designed for a seismic factor of .45g. This high factor was resisted without much special provision in the superstructure. The main structural problem occurred in the walls below grade, due to the very high combinations of active and passive lateral soil pressures. The necessity of interior wall stiffening to resist the high bending moments and shears, and the two-way spanning of the wall panels contributed significantly to the complexity of the structural design of the box-type structure. An isometric view of this structure is shown in Figure 14-5.

Elements of the substructure also perform the essential hydraulic function of controlling and directing the flow of water so that there is a very significant combination of form and function in design. The spacing and layout of floor slab openings and supporting beams must be carefully co-ordinated with equipment and access requirements. See Figure 14-6. In some cases, the structural analsyis is straight-forward and presents little difficulty, while in others it may be very involved. An example of a complex case would be a station with a rectangular pump pit deep below grade, having an inlet transition and interior walls, and with the entire station designed to be resistant to high seismic forces.

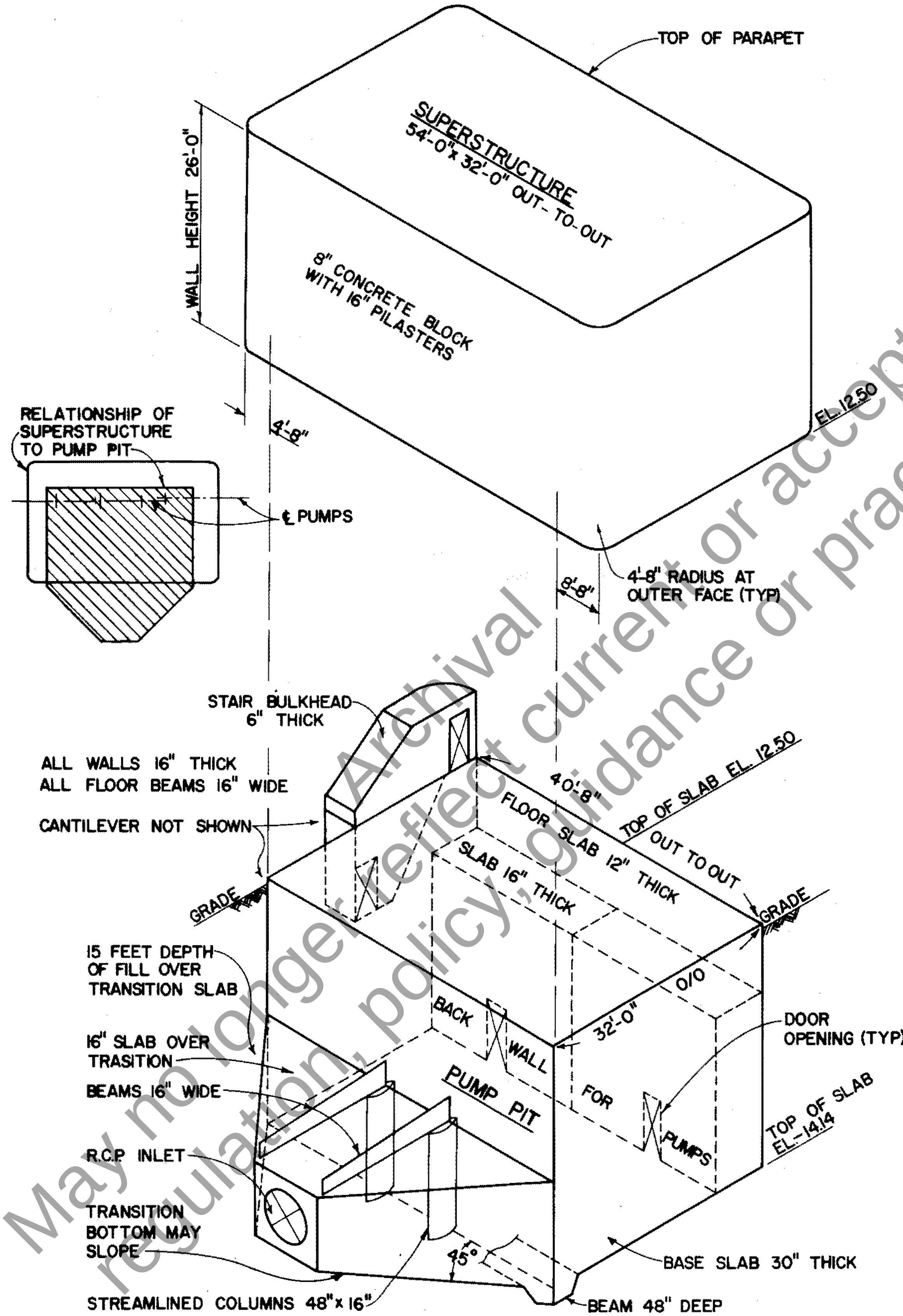


FIGURE 14-5 ISOMETRIC - PUMP STATION STRUCTURE

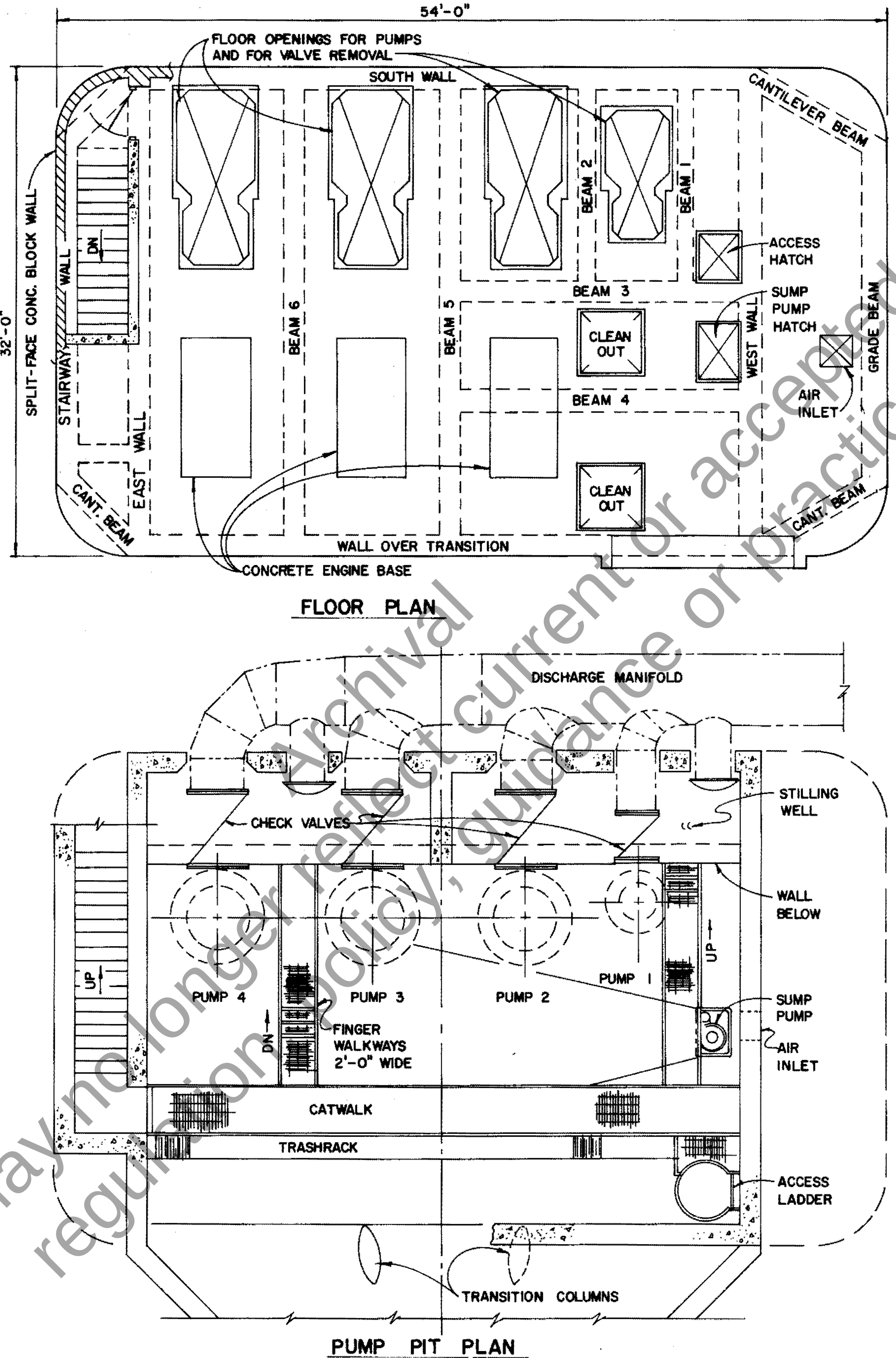


FIGURE 14-6 PUMP STATION LAYOUT

For pump stations, mass and uniformity of concrete sections is preferable to thin, highly stressed and highly reinforced members. This leads to some sensible simplification, but even so the complexity of such a box structure with apertures in floors and walls requires careful analysis, design and detailing. Concrete sections in a pump station should be generously proportioned. Due to the difficulties of forming, there is little to be gained by reducing sections to an assortment of minimum sizes. Also, the added weight of the structure helps to offset buoyancy and to dampen vibrations. Computer-aided design including dynamic analysis is recommended.

Masonry in the superstructure can be designed to withstand high seismic loads. It is essential that all másonry be reinforced, and that all block cells be grouted. If brick is used, a continuous grout core is required. These types of construction are normal in high seismic areas. The use of pilasters on the interior of the walls is more or less essential for the support of crane rails for a top-riding crane, and their combination with a concrete roof provides the box structure required. If insulation of the building is required, it should be internal, rather than hollow wall construction.

14-E. WATERPROOFING AND MISCELLANEOUS METAL

Pump stations require many special features built into their general construction. A selection of these is described in this Section. General building construction details in common usage are not referred to. The sequence of coverage is from bottom of excavation to top of roof, utilizing a wet-pit design as the example.

Waterproofing of the exterior of the pump pit may be necessary. This can be accomplished economically by a rolled-on or hot mop membrane. Alternately corrugated cardboard panels packed with bentonite grains can be used, or PVC sheeting with ribs keyed into the concrete. In a caisson-type station, exterior waterproofing is impractical and dependence must be placed on impermiable concrete walls.

On occasions, the inlet pipe may be of pressure type with rubber gasket joints, and it may also be necessary to allow for movement between the station and the inlet line. A suitable detail is shown in Figure 14-7.

In the pump pit itself the trash rack should be fabricated from A36 structural steel and a modular design using a number of similar panels is convenient. A maximum clear space between bars of less than one and one-half inches is desirable, to prevent passage of a 2 x 4 or similar object which might damage a pump. The

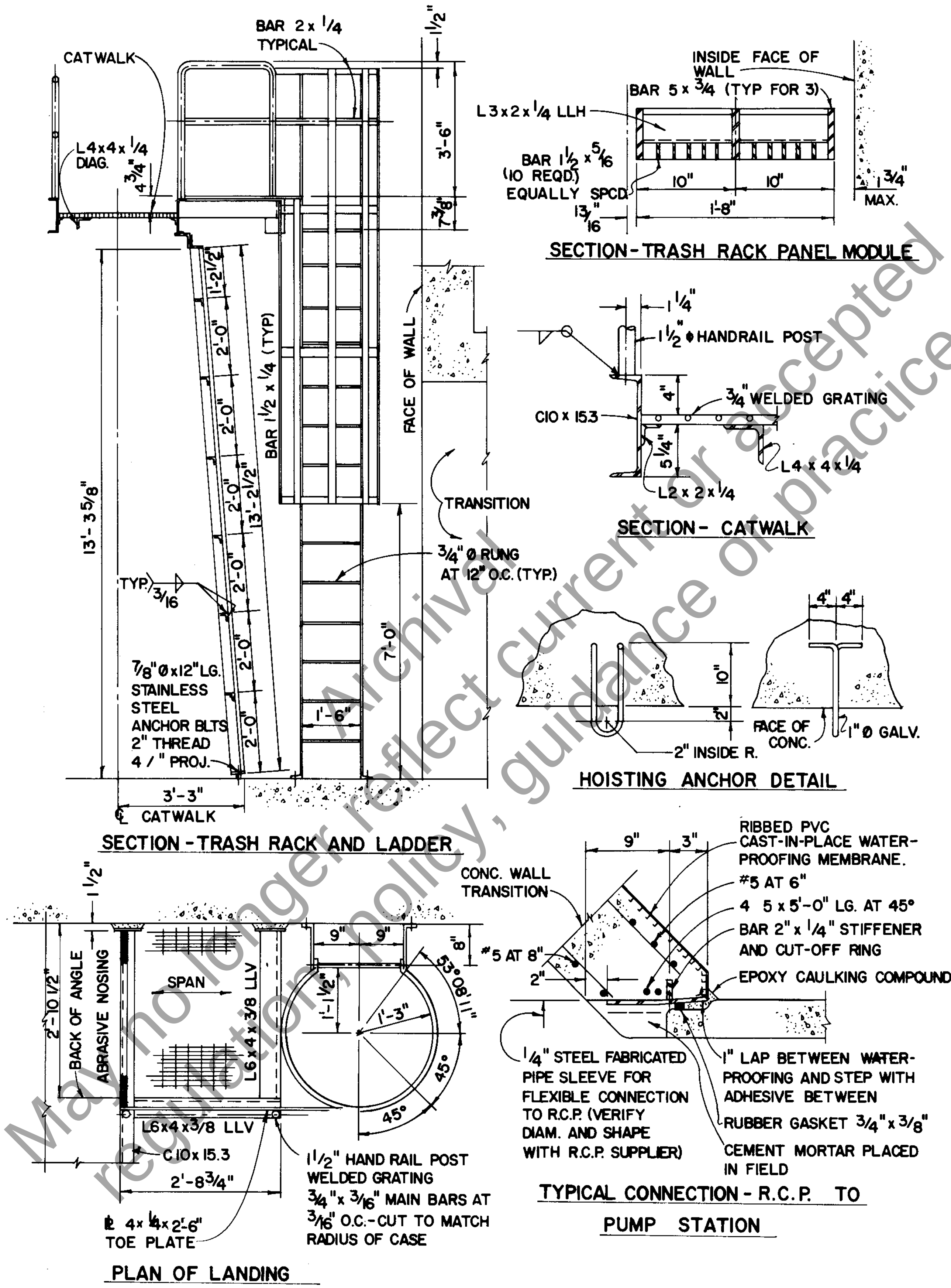
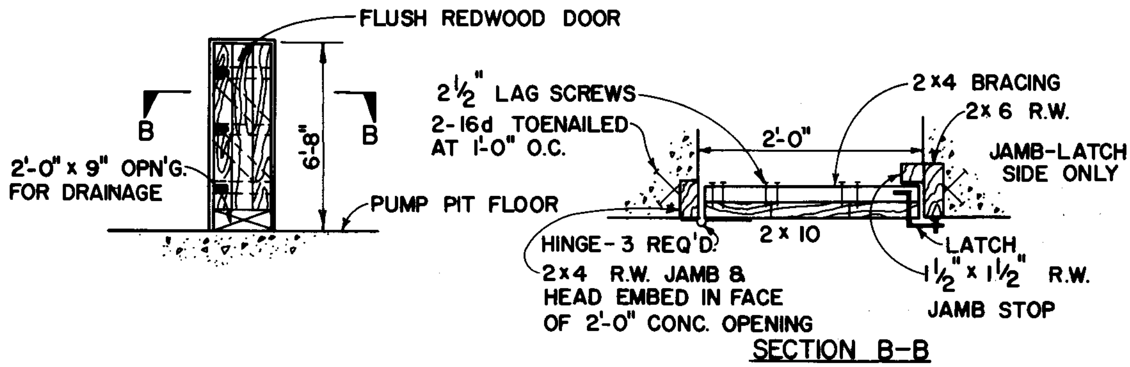
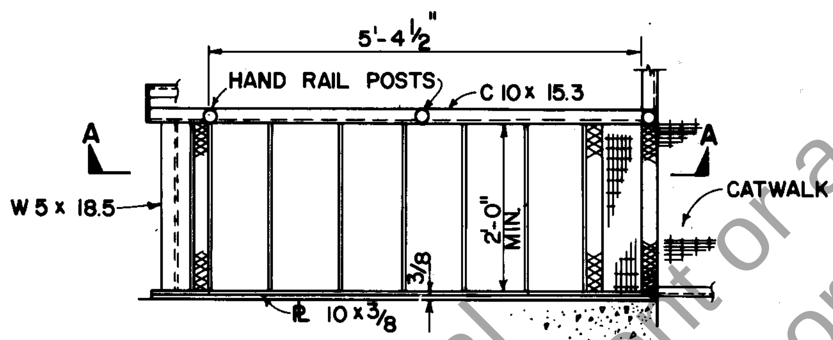


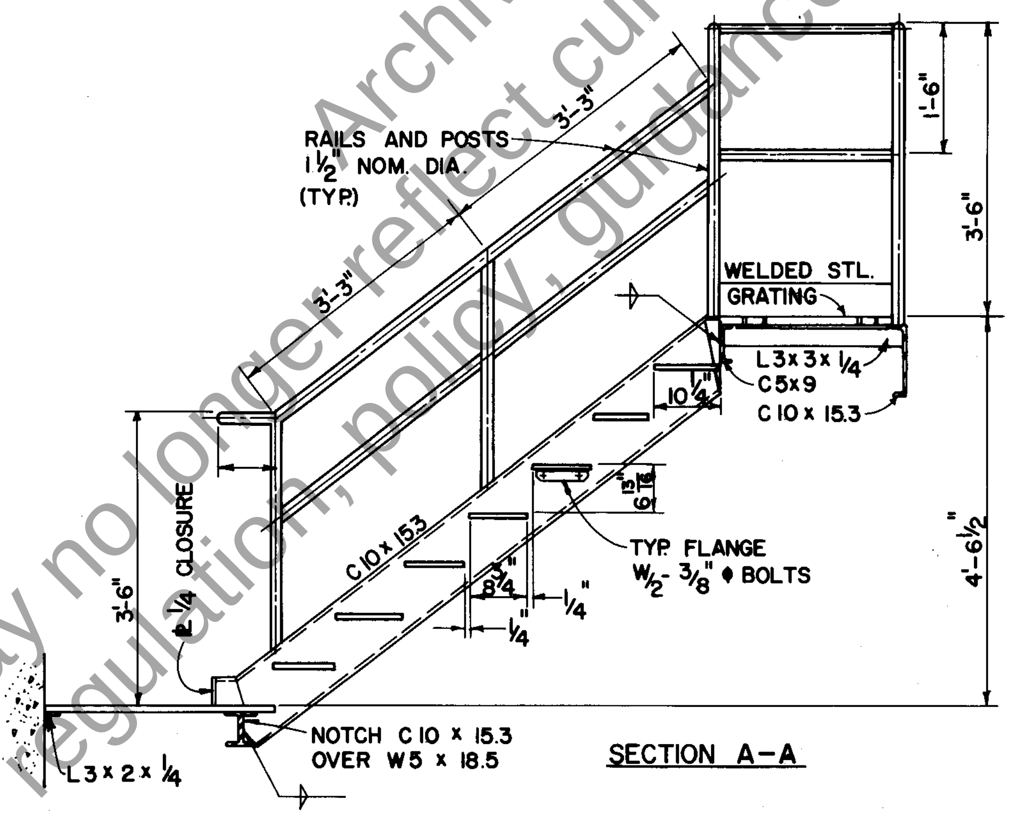
FIGURE 14-7 STEEL FABRICATION DETAILS



REDWOOD DOOR DETAIL



PLAN-STAIRS



SECTION A-A

PORTION OF DOG-LEG STAIR IN 4'-7" WELL

FIGURE 14-8 STAIRWAY AND DOOR DETAILS

trash rack panels are attached to the base slab with corrosion-resistant stainless steel bolts and are bolted at the top to the catwalk. The pattern of the trash rack and its slightly sloping face are intended to facilitate cleaning of the face by raking from the catwalk when necessary. A caged ladder gives access to the upstream portion of the pump pit and transition. See Figure 14-7.

The catwalk extends for the entire width of the pump pit allowing full access to the trash rack, and also by means of finger walkways to other equipment, and to a stairway to the bottom of the pump pit. The catwalk is suspended at several points from the concrete beams below the floor slab, but it is also designed as a horizontal truss to resist the force of moving water against debris on the face of the trash rack.

The catwalk and walkways are made of welded grating and channels. The channels serve as side stringers, and as a toe-plate. A four-inch high toe-plate is needed to meet OSHA requirements. A pipe handrail of required height is attached to the channel. The finger walkways and the stairway are two feet clear width, again meeting OSHA minimums. Stairways are preferred to ladders, since ladders are generally more hazardous, especially when tools or equipment are being carried. See Figure 14-8. Minor, but very useful, accessories in the pump pit are the hoisting anchors embedded in walls or overhead concrete, as in Figure 14-7. These enable rigging to be secured any time dismantling or removal of pumps is required.

All structural steel in the pump pit is welded into sub-assemblies and then galvanized to protect against corrosion. The sub-assemblies are bolted together during installation. Bolted connections avoid the necessity of repairing the galvanizing which would be necessary after field welding. Care should be taken in designing the sub-assemblies with compatible metal thicknesses so that excessive distortions do not occur during the galvanizing process.

For the best hydraulic conditions, a solid backwall behind the pumps should be provided. Therefore, manway openings in the backwall should be closed, except for drainage openings. Wooden doors with redwood verticals, ledged and braced, are satisfactory. These should be set in redwood frames and attached to the concrete by embedded toenails. Door details are shown on Figure 14-8.

The access stairway from the pump pit to the engine room or pump room is enclosed and has a bulkhead with a gasketed gas-tight door. This is provided to seal off the pump pit and prevent gasoline or other explosive vapors from entering the super-structure. Marine-type bulkhead doors are sometimes used, but their high threshold, restricted opening and screw clamps are inconvenient.

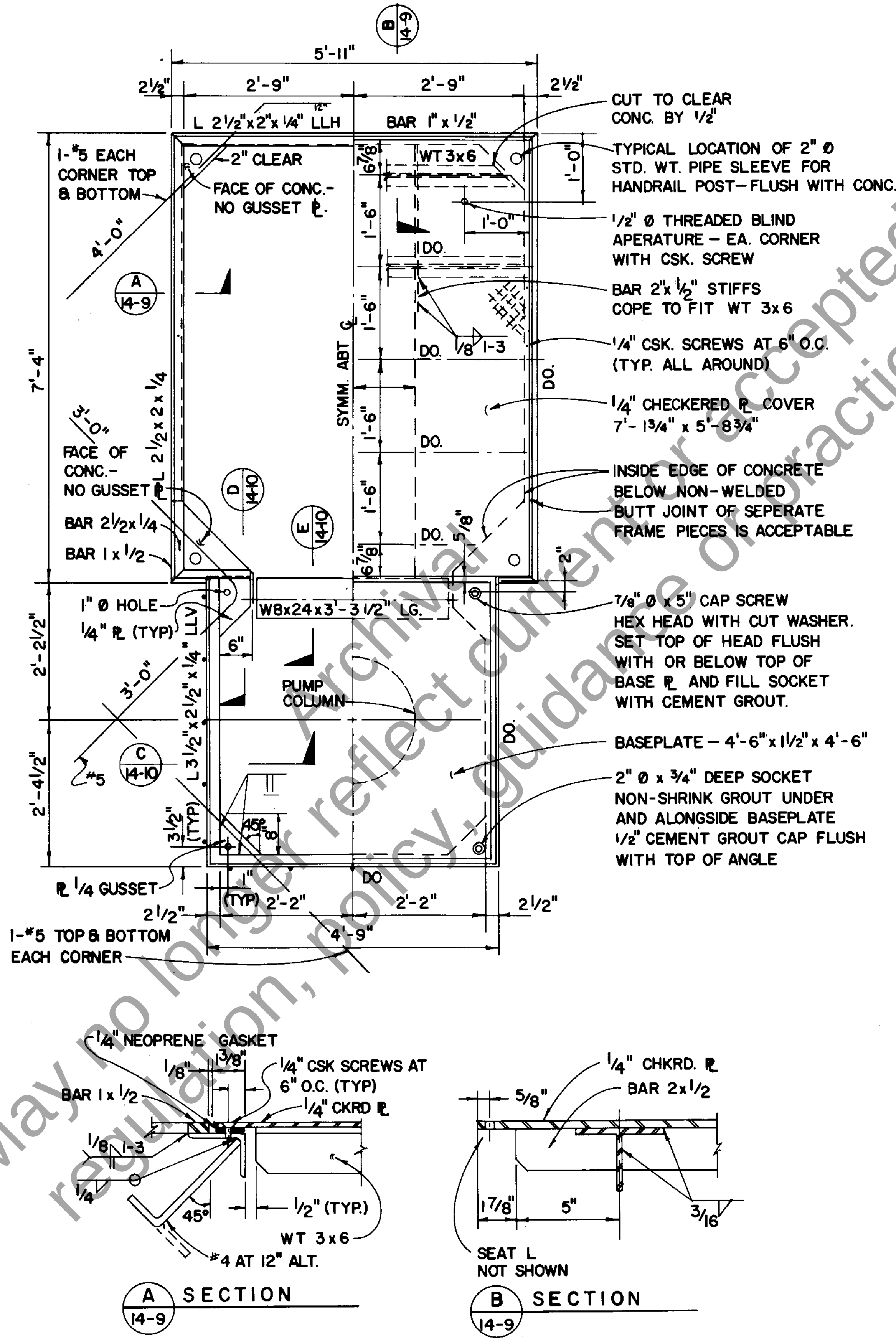


FIGURE 14-9 PUMP BASE FRAME DETAILS I

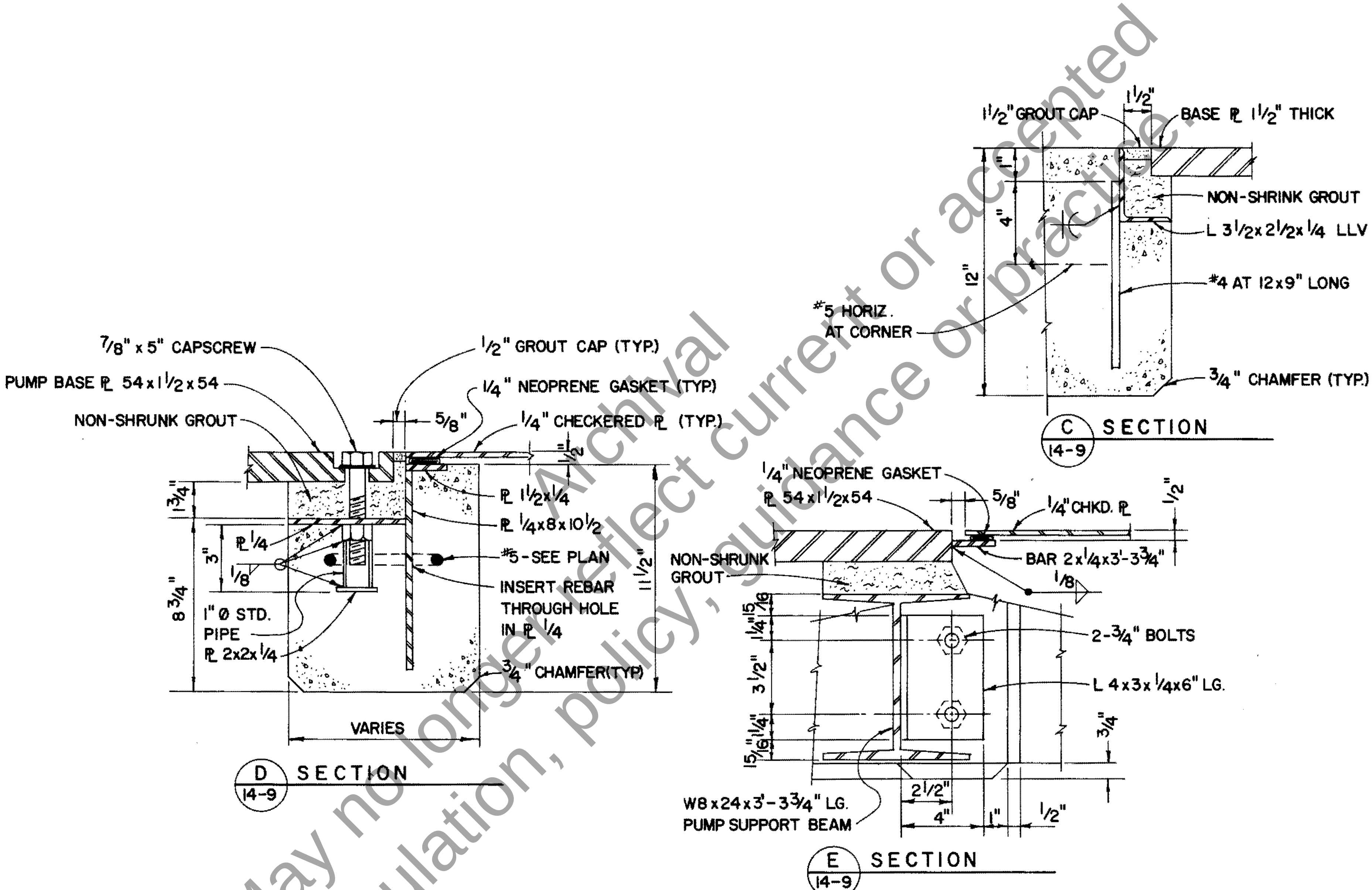


FIGURE 14-10. PUMP BASE FRAME DETAILS II

The pump pit plan and floor plan, Figure 14-6, show the pump pit items referred to, and also the layout of the openings in the floor. Each pump must be set in the pump pit and its motor driver or its gear-head if engine driven must be above the pump room floor. Therefore, an aperture in the floor is required to permit removal of the pump and its elbow and also removal of a check valve if used.

The pump must be securely attached to the concrete floor and a checkerplate cover is provided over the rest of the opening, gasketed and held in place with countersunk screws to be gas tight. An elaborate fabricated pump base is required, securely embedded in the top of the concrete floor. See Figures 14-9 and 14-10. This also is fabricated of A36 steel and is galvanized after fabrication.

Other required floor openings should have an embedded frame and checkered plate to close the opening. Where these openings are large and a heavy floor load is provided for, it is necessary that stiffening ribs be welded to the underside of the checkered plate, and that threaded sockets be placed near the corners so the overhead crane may be used for their removal when necessary. Pump baseplates are normally quite thick and it is desirable to recess the anchor bolts to avoid the hazard of personnel tripping. In fact, special care must be taken throughout the pump room to avoid tripping hazards from electrical conduit stub-ups and runs, or from plumbing and piping runs. Much of this work cannot be shown on the plans except in schematic form, so vigilance is essential during construction to avoid conditions which are not satisfactory.

In addition to the main access to the pump pit by concrete stair, a secondary ladder access at the opposite end should be provided as a safety feature. The access hatch when open must be protected by posts and surrounding chains. Similar provisions for guard posts and chains are made at all other removable cover plates.

Personnel doors are provided at each end of the pump room for ready exit. In addition, a wide roll-up door serves for equipment and truck access. Doors are steel, flush panel, with steel frames and the roll-up door can be operated both by electric motor or manually by chain. Door details can be obtained from standard manufacturers' catalogs, as can all necessary data on hardware.

To discourage vandalism, louvers are more suitable than windows for pump station ventilation. Both electric motors and gas engines generate heat, and gas engines require air for combustion. Cross-ventilation is necessary with either type of driver. Fixed or manually controlled louvers suffice for electric motors, but engines should preferably have thermostatically controlled exhaust louvers. The engine fan draws air across the engine and discharges it through the radiator ducting and the thermostatically controlled louvers to the atmosphere. There is a corresponding inlet of air through manually controlled louvers on the opposite side of the building, which can be adjusted depending on ambient temperature. A louver detail is shown on Figure 14-11 and specifications are included in Appendix D - Specifications. If heat-exchangers are used for engine cooling, it is recommended that louvered air inlets with filters be set low in the exterior walls of the superstructure, with exhaust fans at roof level. This or some similar means must be provided to provide for personnel safety and also for engine combustion air.

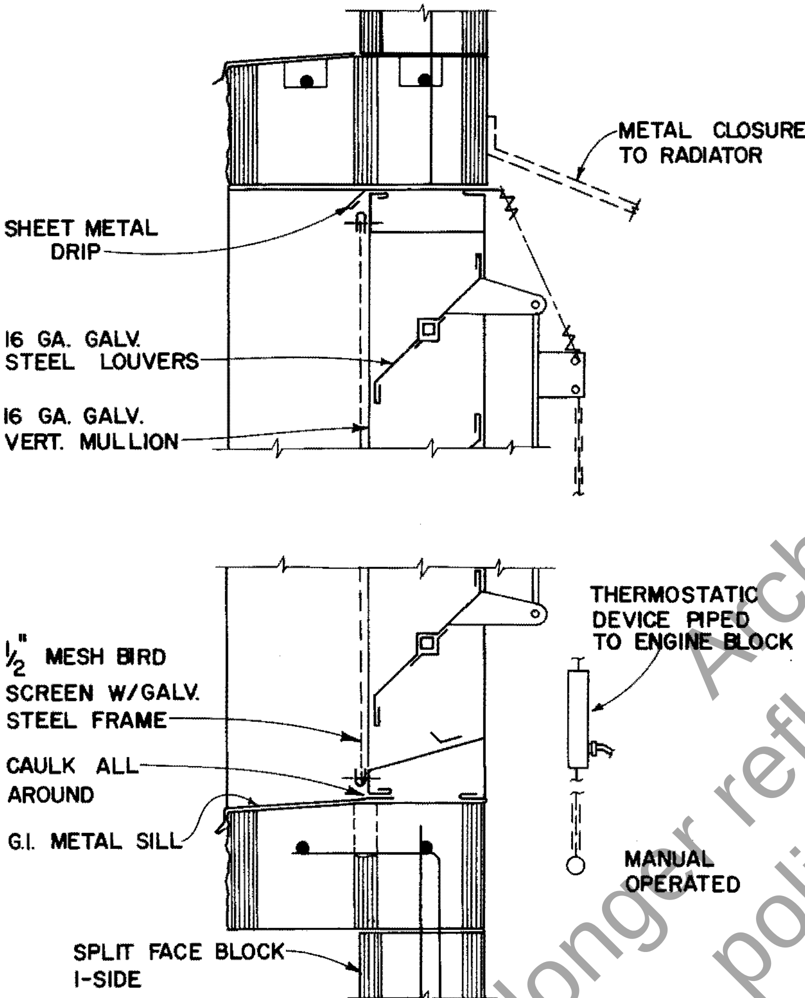
Insulation of engine exhausts is desirable to prevent heat damage and for safety of personnel. Where an exhaust is carried up and through the roof slab, some special provisions are necessary to provide for expansion and to prevent moisture penetration. See Figure 14-11.

14-F. THE NECESSITY FOR LIFTING DEVICES

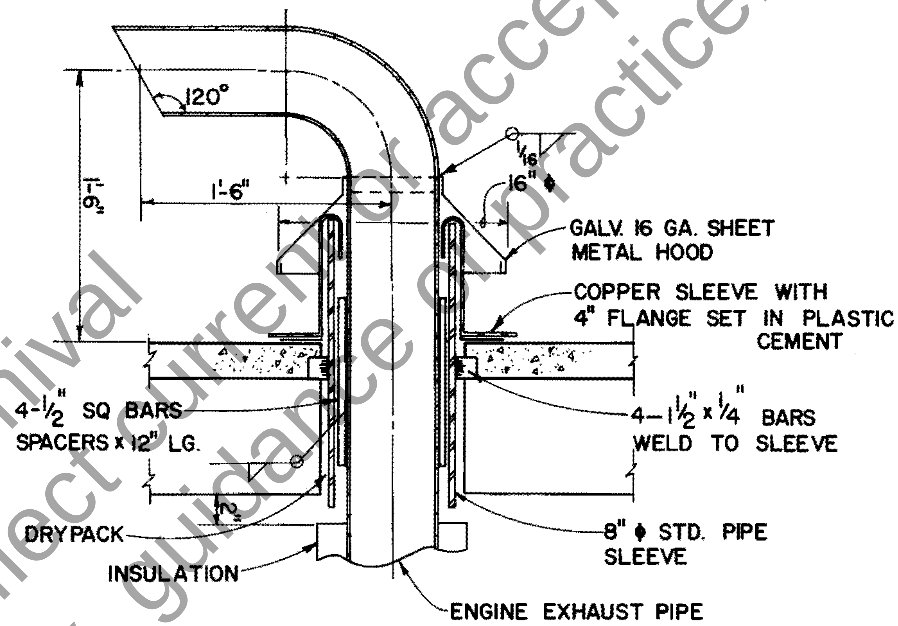
An enclosing structure for a stormwater pumping station presents a problem of access to the pumps and other equipment. At the very least, the enclosure must have roof hatches or covered openings through which equipment can be passed or debris can be removed with a mobile crane. Alternately, overhead bridge-cranes, jib-cranes or monorails may be permanently installed.

Some agencies prefer overhead power-operated bridge-cranes, along with lay-down or work-areas on the pump room floor where equipment can be dismantled or repaired. Others believe it is more cost effective to provide simple hand-chain lifting devices only or to remove equipment from the pump station for repair at a central location.

No single recommendation for handling facilities is made, but it must be remembered that stormwater carries a great deal of mud and debris and the provision of power-operated lifting devices can greatly facilitate debris removal, including loading trucks. The lifting devices may be mobile or permanently installed.



METAL LOUVER DETAILS



ENGINE EXHAUST AT ROOF

FIGURE 14-11. LOUVER AND EXHAUST DETAILS

14-G. OVERHEAD CRANES

There are many manufacturers of overhead cranes, or bridge-cranes as they are sometimes called. A desired standard of materials and workmanship is set forth in Specifications for Electric Overhead Travelling Cranes, published by the Crane Manufacturers Association of America.

Top-riding bridge-cranes, with the end carriages on top of rails set on longitudinal girders, are considered superior to the underhung type where bridge is hung from longitudinal beams set below the roof slab or elsewhere in the structure. But in a pump station this may not be an important factor since the service is Class A-1 (standby), not production, as in a fabricating shop or warehouse. Crane capacity must, of course, be sufficient for largest and heaviest items of equipment to be handled. A 5-ton capacity is normally sufficient.

Bridge-cranes have three directions of movement, longitudinal for the bridge, transversely for the trolley and vertically for the hoist. Any or all of these movements may be manually chain-operated, or they may be completely electrically-powered, which is superior, but costly. Push-button pendant control is standard. See Figure 14-12.

Vertical dimension required under the hook should be clearly shown, to suit pump sections to be removed from the sump. End approach requirement is also indicated, compatible with aisleway width between wall and right angle gear or other equipment. Clearance of roof drains, lighting, electrical switchgear, engine exhausts and the like should not be overlooked. Section 21 of Appendix D - Specifications gives a comprehensive self-explanatory description of requirements.

Various components of bridge-cranes, a typical hoist, and a jib-crane are shown in Figure 14-13. The bridge-crane drive shaft shows the option of an electric motor drive or a hand-chain drive. Either one or the other would be provided, not both. The hand chain is usually limited to smaller bridges of capacity of three (3) tons or less. An example of a simpler and smaller capacity low-head room underhung bridge-crane is shown in Figure 14-14 and Figure 14-15.

The bridge movement is accomplished by pulling on an endless chain hanging within 18 inches of the pump or motor room floor level. The chain wheel should be equipped with a swinging chain guide to prevent "gagging" of the chain when being rapidly handled. The chain wheel must be securely attached to the cross

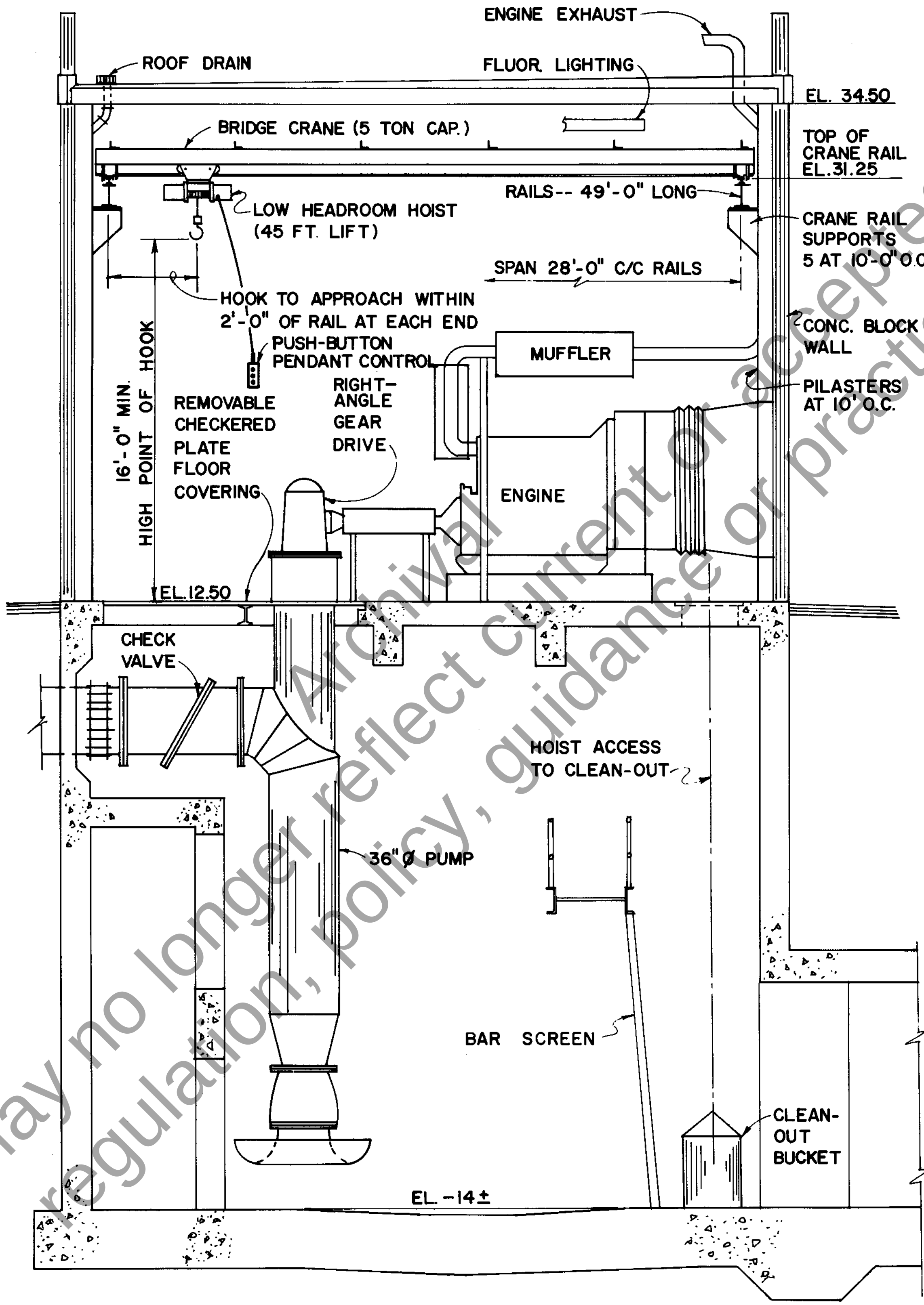


FIGURE 14-12. OVERHEAD CRANE INSTALLATION

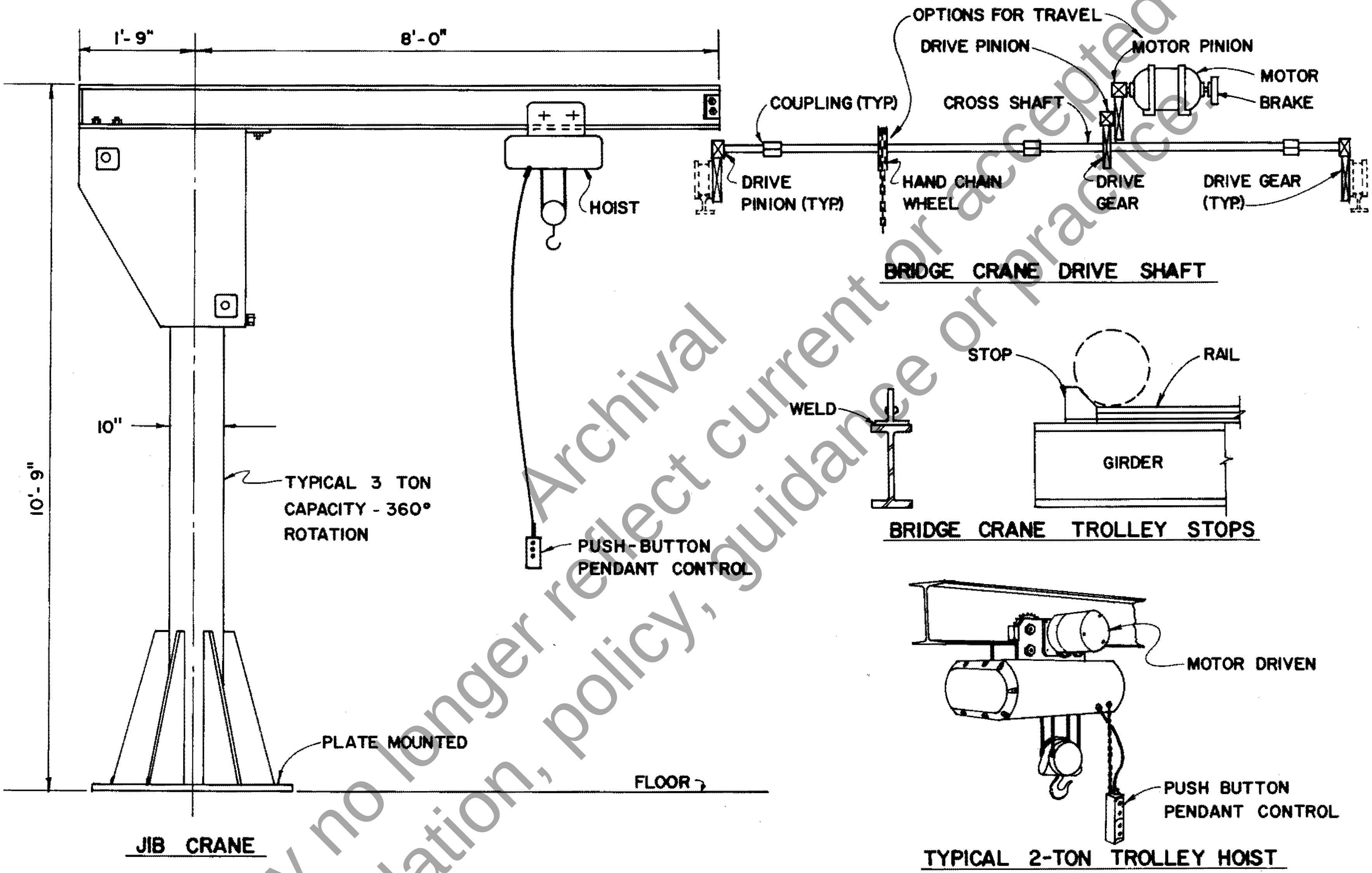


FIGURE 14-13. CRANE AND HOIST COMPONENTS

shaft which should be high-grade cold rolled steel and should extend the full length of the bridge on one side. The cross shaft should be supported at not less than 7'-0" centers by antifriction bearings with grease fittings. A pinion gear should be keyed to each end of the drive shaft to engage the gears on the driving truck wheels. Handrack drive shaft couplings should be mounted within eighteen (18) inches of each end of shaft to simplify maintenance work.

14-H. MONORAILS

A monorail system is a simpler method of handling pumps and equipment, but it is limited, since travel of the hoist is available in one plane only. A configuration with more diversity is shown in Figure 14-16. The monorail system may be designed to accommodate any portion of the gross weights of equipment with suitable safety factors.

The hoist may travel on a monorail by a hand racking system, or may be electrically powered. The hoist should be electric motor operated by a pendant control, or by a push button station located in the building, at a central location. Power to the hoist is usually provided by a reeling cable or tag line. The hook should be mounted in a thrust bearing so that it may be rotated under rated load. The hoist should have right and left hand grooved drum to avoid twisting of the block.

14-I. JIB-CRANES

Jib-cranes have a horizontal arm pivoted at one end, which can swing in a full circle in some cases, or less according to the type of mounting. A hoist, electric or manually-powered, can be positioned as required along the horizontal arm. Horizontal movement of the hoist or rotation of the arm are usually manual operations. The free-standing mounting with full rotation is shown in Figure 14-13, while the wall-mounted type is shown in Figure 2-11. This type is pivoted at top and bottom and has a tie supporting the horizontal arm, making it less expensive but limited in rotation. However, it is very suitable for the use illustrated. Jib-cranes have limited use for handling mechanical equipment in a pump station but obviously are of value in trash handling.

Low headroom bridge crane
Houston, Texas

Figure 14-14

Low headroom hoist

Figure 14-15

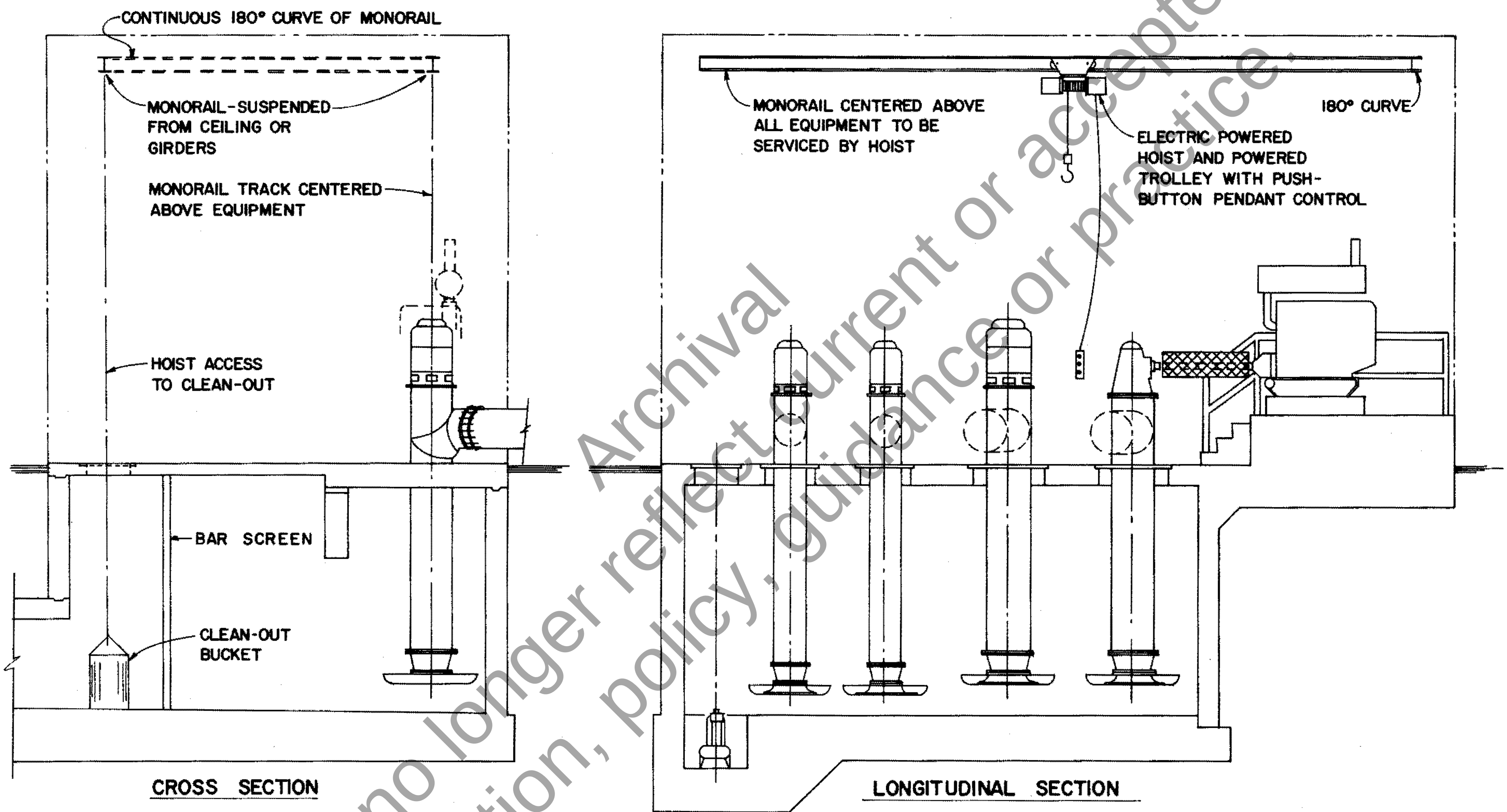


FIGURE 14-16 MONORAIL INSTALLATION

14-J. HOISTS

Regardless of whether an overhead crane, a monorail, a jib-crane or even a simple A-frame is being considered, the hoist is a separate item and possibly the most important element in the lifting equipment.

Hoists may be of manual type, with a single endless chain providing differential action for hoisting or lowering. They are very dependable and safe, and available within the load range required for a pump station. However, manual effort required and slow speed of operation limit their suitability.

Most hoists are electrically powered for the lifting operation and may be suspended from trolleys which in turn are either manually or electrically travelled. As with bridge-cranes, there are many manufacturers nationally, and reference should be made to catalog data. Hoisting and lowering speeds are normally specified together with the vertical range through which the hoist is required to operate. Where a pump pit is very deep it may be necessary to have the hoist fitted with cable drums which are larger than standard, in order to accommodate the extra length of cable. Control is usually by a pendant-type push-button device, the electrical circuitry and wiring being all part of and furnished with the hoist. Inching capability should be specified to enable machinery to be set gently in place. Because of limited vertical clearance, it is often necessary for a low-headroom model to be utilized. Appendix D - Specifications, Section 21, contains data for specifying a hoist, whether it be part of a bridge-crane or other lifting structure.

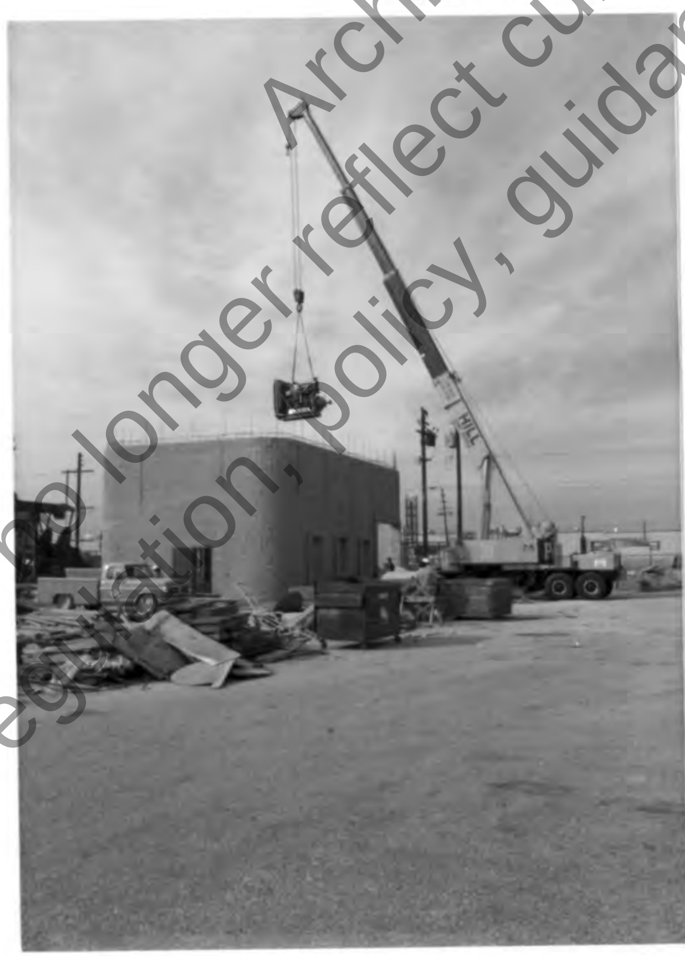
14-K. ROOF HATCHES AND MOBILE EQUIPMENT

To many agencies, mobile equipment justifies the elimination of all hoisting equipment from pumping stations, including those which are powered by gas engines.

Roof hatches must be carefully sized and if possible located directly above each item of equipment. Figure 14-17 shows a circular hatch over each pump, a rectangular hatch over the trash pit and a personnel access hatch. The relative locations can be compared with Figures 2-9 and 2-10 showing the interior of the same station.

Hatches in top of caisson-type station
Detroit, MI

Figure 14-17



Hydraulic crane
lifting engine,
Long Beach, CA

Figure 14-18

Top of station showing accessibility
Detroit, MI

Figure 14-19

Setting 24"
Vertical Pump
Long Beach, CA

Figure 14-20

COURTESY OF THE BILCO COMPANY

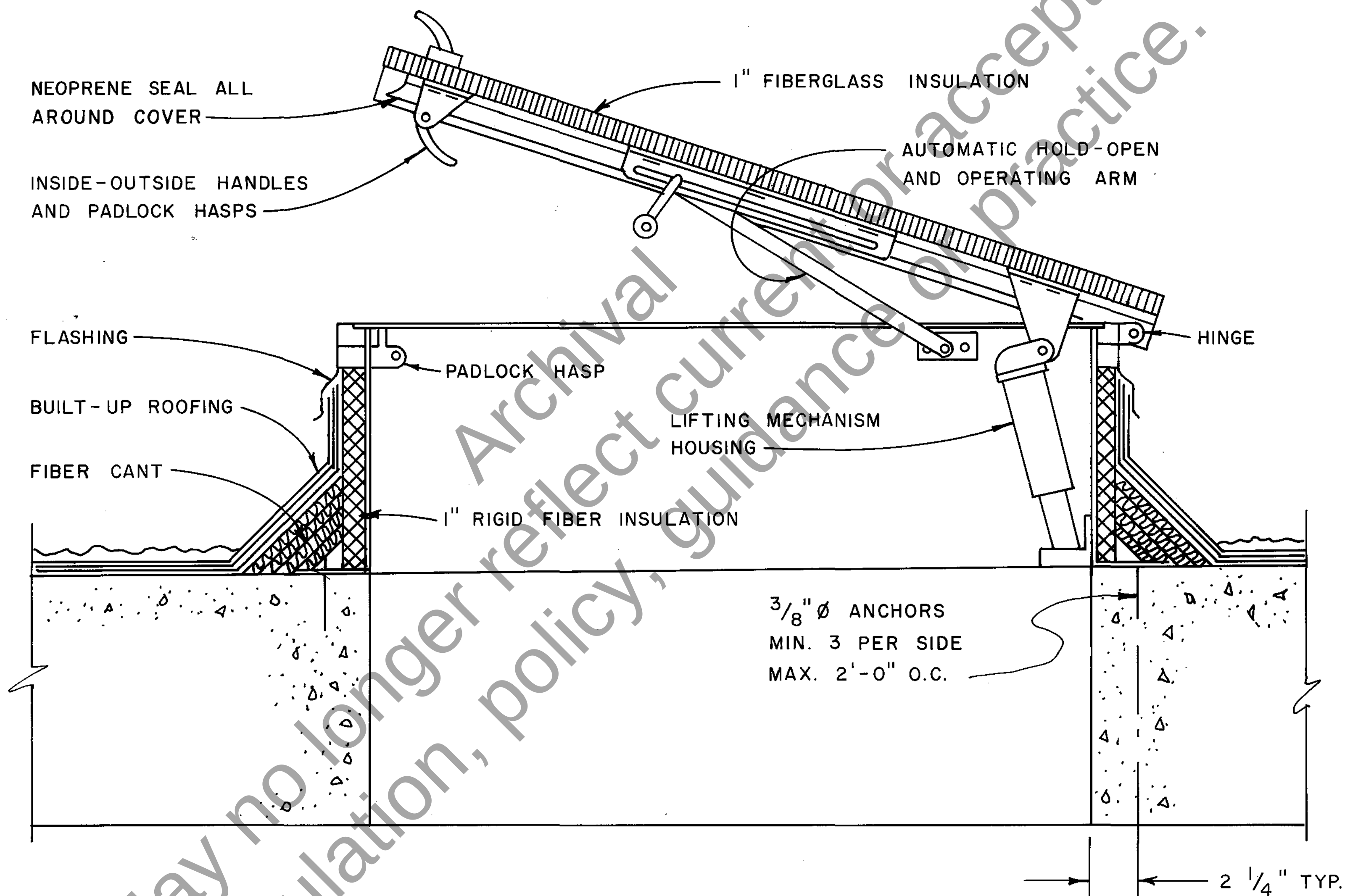


FIGURE 14-21. TYPICAL ROOF SCUTTLE

Rectangular covers will be noted in Figure 2-14, and a comparison should be made with Figure 10-2 which shows the motor and pump which would have to pass through the hatch in the event that their removal was necessary. Figure 14-19 shows general accessibility.

These hatch covers are heavy fabricated metal, and except for the personnel access hatch, can be secured from the inside of the station to prevent vandalism. Circular covers and some rectangular covers will have to be custom designed and fabricated, but it is also possible to use a standard manufactured product, sized to suit requirements. This is shown in Figure 14-21 and is complete with latch and other hardware, and is equally vandal-proof. Use of this product in an actual pump station installation is shown in Figures 2-18 and 2-19, where a single long rectangular roof hatch or scuttle serves for the removal of three pumps. An interesting alternate to conventional roof hatches, used by one agency, is a translucent corrugated plastic covering over a simple structure frame, which can be seen in Figures 2-15, 2-16 and 10-9.

In removing equipment, its rotation to ensure clearance of discharge elbows or other projections is sometimes necessary, but this should present no problem. Where pumps are fitted with suction umbrellas these must be removed in the pump pit. Hoisting eyes embedded in the walls or the overhead beams or slab of the structure are useful in conjunction with come-alongs or other pulling or lifting devices. Figures 14-18 and 14-20 show the use of a mobile crane for equipment installation during construction.

14-L. VENTILATION

Because of its importance to life support and safety, ventilation for even a small pump station will entail careful planning and design. Many stations will not be as complex as the examples which follow, but the figures and the specifications should be helpful.

For pump station ventilation, the type of fan in common use is the belted vent set, which consists of a usually backward-curved centrifugal blade which is in a scroll-type housing with rectangular outlet of given area. The blade wheel is sized to provide the required output in cubic feet per minute and the motor runs at constant speed. By selecting the correct pulleys the units are factory set at the correct operating speed to produce the static pressure required. The static pressure is measured in inches of water column and depends on inlet or outlet conditions and the length and cross-sectional area of ducting. The higher the static pressure, the more fan motor horsepower required. Two belted vent sets were used to ventilate the pump pit of the wet-pit station illustrated in Chapter 15. - Station Design Calculations and Layouts, Figures 15-1 through 15-5.

Natural ventilation for the superstructure of the station is provided by means of louvers and doorway openings. The engines when running exhaust through their radiator louvers and the louvers opposite must be open. The mezzanine office, which has no opening windows, has a ceiling-mounted exhaust fan. When the office door is closed, exterior air enters through a wall vent and is heated, if necessary, by an electric heater. The pump pit is sealed off from the superstructure, but two fans are provided in the pump room. One draws in outside air and discharges into the west side of the pump pit. The other fan on the opposite side of the pump room draws air, possibly contaminated with gasoline fumes, from the east side of the pump pit and discharges it above the roof of the building. This creates proper cross-ventilation of the pump pit.

The fans are run automatically on a timer cycle and provide at least six air changes per hour based on the pump pit volume, which in this case is 30,640 cubic feet. The two fans are sized to deliver 3,000 cfm each, at 1" static pressure. Therefore, they run about half of the time when needed. The fans are shut off in dry weather periods or when the station is unoccupied. The gas presence detector monitors the sump condition at all times and would give an alarm over the telemetering system if a gas condition existed. The fans could then be run to clear the hazard.

Figures 14-22 and 14-23 show a dry-pit station with a centrifugal fan mounted near the bottom of the pit. In this case, there is a long suction duct from grade and a free discharge from the fan. Operating procedures for some dry-pit stations require the fan to be run for a minimum of ten minutes before personnel may descend the ladder into the pit, and the fan is to be run continuously while any personnel are in the pit. In Figure 14-24 a small centrifugal fan is illustrated, drawing air from a circular caisson-type sump at a Texas station. The air enters horizontally and is discharged vertically up the galvanized exhaust duct. The fan discharge in cubic feet per minute in relation to the sump volume is not known. A wall-mounted exhaust fan in the superstructure of a caisson-type station is illustrated in Figure 14-25.

The fan volume is defined as the volume in cubic feet per minute, passing through the fan outlet. In normal application, the volume leaving the fan is substantially equal to that entering, since the change in specific volume between fan inlet and outlet is negligible. The outlet velocity of a fan is obtained by dividing the air volume by the fan outlet area. It is the velocity which would occur at a point removed from the fan in a discharge duct having the same cross sectional area as the fan outlet. It is important that the fan outlet velocity does not describe the velocity conditions which exist at the fan outlet, since all fans have non-uniform outlet velocity. The fan velocity pressure is equal to the outlet velocity divided by 4,005 and squared. The fan total pressure is the difference between the total pressure at the fan outlet and the total pressure at the fan inlet. The fan static pressure is the fan total pressure less the fan velocity pressure, and is the usual condition to be determined prior to selection of a fan. Manufacturers' literature lists fan outputs against various static pressures, stated in inches of water column. The static pressure can be determined from tables based on duct length or other field conditions. Fan motors may be 110 or 208 v. single-phase or 480 v. three-phase. Refer to Appendix D - Specifications, Section 26, for a brief but adequate sample specification for inlet and exhaust fans.

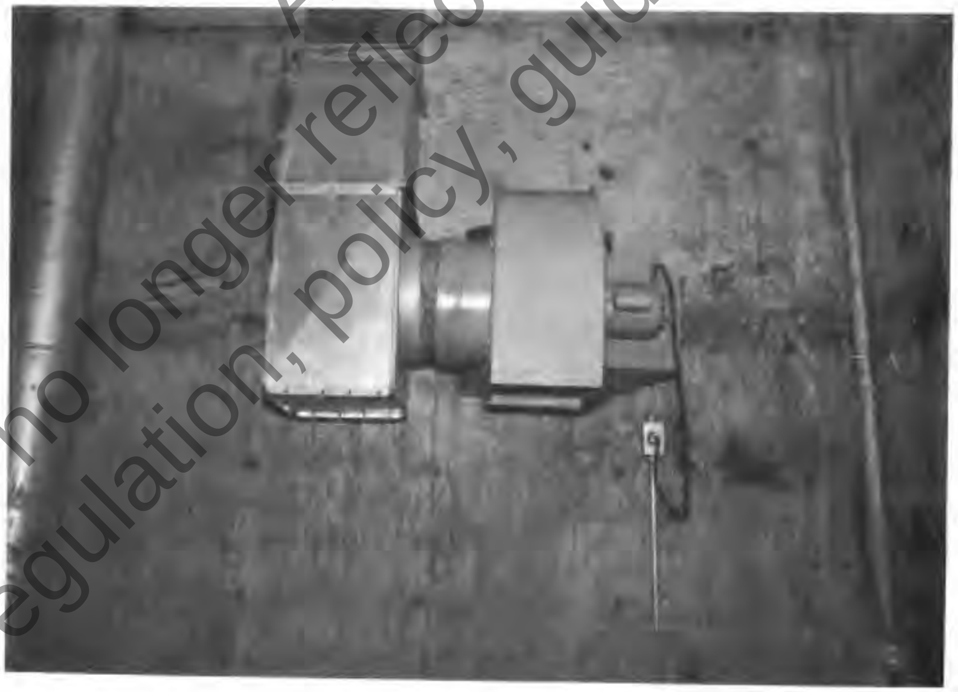
14-M. WATER SUPPLY AND SANITARY PLUMBING

It is assumed that a supply of potable piped water is available near the pump station. Arrangements must be made with the water company to provide the type of service required, which they will normally do by laying a service connection from their nearest main and installing a meter at the property line. Downstream of the meter and before any branch, a backflow preventer must be installed. Depending on the type of station, the water supply may be simply to one or two hose bibbs for washdown or to a larger number of outlets for various purposes. A second backflow preventer on the domestic supply may be requested if such a service is required for potable water, wash-basin or water-closet. All outlets not on a domestic supply must be clearly marked as non-potable, not fit for drinking, regardless of source.

One of the most important and frequently overlooked functions is to provide an initial stream of water prior to pump start-up, for the purpose of ensuring that accumulations of mud, silt and grit are properly fluidized, and that the pump "sees" a suitable fluid instead of a damaging accretion of solids containing insufficient water. Figure 14-26 shows such an arrangement with a two-inch supply to the agitator spray ring at the sump pump. The complete isometric of the water supply piping for a station with three engines is shown in Figure 14-27 and is self-explanatory, particularly showing how for convenience water is piped to all points of need and how solenoid valves are utilized in some locations to start or stop flow as needed. Piping may

Wet-Pit station showing fan and inlet duct
Los Angeles, CA

Figure 14-22



Same fan, ducting and power connection

Figure 14-23

Centrifugal fan and exhaust duct
Houston, TX.

Figure 14-24

Wall-mounted
exhaust fan,
Detroit, MI.

Figure 14-25

be galvanized steel, copper or polyvinyl choride (PVC). The change from one piping material to another to suit location and conditions can be seen, with the provision of di-electric bushings at changes of metal to prevent deterioration due to electrolysis. Note that the piping isometrics and details show the intent only. The physical locations, field supports and adjustments in routing require careful field layout and inspection to ensure that sightly, efficient and hazard-free installations result.

Figure 14-27 shows the water supply piping to wash-basin and water-closet, and Appendix D - Specifications, describes suitable fixtures for industrial use. A small electric hot-water heater is also sometimes provided. The sanitary sewer connection (cast-iron) with waste vent to roof, and the exhaust fan are also all specified, and as these are details of general building construction, no further description should be necessary.

14-N. SUMP PUMP AND MISCELLANEOUS PIPING

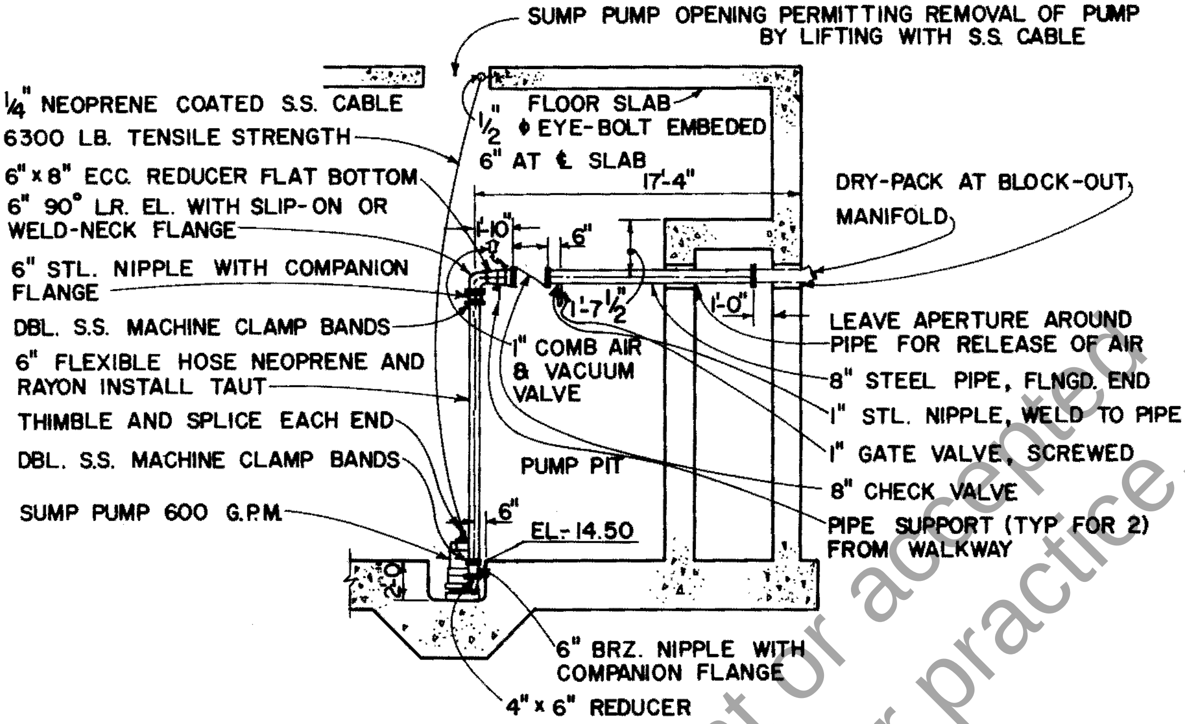
Sump pumps in dry-pits are of very small capacity, see Figure 12-19. They are required to handle only small quantities of water, such as from pump packing and dismantling of equipment. There will be very little solids content in the water, consequently a small diameter galvanized discharge pipe with screwed elbows and other fittings will be satisfactory.

Where the sump pump is directly exposed to stormwaters, and to random dry-weather inflows, as in a wet-pit station, the discharge line must be of larger size and as free as possible from obstructions. If the line is too small or has reverse elbows, there is likelihood of plugging and the sump pump becoming inoperable. Most sump pumps in this service are of submersible type, although there are non-clog recessed-impeller type sump pumps in service with extended shafts and conventional motors.

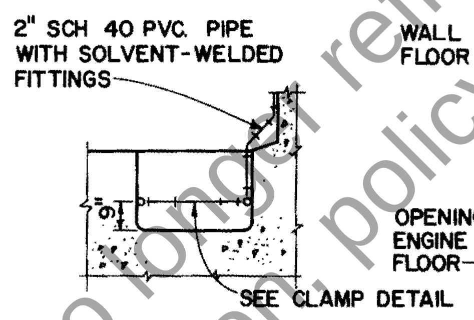
It is a great advantage to be able to readily withdraw the sump pump to the pump room floor and a means of providing for this is shown in Figure 14-26, using an adequately sized flexible hose. Fittings downstream of the hose are even more generously sized with provision for air-release and drainage. Details also show relationship of sump pump sump to the opening in pump room floor above. See Figures 2-9, 15-4 and 15-5.

14-O. FUEL SUPPLY

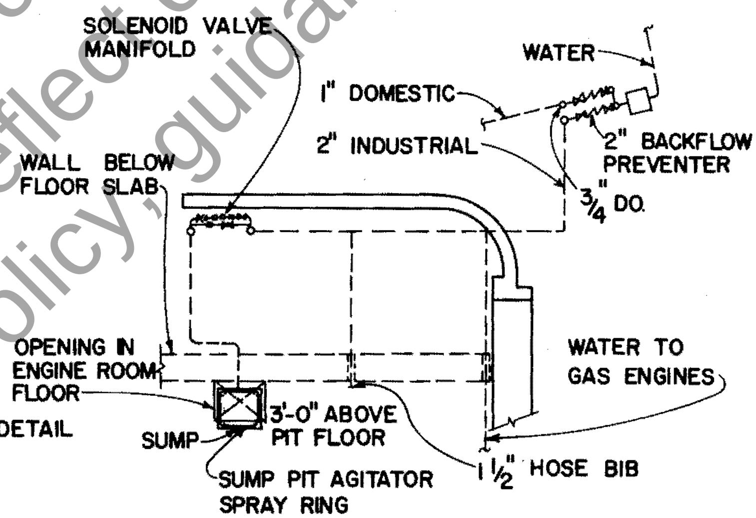
Fuel supply includes both natural gas and LPG for engines. The necessary provisions and equipment required for the fuel supply



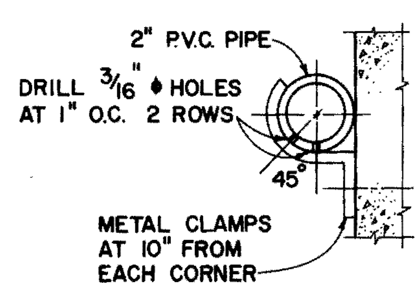
GENERAL ARRANGEMENT OF SUMP PUMP AND DISCHARGE LINE



AGITATOR SPRAY RING



PLAN



CLAMP DETAIL

FIGURE 14-26 DETAILS OF SUBMERSIBLE SUMP PUMP, DISCHARGE LINE, AND AGITATOR SPRAY RING

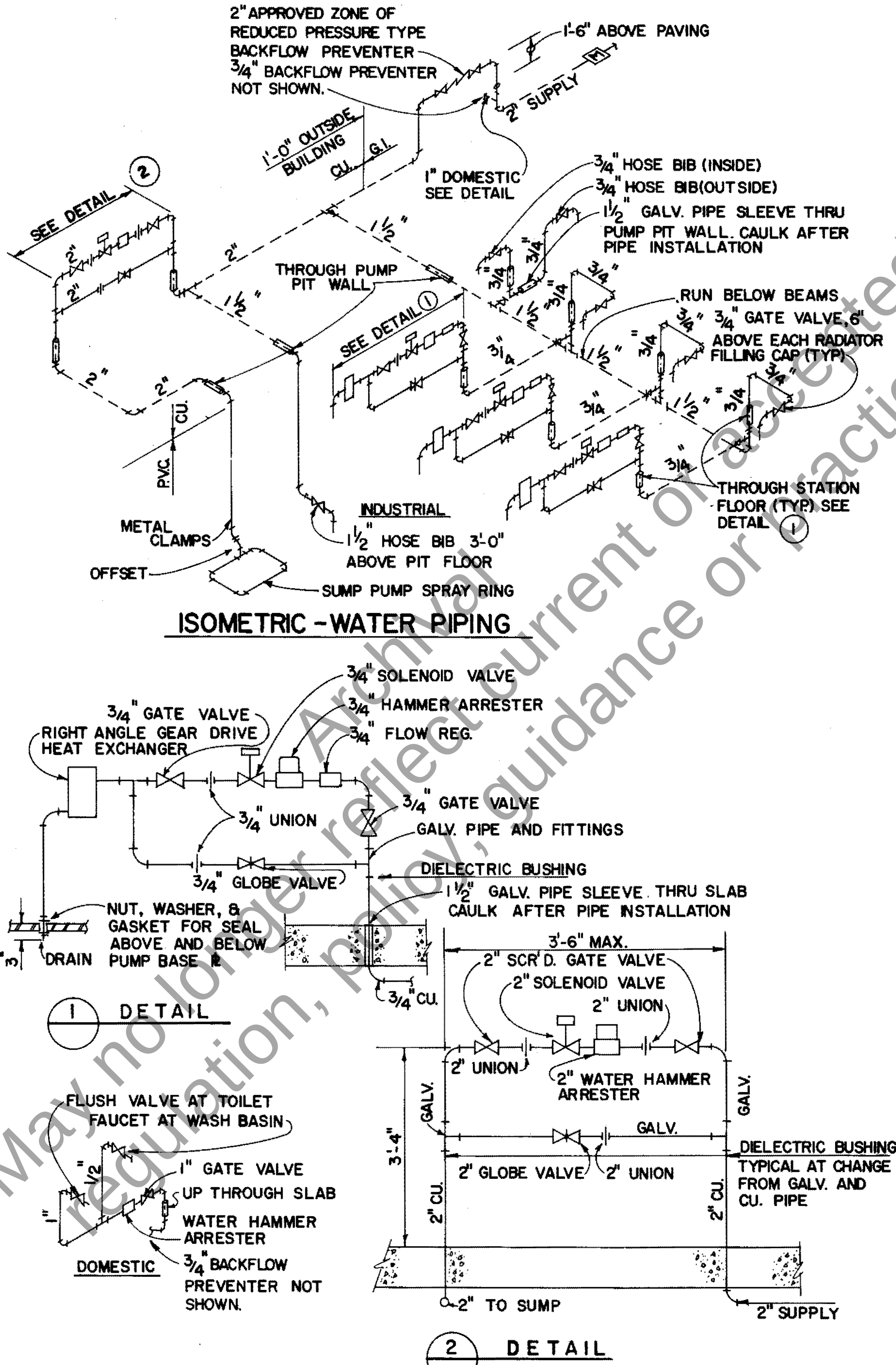


FIGURE 14-27. WATER PIPING DETAILS

are illustrated in Figures 14-28 and 14-29, but where only one source is to be used, the system can be simplified accordingly. Switching from one supply to the other is effected manually and where natural gas can be piped in the LPG is usually only for stand-by or emergency use.

Natural gas is supplied through a meter furnished by the utility company with regulators to reduce the pressure to required operating levels. Natural gas piping may be made up with screwed fittings. LPG is a liquid which is under pressure at ambient temperatures, and socket weld fittings are required.

Strict regulations usually govern LPG storage and piping, including permissible capacity of tank and separation from adjacent structures.

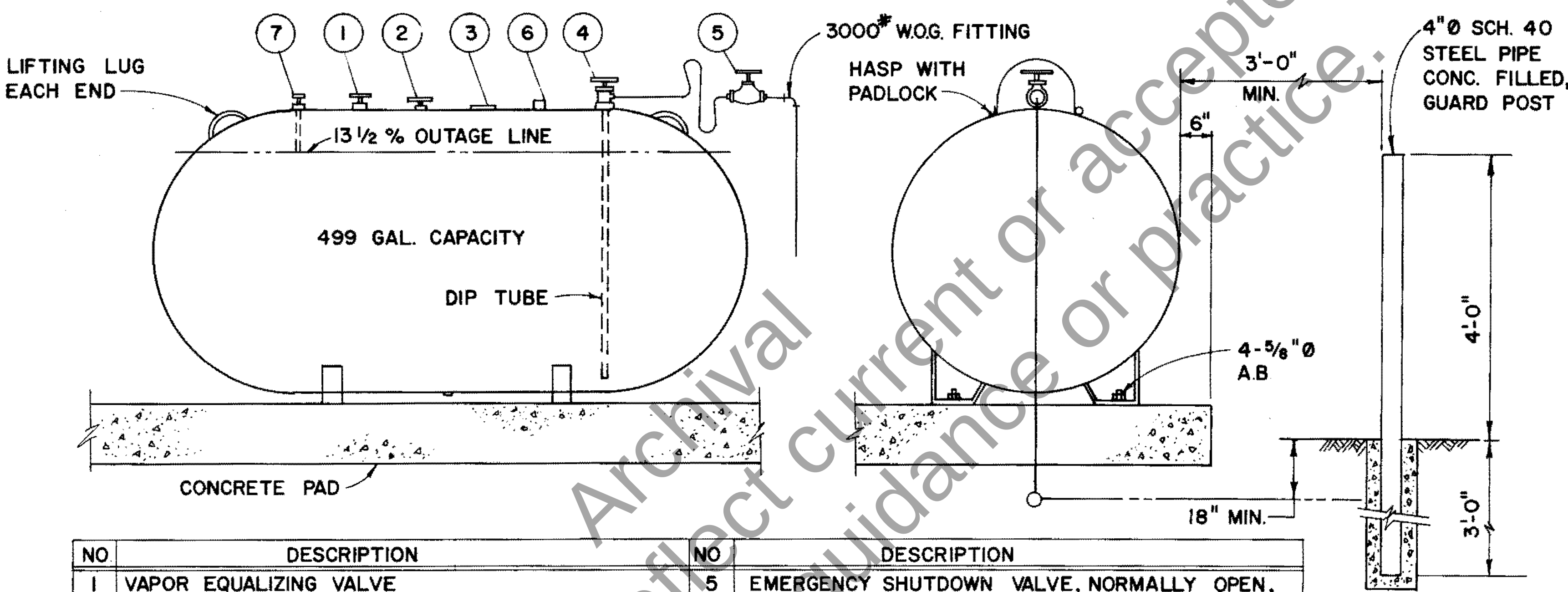
14-P. PROTECTIVE COATING PRINCIPLES

Coatings are the most commonly used method for combatting corrosion, and painting is the commonest form of protective coating for metals. Coatings work on the principle of completely separating the metal to be protected from the corroding elements so as to prevent or minimize the reaction that may occur.

Protective coatings are usually colored and may serve the added purposes of improving appearance, identifying various types of piping, structure or equipment, and of improving safety in compliance with OSHA.

Pumps and other machinery, electrical switchgear and equipment, structural steelwork and metal piping in any pump station are susceptible to the mechanism of corrosion from various sources, such as humid climate, airborne gases and industrial wastes, sewage, decaying vegetation and other harmful materials that may enter the station. The designer must recognize and protect against the possible consequences of deterioration by corrosion, since pump station shutdowns or unsatisfactory operation can and do occur as a result of the corrosion of pumps or other machinery and equipment.

Painting, epoxy or bitumastic coatings, pressure sensitive tape, galvanizing and cement mortar coating or lining are the principal methods of applying protection to steel. Polyvinyl chloride (PVC) jacketing is sometimes applied to electrical conduit or other equipment. Waterproofing sealers and paint are applied to concrete, masonry and wood as necessary.

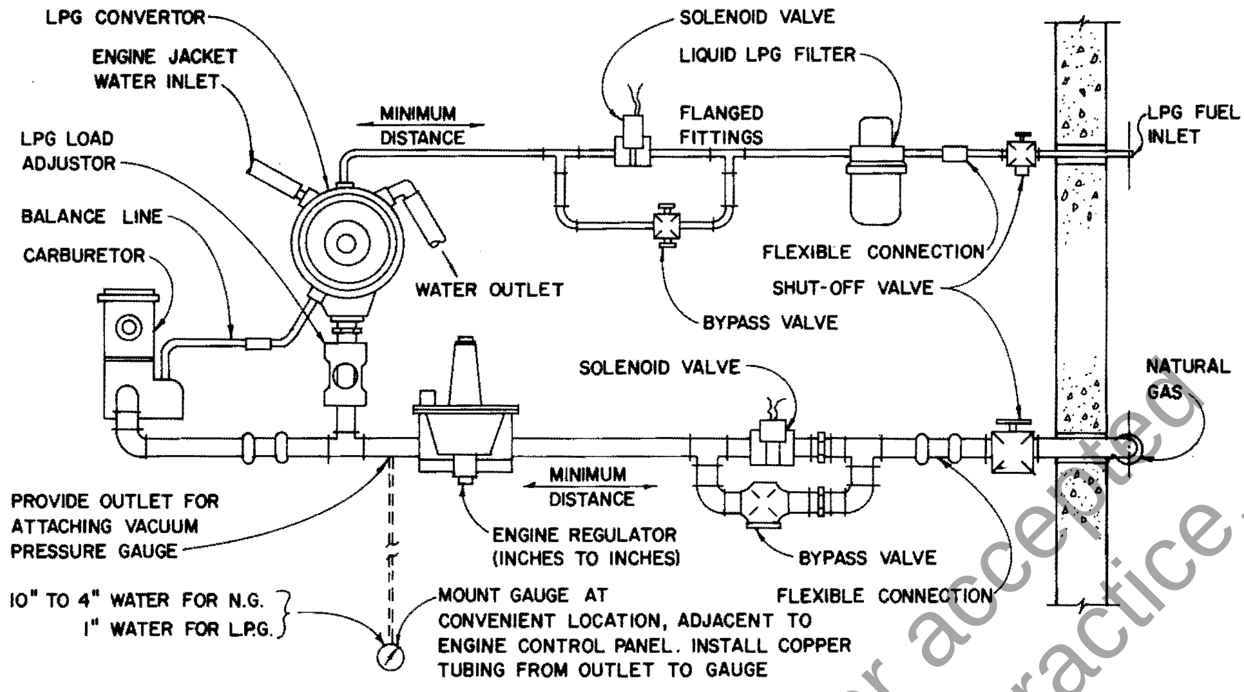


NO	DESCRIPTION	NO	DESCRIPTION
1	VAPOR EQUALIZING VALVE	5	EMERGENCY SHUTDOWN VALVE, NORMALLY OPEN,
2	DOUBLE CHECK FILLER VALVE		WITH INTEGRAL RELIEF VALVE
3	SAFETY VALVE	6	LIQUID LEVEL GAUGE
4	LIQUID FUEL SUPPLY VALVE W/BUILT-IN EXCESS	7	FILLING LEVEL INDICATION
	FLOW CHECK VALVE		

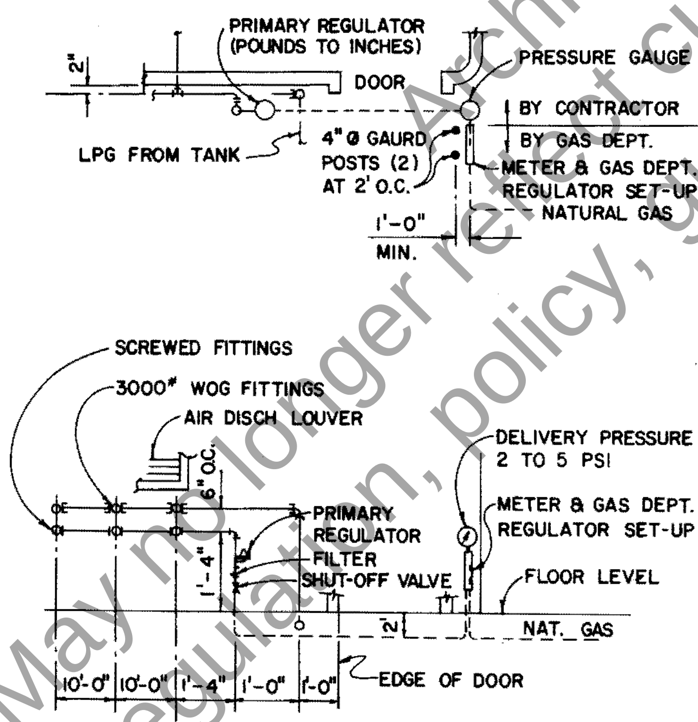
NOTES

1. TANK SHALL BE SPOT RADIOGRAPHED PER PARA. UW-52, SELECTION VIII, ASME CODE FOR UNFIRED PRESSURE VESSELS.
2. TANK CONSTRUCTION SHALL COMPLY WITH ALL REGULATIONS OF LONG BEACH FIRE DEPARTMENT AND STATE OF CALIFORNIA DIVISION OF INDUSTRIAL SAFETY.
3. WARNING SIGNS READING "FLAMABLE" AND "NO SMOKING OR OPEN FLAME PERMITTED WITHIN 25 FEET" SHALL BE POSTED ON TANK OR ADJACENT TO IT. LETTER SIZE SHALL BE 5'.
4. PIPE SYSTEM SHALL BE SOCKET WELDED AND SHALL BE TESTED AT 125 P.S.I. UNDERGROUND PIPING SHALL NOT BE COVERED UNTIL AUTHORIZED BY STATE INSPECTOR.

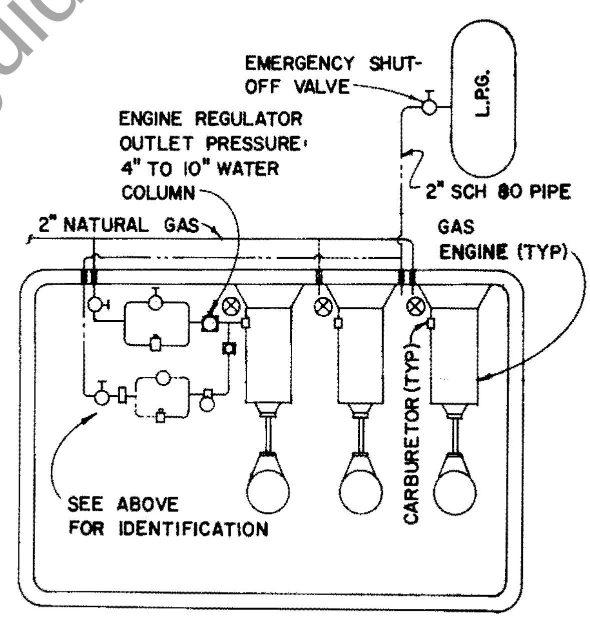
FIGURE 14-28. LPG TANK AND PIPING INSTALLATION



SCHEMATIC DIAGRAM - NATURALLY ASPIRATED DUAL FUEL GAS ENGINE



NATURAL GAS & LPG SUPPLY



GAS ENGINE - TYPICAL DUAL FUEL SUPPLY

FIGURE 14-29. FUEL SYSTEMS

The field of protective coatings is immense and confusing, which may lead to the specifying of primers and finish coats which are incompatible, or other errors. Reference to a representative selection of manufacturers' current literature is essential, and care must be taken to keep specifications up to date since development continues and product changes are frequent.

14-Q. PAINTS

Hundreds of different types of paint coatings are available. Many of the paints consist of proprietary compounds that are sold under various trade names. This can make paint selection confusing, but generally each type of paint is sufficiently described by the manufacturer that its suitability for the intended purpose can be properly judged.

A basic reference for painting steel is the Steel Structures Painting Council (SSPC) Standard Specifications. In addition to covering various types of paint, there are specifications for surface preparation, meaning the removal of rust, scale, grease and other contaminants. From simple wire-brushing and the use of solvents, the surface preparation may extend to sand or shot-blasting to white metal, which forms a toothing on the metal surface which is compatible with the highest standard of paint adherence and performance.

Coating thickness is measured in mils, or one-thousandths of an inch. The specified thickness usually requires a primer and two coats of the finishing material. Paint application also requires various safeguards intended to ensure compliance with specifications and avoidance of error or deception and the elimination of thin spots or pin-holes to bare metal.

Oil paints, based on natural oils from plants and fish, are easy to apply and relatively inexpensive, but their resistance to acid fumes is not very good. Oil paints are permeable to moisture and are recommended only for mild atmospheres. Alkyd paints are resins obtained from the reaction of phthalic anydride and glycerine, and generally require baking to dry, but this can be avoided by combining them with an oil base. Alkyd paints have superior corrosion resistance to oil paints. Emulsion or water-base paints contain an emulsified resin in a water vehicle. There are many systems of this type, including polyvinyl acetates and acrylics. The main attractions of the water base paints are the ease of application, little odor, and easy cleanup. Urethane paints are made by reacting isocyanates with polyols. They have good toughness and abrasion resistance, and their corrosion resistance may approach that of the vinyls and epoxies. Vinyl paints are made by polymerization of compounds containing the vinyl group and are more corrosion resistant than oil-based or alkyd-based coatings.

14-R. EPOXY COATINGS

Epoxy coatings are formed by reacting epichlorhydrin with polyphenols, resulting in a variety of coatings classified by their method of hardening. Amine-hardened epoxy coatings consist of two components, the hardener and the resin, that are mixed just before using. These are the most resistant to chemicals. Polyamide-hardened epoxy is less resistant to acids but is tougher and more moisture proof. Coal-tar epoxy is a combination of epoxy resins and coal tar pitch. It can be applied to steel without a primer and gives good resistance to fresh and sea water, soil and inorganic acids.

Epoxy coatings have been found to give reliable service when used for pumps, discharge piping and items in the pump pit, justifying their greater first cost compared with paint systems. Coatings should be shop applied as far as possible, with thorough prior surface preparation. A total dry film thickness of 15 to 18 mils is desirable. To avoid erosion, velocity of water in pumps, piping and manifolds should be limited to ten feet per second, which is in any case compatible with the need to minimize head loss. A vertical pump with epoxy coating is shown in Figure 14-20.

14-S. GALVANIZING AND OTHER COATINGS

Galvanizing is the most effective method of protecting fabricated structural steelwork against the environment prevailing in a pump pit. It is especially effective in humid climates. The general method of galvanizing is to dip the structural steel assembly into molten zinc. This is known as the hot-dip or electrodepositing process and two ounces of coating per square foot meets the applicable standard. Repair of galvanizing where necessary is done by an on-site zinc metallizing process, or by application of zinc oxide-zinc dust paint.

Galvanizing should be used to protect all trash racks, ladders and the like. See Figure 14-7. Galvanizing has been used for vertical pumps as will be seen in Figure 14-24 and also for discharge piping as in Figures 14-22 and 14-23.

Coal-tar or bitumastic coatings are mixtures of coke oven by-products and organics and may be applied hot, or emulsified for use at ambient temperatures. This method of coating is favored for underground pipelines, the preparation, coating and wrapping of pipe joints being a conveniently mechanized operation. These coatings are not so readily utilized for items of pump station equipment.

Cement mortar lining is frequently used for steel water pipe, the autogenous healing of the lining representing a very desirable feature where the line is always full of water. This is not the case with a pump station and so the application is less suitable. However, a cement mortar jacket on the exterior of a buried steel manifold is an ideal usage. See Figures 8-1, 8-2 and 8-3.

Pressure sensitive tapes are a combination of flexible polyvinyl chloride backing over an inner layer of butyl rubber or similar adhesive. These are easily applied by wrapping around pipe or fittings and have their place in protecting buried lines such as gas or LPG supply lines.

Polyvinyl chloride jackets are often applied to electrical conduits. The metal surface is sandblasted to near-white metal and a polyvinyl chloride tie coat is sprayed or brushed directly onto the metal or applied over a zinc-rich primer for use with acrylic modified high molecular weight polyvinyl chloride finish coats.

14-T. RECOMMENDED APPLICATIONS AND COLOR CODING

Epoxy coating is recommended for wet-pit vertical pumps, sump pump, discharge piping, fans, ducting, LPG tank and piping. Oil paint (enamel) is recommended for pump motors, engines and gear drives, crane and crane beams, electrical switchgear, metal doors and windows and miscellaneous metal. Galvanizing is recommended for structural steel in the pump pit, and can be used extensively for many items or locations.

Masonry, if painted, should be sealed with waterproofing and a vinyl-acrylic paint used.

Tape or cement-mortar should be used for buried piping.

Suitable detail will be found in Appendix D - Specifications, although the use of manufacturers' or trade names may be objectionable unless multiple sources are stated.

Finally, OSHA requires that any physical hazards in industrial plants must be color marked. Some of the examples in stormwater pumping stations are:

Fire extinguishers and/or locations designating same	red
Danger signs	red
Emergency stop buttons on engines or other machinery	red
Inside of movable guards for transmission equipment (drive shafts, gears, etc.)	orange
Unguarded edges of platforms, pits and walls	yellow
Handrails, guardrails - top and bottom treads of stairways	yellow
Lower pulley blocks and cranes	yellow
Travelling cranes or areas thereon	yellow
First aid kits	green

14-U. FIRE PROTECTION

Many pump stations, such as a small station constructed entirely with non-combustible materials and having small electrically-powered pumps, with means of immediate egress, do not require special fire protection equipment, not even a chemical fire-extinguisher. Any electrical fire would probably occur while the station was unattended. While this would be damaging to equipment, it would not be hazardous to personnel.

With larger stations, the pumping equipment is more complex, and lubricating oil may be spilled, or wiping rags may be carelessly left about. Here, chemical fire extinguishers should be provided, and there should be doors at opposite ends of the building, equipped with panic bars.

14-V. INTRUSION ALARMS

Photo-electric cells which receive invisible beams crossing openings have been used for many years and are reliable. It is usual to locate the projectors and receivers so that beams cross all wall openings. A mirror is sometimes used to reflect a beam along a second wall, and reduce the equipment required. An intruder will break the beam and cause an alarm to sound, usually at a remote point, utilizing the telemetering system.

An alternate system is the microwave transceiver capable of detecting movement of a man-sized object and giving an alarm. Other systems are available. Local inquiries are recommended.

14-W. GAS DETECTION SYSTEM (FUEL PRESENCE ALARM)

Many stations, such as the dry-pit station with ventilated below-pavement storage box, do not need a gas detection system. The wet-pit station with a large closed rectangular pump pit does, because there is always a danger of lethal accumulations of hydrogen sulphide (H_2S) from decaying vegetation or organic material in unventilated drain lines in addition to the flammable (gasoline) hazard. See Figure 14-32. Information from the detector can be made available at a remote point by telemetry, as described in Section 14-V.

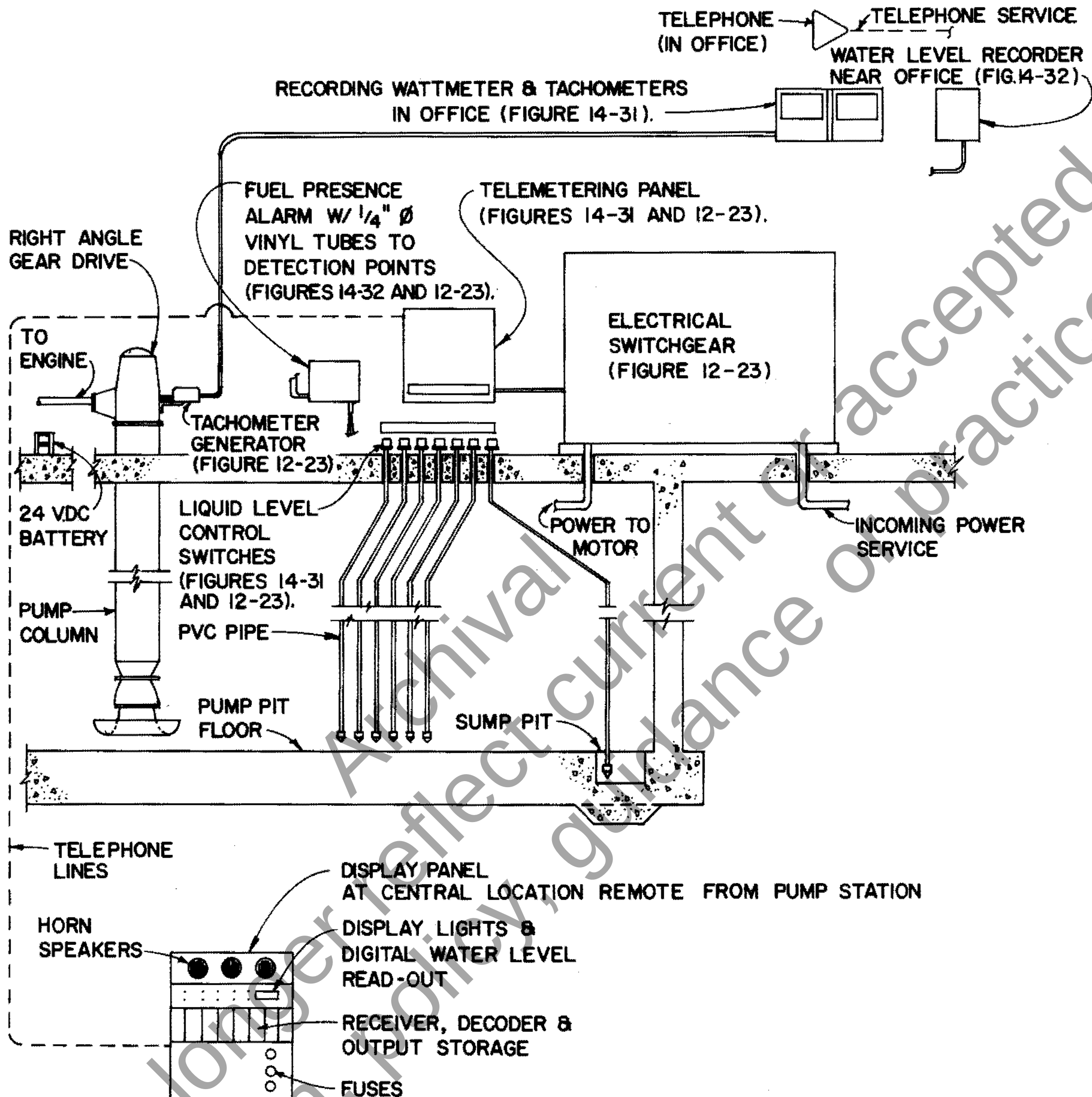
14-X. INSTRUMENTATION

Instrumentation as applied to pump stations is the recording of water levels in the sump, the hours during which pumping equipment is operated, and rotating speed or power consumption. It provides the basic information from which the total quantity pumped can be calculated, and the engine or motor operating hours can be determined. It is important to some agencies, not to others.

The pump operation is, of course, interrelated with the starting and stopping control, so that the pressure switches and air risers which may be utilized for this function are for convenience grouped with the instrumentation. Figures 14-30 through 14-32 show details of the components of the instrumentation.

14-Y. SUPERVISORY CONTROL - TELEMETERING

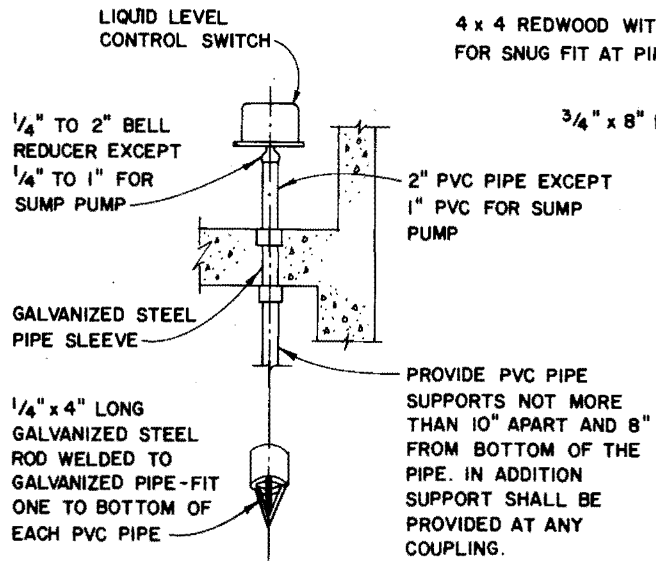
Supervisory control in its simplest sense means that authorized persons may be able to observe whether the pumping station is operating satisfactorily at times of need, and if this is not the case, they are able to call for remedial action.



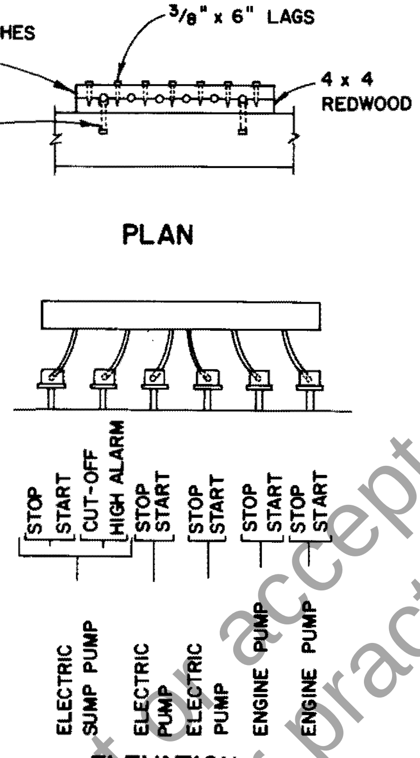
DISPLAY PANEL LIGHTS

1. SIGNAL FAILURE
2. POWER FAILURE
3. LOW GAS HAZARD
4. HIGH GAS HAZARD
5. RECORDING INSTRUMENT FAULT
6. OPERATOR IN BLDG. (DISARMS INTRUSION ALARM)
7. SUMP PUMP START LEVEL
8. SUMP PUMP RUNNING
9. PUMP 1 (ELECTRIC) RUNNING
10. PUMP 2 (GAS ENGINE) RUNNING
11. PUMP 3 (GAS ENGINE) RUNNING
12. PUMP 4 (GAS ENGINE) RUNNING
13. HIGH WATER LEVEL & INTRUSION ALARM.

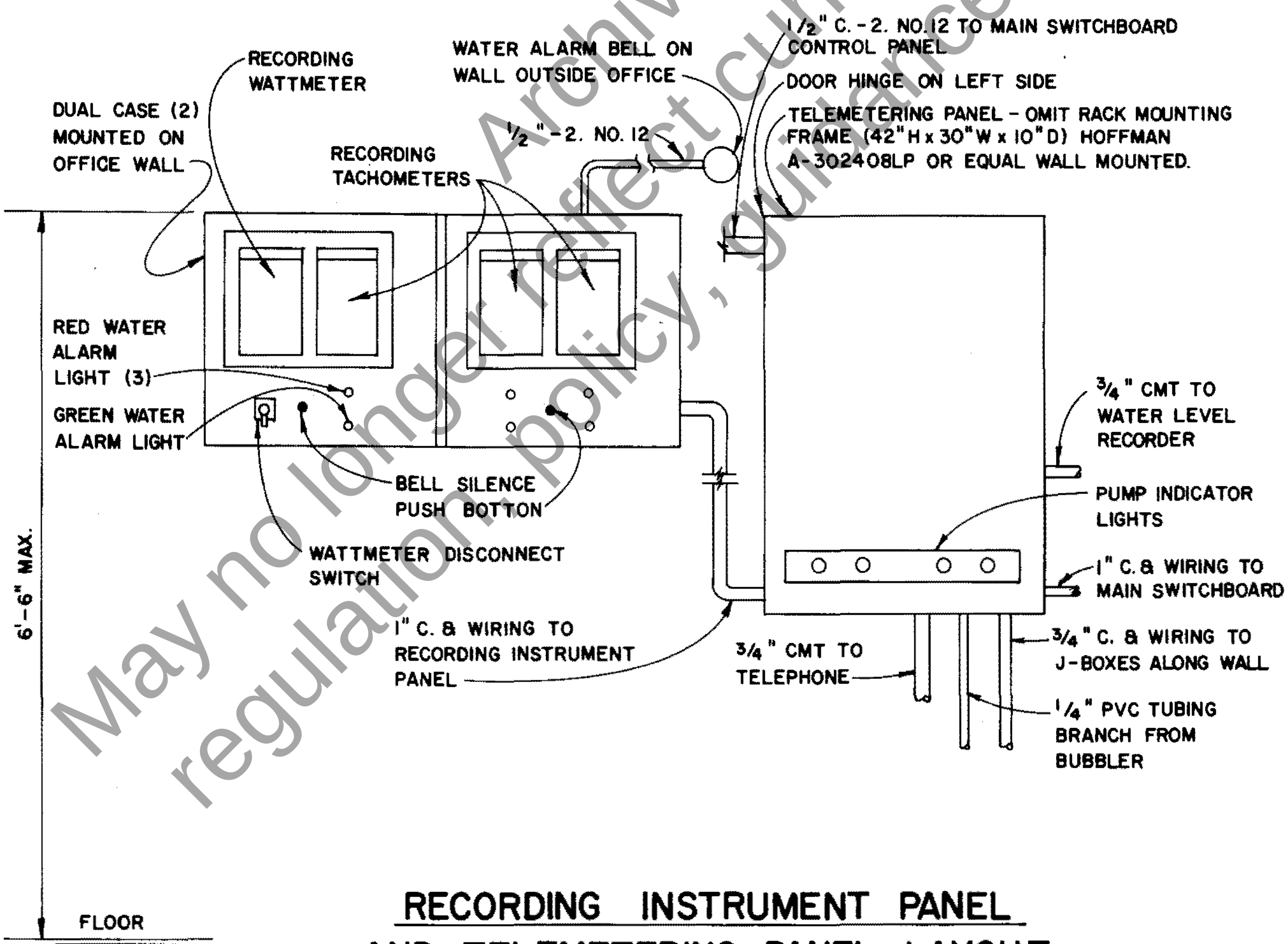
FIGURE 14-30. CONTROLS AND INSTRUMENTATION LAYOUT



STAND PIPE FOR LIQUID LEVEL SWITCHES

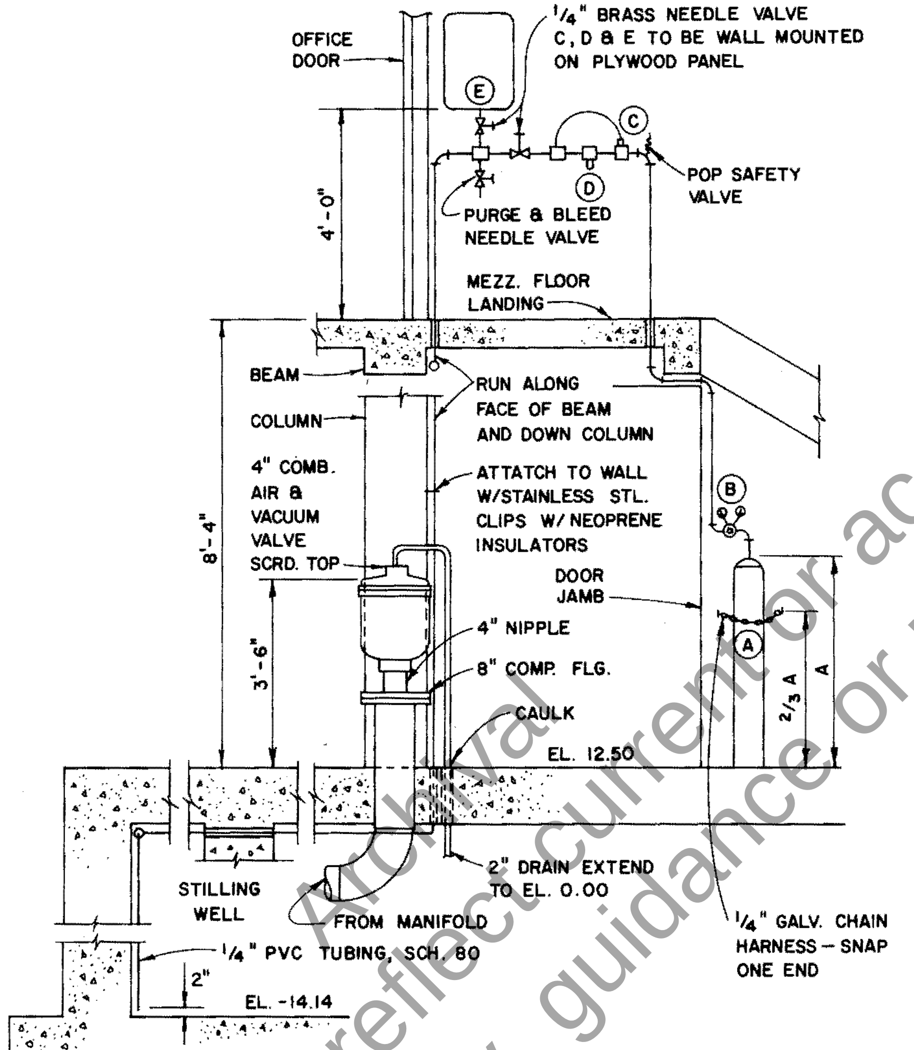


LIQUID LEVEL CONTROL SWITCHES



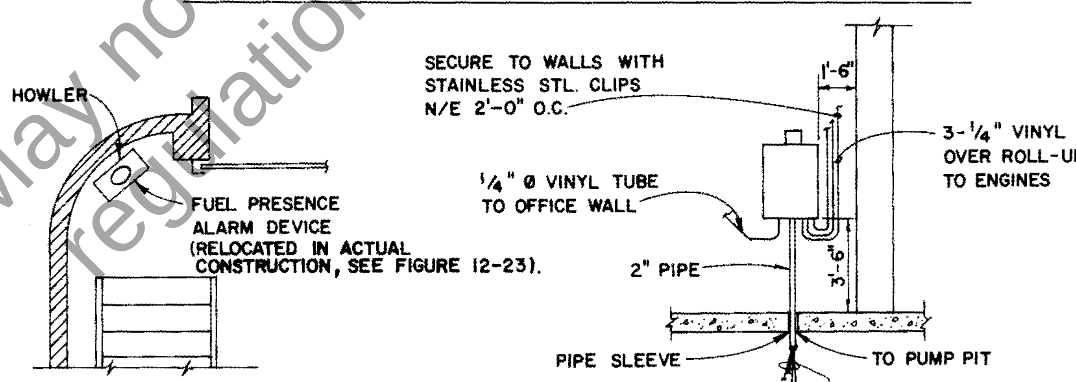
RECORDING INSTRUMENT PANEL AND TELEMETERING PANEL LAYOUT

FIGURE 14-31



A STANDARD 220 CU. FT. OIL-PUMPED NITROGEN CYLINDER.
B HIGH-PRESSURE REGULATOR, AIRCO STYLE 1124 OR EQUAL.
C CONSTANT FLOW REGULATOR, CONOFLOW MODEL H-21 OR EQUAL.
D BUBBLER SIGHT FEEDER, MIRRIAM MODEL C-1241 OR EQUAL.
E 12" CHART, 7-DAY ROTATION, 110 V., 1Ø ELECTRICALLY OPERATED RECORDER RANGE BETWEEN 0-10 & 0-200 AS SPECIFIED BY CITY, DUST & MOISTURE-PROOF CASE, WALL MOUNTED, BRISTOL 1G-500-15-E1AX-2131X OR EQUIVALENT BY FISCHER & PORTER OR CITY APPROVED EQUAL.

WATER LEVEL RECORDER WITH GAS PURGE



PLAN

ELEV.

FUEL PRESENCE ALARM DEVICE

FIGURE 14-32

The Caltrans sations are fitted with signal lights which indicate if the pump station is operating. Highway patrol officers can observe the lights when driving by and radio in if the situation demands. See Figures 2-7 and 3-2.

In a more sophisticated, but completely orthodox manner of supervisory control, the operating functions of any station may be telemetered from the station to a control center. Telemetry makes use of leased telephone lines or radio-link connecting the station to the center, and as many functions as desired may be continuously transmitted. This enables the control center to be aware of the status of any station at all times and to take appropriate action when required to correct malfunctions or other unsatisfactory conditions. In addition to reporting pumps running, the system can also show unauthorized intrusion and gas presence, high water level and sound alarms as required.

Figure 14-30 shows in diagrammatic form the relationship between electrical supply and data acquisition from tachometer, wattmeter, gas detector system and other components. This information is passed to the telemetry cabinet, encoded and passed over the telephone lines to the remote display panel. The unattended station is designed to start and stop pumping as required in response to water level and report operational status continuously to the control center. This is in keeping with current practice in various industrial and governmental applications and is in no way unusual. Although of no application in regard to stormwater pumping, it is quite usual for an operator at a central location to be able to start or stop pumps, open and close valves and perform similar functions at stations far distant by the use of telemetry.

14-Z. SUMMARY

As a whole, the architectural-structural content accounted for about two-thirds of the total work of preparation of plans and specifications for the rectangular wet-pit type of station illustrated in various figures in this chapter and also in Chapter 15 - Station Design Calculations and Layouts. Provision has to be made for many items so that the overall co-ordination of the design is most important.

* * * * * * * * * * * *

CHAPTER 15. STATION DESIGN CALCULATIONS AND LAYOUTS

15-A. GENERAL

Chapter 6. - Wet-Pit Design, sets forth the complex criteria to be satisfied when designing a rectangular wet-pit with vertical pumps. An example of how this is done is given in this Chapter. Reference is also made to Chapter 4. - Collection Systems, and Chapter 8. - Pumping and Discharge Systems which also have much relevant information.

Consistent with Chapter 14. - Construction Details, this chapter concentrates on the hydraulic design of the rectangular wet-pit and its layout to suit equipment and function. It does not cover the structural calculations required for a pump station. These may be complex also and very much more lengthy than calculations for the development of the wet-pit itself. However, any guidance that is needed can be readily found elsewhere. Hydraulic and structural calculations, together with general layouts for the caisson-type wet-pit and for the dry-pit and other types will be generally less demanding. Nevertheless, benefit can be drawn from the content of this chapter, even if simpler types are being designed.

It is essential that the calculations for a rectangular wet-pit be complete and set out in an orderly and logical manner, with reasoning, so that they may be readily reviewed and checked. The set of calculations which follows is for the station shown in Figures 15-1 through 15-5, which has been constructed. It is the Westside Pump Station, Long Beach, CA., designed for the City of Long Beach to the criteria of the Los Angeles County Flood Control District. Determination of the discharge Q, the elevations and the basic selection of the equipment had been made by the employing agency and preceded these calculations. A tentative layout had also been made by the City and was followed in the final design. This emphasized the hydraulic correctness of the pump pit and avoided the use of interior columns for direct support under engines. It will have been noted that columns, or other supporting members not subject to flexure are recommended elsewhere in the Manual.

No verification for the determination of Q as 181 cfs is given, but this is not necessary for our example. The principles upon which the selection of equipment and the determination of elevations were based are set out in earlier parts of the Manual to which reference should be made. The selection of four pumps and their sizing follows Section 4. - Collection Systems, Page 4-11. It was an agency choice to utilize one electric pump (first-on) for 15% of Q and three engine-driven pumps of equal size for the remaining 85%.

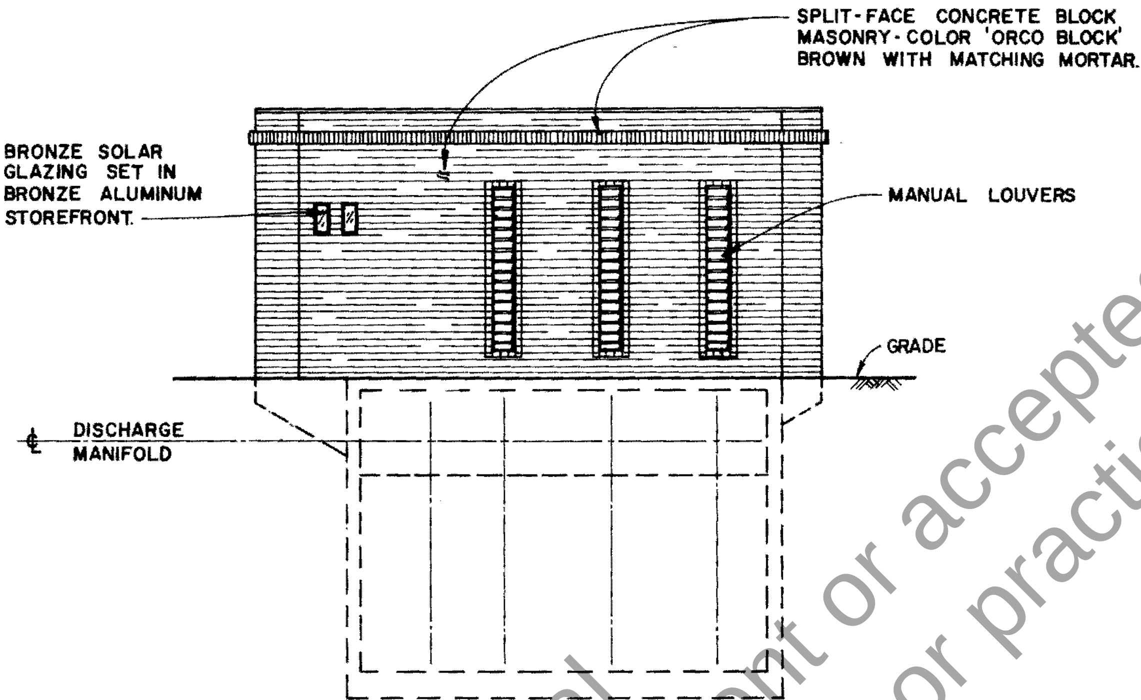
The collection system as originally designed is described in Pages 4-16 through 4-18 and Figures 4-8 and 4-9. The pump pit area A, shown on Page 4-18 as determined in this Chapter, is computed on Page 15-11. Note that design of the pit is a matter of developing a trial layout and adjusting the dimensions and elevations to suit the criteria requirements. From the pump size a bell and umbrella diameter can be determined, and the pump spacing is 10 feet to suit the engine drivers. Because the pump pit and the superstructure did not need to be the same size, an interior backwall and stilling well were developed, adding to the sump area and improving the volume available for pump cycling considerations. The smaller electric pump was set closer to the back wall than the larger pumps because of its smaller bell. The dimensions to end walls were developed from space requirements and are not strictly to suit minimums for pumps. In determining the area of the pump pit, space requirements for equipment must first be satisfied, and the length in the direction of flow must meet the recommendations given in Figure 6-2. As the calculations develop, it is usually necessary to step back and adjust some previously set dimensions or elevations in the layout until all requirements, clearances and functions are properly satisfied.

During the course of the actual work, the design of the pump station and also of the collection system were proceeding concurrently. The two elements were properly matched, usable storage was checked and pump cycling criteria were met. See Pages 4-16 through 4-18. It was then found that due to existing underground construction, the collection system would have to be lowered. This greatly increased usable storage, and cycling ceased to be a consideration. The invert of the transition structure which was to have been steeply sloped was sloped only from -14.10 at the inlet to -14.22 at the bottom of the pump pit. It appeared inappropriate to lower the design water level and a slight pressure head (3.8 feet) on the inlet line was accepted.

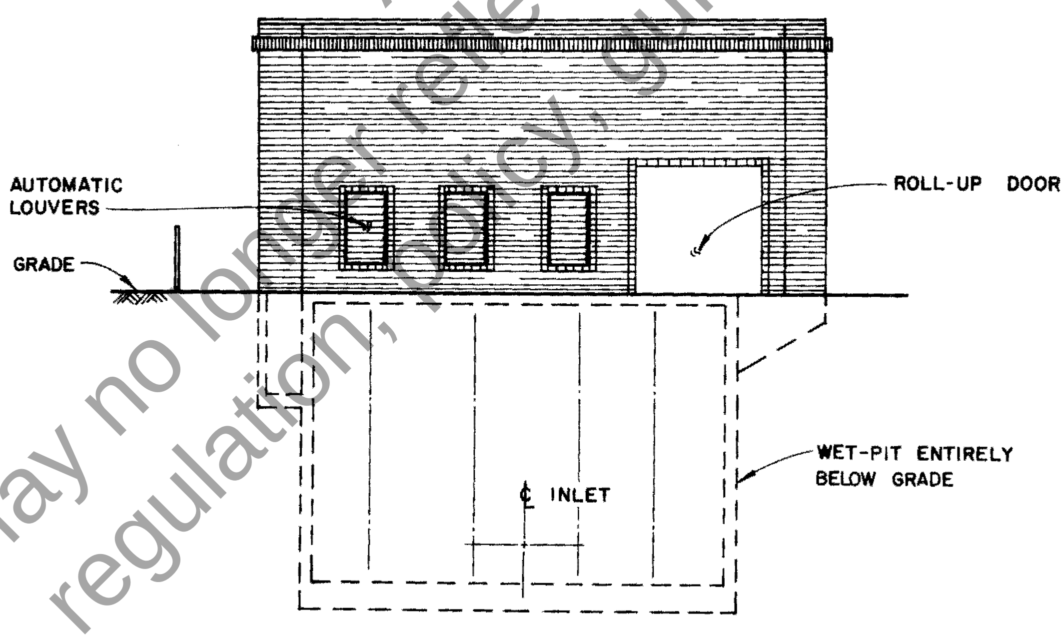
Proceeding with the design, the operating conditions are first described. The calculations follow in manuscript form, as an edited copy of what was done for the original design work. This format enables sketches to be included as needed for illustration.

15-B. OPERATING CONDITIONS

The discharge line invert at the exit flap-gate is El. -0.04. The soffit of the 54" line is therefore El. + 4.54, which is below high tide level. Because of poor seating of the flap gate due to marine growth and low seating head available, the discharge line will become filled with water to high tide level which is +4.74 (highest recorded).

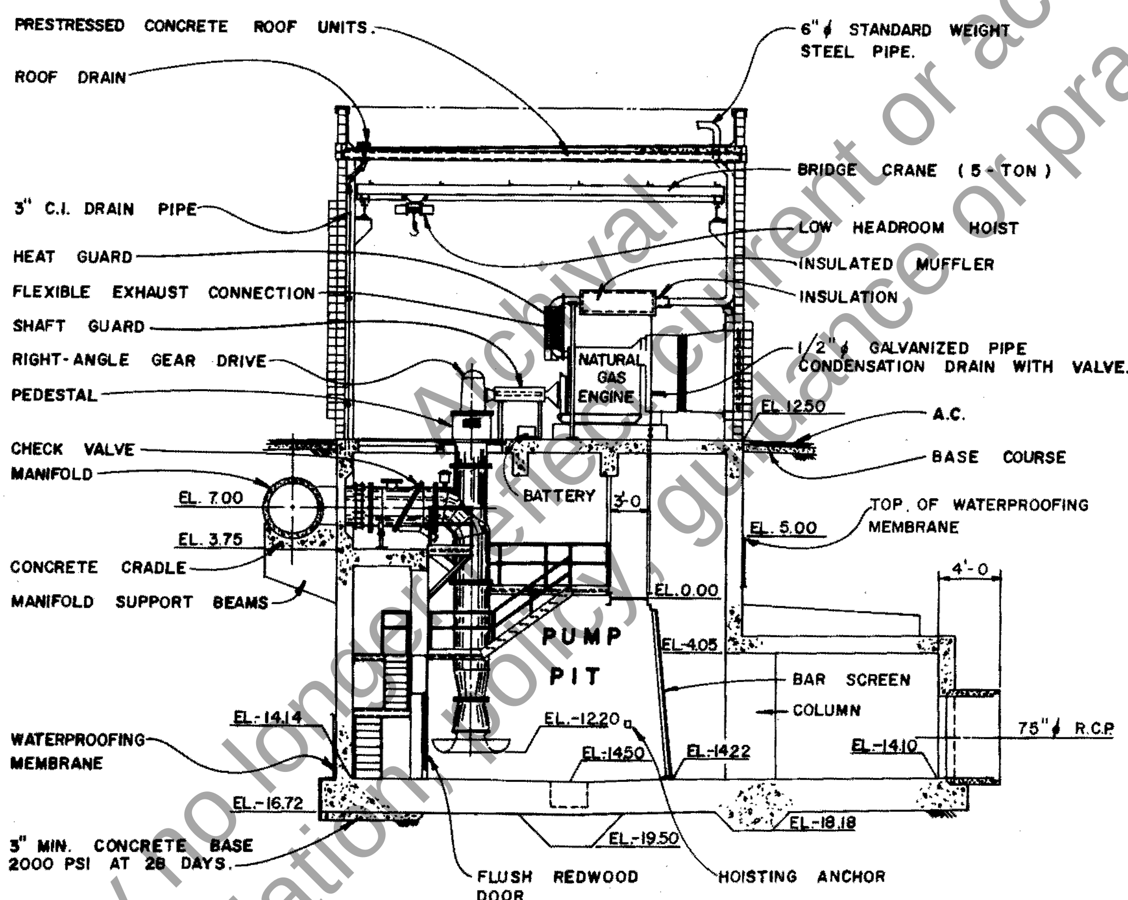


SOUTH ELEVATION



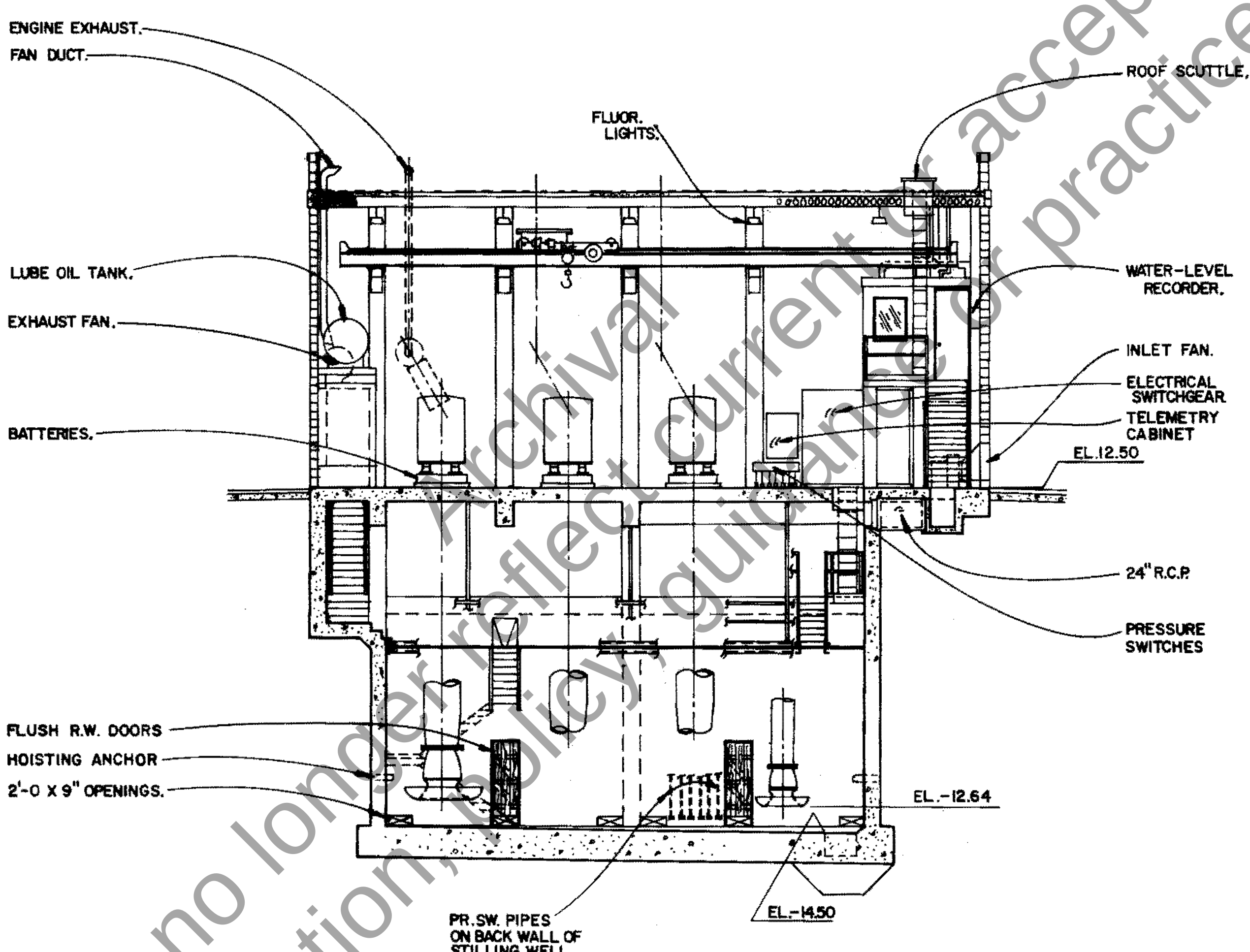
NORTH ELEVATION

FIGURE 15-1



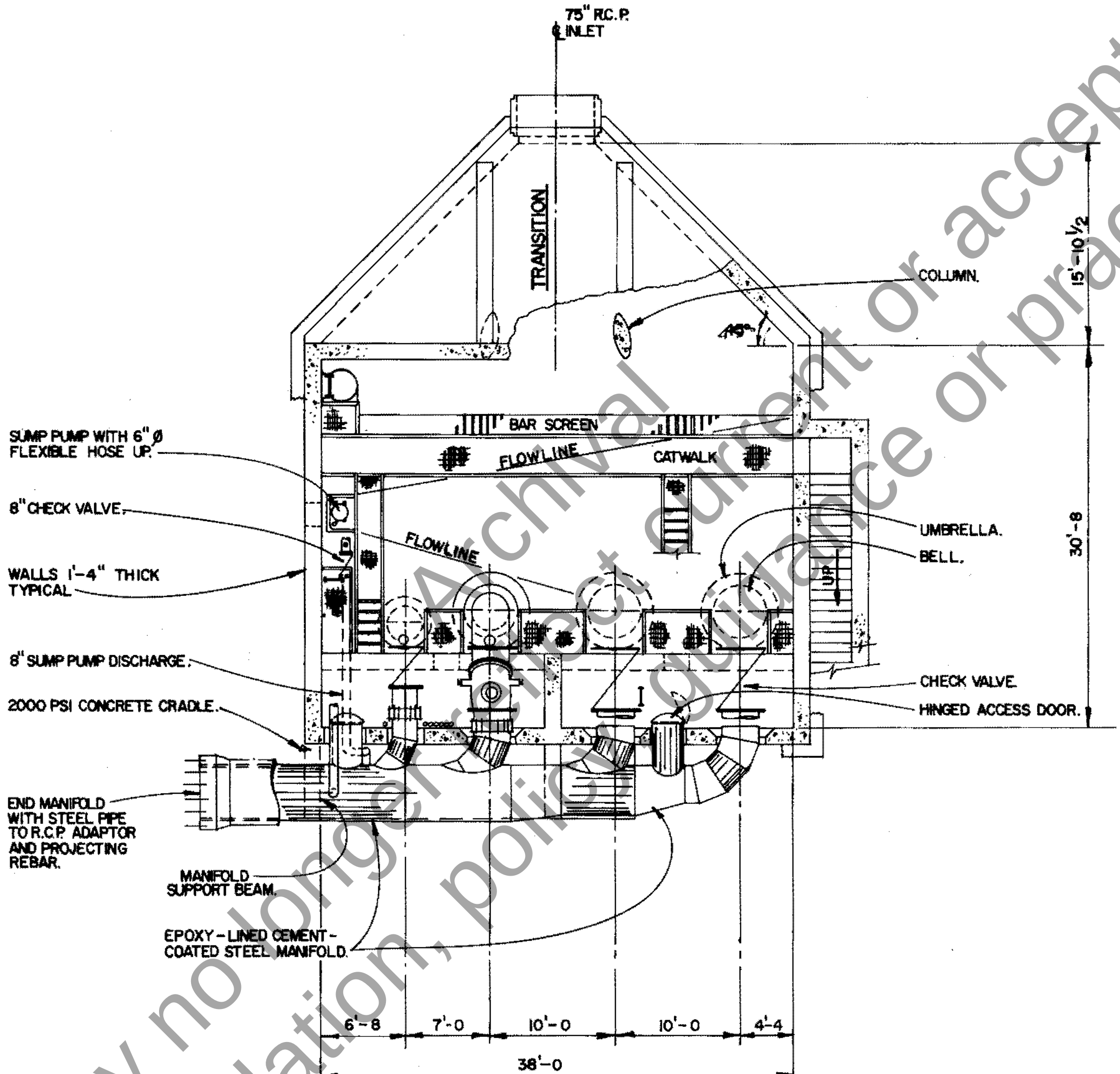
TRANSVERSE SECTION

FIGURE 15-2



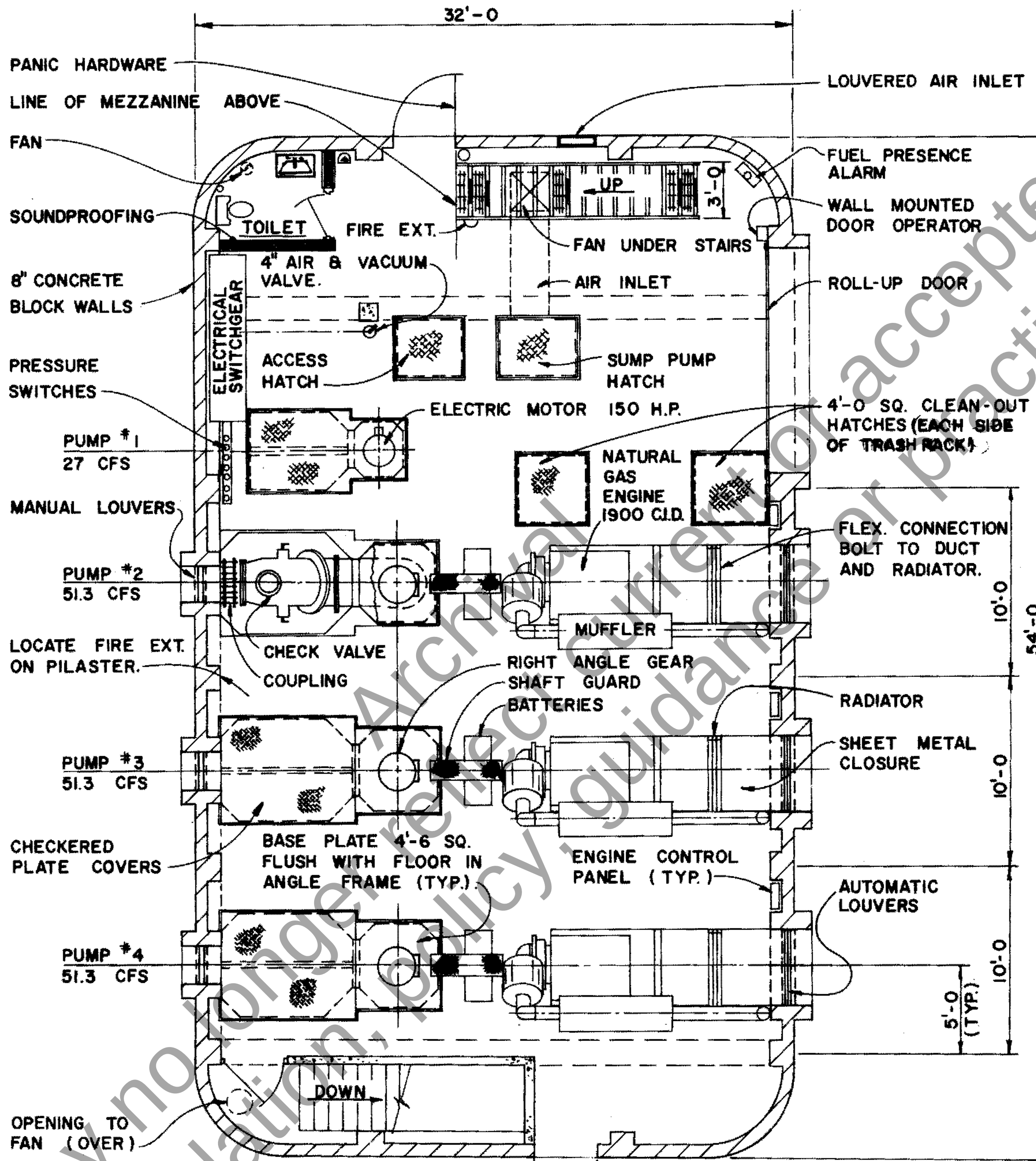
LONGITUDINAL SECTION

FIGURE 15-3



PUMP PIT PLAN

FIGURE 15-4



FLOOR PLAN

FIGURE 15-5

The invert of the discharge manifold at the station is El. +4.75. Therefore it may be assumed that no sea-water can ever reach the pump check valves, the lowest invert of which is El. +5.50. Air which is displaced by entering sea-water will discharge from the top of the manifold into the pump pit through a combination air relief and vacuum valve. See Figure 14-32.

When the tide is backing up in the discharge line, the small pump will start normally at El. -7.05 and deliver at minimum TDH (maximum Q) into the empty portion of the discharge line, the water displacing the entrapped air through the relief valve. As the line quickly fills the head will rise slightly, and then when the line is filled the pump will go to shut-off head as it begins to accelerate the entire column of water in the discharge line. Gradually, as the column accelerates to a velocity of approximately 1.70 ft./sec. (corresponding to 27 cfs discharge), the TDH against which the pump is operating will drop towards minimum value. Motor size for the small pump must satisfy maximum shut-off head for pumps selected, which approximates 150 HP. If the required horsepower is exceeded by only a small percentage (less than 10%) a 150 HP motor will be satisfactory. This is because the customary 1.15 service factor of the motor makes allowance which is compatible with the extremely short load duration.

This situation does not affect the engine selection as the engines are started at slow speed and idle there for a pre-set time before slowly increasing speed. Since the pump head varies as the square of the speed ratio and horsepower varies as the cube, as the engine increases speed from idle to normal operating speed, the pump will be able to accelerate the mass of water in the discharge line without overloading the engine at any point in the acceleration cycle. The engine is selected based on the maximum pump horsepower required under the maximum head condition, which is about 180 HP. Allowing some tolerance on pump manufacturer's curve data, use 190 HP for required engine horsepower at continuous rating.

It is very unusual in stormwater pump station design to encounter operating conditions such as described, which require pumps to fill a discharge line and then accelerate the column of water. However, the example does point out what is meant by shut-off head and the horse-power requirement involved. Another relatively unusual matter was that at least four manufactuers of vertical pumps had models capable of meeting design conditions with a high percentage of efficiency. In many cases the required percentage of efficiency may be specified lower so that sufficient competition results.

15-C. STATION DESIGN CALCULATIONS

Q (PER CITY OF LONG BEACH) = 181 CFS
MAX DESIGN WATER SURFACE ELEVATION = −4.05 (ORIGINAL SOFFIT OF 75" INLET)
MAX WATER SURFACE ELEVATION, CHANNEL 2 = +4.74 } ABOVE MEAN SEA L.
GROUND SURFACE ELEVATION AT STATION = +12.50
INLET PIPE 75" DIAM, SLOPE .001, INVERT = −14.10
TRIBUTARY SYSTEM AND LINE STORAGE (FIGURE 4-8)
INVERT OF DISCHARGE IN CHANNEL = −0.04
LENGTH OF DISCHARGE LINE IS ± 1213 FEET R.C.P.

SELECTION OF PUMPS

3 GAS-ENGINE DRIVEN PUMPS WILL TOTAL 85%
1 ELECTRIC-MOTOR DRIVEN PUMP WILL BE 15%
181 CFS = 100%

CAPACITY OF EA. ENGINE-DRIVEN PUMP = 51.33 CFS
Q_P = 23038 GPM

CAPACITY OF ELECTRIC-DRIVEN PUMP = 27.0 CFS
Q_P = 12118 GPM

STARTING SEQUENCE

	EL.
PUMP NO. 1, 27.0 CFS ELECTRIC DRIVEN, 1ST TO START,	−7.05
PUMP NO. 2, 51.33 CFS ENGINE DRIVEN, 2ND TO START,	−6.05
PUMP NO. 3, 51.33 CFS ENGINE DRIVEN, 3RD TO START,	−5.05
PUMP NO. 4, 51.33 CFS ENGINE DRIVEN, 4TH TO START,	−4.05

BOTTOM OF PUMP PIT

EL. = −14.22, AS DETERMINED BY DRAINAGE FROM INLET. SUITS MAIN PUMP SUBMERGENCE, WITH $S/D = 1.04 > 0.8$. MIN. CYCLING TIME OF ELECTRIC-DRIVEN PUMP, COMPUTED ON PAGE 4.18 IS NOT RELEVANT.

STILLING WELL

PENETRATIONS IN PUMP PIT BACK WALL PROVIDE STILLING WELL FOR PRESSURE SWITCHES, ACCESS TO BOTTOM OF PIT, AND WELL PROVIDES ADDED SUMP AREA

PUMP PIT DESIGN

TRANSITION ANGLE = 45°

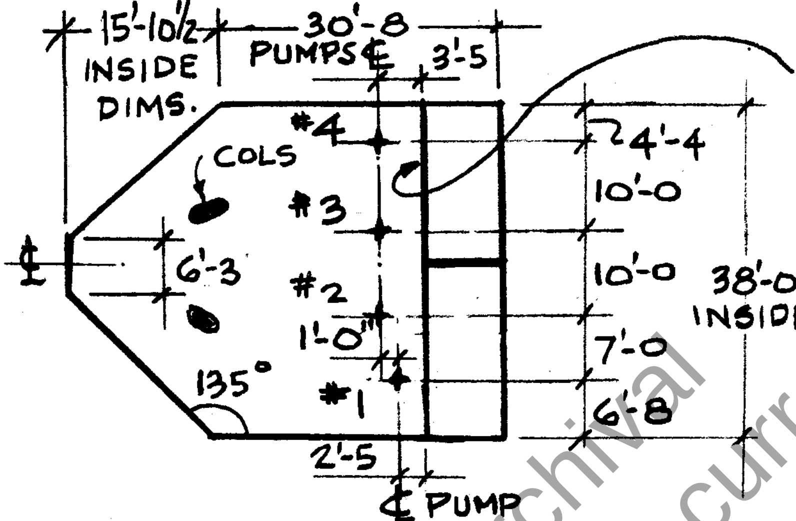
INVERT OF PIT = − 14.22

DESIGN W.L. = − 4.05

WIDTH OF PIT = 38'-0" BETWEEN SIDE WALLS

C.S. AREA = 38.0 × 10.17 = 386.5 □' AT Q = 181 CFS

VELOCITY v = 181/386.5 = .47 FT/SEC < V_{TR} = 2.0 (FIGURE 6-1)
< 1.0 RECOMMENED MAXIMUM



FACE OF BACKWALL 1'-4 THICK

AREA OF INTERNALS

38 × 1'-4 = 51

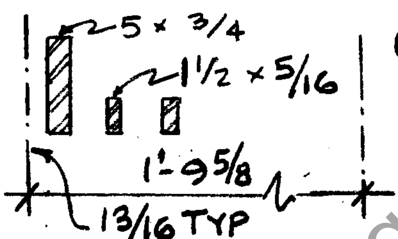
4'-8 × DO = 6

2⅔ × 4'-0" × 1'-4" = 7

64 S.F

TO PAGE 15-11

TRASH RACK (MODULAR CONSTRUCTION) (FIGURE 14-7)



(3 × ¾) + (10 × 5/16) = 5⅜ Σ BARS

v = .47 × $\frac{21.625}{16.25}$ MODULE / NET SPACE

= .62 FT/SEC H_L NEGLEGIBLE

ABRUPT CHANGES

ALLOW 5D FROM ℄ MAIN PUMPS TO DOWNSTREAM END OF TRANSITION. D = 4'-0" MAX. (AURORA PUMPS 30L M36)
5 × 4'-0" = 20'-0"   (SEE PAGE 6-8).

ACTUALLY PROVIDED = 15'-8" ℄ PUMP TO TRASH RACK BASE
+ 4'-4" TRASH RACK BASE TO TRANSITION
TOTAL = 20'-0"   O.K.

ACCESS STAIRWAY - STAIRWAY TO STAIR-WELL WILL NOT CREATE TURBULENCE AFFECTING MAIN PUMPS. EFFECT OF APERTURES IN BACKWALL IS NOT CONSIDERED TO HAVE ANY SIGNIFIGANCE, AS REDWOOD DOORS HAVE BEEN PROVIDED TO MAKE WALL SMOOTH. SMALL BOTTOM OPENINGS PROVIDE WATER COMMUNICATION.

PUMP PIT DIMENSIONS

MAIN PUMPS 51.33 CFS

D (BELL ϕ) = 48" AURORA 30LM36
42" JOHNSTON 30LS
37" PEERLESS 36MF
} USE 48"

B (BACKWALL CLEARANCE) = .25D WITHOUT UMBRELLA
— DOES NOT GOVERN
(SEE FIGURE 6-3)
.10D WITH UMBRELLA = 4.8"
UMBRELLA ϕ 72" ∴ 36 + 4.8" = 40.8" USE 41"

C (BOTTOM CLEARANCE) = .5D MINIMUM USE 24"

Y (TRASH RACK TO BACKWALL) = 15'-8" + 3'-5" = 19'-1" = 229"
(SEE FIGURE 6-2) 23,038 GPM = 225" < USE 229"

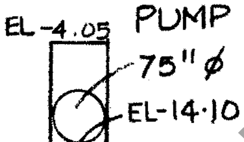
M (PUMP SPACING) (FIGURE 6-2) 23,038 GPM = 86"
86" < USE 120" (GOVERNED BY ENGINE CLEARANCES)
SPACING TO SMALL PUMP, 12118 GPM USE 84"
(MIN. DIM. FROM FIGURE 6-2 = 66" < 84")

SUCTION UMBRELLA 51.33 / 2.0 = 25.66 SQ FT AREA MIN.
= 5.716' ϕ = 68.59" USE 72" ϕ

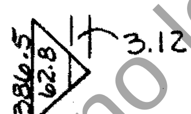
SUBMERGENCE (.85 BELL ϕ, WITH UMBRELLA) = 40.8"
48"
USE 3'-5"

PIT CAPACITY

EL -14.22
EL - 4.05



PUMP PIT 38' WIDTH × FRONT/BACK 29.33 × 10.17 = 11335 CU.FT.
VERT C.S AREA = 386.5 □'
TRANSITION INLET 10.17 × 6.25 = 62.8 □' AREA.
TRANSITION LENGTH = (38 - 6.25) / 2 = 15.875'



15 - 10½
3 - 1½
386.5 × 19 - 0 / 2 = 3672 LESS 62.8 × 3.12/2 = 98
LESS 62.8 × 3.12/2 = 98
3574

Σ CAPACITY = 11335 + 3574 = 14909 CU FT

PIT AREA

30'-8 × 38-0 = 1165
15'-10½ × (38-0 + 6'-3)/2 = 351
LESS BACKWALL AND COLUMNS = - 64 (PAGE 15-10
1452 S.F.

SELECTION OF MAIN PUMPS

54" ϕ DISCHARGE $\quad A = 4.5^2 \times \pi/4 = 15.90\ \square'$

$V = 181/15.90 = 11.38$ FT/SEC

$H_{V_{54"}} = 11.38^2/64.4 = \underline{\underline{2.01\ \text{FT.}}}$

36" ϕ DISCHARGE $\quad A = 3.0^2 \times \pi/4 = 7.07\ \square'$

$V = 51.33/7.07 = 7.26$ FT/SEC

DISCHARGE PIPE INVERT IS -0.04 WITH FLAPGATE

DISCHARGE SOFFIT IS $-0.04 + 4.50 = +4.46$

DESIGN STATIC HEAD IS DIFFERENCE BETWEEN HIGH TIDE $+4.74$ AND MAX. ALLOWABLE (DESIGN) WATER SURFACE IN SUMP OF -4.05

$\therefore$ DESIGN $H_S = 4.74 + 4.05 = \underline{\underline{8.79'}}$

MAX. STATIC HEAD IS DIFFERENCE BETWEEN HIGH TIDE $+4.74$ AND MIN. WATER SURFACE IN SUMP (FOR MAIN PUMPS) OF -8.05 (STOP ELEV. OF PUMP #2)

$\therefore$ MAX. $H_S = 4.74 + 8.05 = \underline{\underline{12.79'}}$

FOR SMALL PUMP #1, MAX $H_S = 4.74 + 10.23 = \underline{\underline{14.97'}}$
(BASED ON STOP ELEV OF -10.23 FOR PUMP #1)

MIN. STATIC HEAD OCCURS WHEN SEA WATER LEVEL IS BELOW INVERT OF DISCHARGE AND MAX. ALLOWABLE (DESIGN) WATER SURFACE IN PUMP PIT OF -4.05 OCCURS

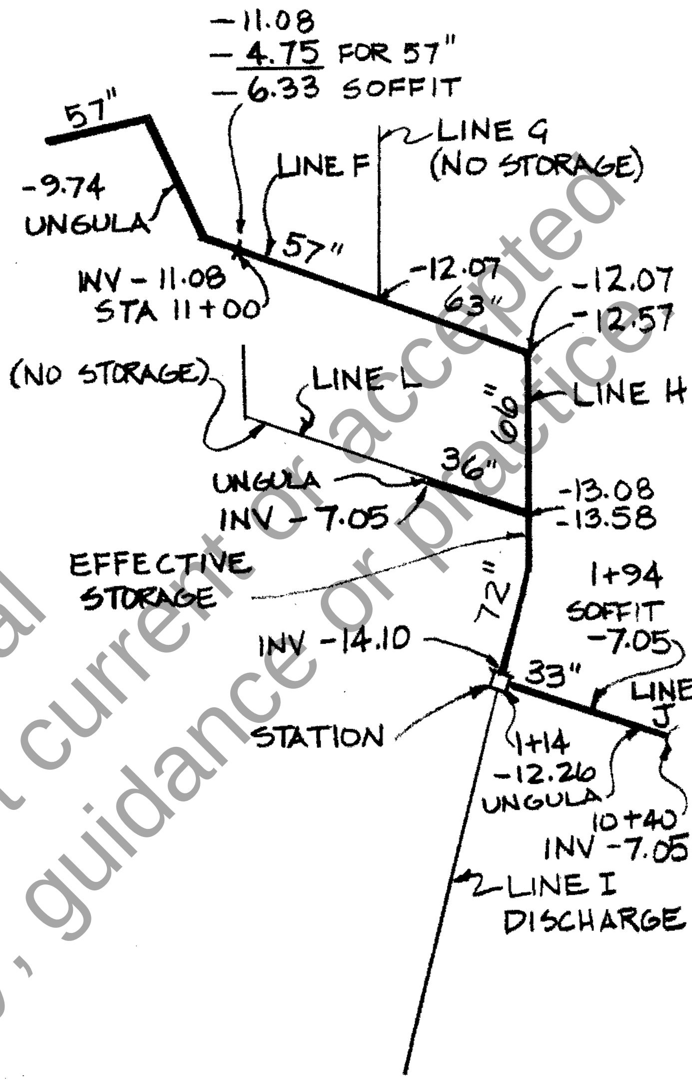
$\therefore$ MIN $H_S = \left(-.04 + \frac{4.5}{2}\right) + 4.05 = \underline{\underline{6.26'}}$

(ASSUME DISCHARGE RUNS HALF-FULL)

LINE STORAGE CAPACITY

DUE TO THE NECESSITY OF LOWERING LINE H AT STA 11 & 12 TO PASS UNDER 27" SEWER THE CAPACITY OF THE SYSTEM HAS BEEN GREATLY INCREASED

APPROXIMATIONS ARE MADE FOR TOTAL LENGTH OF LINES WITH SOFFIT BELOW - 7.05 AND STORAGE IS CALCULATED ACCORDINGLY, WITH A SMALL ADDITION FOR UNGULAS



LINE J JOINS LINE H AT STATION AND A 75" PIPE ENTERS THE TRANSITION.

A COMPARISON SHOULD BE MADE WITH CONDITIONS SHOWN IN CHAPTER 4, FIGURES 4-8 AND 4-9

LINE H 72"

522.7' x 28.27 = 14779

LINE H 66"

518.5' x 23.75 = 12318

LINE F 63"

503.0 x 21.64 = 10888

LINE F 57"

505.0 x 17.72 = 8948

LINE L 36"

± 75 x 7.06 = 530

LINE J 33"

± 80 x 5.94 = 475

47938

ADD FOR UNGULAS ± 5000

TOTAL STORAGE ±53000 CU. FT.

PUMP OPERATING RANGE

PUMP #1, REQD $\Delta h = \frac{15\,Q_P \Delta T - V}{A}$ TO MEET CYCLING CRITERIA

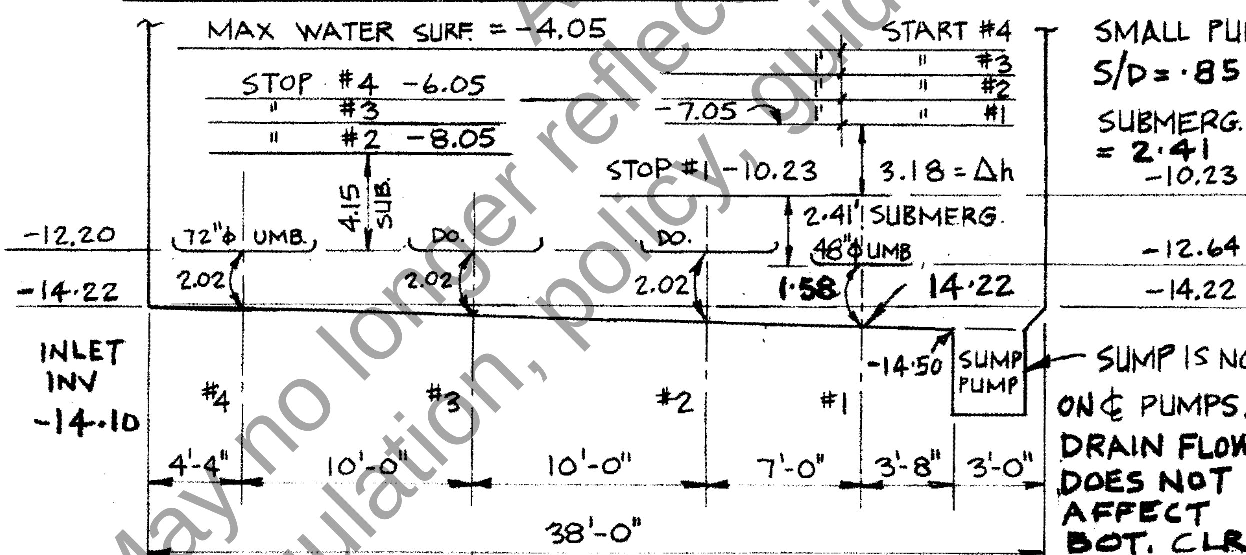
$$= \frac{\overset{6075}{(15 \times 27 \times 15)} - 53000}{1452} = \text{NEGATIVE VALUE (DOES NOT APPLY)}$$

BELL DIAM $D = 34''$
(SEE PAGE 15-22)
$.85 \times 34'' = 2.41'$
C MIN $= .5D = 17''$ USE $19'' = 1.58'$
STOP EL. CAN BE LOWERED TO:

ACTUAL Δh PROVIDED
$= 12.64 - 7.05 - 2.41$
BELL EL. W.L. SUBMERG.
$= 3.18'$
#1 STOP = -10.23

MAIN PUMPS GOVERN DEPTH OF PIT
#2 STOP = EL. -8.05 — -8.05 — S/D = 1.04
SUBMERGENCE = 3.42 MIN. S/D = .85 — 4.15 } PROVIDED
BOTTOM CLEAR = 2.00 (.5×48"φ BELL) — 2.02 } PROVIDED
MINIMUM = -13.47 ACTUALLY -14.22 OK

BOTTOM PROFILE & PUMP STAGING



SMALL PUMP
S/D = .85
SUBMERG. = 2.41

SUMP IS NOT ON ₵ PUMPS. DRAIN FLOW DOES NOT AFFECT BOT. CLR OF 2.02'. FOR #2, #3, #4

PUMP CYCLING TIME AT 27 CFS CAPACITY $\Delta T = \frac{A\Delta h + V}{15\,Q_P}$

$$\Delta T = \frac{\overset{4617}{(1452 \times 3.18)} + 53000}{15 \times 27} = 142 \text{ MIN. OK FOR 150 H.P.}$$

DUE TO DECREASED LINE FRICTION, Q MAY BE GREATER THAN 27 CFS AND ΔT LESS. WAS RECHECKED TO SUIT PUMP SELECTION.

FRICTION LOSSES IN DISCHARGE

A. PUMP COLUMN — STEEL PIPE $\varepsilon = .00015$

$$\frac{\varepsilon}{D} = .00015/3 = .00005 \quad (36'' \phi)$$

$f = .0119$ — COLUMN LENGTH, USE 30'

$$h_f = f\frac{L_e}{D}\cdot\frac{V^2}{2g} = .0119 \times \frac{30}{3} \times \frac{(7.26)^2}{64.4} = \underline{\underline{.10'}}$$

B. CHECK VALVE — 36" ϕ @ 7.26 FT/SEC
PER APCO CURVE $h_f = \underline{\underline{.25'}}$

C. PUMP ELBOW — 36" ϕ @ 23,038 GPM $h_f = \underline{\underline{.29'}}$

D. MANIFOLD ELBOW — 90° - 4 MITERS $\Delta = 22\tfrac{1}{2}°$

$$.08\frac{V^2}{2g} \times 4 = .08 \times \frac{(7.26)^2}{64.4} \times 4 = .26 \qquad h_f = \underline{\underline{.26'}}$$

E. MANIFOLD INCREASERS $h_f = .1\left[\frac{V^2}{2g} - \frac{V_2^2}{2g}\right]$

V_2 (54" ϕ @ 181 CFS) $= (11.38)^2$ (INCREASING VELOCITY)
$V_1^2 = $ (36" ϕ @ 51.3 CFS) $= (7.26)^2$ $\quad h_f = \underline{\underline{.12'}}$

F. MANIFOLD, PUMP #4 TO PUMP #3 ($d = 36''$, $D = 3$)

STR.-THROUGH TEE $= 20D = 60'$ $\quad \varepsilon = .00015$ (STEEL)

$\varepsilon/D = .00005$ REYNOLD'S NUMBER $= \dfrac{50.6\,q\rho}{d\,\mu}$

$$= \frac{50.6 \times 23038 \times 62.4}{36 \times 1.1} = 1.834 \times 10^6$$

$$f = .012 \qquad h_f = f\cdot\frac{L_e}{D}\cdot\frac{V^2}{2g} = \frac{.012 \times 60 \times (7.26)^2}{3.0 \times 64.4}$$

$$h_f = \underline{\underline{.20'}}$$

THE ABOVE THROUGH K. ON PAGE 15-17 ARE SUMMED AS TOTAL h_f (HEAD LOSS DUE TO FRICTION) SEE FIGURE 8-4 FOR DIAGRAM AND TABULATION.

FRICTION LOSSES (CONT'D)

G. MANIFOLD, PUMP # 3 TO PUMP # 2 ($d = 48''$, $D = 4$) $\quad v = \dfrac{2 \times 51.33}{4.0^2 \times \pi/4} = 8.17$ FT/SEC

10' + STR-THROUGH TEE @ 20D = 90'

$\varepsilon/D = .00015/4 = .0000375$

REYNOLD'S NUMBER $= \dfrac{50.6 \times (2 \times 23038) \times 62.4}{48 \times 1.1} = 2.755 \times 10^6$

$f = .011 \quad h_f = \dfrac{.011 \times 90 \times (8.17)^2}{4.0 \times 64.4} = .26$

$h_f = \underline{\underline{.26'}}$

H. MANIFOLD, PUMP # 2 TO PUMP # 1 ($d = 54''$) $\quad v = \dfrac{3 \times 51.33}{4.5^2 \times \pi/4} = 9.68$ FT/SEC

10' + STR-THROUGH TEE @ 20D = 100'

$\varepsilon/D = .00015/4.5 = .00003$

REYNOLD'S NUMBER $= \dfrac{50.6 \times (3 \times 23038) \times 62.4}{54 \times 1.1} = 3.674 \times 10^6$

$f = .0105 \quad h_f = \dfrac{.0105 \times 100 \times (9.68)^2}{4.5 \times 64.4} = .34$

$h_f = \underline{\underline{.34'}}$

J. DISCHARGE LINE

ACTUAL LENGTH DOWNSTREAM OF MANIFOLD	= 1213 FT
90° BEND 4-METER = 20 D	= 90
45° BENDS 4 @ 5 D	= 90
Σ EQUIVALENT LENGTH	= 1393 FT

ε(CONCRETE) = .001 $\quad \varepsilon/D = .00022 \quad$ 181 CFS = 81,233 GPM

$Re = \dfrac{50.6 \times 81{,}233 \times 62.4}{54 \times 1.1} = 4.318 \times 10^6$

$f = .0142 \quad h_f = \dfrac{.0142 \times 1393 \times (11.38)^2}{4.5 \times 64.4} = 8.84'$

BY REYNOLD'S NUMBER, $h_f = \underline{8.84'}$

FRICTION LOSSES (CONTD)   J DISCHARGE LINE (CONTD)

IN LIEU OF THE REYNOLDS NUMBER, THE MANNING FORMULA MAY BE USED FOR DISCHARGE LINES EXCEEDING 100 FT., OR MANIFOLDED INTO A SINGLE LINE (SEE PAGE 8-7)

$$h_f = L\left[\frac{Qn}{1.486\,AR^{2/3}}\right]^2 = 1393\left[\frac{181 \times .013}{1.486 \times 15.90 \times \left(\frac{4.5}{4}\right)^{2/3}}\right]^2$$

$$h_f = \underline{\underline{11.81'}} > 8.84 \qquad \underline{\underline{\text{USE } 11.81'}}$$

K. FLAP GATE   EXIT LOSS $h_f = \underline{.04'}$

T.D.H. = H_s (PAGE 15-12) + H_f SUMMATION + H_v (PAGE 15-12)

DESIGN −4.05 = 8.79 + (.10 + .25 + .29 + .26 + .12 + .20 + .26 + .34 + 11.81 + .04) + 2.01

= 8.79 + 13.67 + 2.01   Q = 23038

= 24.47'   USE 24.5' DESIGN

STOP #4 −6.05 = 10.79 + <13.67 + <2.01 = <26.47'   USE 26.5' MAX.

ALL PUMPS RUNNING & HIGH TIDE)   Q = 21600 GPM @ 26.5' & Q_{STN} = 166 CFS

MIN. STATIC = 6.26 + (13.67 × 50% APPROX.) + $\frac{8.74^2}{64.4}$ = 14.47

(ONE MAIN PUMP ONLY RUNNING)   Q = 28300 GPM = 63.0   USE 14.0' MIN.

(UNLIKELY CONDITION)

$$= \frac{K' d^{8/3} s^{1/2}}{n}$$

$$63 = \frac{K' \times (4.5)^{8/3} \times .006^{1/2}}{.013} \qquad K' = .191$$

KING'S (TABLE 7-14) $D/d = .44 + (\frac{56}{75} \times .01) = .447$

DEPTH OF WATER IN DISCHARGE LINE = .447 × 4.5 = 2.01 FT. OK

TDH (CONTD)

MAX. STATIC $= 12.79 + < 13.67 + < 2.01 = < 28.47'$

-8.05 USE 28.5' TO CHECK H.P.

ALL PUMPS RUNNING

& HIGH TIDE $Q = 19800$

(UNLIKELY CONDITION) MAX H.P. = 170 @ 85% EFFICIENCY

SMALL PUMP, #1 DESIGN $Q = 27$ CFS = 12117 GPM

T. D. H.

@ STOP #4 $- 6.05 = $ 26.5' MAX.

MAX. STATIC
STOP -10.23 $= 14.39 + (\underset{6.84}{\overset{\text{APPROX}}{13.67}} \times 50\%) + 1.18 = 22.40 < 26.5$

(#1 ONLY,
HIGH TIDE) (UNLIKELY CONDITION)

MIN. HEAD $= 6.26 + 6.84 + 1.18 = 14.28$

USE 14.0 MIN.

DESIGN
-4.05 CONDITION AS FOR MAIN PUMP

USE 24.5' DESIGN

AT 14.0' MIN. CHECK Q AND ΔT (PEERLESS 30 MF)

$Q = 15500$ GPM $= 34.5$ CFS

$$\Delta T = \frac{4517 + 53000}{15 \times 34.5} = \underline{111 \text{ MIN.}} \quad \text{OK} > 15 \text{ MINUTES}$$

FIG. 212

PUMP COLUMN. 51.3 CFS / 36" ϕ $v = 7.27$ FT/SEC. < 10.0 OK.

27.0 CFS / 24" ϕ $v = 8.59$ FT/SEC < 10.0 OK.

MAIN PUMPS – SELECTION

DESIGN 23038 GPM @ 24.5' TDH
TDH RANGE 14.0' MIN. TO 26.5' MAX.

AURORA VERTLINE 30 LM 590 RPM

DESIGN	23038 @ 24.5		85%	167.6 H.P.
MIN.	25800 @ 14.0		73%	124.9 H.P.
MAX.	22500 @ 26.5		85.5%	176.0 H.P.
	SHUT-OFF	71.8 FT		289 H.P.

JOHNSTON 30 LS 585 RPM

DESIGN	23038 @ 24.5		82.5%	172.7 H.P.
MIN.	26200 @ 14.0		70%	132.3 H.P.
MAX.	22200 @ 26.5		84%	175.7 H.P.
	SHUT-OFF	70 FT.		291 H.P.

CASCADE 30 MF 580 RPM

DESIGN	23038 @ 25.0		82%	180 H.P.
MIN.	26500 @ 14.0		69%	136 H.P.
MAX.	22200 @ 26.5		83%	179 H.P.
	SHUT-OFF	56 FT.		302 H.P.

PEERLESS 36 MF 585 RPM

DESIGN	23038 @ 24.5		89.6%	159.0 H.P.
MIN.	28400 @ 14.0		80.0%	125.5 H.P.
MAX.	19800 @ 26.5		86.5%	153.1 H.P.
	SHUT-OFF	60 FT		263 H.P.

SPECIFY:

EFF AT DESIGN HD = 82% MIN. SHUT-OFF 64 FT. MAX.
* " " MIN HD = 69% MIN 280 H.P. MAX.
* " " MAX. HD = 82% MIN

* SPECIFYING MINIMUM EFFICIENCIES AT OTHER THAN DESIGN HEAD MAY BE UNDULY RESTRICTIVE AND IS NOT RECOMMENDED.

MAIN PUMPS – DATA

MAKER	AURORA	JOHNSTON	CASCADE	PEERLESS
MODEL	30LM	30LS	30MF	36MF
RPM	590	585	580	585
DISCHARGE	36"	36"	36"	36"
ELBOW LENGTH (FLANGED)	34"	30"	36"	–
BELL·ϕ	48"	42"	49"	37"
BELL AREA	12.57	9.62		7.47
BELL VEL	4.08	5.34		6.87
SUBMERGENCE (W/BELL)	1.55D=74.4"	1.8D = 75.6"	1.8D=72"	–
C	24	21	–	–
B	.75D=36	.75D=31.5	.75D=30	.75D=27.75"
V_1	235	235	235	235
M	88	88	88	88
UMBRELLA ϕ (2 FPS MAX)	72"	72"	72"	72"
V_B	1.91 FT/SEC	1.91	1.91	1.91
SUBMERGENCE (W/UMBR'A)	.85D=40.8	35.7	34	31.5
B .6D	40.8	40.8	40.8	–

UMBRELLA SIZE; (LARGE PUMPS) AREA REQ'D = $51.33/_{2.0}$ = 25.67 SQ. FT.

D REQ'D. = $\sqrt{\frac{4A}{\pi}}$ = 5.712' = 68.62"

USE 72"

(SMALL PUMPS) AREA REQ'D. $27/_{2.0}$ = 13.50 SQ. FT.

D REQ'D. $\sqrt{\frac{13.5}{.7854}}$ = 4.14 = 49.75"

USE 48"

SMALL PUMP - SELECTION

DESIGN 12117 GPM @ 24.5' TDH
TDH RANGE 14.0 MIN TO 26.5' MAX.

(LAYNE & BOWLER)

AURORA VERTILINE 20LM 880 RPM

DESIGN	12117	@	24.5	85%	88.2 HP
MIN	13800	@	14.0	72%	67.7 HP
MAX	11400	@	26.5	85.5%	89.2 HP

SHUT-OFF 76 FT 157 HP

JOHNSTON 20 MS 875 RPM

DESIGN	12117	@	24.5	81%	92.5 HP
MIN	13700	@	14.0	60%	80.7 HP
MAX	11600	@	26.5	82%	94.6 HP

SHUT-OFF 77 FT 145 HP

CASCADE 24 MF 590 RPM

DESIGN	12740	@	24.5	84.5%	94.4 HP
MIN	16300	@	14.0	76.0%	79.0 HP
MAX	11180	@	26.5	78.8%	96.3 HP

SHUT-OFF 77 FT 148 HP

PEERLESS 30 MF 705 RPM

DESIGN	12117	@	24.5	88.0%	85 HP
MIN	15500	@	14.0	82.0%	65 HP
MAX	11800	@	26.5	87.0%	85 HP

SHUT-OFF 144.5 HP @ 57.5

SPECIFY

EFF AT DESIGN HD = 80% MIN
" " MIN. HD = 60% MIN
" " MAX. HD = 75% MIN

* SEE PAGE 15-19

SHUT-OFF 60 FT MAX 150 HP MAX

SMALL PUMP DATA

MAKER	AURORA (L & B)	JOHNSTON	CASCADE	PEERLESS
MODEL	20 LM	20 MS	24 MF	30 MF
RPM	880	880	590	705
DISCHARGE	24"	24"	24"	24"
ELBOW LENGTH (FLANGED)	24"	22"	24"	30"
BELL ∅	34"	28 1/2"	40"	31 1/2"
BELL AREA	6.30	4.43	5.58	5.41
BELL VEL.	4.29	6.09	4.84	4.99
SUBMERGENCE (W/BELL)	1.6D = 4.53	1.8D = 4.28	1.8D = 4.80	1.8D = 4.73
C	17"	14"	16"	16"
B	25.5"	21.5"	24"	23 5/8"
V_1	170	170	170	170
M	65	65	65	65
UMBRELLA ∅ (2 FPS NOM)	48"	48"	48"	48"
V_B	2.15	2.15	2.15	2.15
SUBMERGENCE (W/UMBR'A) .85D	2.41'	2.02'	2.27'	2.23'
B .6B	30"	30"	30"	30"

PUMP THRUST

PUMP THRUST = HYDRAULIC THRUST + WT. OF SHAFTING & IMPELLER

JOHNSTON 194 THRUST FACTOR × 26.5' TDH

+ 15.87 #/FT X 25'

+ 550 # PUMP SHAFTING & IMPELLER

= 5141 + 397 + 550

= 6088 # THRUST

AURORA VERTILINE (L & B)

206 THRUST FACTOR × 26.5 + (15.87 × 25) + 550

= 5459 + 397 + 550

= 6406 # THRUST

PEERLESS

= 6760 # THRUST

SUMP PUMP SELECTION

SUMP & DRAIN LINE VOLUME BELOW PUMP # 1 OFF

(14.22 - 10.23 = 3.99)

= 14205 × 3.99 = 5668 CU FT

USE UNGULA VALUE PER FIG = ± 5000

80010 GS = 10668 CU.FT.

℄ MANIFOLD	7.0
BOTTOM OF SUMP	16.50
H_f & H_v	4.58
TDH =	28.08 MAX

PUMP-OUT TIME

80010/600 = 133 MIN OK

WEMCO 453 600 GPM @ 27.0 TDH 15 HP MOTOR

8 3/4" IMPELLER 1735 RPM

IF VOLUME UNDER BELL GOVERNS

PUMP-OUT TIME = 138 × 1.58/3.99 = 54.8 MIN APPROX

ENGINE SELECTION

USING A 2:1 RIGHT ANGLE GEAR DRIVE RATIO GIVES AN ENGINE SPEED OF 590 × 2 = 1180 R.P.M.
WITH 700 RPM PUMP USE 5:3 RATIO = 1167 R.P.M.
ALLOWING 5% LOSS THROUGH GEAR AND DRIVELINE

$$\text{REQUIRED DISPLACEMENT} = \frac{HP \times 792000}{BMEP \times RPM} = \frac{190 \times 1.05 \times 792000}{75 \times 1180} = \underline{1785.4}$$

ENGINES AVAILABLE TO MEET THIS REQUIREMENT ARE WAUKESHA MODEL 1905 GRU (1905 W INS) AND CATERPILLAR MODEL G-379 NA.

WAUKESHA MODEL 1905 GRU W/H.C. RATIO HAS A MAX. H.P. RATING OF 299 H.P. @ 1180 R.P.M.

$$\text{LOAD FACTOR} = \frac{190 \times 1.05}{299} = \underline{67\%}$$

CATERPILLAR MODEL G-379 NA W/ H.C. RATIO HAS A MAX. H.P. RATING OF 300 H.P. @ 1180 RPM.

$$\text{LOAD FACTOR} = \frac{190 \times 1.05}{300} = \underline{67\%}$$

SHUT-OFF H.P. FOR MAIN PUMPS = 295 H.P. APPROX. THEREFORE ENGINES CANNOT BE OVERLOADED AT 1180 R.P.M. SPEED.

LIMITS UNDER WHICH ENGINES COULD BE SAFELY OPERATED AT SPEEDS IN EXCESS OF 1180 R.P.M. WAS NOT INVESTIGATED AS PART OF FINAL DESIGN.

DRIVE SHAFT SELECTION

DELIVER 200 H.P. @ 1180 R.P.M. BEARING RATED B-10 LIFE. SERVICE FACTOR OF 2. OF 20000 HRS.

RIGHT ANGLE GEAR DRIVE SELECTION

PHILADELPHIA — SPEED REDUCTION RATIO 2:1
MODEL 15 HAS H.P. RATING 414
@ 580 RPM
MODEL 15 HAS DOWN THRUST CAPACITY
= 16,600 # > 6406
MODEL 15 HAS THERMAL RATING
OF 124 H.P. @ 580 R.P.M. 124 < 200
MODEL 15 OK

AMARILLO
CHARTS BASED ON 1.5:1 SERVICE FACTOR
∴ FOR 200 HP AT 2:1 SERVICE FACTOR SELECT
UNIT RATED AT 267 HP WITH 1.5:1 FACTOR
MODEL 60C-500 AT 2:1 REDUCING RATIO IS
RATED 230 HP ONLY AT 1.5:1 SERVICE FACTOR
CHECK MODEL 7BL FOR RATING (NOT LISTED ON CHART)

INLET AND EXHAUST FAN SELECTION

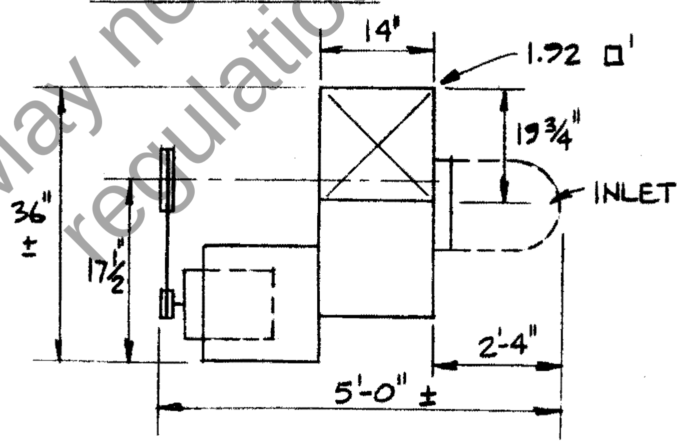
6 AIR CHANGES / HOUR

SUMP VOLUME $1420.5 \times (13.42 - 4.05) = 13310$
$38.0 \times 29.33 \times (11.50 + 4.05) = 17331$
$\Sigma = 30641$ CU. FT.

BLOWER CFM $= \dfrac{30641 \times 6}{60} = 3064$

$= 3064$ CFM @ 1" STATIC

BUFFALO FORGE CO. SIZE 300G BELTED VENT SET
2 HP MOTOR



LOCATE OVER STAIRWAY
EXHAUST DUCT 2.0 □'
TRANSITION TO 36" x 8"
EXIT THROUGH ROOF.

General view of wet-pit station showing many features, including mezzanine office

Figure 15-6

View from office showing engines. Light-angle gears and overhead crane as construction neared completion.

Figure 15-7

15-D. LIST OF EQUIPMENT

This Section summarizes the requirements for a rectangular wet-pit pump station which includes all of the applicable design features and a complete selection of equipment as described in preceding chapters. Figures 15-1 through 15-7 display the layout of selected equipment, and show how it is arranged with proper consideration for safety and convenience of personnel involved in operation and maintenance. The figures also show these factors and how they are integrated with architectural and structural requirements. The following check list is representative of one station only. Certain of the items are discretionary and all of the items will not be necessary at many stations. The designer must be selective in choosing from the options available. For instance, the pressure switch type of control, though reliable, is not necessarily endorsed in preference to types described elsewhere in the Manual.

- Trash Rack
- Hoisting Anchors
- Walkways and Grating
- Stairways and Ladders
- Redwood Doors
- Submersible Sump Pump
- Pressure Switch Risers
- Vertical Pumps
- Air-Release Valves
- Check Valves
- Dresser Couplings
- Discharge Manifold
- Maintenance Platforms
- Access and Clean-out Hatches
- Plumbing
- Gas and LPG Supply
- Engines and Control Panels
- Exhaust System
- Drive Shafts
- Right-Angle Gear Drives
- Electric Motor
- Electrical Switchgear
- Power and Lighting
- Fans and Ducting
- Pump Pressure Switches
- Gas Detector
- Tachometers and Wattmeters
- Water-level Recorder
- Telemetering
- Bridge Crane

15-E. DESIGN CO-ORDINATION

The basic pump pit dimensions were first determined from considerations of hydraulics and equipment selection. The floor plan was then developed to match. The required floor area was greater than that of the pump pit in this case. It was both longer and wider, which led to the false backwall. This in turn provided for the stairwell, stilling-well, and maintenance platform at the check valves.

For convenience and personal comfort, office and toilet facilities are provided. The office with sound-proofing is located at mezzanine level to both save space and provide operator overview of the station interior.

Minimum clearances, walkway and stairway widths, toe plates, handrail heights, ladders and safety cages were checked for compliance with OSHA regulations. Electrical safety was carefully observed.

The effective design of a pump station represents the successful integration of a vast number of factors, but it is believed that few have been neglected or not mentioned in this Manual, and the intent has been throughout to present adequate guide material which can either be used without change or may be adapted to suit particular circumstances.

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CHAPTER 16. RETROFITTING EXISTING STATIONS

16-A. GENERAL

Many agencies may have existing pump stations where operation is undependable or troublesome, or where excessive maintenance is required. Due to poor siting some stations may be vulnerable to flooding. This is illustrated by Figures 3-1, 3-2 and 3-4 in Chapter 3. - Site Considerations, with explanatory text. In this chapter various causes of unsatisfactory operation are briefly discussed. Some examples of modifications and retrofitting are given, as used or proposed to remedy deficiencies of various types. Apart from hydraulic or machinery problems, environmental or security conditions may not be satisfactory. In the latter cases, reconstruction of the pump station enclosure may be necessary for aesthetics, sound abatement, or to prevent vandalism.

16-B. POOR STATION LOCATION OR INLET CONDITIONS

In the following example, the same station was flooded twice over a period of twelve years, in a California location where the number of times of station operation each year is extremely low. Refer to the cover illustration and to Figure 16-1. Built to State of California standards then prevailing, the station serves to drain a local arterial street where depressed below an Interstate highway. At that time vertical pumps were used in combination with the below-pavement storage-box. Figures 2-1 and 2-2 show current practice, where horizontal centrifugal pumps are now used in preference to vertical pumps.

The station discharges into a channel at the top of the embankment and this channel also receives other tributary flows. The first flooding occurred shortly after the station was built, but was not due to malfunction of the station equipment. The discharge channel became blocked and during a heavy storm an overflow occurred, filling the depressed section to a level almost to the top of the station structure.

The second malfunction occurred due to erosion of the embankment face. By the end of a dry season a heavy growth of weeds had accumulated and this was cleared, leaving a bare face. With winter storms a build-up of mud and silt occurred in the storage box and wet-pit as illustrated in Figure 16-1. The pumps did not receive a proper fluid mixture with the result that bearings, impellers and bowls were damaged, the pumps ceased running and flooding occurred. A retro-fit was recommended to pipe city water

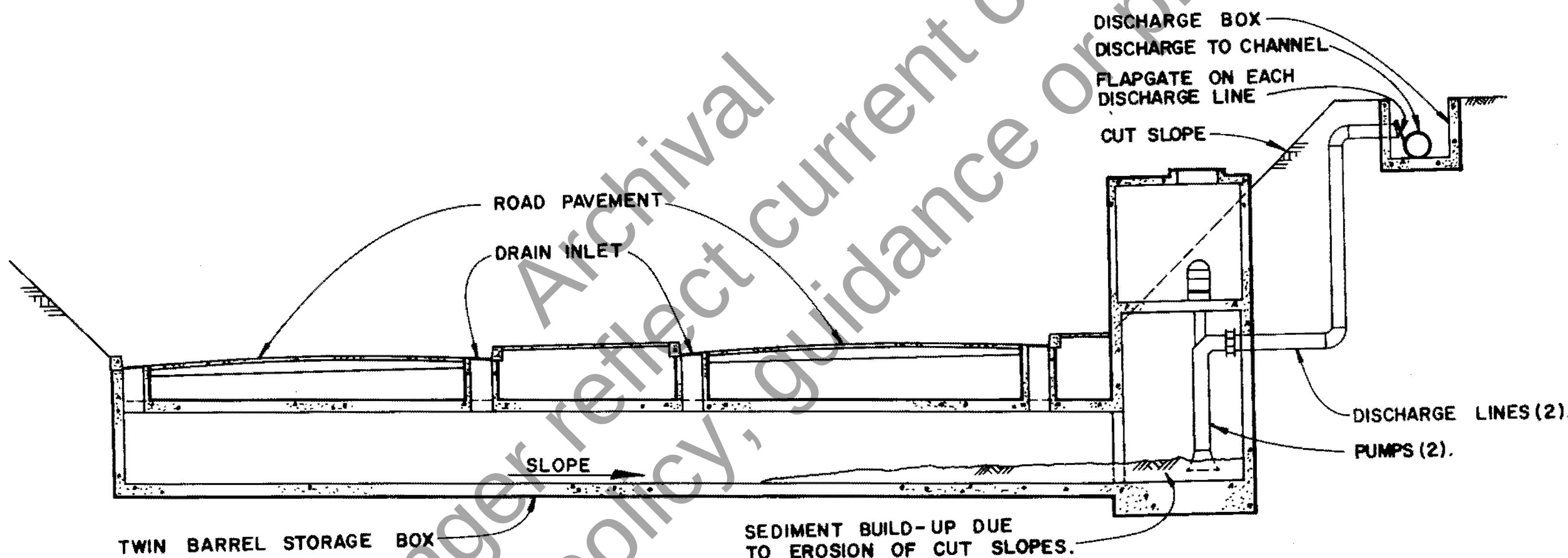


FIGURE 16-1. WET PIT STATION WITH STORAGE BOX

A SUPPLY OF CITY WATER IS PROPOSED TO FLUIDIZE THE SEDIMENT PRIOR TO PUMP START.

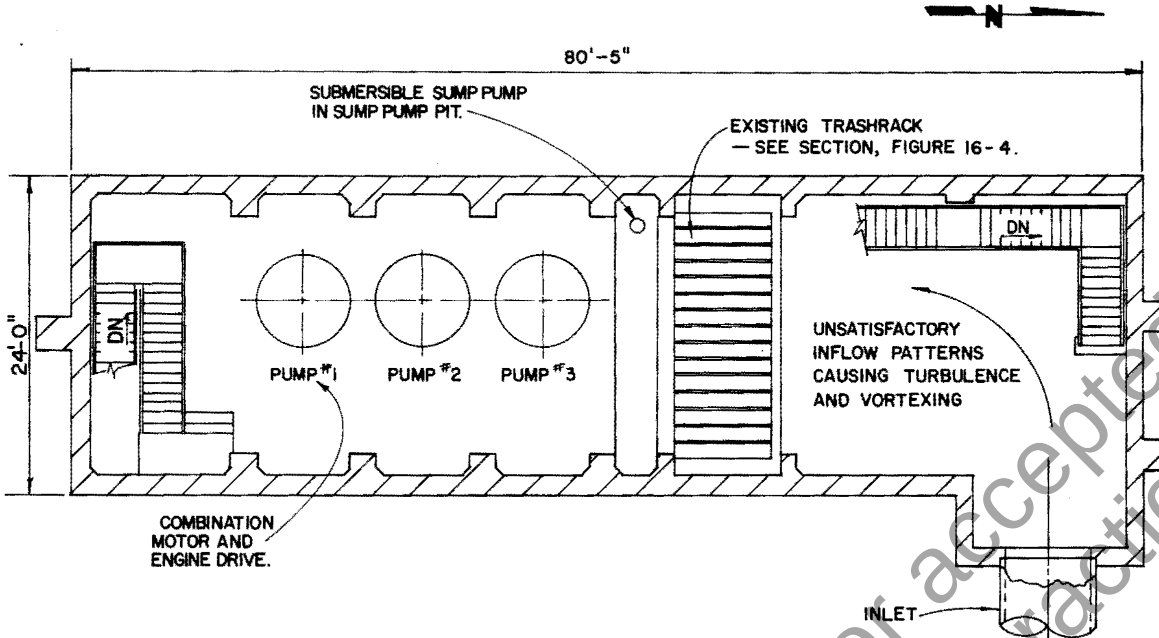
to the station and so flush mud from the vicinity of the pumps. Reference may be made to Figure 14-26 showing an agitator spray ring for small submersible pumps, with time-delay pump starting feature, allowing sufficient time for flushing action of piped water before pump start.

16-C. HYDRAULIC DEFICIENCIES

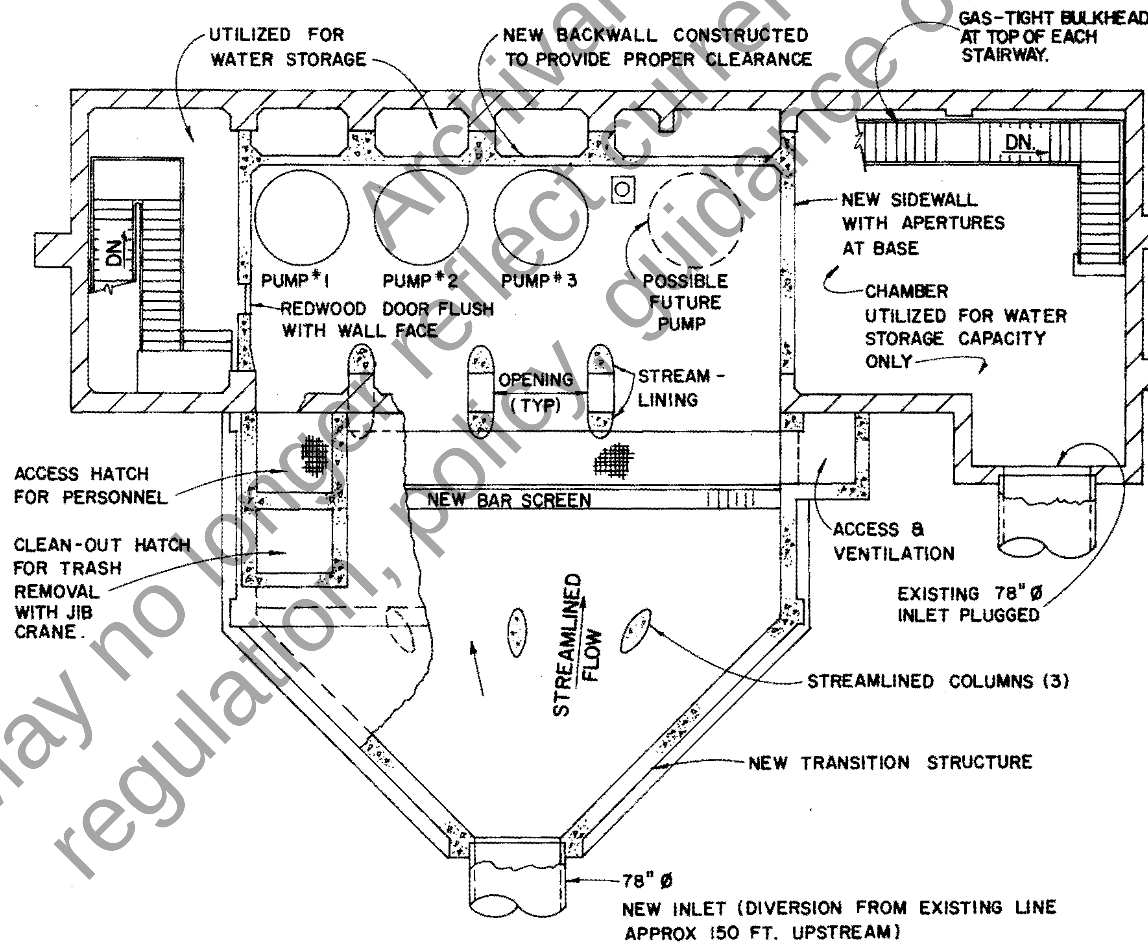
Considering vertical pumps, one of the principal causes of unsatisfactory operation is an improperly designed wet-pit. Proper criteria are set forth in Chapter 6. - Wet Pit Design, but many existing stations were designed prior to the present state of knowledge, or recommendations were not followed.

Where there are vertical pumps in a common pit, there must be adequate submergence, adequate spacing and proper flow of water towards the pumps. Although there should be streamlined flow at limited velocity, many stations have layouts which result in excessive velocity, turbulence and vortexing, which cause cavitation and reduced output. In many stations vertical pumps are too closely spaced, or have either excessive or insufficient clearances from concrete structures.

Cases exist where several pumps in a rectangular pit receive flow in line with their common centerline, instead of at right angles to it. When these pumps are running, they interfere with each other, reducing individual outputs substantially. An example of such a condition is illustrated in Figure 16-2, and its correction by construction of an inlet transition is shown. Another problem which results in turbulence and vortexing in the flow to the pumps is an improper trash rack design as illustrated in Figure 16-3. Flow is required to pass under a solid board obstruction, then over an obstructing wall. Large objects such as pieces of lumber or even automobile tires have been known to pass under such trash racks. A metal bar screen is much more effective, giving positive protection and less obstruction to flow. A modification from trash rack to bar screen is shown in Figure 16-4. Other possible corrections are also shown. These are removal of obstructions and addition of false backwalls and sidewalls to provide recommended clearances from pumps. The latter can sometimes be constructed out of heavy redwood planking at less cost than for concrete construction. As remedial measures, baffles or splitters are sometimes installed between pumps on a trial-and-error basis. Results may or may not be effective. The best way to approach problems of this nature is to have a scale model pump pit constructed at a hydraulic laboratory. By using one-quarter scale or similar and simulating conditions, the necessary modifications to produce good operation can be determined.



PLAN — BEFORE RECONSTRUCTION



PLAN - AFTER RECONSTRUCTION

FIGURE 16-2. PUMP STATION RECONSTRUCTION

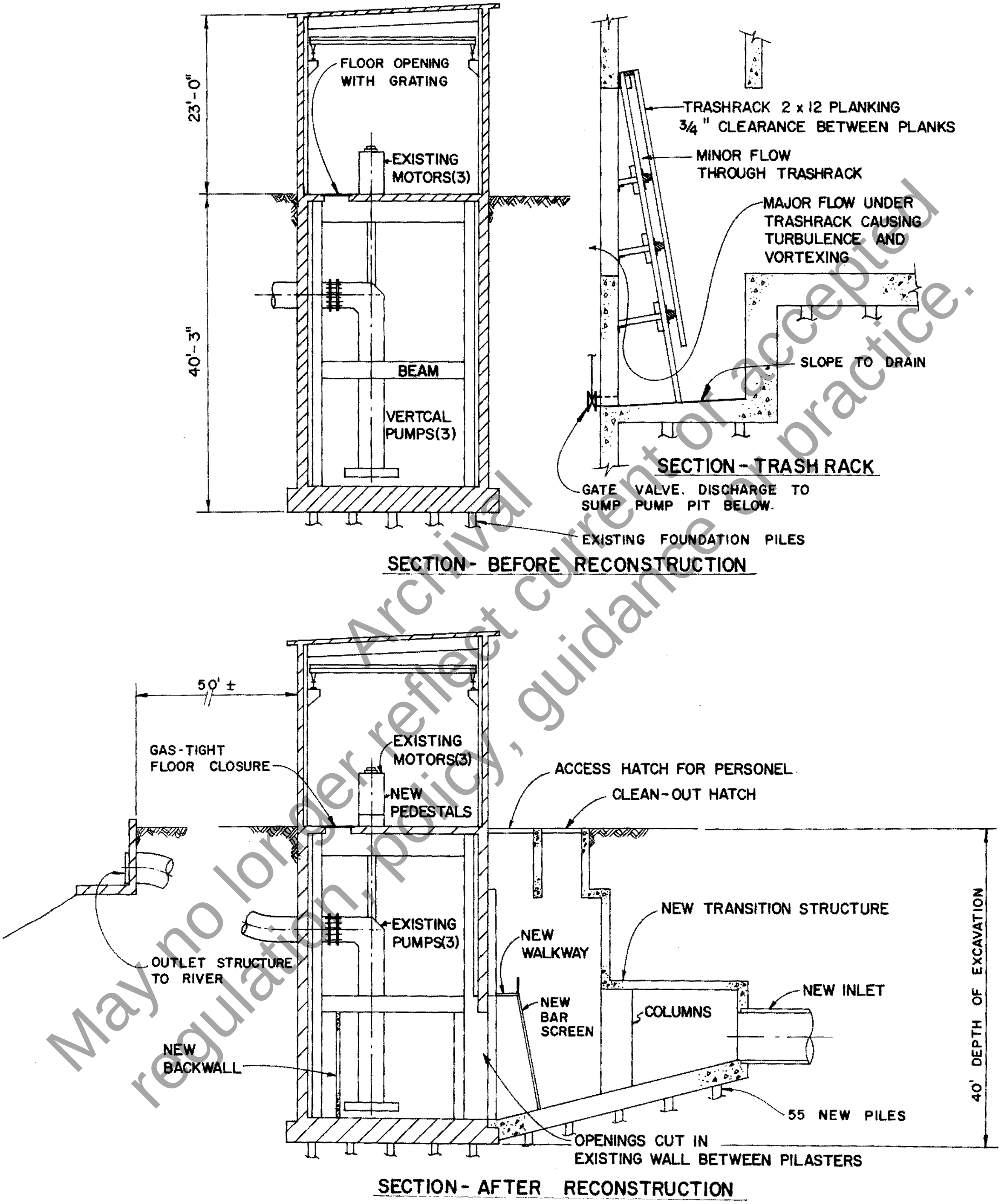


FIGURE 16-3. PUMP STATION RECONSTRUCTION

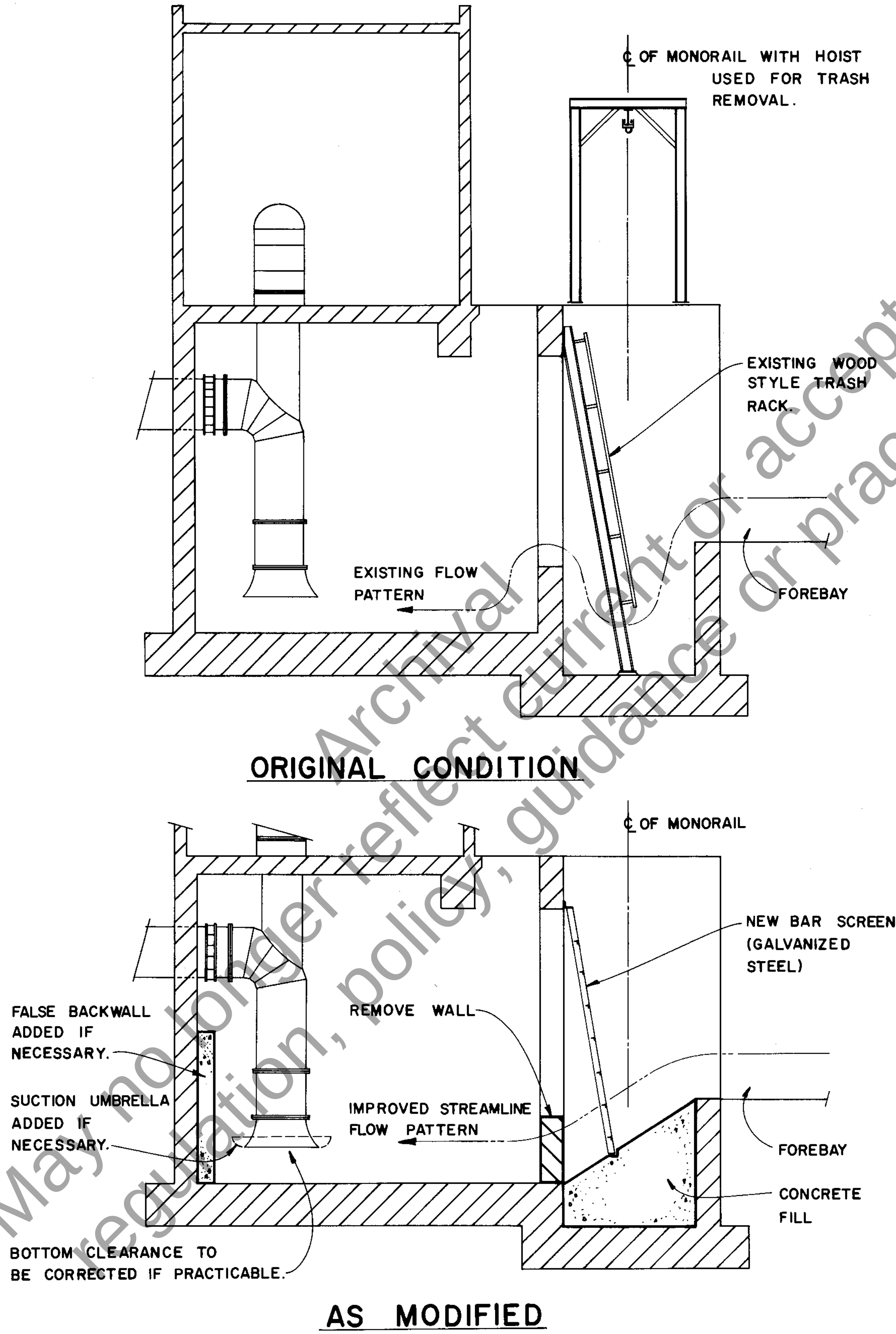


FIGURE 16-4. BAR SCREEN AND OTHER IMPROVEMENTS

One such laboratory operated by the Federal Government is located at the U.S. Army Corps of Engineers, Waterways Experiment Station at Vicksburg, Ms.

In the case of horizontal pumps, poor end-suction conditions can cause pre-rotation and improper performance, but no specific example of a deficiency and its correction can be offered.

16-D. REPLACEMENT OF PUMPS

There are cases on record where vertical pumps have been replaced, or where volute or angleflow pumps have been used in a wet-well/dry-well configuration and after years of service have been replaced by a different type of pump. A retrofit of the latter type is shown in Figure 16-5. Note that the wet-well was remodelled and two submersible pumps were installed in it. The dry-well was partially filled with sand and a new floor was constructed to support a modified discharge manifold. Ventilation and heating were added together with a small sump pump. The actual installation is on the Bronx Parkway, New York.

16-E. GAS-TIGHT SEALING, AND OSHA REQUIREMENTS

Reference was made to the merit of the storage-box in isolating the pump station from the collection system. Reference was also made in Chapter 6. - Wet-Pit Design, to the necessity for isolating the pump room from the pump pit by gas-tight gasketted floor plates or bulkhead doors. This sometimes, therefore, becomes a specific retrofit item. Details of suitable floor plates and frames are shown in Figure 14-9. Ladders and safety-cages are also illustrated. It is known that in order to comply with OSHA regulations, the State of California found it necessary to do certain retro-fitting of pump stations for safety purposes. Possibly other states have had or will have similar programs.

16-F. COST COMPARISON OF ALTERNATE METHODS

The present-day cost of retro-fitting a pump station may far exceed the original cost of construction. Therefore, agencies faced with the necessity of doing such work may be disposed to carefully examine alternates. Figures 16-2 and 16-3 are reproduced from actual plans. A deep cofferdam excavation was required to forty feet depth alongside a tidal river with attendant dewatering expense. 52 concrete piles were required to provide support for the transition structure equivalent to the support of the

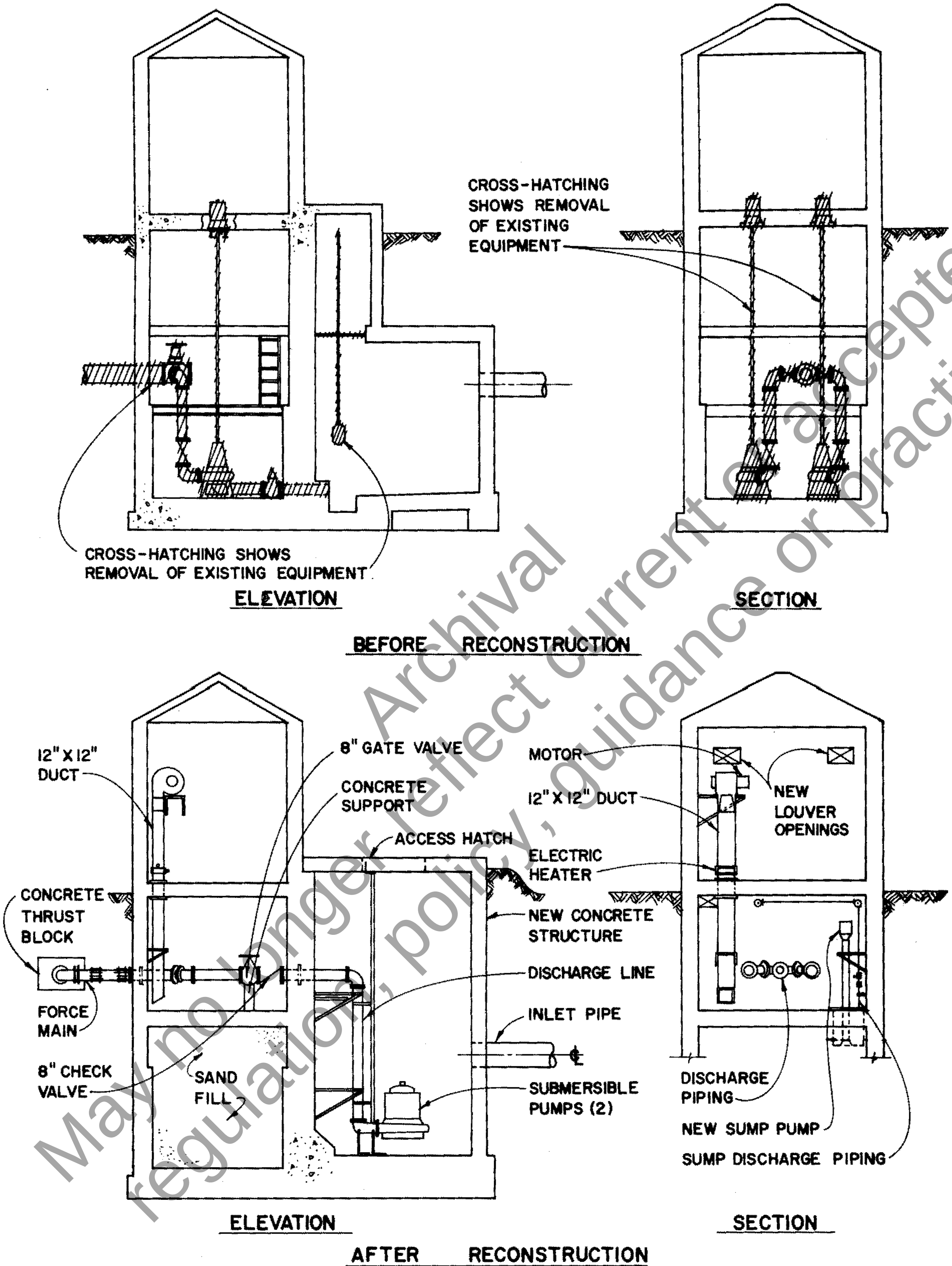
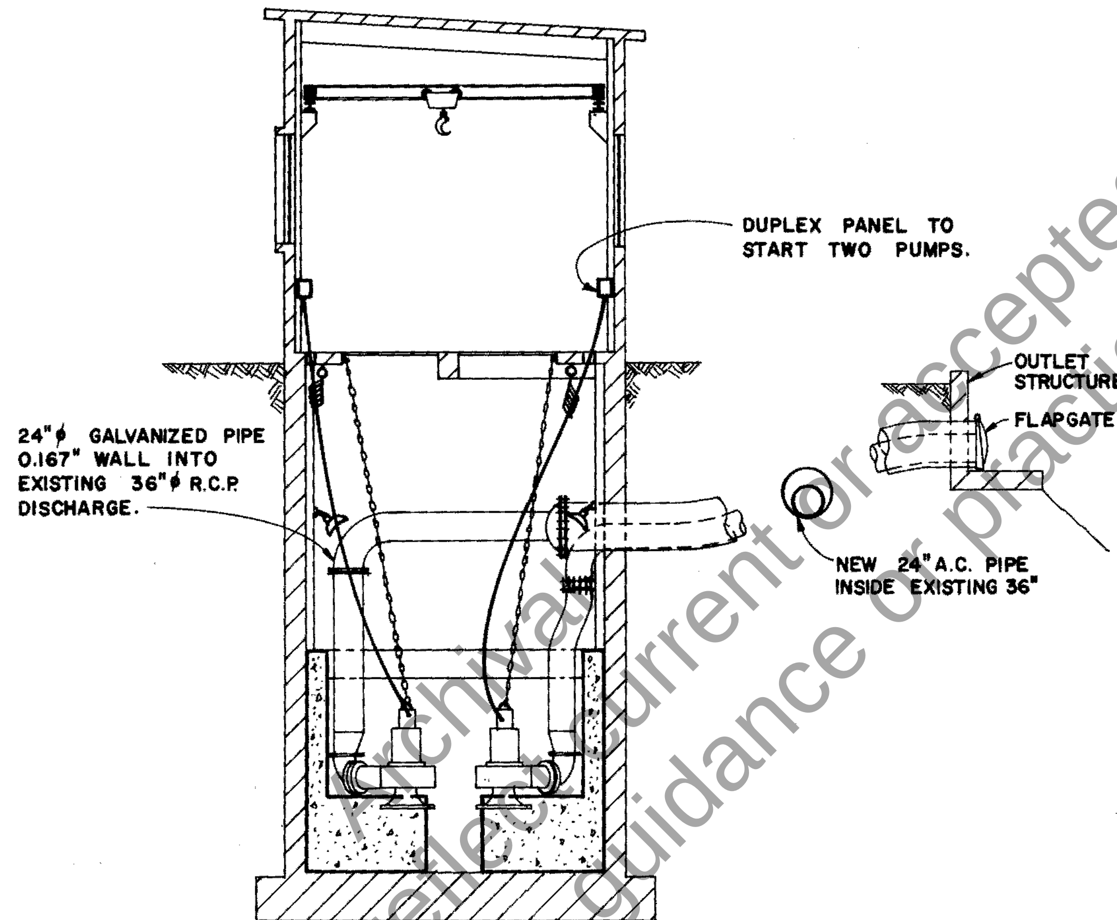


FIGURE 16-5. PUMP STATION RECONSTRUCTION



LARGE SUBMERSIBLE PUMPS AND COMBINED DISCHARGE

FIGURE 16-6. STATION CROSS-SECTION

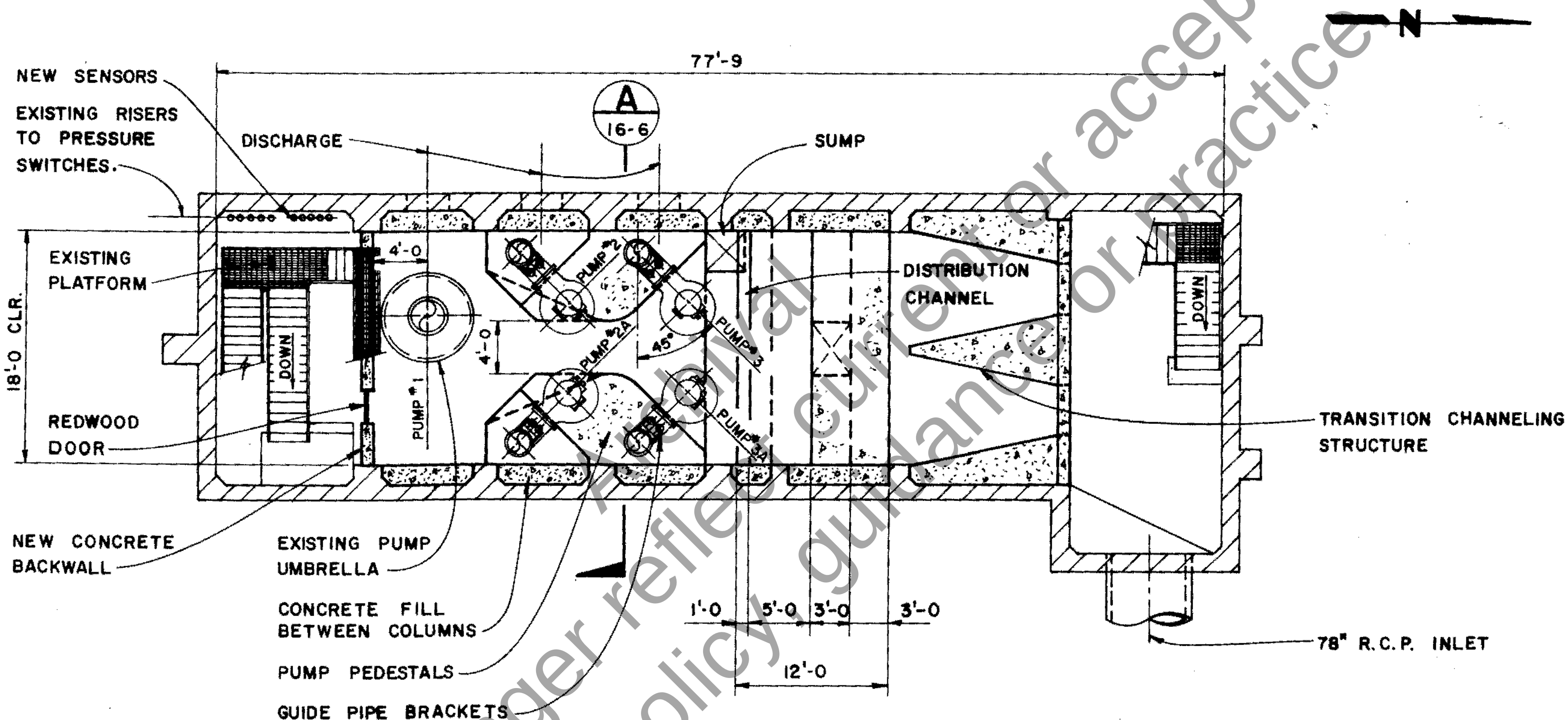
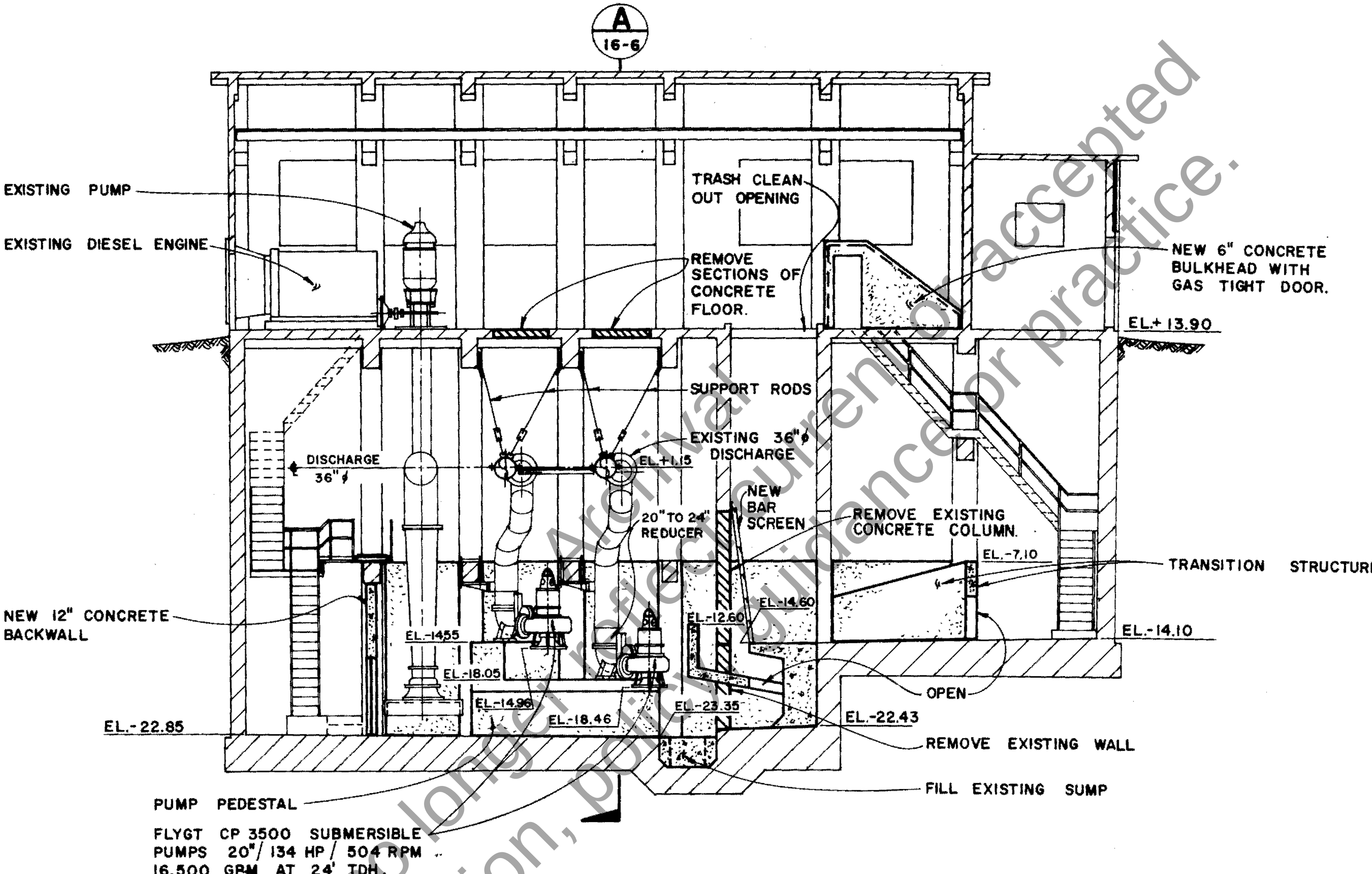


FIGURE 16-7. PUMP PIT PLAN

ALTERNATE RETRO-FIT WITH 4 LARGE SUBMERSIBLE PUMPS WITH ONE EXISTING VERTICAL PUMP RETAINED.



LARGE SUBMERSIBLE PUMPS IN COMBINATION WITH ONE VERTICAL PUMP

FIGURE 16-8. LONGITUDINAL SECTION

existing structure. False back walls and side walls and a new bar screen were to be installed; Stair bulkheads and gasketted floor plates were to provide for safety of personnel; Pedestals were to be installed between pumps and motors for greater ease of maintenance and shaft adjustment. Due to shortage of funding the back walls, side walls, stair bulkheads, floor plates and pump pedestals were deleted from the plans and bids were taken in April 1981 for the reduced scope as described. Low bid was $565,720. The station design Q is 222 cfs at 24 ft TDH and this has not been achievable due to the hydraulic deficiencies existing. To assure 222 cfs discharge the agency will spend $2,548 per cfs.

Because of the evident high cost of reconstruction an alternate design was proposed using the up-to-date technology of large submersible pumps. The work was to be done entirely within the existing structure and bid at $484,574 for a saving of $81,146. Two existing vertical pumps, both recently reconditioned would be salvaged for use elsewhere. Since the December 1980 installed cost of two similar pumps was $130,000 the salvage credit would be substantial, and additive to the $81,146. The gas-tight feature was retained.

The entire work is illustrated in Figures 16-6 through 16-8. Special provisions were made to ensure proper flow to the one vertical pump with combination engine and electric motor drive, which the agency desired to retain. A stair-step arrangement of the submersible pumps was used and the entire design was highly endorsed by the pump manufacturer, Flygt Corporation. Pertinent details are shown on the figures. Regardless of the potential savings, the agency proceeded with the work as shown in Figures 16-2 and 16-3.

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