Part 2

SEWERAGE MANUAL

(with Eurocodes incorporated)

contents related to Eurocodes highlighted in green

Pumping Stations and Rising Mains

Second Edition, May 2013

DRAINAGE SERVICES DEPARTMENT

Government of the Hong Kong
Special Administrative Region

CONTENTS

FIGURES

1. INTRODUCTION

1.1 SCOPE

Part 2 of this Manual offers guidance on the planning, design, construction, operation and maintenance of the sewage pumping stations and rising mains in Hong Kong. For guidance on gravity sewerage system, please refer to Part 1 of this Manual. DSD has also promulgated Practice Note No. 1/2011 "Design Checklists on Operation & Maintenance Requirements" which can be reached on DSD's internet home page : www.dsd.gov.hk. Readers are requested to go through the Practice Note, or its latest version, when designing sewage pumping stations and rising mains to ensure that the final products satisfy the operation and maintenance requirements of the maintenance authority.

1.2 ABBREVIATIONS

The following abbreviations are used throughout this Part 2:

ADWF	Average Dry Weather Flow
ArchSD	Architectural Services Department
APCO	Air Pollution Control Ordinance
BD	Buildings Department
BS	British Standard
BSI	British Standards Institution
BS EN	European Standards adopted as British Standards
BWL	Bottom Water Level
CEDD	Civil Engineering and Development Department
DSD	Drainage Services Department
DWF	Dry Weather Flow
DWFI	Dry Weather Flow Interceptor
E&M	Electrical & Mechanical
EC	Eurocodes (i.e. European Standards EN1990 to EN1999)
EM&A	Environmental Monitoring & Auditing
EMSD	Electrical and Mechanical Services Department
EN	European Standard
EPD	Environmental Protection Department
EIAO	Environmental Impact Assessment Ordinance
FRP	Fibreglass Reinforced Plastic
FSD	Fire Services Department
GEO	Geotechnical Engineering Office (formerly known as Geotechnical Control Office)
GRP	Glass Reinforced Plastic
HATS	Harbour Area Treatment Scheme
HDPE	High Density Polyethylene
HyD	Highways Department
ICA	Instrumentation, Control and Automation

ISO	International Organisation for Standardisation
MDPE	Medium Density Polyethylene
NCO	Noise Control Ordinance
NPSH	Net Positive Suction Head
P/S	Pumping Station
SCA	Sewerage Catchment Area
SCADA	Supervisory Control and Data Acquisition System
SMP	Sewerage Master Plan
SMPR	Sewerage Master Plan Review
SSS	Sewage Strategy Study
STW	Sewage Treatment Works
SWL	Safe Working Load
TWL	Top Water Level
UK NA	United Kingdom National Annexes to Eurocodes
uPVC	Unplasticized Polyvinyl Chloride
UPS	Uninterrupted Power System
WCZ	Water Control Zones
WPCO	Water Pollution Control Ordinance
WSD	Water Supplies Department

1.3 DESIGN STANDARDS

1.3.1 Mechanical and Electrical Systems

The following design standards, or their latest versions, are to be adopted, except otherwise stated in this Part 2:

Design Elements	Design Standards
Switchboard	BS EN 60439-1, 61439-1 & 2
Lightning protection	BS EN 62305-1 to 4
Lifting appliance	BS 2853 and BS EN 1993 & 13001
Design of pipelines on supports/piers	BS 8010

1.3.2 Sewerage Structures

In Hong Kong, sewerage structures are currently designed to BS, either directly as in the case for water retaining structures to BS 8007, or indirectly as in the case for structures subject to highway loading to BS 5400 customized by the local guiding document. In view of the progressive replacement of BS by EC (EN 1990 to EN 1999) and their UK NA through the promulgation of BS EN standards since March 2010, Government has planned to migrate from BS to EC and UK NA in 2015. To cope with the migration, a transition period from 2013 to 2014 is set out during which the designer may opt for using BS or EC and UK NA in conjunction with local guidance/documents as appropriate for structural design of the sewerage structures (e.g. manholes or tunnel sewers in Part 1, or sewage pumping stations in this Part 2, etc.). Starting from 2015, the use of EC and UK NA cum local guidance/documents as appropriate will become mandatory. The following design standards, or their latest versions, are to be adopted, except otherwise stated:

Design Elements/Loads	Design Standards
Imposed loads	Code of Practice for Dead and Imposed Loads, BD
Traffic loads	Structures Design Manual for Highways and Railways, HyD
Wind load	Code of Practice on Wind Effects in Hong Kong
Reinforced concrete structures	BS EN 1990 and BS EN 1992 (in general)
- Pumping Station	- BS EN 1992 (superstructure) and BS EN 1992-3 (substructure)
- Tunnel lining	- BS EN 1992-3 (liquid retaining properties) and GEO Manuals, Guidelines and Publications (geotechnical)
- Manholes (other than standard manholes in DSD standard drawings) and Chambers	- BS EN 1992-3
Foundation	
- Deep and shallow foundations	- Code of Practice for Foundations, BD (structural design) and GEO Manuals, Guidelines and Publications (geotechnical design)
- Reinforced concrete design for raft and pile cap	- BS EN 1992
Earth retaining structures	Guide to Retaining Wall Design, GEO

Recommended design parameters for concrete and steel reinforcement are given in Table 3.

1.4 DESIGN FLOW

An essential element in the design of a pumping system is the consideration of initial flow and subsequent build-up of flow with time. Reference should be made to Chapters 3 and 4 of Part 1 of the Manual.

Temporary or permanent measures have to be allowed for in the design, construction, commissioning and operation of the pumping system in order to deal with the flow build-up. These measures include variable speed drive for pumps, number of pumps, phased implementation, temporary diversion of flow to facilitate commissioning and septicity control.

1.5 DESIGN MEMORANDUM

It is essential to summarise key information into a design memorandum for easy retrieval and reference in future. The project engineer should prepare the design memorandum detailing the following aspects:

(a) background of the project;

(b) area served, population and flow build up;

(c) selected basic scheme plus the possible alternative schemes, together with a brief account of why the basic scheme was selected;

(d) design concept and criteria and their justifications (as pumping system should be avoided/minimized as far as practicable), which include the system characteristics, design philosophy of the control system, recommended operation, list of major equipment, assumptions in the design plus appendices showing key design data and the key elements of work, such as number of pumps, heads, capacities; and

(e) other requirements of the project (including septicity and odour control, measures to tackle different flow conditions and conditions required for proper commissioning).

Other concerned parties, such as the operation and maintenance authorities, should also be consulted when preparing the design memorandum.

1.6 ENVIRONMENTAL ASPECTS

In the design of the pumping system, the environmental aspects should be given due considerations. Reference should be made to the Environmental Impact Assessment Ordinance (EIAO), the Water Pollution Control Ordinance (WPCO), the Air Pollution Control Ordinance (APCO), the Noise Control Ordinance (NCO) and the relevant Technical Memoranda.

1.7 REQUIREMENT OF SUSTAINABILITY

The areas of concern on top of economic, social and environmental aspects for sustainability in the design of sewerage are energy requirement and odour control. They are closely related to the size of the network.

It should be noted that the sewage pumping system is not only part of a pipe system for conveying sewage, it is also a reactor inside which microorganisms are breaking down the organics and consuming the very limited dissolved oxygen.

The size of the rising mains, pump sets and pump sumps and the envisaged development phasing are common factors that have an impact on energy requirement for conveying sewage.

Septicity should be avoided, as it does not only cause corrosion but also produce odour causing nuisance. It is therefore preferable to prevent the septicity of sewage, by reducing its residence time in the pumping system, mechanical aeration or supply of chemical oxygen, rather than relying on containing and treating the odour.

1.8 HARBOURFRONT ENHANCEMENT REQUIREMENT

According to the General Circular No. 3/2010 with respect to Harbourfront Enhancement, the Hong Kong SAR Government is committed to protect, preserve and beautify the harbour. Designers' special attention is drawn to the fact that once their proposed facilities or temporary works areas have encroached upon the Harbourfront areas as referred to in the General Circular, they would be subject to the Harbourfront principles and guidelines so as to meet the public aspirations for a vibrant, green, accessible and sustainable harbourfront.

The designers are required to go through the checklist annexed to the circular and should satisfy themselves that such facilities and temporary works area are essential and would be able to obtain support from the public before finalization of any part of the design affecting the Harbourfront areas as referred to in the General Circular. Even so, designers are to engage the public at the earliest possible juncture so as to allow for comments and suggestions from the stakeholders on their proposals in order to maximize the level of public enjoyment to the concerned areas or facilities.

In particular, designers should be vigilant that the occupation of Harbourfront areas by public facilities that are environmentally unpleasant or incompatible with the Harbourfront are not supported in the first place. Where there are no better alternatives after taking into account cost and other relevant factors, designers should keep the footprint to a minimum as far as possible, and implement necessary mitigation measures to reduce the impact on the Harbourfront. In addition, access to Harbourfront should be reserved where practicable for public use and landscaped to compensate for the occupation of the Harbourfront areas by such public facilities.

2. PUMPS AND COMPONENTS

2.1 TYPES OF PUMPS

Pumps may be classified as kinetic energy (rotodynamic) or positive displacement types. Kinetic energy types are those that apply energy to the fluid to create velocities that subsequently are converted to pressure head. Positive displacement types are those that apply in the form of direct force, continuous or intermittent energy to the fluid to produce the lift or pressure head.

		Pump Type
Kinetic Energy (Rotodynamic)	Centrifugal	Single or Double Entry Volute
		Two Stage Volute
		Multistage Split Casing or Barrel Casing
		Single or Multistage Stage Well
	Mixed Flow	Volute
		Bowl
	Axial Flow	Well
Positive Displacement	Rotary	Progressive Cavity
		Sliding Vane
		Peristaltic
		Screw
		Lobe
		Gear
	Reciprocating	Diaphragm
		Plunger
		Piston
	Open	Archimedean Screw

Pumps in the kinetic (rotodynamic) category can be divided into classifications such as centrifugal, mixed flow and axial flow. Centrifugal pump is the most common type appropriate for sewage pumping applications.

Positive displacement pumps can be classified as reciprocating, rotary and open types. The Archimedean screw pump is the common type in this category suitable for pumping sewage.

For sewage pumping, only rotodynamic pump and Archimedean screw pump are used in DSD. For sludge pumping, ram pump, progressive cavity pump and diaphragm pump are widely used.

2.2 CENTRIFUGAL PUMPS

For rotodynamic pump, different designs are available to cover wide operating range. It is relatively compact. More skill is needed for installation and maintenance. Operating characteristics could be determined at factory. Flow rate is adjustable by changing the impeller diameter and speed. It is needed to consider suction head, pump sump, and surge in the design. Cavitation and pump vibration are major concerns. Material selection is important to balance erosion and corrosion. Solid passage, motor efficiency, pump efficiency, flow control issues and life cycle cost should be considered in selection of pumps.

Centrifugal pump is the most common type of rotodynamic pump used in sewage pumping. A centrifugal pump consists of a set of rotating vanes (impellers), enclosed within a housing or casing and used to impart energy to a fluid through centrifugal force. Impellers of centrifugal pumps can be classified according to major directions of flow in reference to axis of rotation:-

(a) Radial-flow impellers;

(b) Axial-flow impellers; and

(c) Mixed-flow impellers, which combine radial- and axial-flow principles.

Radial flow and mixed flow pumps are commonly used for sewage pumping station with high head requirements. Vertical installation is normally used since no priming operation is necessary in starting and small space is required.

Axial flow pumps are commonly used for floodwater pumping station with high flow and low head requirements.

Apart from the three common types of impellers, screw-centrifugal impeller is also widely used for pumping sewage. It has the advantages of high head and large impeller throughlet.

Centrifugal pumps are susceptible to clogging by large solids in raw sewage. It is necessary to provide a screening device before the sewage entering the pumps. Pumps can be designed with sphere-passing capacities of 75mm in diameter.

2.3 ARCHIMEDEAN SCREW PUMPS

In applications where large quantities of sewage and water are raised at comparatively low head of less than 8.5 metres, Archimedean screw pumps are particularly suitable. The Archimedean screw pump is a screw rotating in a trough The actual volume lifted depends on the diameter of the screw pump, the speed of rotation, the angle of inclination and the depth of submergence at the lower end of the pump. The pump unit can be driven by a variable speed motor for variable flow rates.

They can handle large solids in the raw sewage but it is advantageous to install coarse bar screen with 75 mm to 150 mm spacing at the inlet to prevent large objects such as timber board from damaging the screw.

Archimedean screw pumps are simple in design. Less skill is required for maintenance. Installation is tricky because of its bulkiness. The gap between the trough and screw flight affects pump performance. Pump rate can only be determined after installation and has implication on selection of pump motor, coupling, gearbox, V-belt drive. The issues of greasing, safety, flow control, pump & motor efficiency and materials of construction should be considered in the design of Archimedean screw pumps.

2.4 SELECTION OF PUMPS

Considerations for the selection of pumps include:

(a) the characteristics of the pumped fluid;

(b) the initial flow and subsequent build-up of flow with time;

(c) operating range;

(d) the head requirement;

(e) the availability of land;

(f) the cost; and

(g) the operation and maintenance requirements.

2.5 PUMP MOTORS

Sewage pumps are normally driven by electric motors.

Motors can be installed on ground floor with the pumps mounted on the base of dry well for protection from flooding. Long intermediate shafts are required to drive the pumps.

Immersible pumps with direct drive motor installed in dry well are used in medium to large size sewage pumping stations. No long intermediate shaft is required. The motors are hermetically sealed to prevent the intrusion of sewage if the dry well is flooded.

Submersible pumps with direct drive motor are widely used in small to medium size sewage pumping stations. The pumps are installed in wet well with submersible motors. The motors are hermetically sealed to prevent the intrusion of sewage. Space of the pumping stations can be reduced since no dry well is required.

3. PUMPING SYSTEM

3.1 INTRODUCTION

At the conceptual design stage, it is important to consider whether pumping is really necessary. The alternative of a deep gravity sewer should be evaluated carefully. Even when pumping is required, the length of the rising mains should be kept as short as possible to provide the required head or overcome the physical constraints.

3.2 DESIGN PHILOSOPHY

The overall design philosophy of the pumping system has changed from a total utilitarian approach to a balanced design with due considerations of functional, environmental and a total life cycle cost aspects. For pumping systems in the vicinity of sensitive receivers such as beaches, residential area and commercial buildings, reliability of the system and avoidance of nuisance are of key concerns. Bypass or overflow of raw sewage into sensitive receiving water bodies even in emergency situations should be avoided where possible.

To enhance system reliability and avoid the nuisance to the sensitive receivers, particular attention should be paid to the following issues:

(a) Design flow and head (please refer to Section 1.3)

(b) Standby power supply or temporary storage (please refer to Section 5.5)

(c) Standby pumps (please refer to Section 3.4)

(d) Overflows and emergency bypass (please refer to Section 4.2.3 (5))

(e) Twin or multiple rising mains (please refer to Section 3.5)

(f) Odour and noise control (please refer to Chapter 10)

The design of a pumping system should include identification of the system characteristics, determination of the number of pumps, control water level, the capacity of the pumping system, design philosophy of the pump control system, emergency measures for equipment failure, power breakdown, and excessive incoming flow. The energy consumption should also be considered in the design of a pumping system. The energy input should be kept at minimum without sacrificing the reliability of the system. For example, from energy saving point of view, keeping the water level in the wet-well as high as practicable would help minimize the pumping head.

3.3 OPERATING CHARACTERISTICS AND SYSTEM CURVES

A pumping system may consist of inlet piping, screens, pumps, valves, outlet piping, fittings, open channels and/or rising mains. When a particular system is being analyzed for the purpose of selecting a pump or pumps, the head losses through these various components must be calculated. The station loss (i.e. the loss on the delivery pipework from the pump discharge to the common header) should also be considered. The frictional and minor head losses of these components are approximately proportional to the square of the velocity of flow through the system and are called the variable head.

It is also necessary to determine the static head required to raise the liquid from suction level to a higher discharge level. The pressure at the discharge liquid surface may be higher than that at the suction liquid surface, a condition that requires more pumping head. The latter two heads are fixed system heads, as they do not vary with rate of flow. Fixed system heads can be negative, if the discharge level or the pressure above that level is lower than suction level or pressure. Fixed system heads are called static heads (Metcalf & Eddy, 1981).

A system head curve is a plot of total system head, variable plus fixed, for various flow rates. It may express the system head in metres and the flow rate in cubic metres per second. A typical system head curve is shown in Figure 1.

Procedures to plot a system-head curve are:-

(a) Define the pumping system and its length;

(b) Calculate the fixed system head;

(c) Calculate the variable system head losses for several flow rates; and

(d) Combine the fixed head and variable heads for several flow rates to obtain a curve of total system head versus flow rate.

The flow delivered by a centrifugal pump varies with system head. Pump manufacturers provide information on the performance of their pumps in the form of characteristic curves on head versus capacity, commonly known as pump curves. By superimposing the characteristic curve of a centrifugal pump on a system-head curve, the duty point of a pump can be determined.

The curves will intersect at the flow rate of the pump, as this is the point at which the pump head is equal to the required system head for the same flow.

The discharge capacity for multiple pumps will not be simply the sum of the discharge capacity of individual pumps because the system-head curve for multiple pumps will be different from that from a single pump (Metcalf & Eddy, 1981).

3.4 NUMBER OF PUMPS

The number of pumps to be installed depends on the station capacity, the range of flows, the power rating and flow rate of each pump. The maximum discharge rate from a pumping station, when all duty pumps and rising mains are in use should be slightly greater than or equal to the maximum incoming flow to the station. Pumps should be selected with head-capacity characteristics that correspond as closely as possible to the overall station requirements. Standby capacity is required so that should any of the pumps in the station be inoperable due to routine maintenance or pump failure, the operation of the station can still be maintained. For instance, in a station where a single duty pump provides the duty output, a second pump of equal capacity is mounted. Where three duty pumps of equal capacity are required to meet the maximum design flow conditions, a fourth pump of similar capacity is provided as standby. Two or more standby pumps should be considered for pumping stations of large capacities.

For large capacity pumping system with sewage flow ranges varying widely and highly variable system head, different sizes of pumps should be considered to minimize the power cost. The assessment of the number of duty pumps and pump capacity are usually based on the ultimate flow projection and the projected flow build-up. To cater for slow build-up of flow in the early years of operation, phased installation of pumps or using of smaller diameter impeller or variable speed drives should be considered. Pony pump for initial low flow period or other methods should also be considered in the design. If the staged capacity of the pumping station is still much higher than the sewage flow actually encountered in the initial operational period, it may lead to O&M problems, such as inefficient pump operation and high pump start/stop frequency, which in turn result in excessive hydraulic surge to the pump and piping and fittings and damage to the pump and starting switchgears.

3.5 TWIN OR MULTIPLE RISING MAINS

The use of twin or multiple rising mains should be considered on a case by case basis. The main factors for considerations include the design elements, the risk assessment and cost benefit analysis.

Considerations for the design elements comprise the rate of build up of flow, the range of flow conditions, the range of velocity in the mains, the availability of land for the twin or multiple mains and associated valve chambers as well as the complications in pump operations.

A thorough risk assessment should be carried out which should include the likelihood of main bursting, the consequence of failure, area affected, sensitive receivers affected such as beaches, the feasibility of temporary diversion or tankering away.

A cost benefit analysis should include all tangible factors (such as cost of pipework, land cost, energy cost, etc) and intangible factors (such as nuisance, closure of beaches, etc).

Twin or multiple rising mains should be considered in the following circumstances:

(a) To accommodate a wide range of flow conditions such that the velocity in the mains can be kept within acceptable limits. For instance, a pumping system serving a new development may have very low initial flows with a slow build up of flow.

(b) To provide continued operation for a major pumping system when one of the mains is damaged and where the failure of system would have serious consequence.

(c) To minimize adverse environmental impacts to sensitive areas such as beaches.

(d) To facilitate future inspection and maintenance of major pumping system while the normal sewage flow can be maintained.

When twin or multiple mains are found to be preferred, it is advisable to use both mains as duty rather than one as duty and the other as standby from an economical and operational point of view. Should one of the duty mains be taken out of operation, the remaining one would still be able to deliver a higher quantity of flow at a higher velocity. The occurrence of overflow or bypass can be minimised or even eliminated. Septicity in the standby mains would also pose an operational and maintenance problem.

3.6 CAVITATION

Cavitation occurs when the pressure in the flow stream approaches the vapour pressure of water. For a centrifugal pump, the lowest pressure occurs at the impeller eye (or inlet). As cavitation can destroy pump parts and is usually accompanied by vibration, cavitation in pumps has to be avoided by providing adequate submergence to suit the limitations of the pump. Reference should be made to the recommendations of pump manufacturers.

Net Positive Suction Head (NPSH) is the term used to describe pump cavitation characteristics. $NPSH_{av}$ is the total suction head, determined at the suction inlet and referred to datum, less the absolute vapour pressure of the liquid in m of liquid pumped. $NPSH_{re}$ is the head needed to get stable flow into the pump impeller.

$$NPSH_{av} = h_{baro} + h_s - h_l - h_{vp}$$

where h_{baro} = pressure head acting on suction water level

h_s = height from suction water level above the reference level of impeller

h_l = total head loss in suction line

h_{vp} = vapour pressure head of liquid being pumped

To prevent cavitation, $NPSH_{av}$ must always be greater than $NPSH_{re}$.

3.7 ECONOMICS

As the size of the rising mains increases, the velocity and the system head will decrease, with savings in the cost of pumping. The increase in the capital cost of rising mains will be offset by the power cost of pumping. However, it is also important that the velocity in the mains should be within suitable range to minimise the deposition of solids.

Excessive hydraulic head losses are to be avoided. Reference should be made to Chapter 7 for recommendations on the velocity in rising mains. Therefore, combinations of different sizes of rising mains and the system head should be evaluated, taking into account both the capital cost and the energy cost of pumping. The overall pumping system efficiency shall be investigated and optimised for the selection of best total life cycle cost solution.

3.8 SURGE ANALYSIS

Unsteady flow can occur under a wide range of pump operation scenarios including pump start, pump cut off, pump breakdown, power failure or malfunctioning of check valve. This can result in considerable changes in pressure. These hydraulic transient conditions are also known as water hammer phenomenon. Please also refer to Chapter 7.

The surge effects are considered significant for the large pumping systems with long rising mains. Surge analysis should be carried out to assess the effect of hydraulic transients on the pumping system with the following objectives:

(a) to assess the transient pressure changes along the rising mains during normal and abnormal pumping cycles (such as power failure or sudden breakdown of pump, check valve);

(b) to identify any potential operation problems in the pumping system; and

(c) to investigate and evaluate options on surge protection methods so as to arrive at the most cost effective solution to overcome the problems identified in (b) and to ensure the pressure rating of rising mains is not exceeded.

The tasks involved in the surge analysis are:

(a) build up a mathematical model on computer for the proposed system;

(b) conduct surge analysis;

(c) provide interpretation of the results of transient simulations;

(d) identify potential problems areas;

(e) recommend modifications to the proposed system;

(f) recommend instrumentation for long-term monitoring;

(g) evaluate the effectiveness of proposed modifications;

(h) re-analyze to prove satisfactory performance; and

(i) prepare draft and final report.

For simple cases, the surge analysis can be carried out graphically (Ref Parmakian J

(1963) & Linton et (1972)). Sensitivity analysis may also be carried out to evaluate the effects of change of major parameters such as pipe loss, operating levels on the pumping system. For large and complicated pumping systems, the use of physical surge models to verify the results of the graphical method can be considered, if practicable.

4. DESIGN OF SEWAGE PUMPING STATIONS

4.1 TYPES OF SEWAGE PUMPING STATIONS

4.1.1 Classification of Sewage Pumping Stations

Sewage pumping stations are designed to pump sewage from one place to another and are usually used for conveying raw sewage to the sewage treatment plants, or conveying treated effluent to the water receiving bodies. Sewage pumping stations can be broadly classified as follows:

(a) wet well/dry well pumping stations;

(b) submersible pumping stations; and

(c) screw pumping stations (or Archimedean screw pumping station).

4.1.2 Wet Well/Dry Well Pumping Stations

In this type of pumping station, the centrifugal pumps (or more formally ‘rotodynamic pumps’) are located in a dry well and draw sewage from an adjacent wet well through suction pipes. Three common arrangements are:

(a) Vertical centrifugal pump in dry well with extended driveshaft with universal joints from motor at ground level.

(b) Vertical centrifugal pump in dry well combined with direct drive motor.

(c) Immersible pumps in dry well which can service in flooding.

Among the three possible arrangements, option (a) or (c) is preferred as this could avoid the danger of motors being damaged by flooding of the dry well. Vertical centrifugal pumps combined with direct motors should only be used if flooding is not likely to occur. A superstructure is usually constructed above ground level for accommodating the electrical switchgear and pump motors.

With wet well/dry well configuration, pumps can be inspected easily and maintained with regular checks on bearings, glands, seals, etc. in situ. Isolating valves are to be provided on the suction and delivery sides of each pump so that inspection and clearance to the pump interior can be made through the access covers in the casing.

A typical arrangement of wet well/dry well pumping station is shown in Figure 2. This type of pumping station is usually required for large pumping installations with high flows and high heads.

4.1.3 Submersible Pumping Stations

In this type of pumping station, the centrifugal pumps are mounted at the bottom of a single wet well and draw sewage through the bottom of the pump body and the flow is pumped into the discharge pipework connected to the pumps. The pumps are provided with a guide rail and low level coupling system which allow the pumps to be positioned or removed easily. Since no bolting or unbolting is required, personnel is not required to enter the sump for positioning or replacement of pumps. The unit would automatically connect to and disconnect from the discharge pipework when it is lowered or raised from its supporting stands.

Submersible pumping stations are normally more economical than wet well/dry well pumping stations unless the duty pump power requirements are in excess of the available limit of submersible pumps. A typical arrangement of submersible pumping station is shown in Figure 3.

For installations with large flows requiring several duty pumps, a superstructure is usually constructed above ground level to house the electrical switchgear and the overhead lifting device above the pumps. For installations with relatively small flows requiring only one duty and one standby pumps, the electrical control panel is usually mounted within a ground level weatherproof pillar box and a superstructure is not required. A suitably rated floor mounted lifting davit or movable A-frame with chain block is required for hoisting the pumps out of the sump for maintenance. However, in view of public concerns on nuisances such as noise, odour, visual impact, etc. as well as facilitating urgent repair under adverse weather conditions, the provision of superstructure is highly recommended.

4.1.4 Screw Pumping Stations

The general layout of a screw pumping station consists of the inlet chamber, the screw pump troughs and the discharge chamber above which the motor and control room is located. Screw tubes of the pumps are supported by lower and upper end bearings, which are located inside the wet sump and motor room respectively. Upper end bearings mounted on concrete plinths are preferred to wall mounted ones. A smaller wet sump is required for the screw pumps comparing with centrifugal pumps. A typical arrangement of screw pumping station is shown in Figure 4. The typical characteristics of screw pump are shown in Figure 5. Structural limitation, however, controls the maximum head to about 8.5 m. For higher lifts, the screw pumps may be staged, and consultation with the pump manufacturers is recommended.

Screw pump is cavitation-free. Maintenance is easy due to fewer parts and simple construction. There is less wear of bearings due to low speed of revolutions (20 to 40 rpm).

4.2 WET WELL/DRY WELL PUMPING STATION DESIGN

4.2.1 Wet Wells

Wet wells are required in pumping stations to store the sewage before it is pumped. Equally important functions of the wet wells are to provide sufficient submergence of the pump suction inlets to prevent vortex formation and to make the transition of flow from the sewer to the pump suction pipe as smooth as possible.

A wet well is normally divided into two or more compartments to facilitate cleaning and maintenance. Each compartment should have an individual inlet and penstocks to facilitate the diversion of flow from one compartment to another when it is not in service.

A wet well should be so arranged to minimise stagnant space where solids are likely to deposit. Benching should be provided to ensure smooth and even distribution of flow to the pump suction entrances. Sewage flow inside a wet well should not have to travel past one pump suction inlet to reach another inlet. The plan area of the wet well should also be reduced to a minimum.

A wet well should be particularly designed to cater for highly corrosive sewage attack to submerged concrete surfaces and sulphide gas attack to concrete surfaces in the confined or badly ventilated space above the sewage. Concrete protective coating should be applied to mitigate the impact of sulphide gas attack unless strong justifications are provided for not doing so. The design of protective coating should be carried out in consultation with the suppliers and the maintenance party.

4.2.2 Hydraulics

The hydraulic design of wet wells is very important as it has serious implications for the performance of the pumps. Badly designed wet well can introduce cavitation, vortices and turbulence, which not only affect pump performance but can also cause damage to the equipment itself thus resulting in heavier maintenance.

For major pumping stations, it is good practice to carry out physical hydraulic model tests for the wet well to ensure that uniform hydraulic distribution is achieved at all flow conditions and pump operations. Physical model tests can also assist the designers to modify the layout of the wet wells so as to avoid formation of the followings:

(a) vortices and air entrainment which can significantly reduce pump efficiency and cause vibration resulting in damage to bearings;

(b) pre-swirl in pump intake, which rotates in opposition to a pump impeller, can reduce pump efficiency, causes cavitation and damage to bearings; and

(c) stagnant zones of sediment deposition.

In small pumping stations the problem of vortices and air entrainment can be overcome by the use of a vertical drop tube attached to the incoming sewer, whereas in larger stations, a baffle wall system is to be used. Typical arrangements of drop tube and baffle wall are shown in Figures 6 and 7.

4.2.3 Wet Well Volume and Control Levels

The requirement for wet well storage depends on the sewage inflow rate and the capacity of the pumps used.

For pumping station equipped with pumps of single speed drives, the start/stop of pumps is governed by the control levels. The following points should be noted in designing the control levels of a wet well:

(1) *Bottom Water Level (BWL).* The bottom water level is where both duty and standby pumps are switched off when the sewage dropped down to this level. It should be set as low as possible to minimise the stagnant storage but retaining sufficient submergence to prevent vortex formation and to provide sufficient suction head at the pump inlets. Both duty and standby pumps are switched off at this level.

(2) *Depth.* The level difference between the bottom water level and the wet well floor level should be kept to a minimum stagnant storage volume.

(3) *Top Water Level (TWL).* The top water level is set such that there is sufficient volume between this level and the bottom water level to limit the number of pump starts per hour to an acceptable number, generally 10 times per hour. Duty pumps are switched on at this level. For large pumps, the number of starts per hour may be required to be reduced to 4 to 6times per hour. For pumping station with small flow or small initial flow, smaller pumps and narrower level settings should be considered to minimize the formation of septic condition in the pump well. High voltage motors for pumps are designed for a lower frequency of start/stop and it is necessary to refer to the pump manufacturers on the optimal frequency of start/stop. The volume between top water level and bottom water level for a single pump operation is given by the following equation:

$$V = 900Q/N$$

where V = control volume in litre
Q = pump capacity in litre per second
N = allowable number of start of pump per hour

(4) *Maximum Top Water Level (MTWL).* The designer should check the water level at which surcharging of the upstream sewers will occur, and determine the top water level for the wet well with reference to such level. MTWL is usually only reached when the duty pump is unable to cope with incoming flow. The standby pumps are switched on at this level.

(5) *Overflow Level (O/F).* Despite ample design capacity in sewers and pumping stations, there may be times when excessive flows, blockage or operational failure of the pumps occur in the system. It is, therefore, a good practice to provide an overflow or emergency bypass arrangement at or near to all pumping stations. These arrangements will allow sewage to flow to

the most suitable discharge points when the sewage level inside the wet well rises to a predetermined level beyond which pollution may result from the occurrence of sewage overflow at manholes of the upstream sewers or flooding of the pumping station. However, the acceptability and the location of discharge should be carefully assessed in the design stage. A distance of 150 m from sensitive areas is preferred. The opening of the overflow should not be obstructed by any form of screens with bar spacing less than 25 mm as the screen will be easily blocked by screenings, thus resulting in flooding of the pumping station and the upstream catchment.

(6) For small pumping stations where the sewage flow is small, a simple switching arrangement as shown in Figure 8 will be satisfactory. For large pumping stations, the pump-on and pump-off switching are usually staged in order to achieve a gradual building-up and subsidence of flow in downstream sewers and/or treatment works as shown in Figure 9. A minimum difference in levels of 100 mm to 150 mm should be allowed so that switching would not be affected by turbulence.

For pumping station equipped with pumps of variable speed drives, the pump rate can be adjusted with reference to the sewage inflow rates, and thus the pumps can run non-stop. The designer should still set an appropriate overflow level to cater for situations when excessive flows, blockage or operational failure of the pumps occur in the system.

4.2.4 Arrangement of Suction Pipe

With dry well pumps and suction pipe, the pumps should be able to generate sufficient velocity in the flow to move the deposited solids to and through the pumps. The suction pipe entry consists of a bend with open face downward, preferably with a bell-mouth, and long radius bend to reduce the entry losses.

The dimensions of (i) the face of suction pipe end from the floor (ii) the distance of suction pipe from front wall and side walls and (iii) the distance between the suction pipes where two or more suction pipes are employed, should comply with the minimum required by pump manufacturers.

When submersible pumps are used, the suction is usually on the underside of the pump. The spacing of the underside of the pump from the floor is synonymous with the distance of the face of bend from the floor as in dry well pumps, and the space between pumps is similar to those of dry well pumps in the case of small pumps. For larger pumps, the manufacturers' recommendations should be complied with in order to obtain the desired performance.

4.2.5 Dry Well

In general, a dry well should be of sufficient size to allow personnel to move around the machinery as well as dismantle and assemble it. Access for maintenance is of prime importance in dry well installation. The space required for removal of pump covers, etc. should suit the largest machinery to be installed. The following points should be noted for the pipework arrangement in dry well and the floor drainage for dry well:

(1) *Pipework arrangement in dry well*. The pipework inclusive of fittings and valves should preferably be so arranged that total rearrangement or dismantling is not necessary to allow replacement or maintenance of any component. Provision of make up pieces and dismantling joints in appropriate locations may greatly simplify later maintenance or possible augmentations. However, in consideration of possible replacement of machinery with perhaps larger units in future, a more generous allowance of space should be made. It should be noted that the delivery manifold connecting delivery pipework from each pump should not be vertically above the delivery pipework as this will allow solids to settle on and build up within the pipework from the standby pumps.

(2) *Floor drainage for dry wells*. Dry wells are designed to remain in a dry condition. Water from various sources such as seepage through seals of concrete walls and pipes passing the walls, surface water, sewage from pumps and valves during maintenance, washwater from cleaning etc. should be removed from the dry well to the wet well. The dry well floor should be graded to a sump and a sump pump installed to pump such water to the wet well. The delivery discharge should be installed above pumping station flood level to ensure that water cannot siphon back to the dry well.

4.3 SUBMERSIBLE PUMPING STATION DESIGN

The design of submersible pumping station is similar to a wet/dry well pumping station except that it does not have a dry well.

4.4 SCREW PUMPING STATION DESIGN

4.4.1 Key Design Parameters

The major design parameters are:

(a) angle to the horizontal at which the screw is installed;

(b) external diameter of the screw;

(c) trough dimensions;

(d) diameter of the screw shaft or tube;

(e) number of threads or starts on the screw;

(f) pitch of the screw;

(g) speed of rotation of the screw;

(h) length of screw that is fitted with blades;

(i) inflow conditions or the design of the bottom end of the screw; and

(j) discharge conditions or the position of the spill point.

The angle of inclination to the horizontal affects the length of screw pump and the static lift. It is not economical to increase the angle of inclination above 40 degree. As the angle of inclination to the horizontal becomes steeper, the capacity of a given screw pump will drop. Very often, an inclined angle ranging from 35° to 38° is used for design of screw pumping station in Hong Kong (Ritz, 1968).

The total head is limited by outside diameter of inclined angle of screw. It is generally as follow:

Diameter	Maximum Head
400 mm - 1000 mm	about 5.0 m
1100 mm - 2000 mm	about 7.5 m
2100 mm - 3000 mm	about 8.5 m

Lubrication in the form of grease rather than oil is preferred for lubricating the bottom bearing of the screw pump as oil is recirculated in a closed loop and any contamination by sewage ingress would cause damage to the bottom bearing. Grease lubrication is driven by a separate pump interlocked with the main screw pump operation and does not present contamination problem.

4.4.2 Screeding Requirements

In the design of screeding to the screw pump trough, the following requirements should be considered:

(a) the minimum gap between the trough (before screeding is applied) and the screw pump should be within 50 mm to 100 mm wide;

(b) the surface of the trough should be roughened for proper adhesion of screeding;

(c) the mix design of the screeding should not contain bonding agent to avoid damaging the coating of the screw pump; and

(d) the final profile of the screeding should be carried out in accordance with the pump supplier's recommendation.

4.5 PUMP CONTROL

An automatic pump control system should be provided to determine how the pumping stations operate in response to the changes of the incoming flow conditions without manual inputs. Two types of design are commonly found in the DSD installations and they are on/off control and flow-pacing. The design of the control system should suit the needs of the pumping system.

On-off control is simple and can be used in small pumping station. When the control volume is determined (refer to Section 4.2.3), the pump control level can then be determined. The pumps should start and stop according to the pre-determined pump control levels. Since there may be ripple in the pump sump, delay start or stop of the pump by 3 to 5 seconds would enable the system to cope with the possible measurement error. The control system should prohibit the pump to start more frequent than the permissible number which depends on the power system and the design of the motor.

Flow-pacing was in the past used in large pumping station. It has become more popularly for all range of pumping system because of the use of variable speed drive. The speed of the pump is adjusted to maintain the pre-set water level in the pump sump. The control system should keep the pump running continuously rather than intermittently and try to keep the water level as high as possible because this can reduce the pumping energy. The control system should enable the pump to run close to the best efficiency curve. The system should prevent the pump running at resonance speed and the frequency should be determined during commissioning stage. The relationship between pump speed and discharge of a rotodynamic pump is not linear. The pump characteristics must be checked to ensure the compatibility between the control system and the pump.

Water level in the pump sump is usually the determining input parameters for the control system in any kinds of control systems and suitable instrumentation should be provided.

The control system should also coordinate with the operation of other associated equipment, e.g. the opening and closing of the upstream and downstream valves or penstock.

5. ANCILLARY FACILITIES OF SEWAGE PUMPING STATIONS

5.1 GENERAL

In the design of a pumping station, besides pumping system, ancillary facilities such as power supply & reliability, screening removal, lifting appliances, lightning protection considerations, penstock/stop log design, signalling & remote control and plant security shall be considered and be properly coordinated to best suit the overall design and environmental licences requirements of the pumping station. The guidelines for these facilities are described in this chapter. Noise and odour control, ventilation and flow measurement are also common features in a pumping station and they will be described in Chapters 10 and 11. For fire services and air-conditioning system, their design should conform to the standard for government buildings in Hong Kong with due consideration of the environment and situations of the sewage pumping station and system.

In general, because of corrosive environment, all equipment of the pumping station and pumping system shall be designed for such environment.

5.2 ELECTRICAL SYSTEM AND SUPPLY

5.2.1 General

A sound electrical system is essential for safe and reliable operation of a pumping system. The arrangement for providing the electricity supply to a pumping station should be determined in liaison with the power companies. Special attention is drawn to the following:

(a) maximum demand and the estimated load profile;

(b) maximum instantaneous load;

(c) supply voltage;

(d) power transformer;

(e) security and reliability of power supply;

(f) starting equipment;

(g) statutory regulations;

(h) energy efficiency and power quality;

(i) renewable energy equipment.

5.2.2 Maximum Power Demand

In determination of maximum power demand for the pumping station, special attention shall be drawn to the following:

(a) The maximum number of pumps that are permitted to run at the same time and their respective power rating.

(b) The power demand shall take into account the operation of all ancillary facilities and services e.g. auxiliary pumps, mechanical screens, deodorization system, ventilation, lighting and lifting appliances etc.

(c) Allowance for efficiency deterioration of equipment, future expansion and addition of equipment e.g. additional pumps for catering increasing flow. It will have impact to the sizing of main electrical switchboard/switchgear and the power company transformer/supply.

(d) The type of tariff to be used with reference to maximum power demand and the general load pattern of the pumping station for optimal energy costs.

5.2.3 Maximum Instantaneous Load

The maximum instantaneous load will usually occur when the last pump is started with all other ancillary services in the station running concurrently. However, there may be intermittent loads from other electrical equipment which also contribute to the maximum instantaneous load. The instantaneous load is the main issue which may cause the voltage dip of the system and it is an essential criterion for the selection of the power transformer, generator, and protection settings of the pumping station.

The permissible maximum instantaneous load will generally be stipulated by the power supply company and this will dictate the design of appropriate starting method e.g. auto-starter, variable frequency drive, star-delta to reduce the starting current of each pump.

5.2.4 Supply Voltages

The power rating of the motors is a major factor in determining the supply voltage to the pumping station and accommodation needs to be provided for the transformers and switchgears.

(a) General

(i) The power backup arrangement in case of power failure shall be considered in choosing of low voltage (i.e. 380V) and/or high voltage (i.e. 3.3kV or 11kV) as the operation voltage; hybrid arrangement with some supplementary/backup/standby pumps being supplied by low voltage shall also be considered.

(ii) Wherever practical, the transformer room should be located at the site boundary but close to the pumping station main switchboard.

(iii) For supply voltages at or in excess of 11kV, the power companies usually require separate accommodation for the transformers with access.

(iv) In general, separate access to the power company's equipment room shall be provided as far as practicable.

(v) Protective coating of some critical electrical control and equipment to work under corrosive environmental shall be considered where necessary.

(b) High voltage switchgear

The high voltage switchboards (3.3kV - 11kV) shall be factory-built, type tested to relevant BS/IEC standards to withstand the minimum electrical and mechanical stresses due to short-circuit current of not less than 20kA for 3 seconds, and be graded with power company fault level. The circuit breaker shall be metal-claded, vacuum break type, withdrawable and lockable, rated for fault making and breaking, and shall have an earthing switch to earth the incoming mains cable.

All LV and control wiring shall be isolated from the HV circuits and shall be in separate chambers or enclosures.

Switchboards shall be designed with the busbar extensions at each end and shall have blank covers fitted over the ends of the busbar chambers.

As far as possible, the switchboard shall be accommodated inside a well-conditioned switch room against moisture and temperature. For working under slightly corrosive or polluted environment is anticipated, the insulation level of insulators and their creepage distance shall be checked against appropriate BS/IEC standard for the intended use.

(c) Low voltage switchgear

Low voltage switchgear shall be designed to operate at 380V 3-phase or 220V 1-phase with insulation voltages not less than 660V. The installation shall comply with the local wiring regulations. The switchgear shall be of robust design and with front and rear access as far as possible and in. The switchboard internal assemblies shall be segregated according to BS EN 60439-1 Form 4 or the latest version of the standard with the degree of protection of IP44 and include barriers between each of its units to ensure safe maintenance on any circuit during normal operation with the remainder of the board alive. For switchboard to be located outdoor, degree of protection of IP54 shall be achieved.

Switchboards shall be designed with the busbar extensions at each end and shall have blank covers fitted over the ends of the busbar chambers. The busbar shall be made of tinned copper and the arrangement of the busbar system shall have been type tested to 50KA for 1 second according to BS EN 60439-1 or the latest version of the standard.

The electrical control such as protection system/relay shall be implemented with measures to prevent unnecessary tripping e.g. due to voltage dip. Example is that the power supply to the protection system is to be supplied by d.c. and with battery backup.

5.2.5 Power Transformer

The transformer shall be of robust design either in cast-resin type or gas-insulated type with a lifetime of at least 25 years, at rated outputs under the specified conditions and maintained according to the manufacturer's recommendations. The designer shall also check with relevant environmental regulations/ordinance on insulation oil/resin permitted to be used in Hong Kong for the transformer.

The transformer tanks shall be constructed of steel and hermetically sealed. Windings shall be uniformly insulated and be either copper or aluminum. The unit shall be naturally air cooled and be designed to be able to equip with fans to allow a minimum increase in rating of 25%.

The transformer shall be sized to suit both the maximum demand and the maximum instantaneous load of the plant without causing the excessive voltage dip under the start up of the maximum load. Future expansion and addition of equipment shall also be considered in sizing of the transformer.

The designer shall check the site grounding condition and determine if solid-earth or resistor-earth is to be employed for the transformer. In either cases, it shall be capable of withstanding a short-circuit on their secondary terminals with the highest declared fault level present at the primary side. If the design may result in parallel operation of transformers especially in 11 kV system integrated with low voltage system or connected with distributed generators, the protection equipment and setting shall be properly designed and graded with power company fault level allowance.

5.2.6 Security of Power Supply

In order to minimize the chance of sewage overflow or by-pass due to prolonged power failure, interruption to & fluctuation of supply causing stoppage of equipment, the security of the power could be upgraded by duplicating the supply feeders to the pumping station or by the provision of a standby generator. The design criteria of the standby and secure power supply are further described in Section 5.5 "Standby and Secure Power".

5.2.7 Starting Equipment

The limitations on starting a pumpset can be estimated according to the maximum instantaneous load acceptable as stipulated by the power companies. In general, the pumpset with motor rating larger than 7.5kW shall require assisted starting to restrict starting surges on the main supply to either a maximum current value or a percentage of normal full load current (NFLC), e.g. 2.5 x NFLC. Motor starter circuits which include equipment to reduce starting surges are referred to as 'assisted-start' systems. A variety of 'assisted-start' methods are available, namely, star-delta, auto-transformer, soft-start, variable speed drive.

For sewage pumps, the starting torque is critical. When selecting an 'assisted-start' which relies on a reduction in voltage, it is important to check and ensure that the starting torque of the pump is adequate for the proposed application.

5.2.8 Statutory Regulations

The design of the electrical system shall comply with the supply rules of the power companies and the statutory requirements of the Electricity (Wiring) Regulations of Hong Kong and its Code of Practice.

5.2.9 Energy Efficiency and Power Quality

In the design of electrical system and selection of electrical equipment, the appropriate energy code published by the Electrical and Mechanical Services Department shall be observed. In addition, the design shall also made reference to the supply rules and guidelines on power quality, harmonics and voltage dip ride through suggestions of the power supply company.

5.2.10 Renewable energy

The power supply company should be consulted with for connection of the renewable energy generation equipment with the supply grid. The design of the system protection should cover the scenarios arising from grid connection.

5.3 MONITORING AND CONTROL

Supervisory Control and Data Acquisition (SCADA) System is required for the monitoring, control and operation. It comprises intelligent outstations located at the node points and pumping stations, as shown in the schematic form in Figure 10. The system should enable automatic control of the pumping station and acquire the required information from field equipment and transmit it to the control centre. Operation data should be displayed instantaneously and properly logged at the control centre. The historical data should be retrievable for operation analysis and trouble shooting. Un-interruptible power system (UPS) is provided at each outstation and used to power the associated instrumentation, control and automation (ICA) equipment for at least 8 hours after the failure of power supply. A power failure will cause the UPS to continue operating, using its batteries.

In addition to SCADA system, closed-circuit television (CCTV) should also be provided to assist unmanned operation of the pumping station. The CCTV cameras should be placed at strategic locations to provide images showing the conditions of the switchgear, storage pond, overflow bypass, screenings skip, etc. CCTVs should also be used as part of the security measures for the pumping station.

Signals from the SCADA system and CCTVs should be transmitted to the operation control centre. Signal transmission for SCADA system and CCTV system via private broadband digital network is preferred to other means. Due to large amount of data and image transfer, the designer shall check with appropriate telephone services provider for the availability of digital network with the desired bandwidth for the site of the pumping station as earliest as possible.

Auto-dialling for alarms shall also be installed to alert the operator for failure of the digital network. Audio and visual alarms should also be raised at the control panel when equipment failure is detected.

5.4 SCREEN

Screen is required for the protection of the pumps from blockage by large floating objects. As far as practicable, mechanical screen is preferred to manual rake screen or basket screen. Aperture of the screen should be compatible with the solid passage capabilities of the downstream pump. Adequate facilities should be provided for the storage, conveyance and disposal of the screenings. Proper odour containment and treatment for the screen and screenings should be provided.

5.5 STANDBY AND SECURE POWER

It is the general practice of the power companies to arrange a single permanent power supply free of charge for any Government pumping stations within their supply grid. To improve reliability of the pumping stations and to minimise the chance of overflow or bypass of raw sewage, the designer should consider the following:

(a) the feasibility and cost of having dual feeds provided by the power company;

(b) the consequence of flooding due to power failure;

(c) the storage capacity of the pump sump and upstream sewerage; and

(d) the water quality implications on sensitive areas due to emergence bypass or overflow.

There are many ways to provide dual feed from power company depending on the level of reliability required. The designer shall consult the power company in detail and apply appropriate type of dual feed for the pumping station in consideration of feasibility, cost, the security level of the supply and the implication of supply failure.

Another option for standby power is the standby generator if dual feeds might not be feasible or the cost is exorbitant high. In general, it is required to provide a fuel tank of such capacity to allow the generator to run continuously for 6 to 24 hours (or as appropriate). Standard daily service tank of capacity ranging from 250 to 2,000 litres can be used. If the fuel tank exceeds 2,000 litres, underground tank has to be installed. The designer should observe relevant statutory requirements on the fuel tanks with respect to fire protection and oil spillage.

If underground tank is used, it is necessary to install a 450 litres daily service tank and two fuel oil transfer pumps, one duty and one standby, in the fuel tank room or a separate pump room. The fuel transfer pump should start automatically to transfer fuel from the underground tank to the daily service tank when the fuel in the latter falls below a preset level. The pump should stop when the daily service tank is full.

If the provision of standby power is not feasible either on economical grounds or due to site constraint, temporary storage is another alternative. The storage capacity of the pump sump and the upstream sewerage should be at least 2 hours at DWF. In case temporary storage is employed, effective ways to clear the stored/trapped sewage shall be provided.

5.6 LIGHTNING PROTECTION

The designer shall make reference to the BS 6651 - Code of Practice for Protection of Structures against Lightning and the Code of Practice for the Electricity (Wiring) Regulations of Hong Kong. The following sections may be used as a guideline for designing such installations.

(1) Basic Consideration

(a) Need of Protection

The need for protection may be self-evident, for example:

- The structure is very tall or isolated.
- The structure is not protected by nearby high rise structure.
- The structure contains explosive or flammable contents.

(b) Zone of Protection

The zone of protection is the volume within which a lightning conductor gives protection against a direct lightning strike by directing the strike to itself.

(2) Type of protection system

Air-termination network and earlier arrested lightning pole are two commonly accepted lightning protection systems used in Hong Kong. The designer shall consider the following in selection of the appropriate lightning protection system for the site:

(a) The location of the site whether it is in village area of which lightning pole design may be objected by the villagers or in urban area; and

(b) Consultation of the maintenance party in view of plant security and maintainability of the system.

From security point of view, lightning pole design is preferred as it has less easily removable valuable metals as compared to air-termination network.

5.7 LIFTING EQUIPMENT

Pumping stations should have facilities for the servicing of equipment and the removal and replacement of equipment in the building. For large stations, overhead gantry cranes or monorails are usually provided for handling of large pumps, motors and other equipment. For small stations, lifting hooks and chain blocks will be adequate for moving of equipment. If the equipment is of very low maintenance frequency and means acceptable to maintenance party can be made available if required for removal of the equipment for repair, dedicated lifting equipment may not be required.

The design considerations are as follows:

(a) The design Safe Working Load (SWL) of a lifting appliance shall be adequate to cope with the heaviest lift required for the overhaul or maintenance of the plant items concerned. Consideration should also be given to whether the complete assembly has to be lifted by the lifting appliance.

(b) Where the pumping station has a superstructure and there is a number of heavy items to be lifted, provision of an electric overhead crane is recommended.

(c) The covered area and the lift of the crane should suit the equipment to be moved. Excessive or inadequate coverage and lift should be avoided in the design.

(d) Provision of corbels at columns or lifting hooks at the beams of the building may be required for the installation of crane girders or runway beams. The engineer should consider the loads when he designs the structure.

(e) Permanent access should be provided for overhead cranes and isolators should be provided adjacent to the access ladders.

(f) Geared trolleys should be provided for hoists running on RSJ beams to enable manual long travel. Electric hoists or chain blocks should be provided if the hoisting distance is large or operations are expected to be frequent. Load chains should be stored in chain boxes fixed to the chain hoists.

The relevant regulations and design standards are:

Factories and Industrial Undertakings (Lifting Appliances and Lifting Gear) Regulations

BS 2573	Rules for the design of cranes
BS 2853	The design and testing of steel overhead runway beams
BS 449	The use of structural steel in building
ISO 4301	Lifting appliances - Classification

5.8 PENSTOCKS AND STOPLOG

Both penstocks and stoplog are used in pumping stations to isolate the flow or to control the flow direction. The designer shall assess the maintenance requirement and determine whether actuator is required for the penstock and whether stoplog would be more appropriate for the desired isolation if isolation is only required under rare situation as to ease the maintenance effort of the penstock.

5.9 OTHER FACILITIES

Doors in pumping stations must be made large enough for removal of equipment and floor openings or floor hatches of sufficient size should be provided for removing equipment from lower floors. Measures to reduce the risk of vandalism shall be considered for door, windows, fencings and valuable properties. Louvres are usually provided for ventilation. Cable trench should be provided to facilitate cabling works to the electrical panels.

Fresh water should be provided for the operation and maintenance staff for hygienic reasons. Boundary fence walls are normally required at large stations for security reasons. Telephone and digital network are required for communication with other related offices/control centre.

6. LAND REQUIREMENT

6.1 GENERAL

The area required for a pumping station varies with the quantity of flow, pumping head, the type of pump, the configurations of the site, the standby capacity and the type of ancillary facilities to be provided. The ancillary facilities may include the screens, transformer room, surge suppression devices, flowmeter chambers, lifting equipment, standby power supply, ventilation and deodorization facilities, septicity control facilities, emergency overflow structures, slope protective works, vehicular access and parking area. Adequate maintenance access and lifting devices should be provided for easy access to, and removal of, the equipment from the pumping station.

For land reservation purposes, the area requirement for pumping stations can be estimated first by identifying the maximum pumping capacity required. The maximum pumping capacity is the total quantity of flow that can be handled by the total number of pumps including the standby ones. It is preferred to prepare a preliminary layout to estimate the area in the preliminary design stage.

6.2 SCREW PUMPING STATIONS

The area requirement for screw pumping stations can be estimated either by preparing a preliminary layout or referring to the Figure 11 which is derived from the area uptake of existing pumping stations. The area from the curve in the figure only provides for inlet manual raked screens, office and a transformer room. If other facilities such as mechanical raked screens, staff quarter, flow measurement device, deodorization facilities or slope protective works are to be included, additional allowance for land should be made. Particular attention should be paid to the configuration and constraints of the site.

Archimedes' open-type screw pump is much more bulky than the centrifugal pump for the same rating. It requires a very large civil engineering structure to accommodate the pump. The centrifugal pump is more compact than the Archimedes' screw pump and covers much wider operating ranges but demand higher skill for maintenance. Moreover, enclosed screw pumps generally require less land than their open-type counterparts since a massive concrete structure is generally not needed.

6.3 PUMPING STATIONS WITH CENTRIFUGAL PUMPS

The land requirement for pumping stations with centrifugal pumps differs significantly between wet well type and wet/dry well type installations. It is preferred that a preliminary layout should be prepared to estimate the area required. For land reservation purposes, the area can be estimated either from the existing pumping stations of similar capacity or by referring to the Table 1 which is derived from the land uptake of some of the existing pumping stations. The area from the table allows for mechanical raked screen, transformer room, flow measurement and office. Additional allowance for land should be made for de-gritting and screening facilities as well as slope protection works, etc.

7. RISING MAINS DESIGN

7.1 HYDRAULIC DESIGN

7.1.1 Steady State Hydraulics

The hydraulic design of rising mains involves the sizing of the mains and its number to meet the pump operational and the velocity requirements. As for the pump operational requirements, please refer to the system head capacity curve in Chapter 3.

The selection of a suitable size for the rising mains should be based on economic analysis of capital cost and recurrent cost of the pumping system including the power cost. Trial and error approach should be adopted in order to arrive at optimal solution while maintaining the velocity within acceptable limits. The maximum velocity should not exceed 3 m/s which are usually governed by the concerns for the power cost. The desirable range of velocity should be 1 m/s to 2 m/s with due consideration given to the various combinations of number of duty pumps in operation.

For calculation of the frictional head loss in sewer rising mains, the roughness value for sewer rising mains by HR Wallingford (Table 5 in Sewerage Manual Part 1) should be adopted. Due to the vast differences in values among ‘good’, ‘normal’ and ‘poor’ conditions in this connection, adopting the ‘poor’ condition for the design of new sewer rising mains might render selecting pumping facilities unfit for the genuine working condition of the new sewerage system hence working less efficient as they intended to be. Therefore, it is recommended to adopt ‘normal’ condition for new sewer rising mains systems unless potential adverse sewerage impacts are anticipated or there are compelling reasons for other alternatives.

7.1.2 Transient State Hydraulics

Transient state occurs whenever there are changes to the steady state of flow velocity in the rising mains, which can be caused by pump start-up, pump shutdown, closure of valve or power failure. A series of wave is generated and will propagate at approximately the velocity of sound along the mains. The wave propagation will be dissipated by friction or some positive means of damping action till a new steady state is reached. Sometimes, this phenomenon is also known as water hammer or surge. Considerable changes in pressure (positive or negative) commonly known as surge pressure will result.

Surge is likely to be significant in long rising mains or where high velocities occur. For simple case, surge analysis can be carried out by graphical method. For complicated cases, surge analysis can be carried out by numerical analysis aided by computer. (See Chapter 3 for more details).

7.1.3 Surge Suppression Methods

Surge pressure is caused by rapid change in flow velocity in pipeline, it can thus be reduced by slowing down the rate of change in flow velocity. As the amplitudes of pressure surge fluctuate between certain maximum and minimum values, its prevention methods can thus be classified into two main categories as descried in the following two sections.

7.1.4 Negative Pressure Prevention Methods

These methods are mainly to prevent water pressure falling below the water vapour pressure in which water column separation occurs. If the water pressure is increased to above the water vapour pressure, the vapour will suddenly disappear, thus creating excessive pressure. Some commonly adopted methods in order of preference are given below:

(i) Pump Inertia/Flywheel

If the rotational inertia of a centrifugal pump and motor continue to rotate the pump for a while after power failure, water hammer pressure transients may be reduced.

This method usually involves the addition of a flywheel between the pump and motor. Inertia effect of pump rotating assembly is increased by the attachment of a flywheel. The inertia energy provides rotational energy upon pump stoppage, thus preventing rapid drop of pump speed and flow rate. In most cases, the flywheel would have to be impractically heavy. Also, the starting current thereby may be increased.

This measure is relatively simple and is effective on low-head, short pipelines. A large flywheel is required for long pipelines.

(ii) Ordinary Surge Tank

This method involves the installation of a large capacity tank at midway of the pipeline. Water in the surge tank flows into the pipeline immediately after pressure drop, and thus the pressure drop and the following pressure rise are prevented. If the internal pressure of the pipe under normal condition is high, the tank elevation will have to be higher accordingly. In that case, the cost of construction is expensive.

(iii) One-way Surge Tank

This method consists of an one-way tank comprising an ordinary surge tank and an additional check valve installed at a negative pressure zone. When pipe internal pressure and its connections drops below pressure in the tank, the check valve opens, water in the surge tank flows into the pipe, and thus preventing further pressure drop.

A one-way surge tank can usually be made lower than an ordinary one, but one or more tanks must be installed along the pipeline since this tank would not be effective for the whole pipeline. For sewage applications, this method is not suitable if the check valve is less than 100 mm diameter in which clogging may occur.

(iv) Air Relief Valve

Air relief valves are installed at locations of minimum pressures. Air is sucked in the air relief valve when pipe internal pressure is below atmospheric. Upon subsequent pressure rise, the admitted air is then forced out. They are usually installed at convex points of the pipeline (i.e. local high points).

Several air relief valves may be required to be installed along the pipeline if there are numbers of rise and fall in the pipeline.

(v) Air Vessel

A pressurized vessel, with an additional check valve on the negative pressure side and a throttle valve on the positive pressure side, is installed downstream of the pump check valve. If the internal pressure of the pipe is reduced, the pressurized water in the vessel is forced by means of compressed air in a vessel into the pipeline through the additional check valve, thus increasing the internal pipe pressure. Upon excessive pressure rise, water in the pipeline is forced into the vessel through the throttle valve, thus reducing the high internal pressure.

(vi) Pump Bypass with Automatic Reflux Valve

An automatic bypass can be arranged near the pump so that water can continue to flow from the suction to the delivery side even if the pump is stopped by a power failure. The water column comes to rest under the action of the difference in head and of pipe friction; as the flow reverses, the reflux valve arranged in the bypass shuts, and the subsequent pressure rise is less than if the water column had been broken and reunited.

(vii) Pressure relief valve

A pressure relief valve cannot prevent separation of water column if this tends to occur when the pump stops; all it can do is to limit the pressure rise when the column reunites. The usual design does not allow the water to escape freely enough once the pressure setting has been reached, so that the pressure in the pipe is increased above the setting of the relief valve by a considerable friction drop in the valve itself.

For pump system where pressure rise is rapid or its cycle is short, the effect of relief valve is unpredictable because of the delay in its action.

7.1.5 Methods to Reduce Pressure Rise

Subsequent to a pressure drop, the water pressure will begin to rise due to reflection of pressure waves from the discharge to the suction sides, i.e. reverse flow occurs. Thus the pressure rise can be reduced by properly controlling the reverse flow rate. Typical pressure rise reducing measures are described in the following sections.

(i) Slow-closing Check Valve

A dash pot is connected to a valve spindle so that the valve disc closes slowly against reverse flow to reduce pressure rise. This method is suitable for relatively low head.

(ii) Quick-closing Check Valve

A valve is closed forcedly against the slow flow velocity just before the reverse flow occurs, to prevent additional pressure rise due to delay of a valve closure.

(iii) Automatic Shut-off of Main Discharge Valve

Simultaneously with a shut-down of pump, the change of flow velocity is restrained to as small as possible to reduce the pressure rise by controlling a degree of a valve opening by an oil hydraulic mechanism.

Some valves can have a two-step closure mechanism, that is, initially quick-closing and thereafter slow-closing.

7.2 PIPE MATERIAL

The most common pipe material is ductile iron and welded mild steel pipe. All pipes and fittings shall be lined with suitable materials. For use of HDPE or MDPE pipes as rising mains, the required pressure rating should be specified. Please refer to Chapter 5 of Part 1 of the Sewerage Manual of detailed discussion of factors to be considered in the choice of pipe material.

The pipe chosen should be able to withstand a hydraulic pressure of not less than 2 times the maximum working pressure or 1.5 times the maximum surge pressure (after incorporation of surge suppression devices) whichever is the greater.

The thickness of the pipe material should be strong enough to withstand (i) the external load and (ii) the internal pressure. Reference should be made to the literatures such as manufacturer's catalogue, technical literature on material properties and allowable deformation of pipe, effect of creep and type of joints.

7.3 DISCHARGE ARRANGEMENTS

7.3.1 Function of Discharge Sump

A discharge sump is used to dissipate the energy of flow due to the residual velocity head at the discharge end of a rising main in order to achieve a non-turbulent condition before the sewage will gravitate through the downstream system. The downstream system may be a gravity sewer or the inlet work of sewage treatment works.

7.3.2 Layout of Discharge Sump

In the layout design of discharge sump, turbulence should be minimized. Excessive aeration of the incoming sewage should be avoided. Turbulence and excessive aeration can be overcome by the use of a drop tube or a vertical bell-mouth attached to the incoming rising main. A baffle wall can be used alone for stilling the impinging flow or used in conjunction with the drop tube or bell-mouth to produce better result. It should be noted that the discharge level of the rising main must be set at a level higher than the possible maximum sewage level in the sump to prevent backflow to the rising main.

7.3.3 Size of Discharge Sump

In general the discharge sump should be of sufficient size to allow personnel to replace the drop tube or bell-mouth as well as to carry out regular cleaning.

7.4. PROFILE AND VALVES

Where possible, rising mains should be laid with continuous uphill gradient and with general curves on both horizontal and vertical planes. Otherwise, air release valve should be provide at high points and as the profile of the main dictates. Washout should be installed at low points. The arrangement and locations of valves should be planned together with the alignment of the rising mains.

7.4.1 Air Valves

Please refer to the Section 7.1.4 (iv).

7.4.2 Vented Non-return Valves

The air relief valve combined with a vented non-return valve allows air to enter the pipeline freely on separation, but controls the expulsion of air as the column rejoins. This has the effect of creating an air buffer between the column interfaces, reducing the impact velocity of the rejoining column and the surge potential of the system.

7.4.3 Wash-out

The purpose of the washout pipework is to drain the rising main during maintenance. The washout point should be at low points of the pipework and its location should be chosen carefully, taking into account the final discharge point of sewage. For long rising mains, the wash-out should be strategically located at certain intervals to reduce the time required for sewage discharge during emergency. The chamber for the wash-out should be provided with a pump sump so that the wash-out sewage may be tankered away if a direct connection to a sewer or bypass to storm water drain proves impractical on environmental grounds.

7.4.4 Isolating Valves

For long rising mains, isolating valves should be included to allow sections to be isolated and emptied within a reasonable time. Sluice or gate valves are often used as isolating valves.

7.4.5 Access Hatch

For long rising mains, inspection chambers with access hatch and isolating valves should be included to facilitate man or unman entry for close circuit television inspection and maintenance. As access hatch is a potential spot for leakage, it should be only provided at strategic locations and the operation and maintenance division should be consulted.

7.5 THRUST BLOCK

7.5.1 Purpose of Thrust Block

Thrust blocks are concrete blocks designed to prevent pipes from being moved by forces exerted within the pipe by the flow of water hitting bends, tapers, and closed or partially closed valves. In the design of pressurized pipeline, they are essential on flexibly jointed pipelines where any pipe movement would open up the joints in the line and cause water leakage. Thrust blocks are also necessary near valves where a flexible joint is located to facilitate removal of the valve for maintenance purposes. The size of block is dependent upon the deflection of the flow, the size of the pipe and the head of water inside the pipe (WSD, 2004). Please also refer to the recommendations of pipe manufacturers.

7.5.2 Design Assumptions

The following design assumptions are commonly adopted:

(a) Thrusts developed due to changes in direction of pipeline, dead ends or changes in pipe diameter should be considered. Force due to change in velocity head is assumed negligible.

(b) For pipes with flexible joints such as D. I. pipes with socket and spigot joints, etc., all the thrust is assumed to be taken up by the blocks.

(c) For pipes with rigid joints such as welded and flanged joints, welded collars etc., it is assumed that half of the thrust is taken up by the pipe continuity while the remaining half is taken up by the blocks. When loose joints (e.g. flange adaptor, coupling joint, expansion joint etc.) are used in a steel pipeline with rigid joints, such loose joints cannot be located within the calculated safe length for development of ground anchorage on both sides of a bend or from the dead end or reducer/taper on the pipeline. Otherwise, the whole of thrust is assumed to be resisted by the thrust block as in the case of pipes with flexible joints.

(d) 1/6 of passive pressure is allowed to be mobilized in calculating the thrust to be resisted by the blocks under working and testing conditions.

7.5.3 Calculation of Thrust at a Pipe Bend

The general equation for calculating the thrust (T) at a horizontal pipe bend (see Figure 12) is as follows:

$$T = 2p(\pi D2/4)\sin(\theta/2)$$

where p = internal pressure in pipeline
D = internal diameter of pipeline
θ = angle of bend

As the thrust in pipeline is resisted by the dead weight of the thrust block, grade 20/20 concrete is normally used for economic reason. The size of the thrust block is determined by the required frictional resistance developed on the underside of the block and the blocks should be designed to satisfy both the working and testing conditions. In calculating the passive pressure, an overburden of 0.5m can be taken into consideration if depth of cover to a thrust block exceeds or is equal to 0.5m.

(1) *Under Working Condition.* The block should be designed to comply with the following:

(i) Internal pressure in pipeline under working condition shall be taken as maximum static pressure or maximum working pressure, whichever is the greater;

(ii) Factor of safety against sliding (short term working condition) ≥ 1.1 when the thrust block is fully exposed and at the same time the pipeline continues to be in operation;

(iii) Factor of safety against sliding (normal working condition) ≥ 1.5 when the thrust block is under normal working condition and there is no road opening going in the vicinity of the thrust block.

1/6 of passive pressure is allowed to be mobilized and the soil parameters are assumed to be ϕ'= 30° and c' = 0; and

(iv) Factor of safety for bearing capacity ≥ 3.0

(2) *Under Testing Condition.* The block should be designed to comply with the following:

(i) Internal pressure in pipeline under testing condition shall be taken as the maximum working pressure plus 5 bar or maximum total pressure under surge conditions whichever is the greater;

(ii) Factor of safety against sliding (testing condition) ≥ 1.1

1/6 of passive pressure is allowed to be mobilized and the soil parameters are assumed to be ϕ'= 30° and c'=0; and

(iii) Fill material is to be deposited fully over top vertical, taper or blank end thrust blocks to minimum depth of 0.5m prior to the test commencing.

7.6 CONTROL OF SEPTICITY

In the sewerage network, bacteria breaks down the organic components in sewage. If there is a lack of oxygen during the degradation process, septic conditions will occur which will result in the formation of hydrogen sulphide. This causes an offensive smell and is a health hazard. Septicity becomes a problem when the retention time of sewage in the mains is long and the temperature is high or the incoming sewage to the pumping station is already septic. When the pump begin to operate, the heavy sulphide concentration will be discharged through the rising mains to gravity sewer or downstream treatment units where severe corrosion of concrete can take place. Septic sewage will also inhibit the sewage treatment process.

For the estimation of the amount of sulphide, key parameters include BOD or COD, sewage temperature, flow, the gradient of pipe and slime/sewage interface (Pomeroy, 1977).

To control septicity in the rising mains, one of the most common method is to minimize the retention time in the pumping station. Other methods include some pre-aeration in the wet well of the pumping stations or to add controlled dosage of nitrate solution, frequent maintenance of wet well and the direct injection of oxygen into the mains. Care should be taken to check the injection point and the location of air-relief valves, so as to prevent the loss of oxygen through the air relief valves.

For sizing of the rising mains, the ultimate flow is often used. Hence the rising main would be oversized for initial operation period. Oversized rising main would create septicity problem in operation. Twin or multiple rising mains as appropriate with different size to suit for different flow conditions, such as initial and ultimate flow projection should be considered. This is also an effective method for septicity control in rising main.

7.7 EXPOSED PIPELINES AND PIPE BRIDGES

Due to the nature of sewage, covers (pre-dominantly soil cover) are normally provided for sewers/rising mains. However, where buried pipes are not possible for construction and exposed pipelines are the only suitable solution. The following should be considered:

(a) Expansion joints are normally unnecessary in exposed pipelines with flexible joints.

(b) Exposed pipelines should be supported on rollers or rubber pads on concrete blocks to prevent excessive deflection in uneven ground and thrust blocks should be placed at bends if necessary.

(c) Reference can be made to BS 8010 on design of pipelines on supports / piers.

(e) Where the pipe bridge may constitute a hazard to public safety, appropriate measures such as barbed wire or metal spikes must be placed at each end of the pipe bridge to prevent unauthorised access.

(f) The designer should consider the following when designing supports for exposed pipe.

(g) The pier and saddle supports for exposed pipe is assumed to sustain vertical thrust only. All longitudinal components of the thrust due to change in direction or diameter of pipeline etc. shall be resisted by anchor blocks at suitable points of the pipelines.

(h) Design of supports against floatation due to flooding shall be considered separately.

(i) The designer should consult the Advisory Committee on the Appearance of Bridges and Associated Structures (ACABAS) on the aesthetics of the pipe bridge.

7.7.1 Leakage Detection

Relevant maintenance agent should conduct routine inspection of sewers (especially thrust block and rising mains) to ensure the integrity of the sewerage is not undermined by immediate road excavation. Given the severe environmental impact of burst rising mains; suitable leakage detection system should also be installed for pressurized mains.

7.7.2 Planting in the Vicinity of Sewers

With the growing emphasis on environmental friendly/green design, suitable standard conditions governing planting and landscaping in the vicinity of rising mains and sewerage works are required to facilitate inspection and maintenance of sewerage systems:

(a) In general, no trees shall be planted within 3m from both sides of any existing or proposed pipeline.

(b) Turf, plants and minor flowering shrubs may be accepted over sewerage provided they do not have profuse or penetrating roots.

(c) Planting within the space of 1.5m around the cover of any chambers should be avoided.

(d) There shall be free access to all sewerage installations at all times even when the turf, plants and shrubs are mature.

(e) Where the planting and landscaping are carried out by others, details of site formation work and of any proposed structures shall be submitted to DSD for prior approval.

In case of doubt, the relevant operation and maintenance division(s) should be consulted in dealing with any such planting and landscaping works.

7.7.3 Pipeline along Bridge Structures

When pipelines are to be laid along bridge structures, they should be laid in troughs or supported on concrete/steel works cantilevered from the side of the bridge and specially designed for the sewerage with leakage collection system. Special allowance should be made in the design of the pipeline to account for the movement joints of the bridge structure.

7.8 MANHOLES AND CHAMBERS

The following points should be taken into consideration during the design of non-standard manholes and chambers (other manholes and chambers should be referred to DSD Standard Drawings):

(a) They should be kept away from roads wherever possible. If unavoidable, the manholes are strictly not allowed by HyD to cross over two lanes.

(b) In normal cases, DI rectangular, heavy duty covers and frames should be fitted to all manholes and chambers and in rough country areas the cover level should be 300 mm above the surrounding ground level. Where the manhole cover is located in a paved area formed by precast paving blocks and its size is greater than 400mm square, it should be of a galvanised steel recessed type suitable to be infilled with precast paving blocks to maintain the architecturally designed appearance of the paved area.

(c) Permanent drainage to manholes and chambers is unnecessary as they can be easily emptied of water for inspection and maintenance by means of a mobile pump.

(d) Valve chambers are not required on exposed pipelines except at washout valves.

(e) Step ladders should be provided as a means of vertical access to manholes, valve chambers, pump pits etc. when the height of vertical access is 1.2m or over. When the height of vertical access is less than 1.2m, step irons can be used instead.

(f) The size of the air valve chamber must be big enough for inspection and maintenance purposes. A clear distance of at least 150mm from the wall, roof, and floor of the valve chamber to the body of the valve is to be maintained.

7.9 LAYING OF SEWER ALONG SLOPES

The following should be considered when design of rising mains on slopes:

(a) Where sewerage must be laid along slopes, advice should be obtained from GEO as to any precautionary measures which must be taken to prevent the stability of the slope from being jeopardized by leakage from sewer. GEO usually requires precautions as outlined in Section 9.4.7 of the Geotechnical Manual for Slopes to be observed.

(b) Where there is a possibility of leakage into the slope, for example at the crest, which will affect its stability adversely, the provision of leakage collection systems alongside the main to an appropriate point of discharge should be considered. Reference should be made to Sections 5.3.2(4) and 9.7 of Geotechnical Manual for Slopes.

(c) Bolting of pipelines to rock slopes should be avoided as the bolts must then be checked at regular intervals to ensure that they remain tight.

(d) The use of flexible/loose joints for rising mains close to the crest of slopes is not advisable because they are vulnerable to ground movement resulting in leakage.

(e) Where mains are laid up slopes they should be anchored with concrete at the centre of each pipe to prevent movement and where pipes are laid in access roads which traverse slopes they should be laid at the side of the road which leads up the slope.

(f) Consultation with GEO at an early design stage can help to reach a compromised and sensible solution on this particular circumstance.

7.10 SEWERAGE WORKS IN CONJUNCTION WITH ROADWORKS

The following should be considered for planning of rising mains:

(a) Newly constructed or resurfaced roads are normally subject to a road opening restriction extending over several years and it is essential that any rising mains beneath the roads are done in conjunction with the roadworks contractor before the carriageway is completed.

(b) Details of proposed roadworks are normally submitted to DSD where they are circulated around the relevant divisions.

(c) When rising mains are proposed to be laid in future road carriageways/verges or in existing carriageways/verges which are likely to be reconstructed or improved in future, the relevant authority, e.g. HyD or CEDD should be approached as soon as possible with regard to timing and details of such future construction or improvement of the roadworks.

(d) For rising mains to be laid adopting the future road profiles, final road levels should be obtained to facilitate the design of the sewerage profiles.

8. STRUCTURAL DESIGN OF PUMPING STATIONS

8.1 GENERAL

A sewage pumping station can be divided into two parts namely superstructure and substructure. The superstructure mainly consists of the motor control room and office which can be designed as slab, beam and column or as plane frames in accordance with BSI (2002) and BSI (2004). The substructure mainly consists of the wet well or pump chamber which can be designed as liquid retaining and containment structure supplemented by BSI (2006).

8.2 AESTHETICS

The designer should take particular attention in the design of sewage pumping station including the incorporation of environmental friendly features as mentioned by the "Guidelines on Aesthetics Design of Pumping Station Buildings", which is available on the DSD web page.

8.3 DESIGN REQUIREMENTS

The design of sewage pumping station should be able to sustain all combinations of loading during its design life. Both the serviceability and ultimate limit states should be checked.

For pumping station with superstructure such as control room, dead load, imposed load, wind load and impact load, if any, should be considered in the design. Attention should be paid to any machinery load or crane load under operation. For the substructure, earth pressure and loads from underground hydrostatic pressure should be considered. Structural design requirements of the structure, in particular durability and serviceability requirements, are provided in Section 8.3.1 to 8.3.8 below. Recommended design parameters for concrete and steel reinforcement are given in Table 3. The stability of the structure against flotation due to groundwater under most adverse situation should also be checked in accordance with BD (2004/1) or its latest version.

The locations of expansion joints, if required have to be carefully placed to avoid possible movements not anticipated.

The design memorandum and calculations for a pumping station should comprise the following:

(a) the design standards and parameter adopted;

(b) the design assumptions;

(c) the design data;

(d) the design approach and the critical loading cases;

(e) detailed structural analysis with cross reference;

(f) summary of output; and

(g) sketch showing the reinforcement arrangement for critical section.

8.3.1 Exposure Conditions

Since the wet well and pump chamber of sewage pumping stations will generally expose to sewage containing a high concentration of sulphate/aggressive solution which will cause severe corrosion to the reinforced concrete, the substructure of sewage pumping stations should be designed for exposure class "XA" as defined in BSI (2004) or its latest version. If protective measure such as lining to be provided to protect concrete surfaces, the exposure class "XC4" as defined in BSI (2004) or its latest version may be adopted.

8.3.2 Strength of Concrete

Given the required water retaining properties of wet wells or pump chambers, minimum concrete Grade ($f_{ck,cube}$) 45 is recommended under "XA" exposure class and minimum concrete Grade ($f_{ck,cube}$) 40 is recommended under "XC4" exposure class. Since the design equations in the structural design to EC and UK NA are based on cylinder strength (f_{ck}), the designer may make reference to Table 3.1 of BSI (2004) or its latest version, or the following approximate equation for conversion of the cube strength to cylinder strength when carrying out the design.

$$f_{ck} = 0.8 \quad x \quad f_{ck,cube}$$

where f_{ck} = characteristic compressive cylinder strength of concrete
$f_{ck,cube}$ = equivalent characteristic cube strength of concrete

8.3.3 Maximum Permissible Crack Width

The designed maximum permissible crack width shall be designed so that design crack widths should be limited to w_{k1} as defined in BSI (2006) or its latest version. The limiting crack width w_{k1} varies according to the ratio (i.e. h_D/h) of hydrostatic pressure, h_D to the wall thickness of the containing structure, h. For h_D/h less than 5, w_{k1} shall be equal to 0.20 mm while for h_D/h greater than 35, w_{k1} shall be equal to 0.05 mm. Linear interpolation of w_{k1} is allowed for intermediate values of h_D/h in accordance with BSI (2006) or its latest version.

8.3.4 Concrete Cover to Reinforcement

Concrete cover to reinforcement should be provided in accordance with the following normal values for the envisaged conditions of exposure. The value of nominal cover shall be the minimum concrete cover as recommended in BSI (2004) or its latest version plus the allowance for deviation taken as 10 mm. The value of nominal cover shall be indicated on the drawings and be used in design of reinforced concrete structure.

Exposure Class	Nominal Cover (mm)	
	Concrete Grade $f_{ck,cube}$ = 40	Concrete Grade $f_{ck,cube}$ = 45 or above
XA	-	50
XC4	35	35

8.3.5 Specification of Concrete for Retaining Sewage

(a)	Max. free water/cement ratio	0.38
(b)	Min. cement content (kg/m^3)	380
(c)	Max. cement content (kg/m^3)	450
(d)	PFA Content (by mass of PPFAC)	25% ± 3%
(e)	Acid soluble sulphate content, SO_3 (% of total weigh to concrete)	≤ 4
(f)	Acid soluble chloride ion content, (% of total weigh to concrete)	≤ 0.02
(g)	Portion of PFA Replacement (% by mass of cementitious content)	25 – 40
(h)	Equivalent sodium oxide (kg/m^3)	≤ 3
(i)	Temperature of fresh concrete for water retaining structure	≤ 25^{o}C
(j)	Temperature of fresh concrete for non water retaining structure	≤ 32^{o}C
(k)	Temperature of placed concrete	≤ 75^{o}C
(l)	Direct tensile strength (N/mm^2)	
	3 days (for concrete grade C35/45,	1.9

for other concrete grade, BSI (2004) shall be referred)

8.3.6 Reinforcement for Thermal Effect

(a) Reinforcement for controlling shrinkage and thermal movement cracking should be calculated in accordance with Clause 7.3.4 and Annex L and M of BSI (2006).

(b) To be effective in distributing cracking the reinforcement should be placed near the surface of the concrete and small diameter bars at close spacing should be used.

8.3.7 Hydration Temperature

(a) The range of temperature rises (TI) above mean ambient temperature to be used in the design of water retaining structures shall be as follows :
(Maximum cement content : 450kg/m^3)

Wall Thickness (mm)	Temperature TI (^{o}C) for OPC Concrete
300 and less	31
500	43
700	49
1000 and more	56

(b) A further 15% is to be added to the above temperature rises in the design to account for the possible high concrete placing temperature in the hot summer season.

8.3.8 Seasonal Fluctuation of Temperature

Seasonal fluctuation temperature (T2) should be taken as 25^{o}C for members under soil cover. If it is definitely known that concreting will take place in an off summer period, a smaller value can be used. For exposed members T2 should be taken as 30^{o}C.

9. COMMISSIONING OF PUMPING STATIONS

Commissioning is to prove the performance of the pumping station. Since the pumping station is only one component of the sewage collection and transportation system, it is important that the sewerage scheme including the pumping station should be considered as a whole and plan for commissioning of pumping station should be drawn up at the detailed design stage. Relevant operation and maintenance parties should be involved at various stages of the project implementation. In particular, the following items should be considered at the detailed design stage:

(a) The availability of flow;

(b) The build up of flow with time;

(c) The programme of both civil and E&M works should be scheduled to minimize any mismatch in timing. Either adequate float time should be allowed for unforeseen delays or delayed commissioning should be included in the contract documents;

(d) Contingency plan for temporary diversion of sewage or pumping of seawater to fully test the hydraulics, the performance of the pumps and associated equipment such as the control mechanism should be drawn up; and

(e) Any neighbourhood sensitive receivers that might be affected during the construction, commissioning and operation stages, and any temporary or permanent remedial measures need to be included.

During the construction stage, the progress of both civil and E&M works should be closely monitored and possible mismatch should be identified and consequence evaluated. The adequacy of the original commissioning plan should be reviewed and corrective action to be taken. The critical path of the works with milestones should be set up for progress monitoring.

During the commissioning stage, the project engineer should draw up detailed action plan in consultation with relevant O&M parties. The action plan should include:

(a) Submission of operation and maintenance manual to O&M parties

(b) Submission of test and commissioning checklists and programme for commissioning (e.g. connection of flow to pumping station, filling of rising mains) for agreement with O&M parties;

(c) Key performance parameters, e.g. the flow rate, pressure, power consumption, electrical and hydraulic transients, temperature and vibration of pump and motor, etc. to be verified;

(d) Necessary training regarding operation and safety for operators;

(e) Process and Instrument Diagrams showing the major equipment and their operating parameters;

(f) Modes of pump operation during testing and start up procedures;

(g) Hydraulic monitoring program;

(h) Pump efficiency, hydraulic, and functional testing procedures and/or check list for piping and other equipment;

(i) Contingency plan for emergencies such as power supply failure, pump failure, bursting of mains, flooding; and

(j) Any other issues such as safety aspect, precautionary measures.

Testing and commissioning report should be submitted after the test for record and the report should include the commissioning procedures, equipment running record (preferably direct generation from the SCADA system) and comparison of the performance and the design figures.

10. ODOUR AND NOISE CONTROL

10.1 SOURCE OF ODOUR

Odours from domestic wastewater usually result from bacterial activities in the sewer collection system, sewage pumping stations and sewage treatment works. Typical compounds which contribute to odours are hydrogen sulphide, ammonia, thiols or mercaptans, other sulphur containing organic species, amines, other nitrogen containing organic species and organic fatty acids. In many cases, hydrogen sulphide is the dominant odorous compound because of its low threshold limit and is therefore used as an odour indicator (just like E Coli which is used as indicator of faecal pollution).

Odour nuisance could be found in the following operations/ parts of the sewerage system:

(a) from trade waste discharge;

(b) formation of septic sewage (generally in rising mains or after prolong long retention time in the sewerage system);

(c) sludge and screenings treatment and handling;

(d) from sewer vents and air release valves;

(e) from inlet works;

(f) from wet wells of sewage pumping stations; and

(g) from biological treatment systems.

Odour control should start with the planning and design of the entire sewerage and must be considered at the beginning of the design of any sewerage facilities. Preventing sewage to turn septic is of prime importance. Long retention time should be avoided. Sea water containing large amount of sulphate provides more sulphate for sulphide production. Besides, odour nuisance could occur during desludging and repair of sewerage system. Precautionary measures should be taken during the operations to avoid causing odour nuisance.

10.2 ODOUR CONTROL MEASURES

10.2.1 Legislation

Reference should be made to the Environmental Impact Assessment Ordinance (EIAO) and its Technical Memorandum. The requirement is 5 odour units based on average time of 5 seconds. The concentration of H2S as an alternative compliance criterion is also acceptable.

10.2.2 Identification of Principal Odour Sources

It is necessary to identify the principal odour sources before any odour control measure can be implemented.

10.2.3 Control on Formation of Odour

The steps in odour control begin with prevention of the formation of odorous compound in sewage. It is followed by, prevention of the odorous compound to be released from liquid phase to gas phase, containment of odour and finally odour abatement. Long retention time in sewers and particularly in rising mains should be avoided. Dead zones in the pump chamber encourage settlement of solids and also encourage sulphide formation.

The formation of odour in sewage can be controlled either by inhibiting the generation of odour compound in liquid phase or removal of the odour compound formed in liquid phase. The measures of former category includes inhibiting biological activity by pH elevation, such as addition of NaOH and Ca(OH)2; or providing oxygen source for preventing the reduction of sulphate to sulphide by the addition of calcium nitrate, oxygen, etc.. Oxygen injection, nitrate dosing or re-aeration in sewers is the common measures to prevent septicity in sewage before it reaches sewage treatment works. Whilst the measures of latter category includes precipitation of sulphide formed, such as addition of ferric chloride; and oxidization of sulphide formed, such as addition of hydrogen peroxide. In general, the addition of chemical could reduce the hydrogen sulphide emission and at the same time reduce the corrosion of E&M equipment and piping. Therefore, chemical addition should be adopted in conjunction with deodourisation units if the hydrogen sulphide from the sewage is high.

10.2.4 Good Housekeeping

Good housekeeping in collection systems, such as the prevention of the development of anaerobic conditions, and within the sewage treatment works, say by prompt disposal of screenings and grit, will mitigate the production of odorous gases.

10.2.5 Containment of Odour Sources

Odour sources should be confined and isolated as far as possible to prevent dispersion of odorous gas over a wide area. Extent of containments should be kept to a minimum as the cost of any deodorising system is very much depends on the volume of air to be treated. Corrosion could be a problem for containment. Proper considerations should be given to the potential problem and the appropriate measures to guard the sewerage structures against corrosion.

10.2.6 Ventilation

Ventilation is as an important factor to effective containment. For certain processes, such as sludge holding tanks, it is only necessary to isolate the individual sources of odour, whereas with others, such as screenings handling area, sludge press house, etc., it is necessary to enclose and maintain the whole premises under negative pressure to prevent leaking of malodorous gases to the atmosphere. Table 2 lists out the typical strength of hydrogen sulphide at various locations of a sewage treatment works and the recommended volume change. Sometimes the recommended volume change listed in Table 2 cannot be achieved due to site constraint. The designer should be more resourceful in determining the volume change required. For more details on ventilation, please refer to Chapter 11.

10.2.7 Design Modification

Some design modifications may help to control the emission of odour. Maximising the sewage flow velocity in sewers to minimize siltation and slime layer formation, minimizing the length of pumped sections and intermediate storage, pre-aeration of raw sewage to prevent anaerobic condition and the minimization of turbulence of the sewage, minimizing the formation of scum within the sewage treatment works will enhance odour control. Determination of maximum/allowable retention times of the sewage in a system would help choosing appropriate measures to minimize septicity problem.

Sometimes the wet well of pumping station is of considerable depth in order to provide adequate operating volume to prevent sewage from by-passing to adjacent drains in case of power failure. There is a large difference in sewage level between start and stop of the pumps. Incoming sewage dropping into the wet well, especially when the sewage level is low, will release a large amount of odour compounds. Inclusion of Variable Frequency Drive (VFD) control to the pumps in such situation will enable the pumps running at variable speed thus maintaining the sewage pumping in the wet well at a steady level. This will help reduce the formation of odour compounds. Besides, wet well may be designed for normal operating conditions and a storage tank is provided for emergency storage of sewage when pumping station breaks down for whatever reasons such as power failure. Two separate compartments could be provided to meet different needs. From septicity control point of view, minimizing the wet well volume by using variable speed drives could be helpful because they could keep the sewage pumping at a steady level.]

In general, the retention time of raw sewage in the pumping station should not be more than 2 hours. If such condition cannot be fulfilled, additional measures such as aeration, chemical dosing, etc. should be allowed to prevent septicity.

Besides, minimizing the level difference between the inlet and outlet pipes in the discharge chamber (which is considered one of the major problematic areas) from rising main to gravity sewer will also help reducing the formation of odour compounds. Also connection in between the inlet and outlet pipes should be carefully designed so as to minimize the potential odour problem.

In case if the flow will take a long time to build up, it would be necessary to reduce the retention time of the sewage in the system, such as in the wet well, rising mains, sewerage system, etc. so as to reduce the anaerobic condition in these areas. This could be achieved by the installation of a smaller system such as wet well, pumps, rising main, etc. to cater for the initial flow period.

10.3 ODOUR ABATEMENT METHODS

There are basically five main types of odour abatement techniques, namely, adsorption, absorption, incineration, condensation and biological methods. The commonly used techniques by DSD are activated carbon (adsorption), chemical scrubber (absorption) and biofilter and biotrickling filter (biological methods).

10.3.1 Adsorption

This technique involves passing a stream of foul gas through a porous solid material (the adsorbent) contained in an adsorption bed. The surfaces of the porous solid material attract and hold the adsorbed gases (the adsorbate) by either physical or chemical adsorption. The most common adsorbent material used in physical adsorption system for the odour control of sewage treatment works is activated carbon. Factors affecting physical adsorption include:

(a) type and surface area density of adsorbent;

(b) type (such as polarity and molecular size) and concentration of contaminants;

(c) pressure;

(d) temperature; and

(e) relative humidity.

Activated carbon filters are mainly used for physical adsorption of odorous compounds and only a small amount of catalytic carbon is available in the market with capacity to perform catalytic air oxidation of the adsorbed odorous compounds.

The hydrogen sulphide removal efficiency of ordinary activated carbon is not high and it could be enhanced by the use of the Impregnated Vapour-Phase (IVP) Activated Carbon which is a chemically-treated granular carbon to improve vapour-solid phase adsorption, usually impregnated with a caustic such as sodium hydroxide (NaOH) or potassium hydroxide (KOH) for removing acidic odours such as hydrogen sulphide. These impregnants increase the rates of oxidation of hydrogen sulphide. Thus IVP activated carbon has an enhanced capacity over other carbon products even under high moisture level which is frequently encountered in odorous air stream in sewage treatment works. However, the impregnants usually occupy considerable pore space of unimpregnated carbon the undermining the adsorption capacity to other considerable odour substances that are not so effectively dealt with by the impregnant. `

Activated carbon filters alone are more commonly used for low H2S odour level environment or used as secondary polishing unit in sewage treatment works.

Notwithstanding the above, advantages of activated carbon filters alone are:

(a) very simple and easy to operate (except for the regeneration system), consistent and reliable performance operation, and the operation manning level required is relatively low;

(b) short retention time of foul gas in filters, small unit and moderate recurrent capital costs,

(c) easy to design as there are very few parameters needed to be determined; and

(d) media can be repeatedly regenerated on-site and reused (though in Hong Kong this has not been carried out due to site constraints).

Limitations of activated carbon filters are:-

(a) efficient adsorption mostly below 35oC and pre-coolers are thus required if the operation temperature is above this temperature;

(b) at relative humidity over 85%, the adsorption efficiency will decrease which requires installation of humidity control device, e.g. air pre-treatment (dehumidification) with heater; and

(c) pre-filtering system is required to prevent filters from being chocked up by dust.

The competition of H_2S and H_2O for adsorption sites is critical for the catalytic activated carbon as both molecules are similar in size and structure and humidity control is critical. Ordinary activated carbon which is relatively cheap works on pure adsorption and has less demand on humidity control but they usually do not last as long.

10.3.2 Absorption

Absorption involves bringing odorous gas into contact with a liquid absorbent so that one or more constituents of the odorous gas are removed, treated, or modified by the liquid absorbent.

Several types of absorbers are used, including spray towers, plate or tray towers, packed towers (most commonly used) and venturi scrubber. The selection of the best scrubber system involves consideration of the number of scrubbers to be used (whether a single unit can remove all odour substances), any odours associated with particulate or fatty mist so that pre-treatment of odour substances such as pre-filter or mist eliminator is required.

Suitable absorbents are water, caustics, potassium permanganate, chlorinated water, sodium hypochlorite and ozonated water. Pilot work is required to determine the odour removal efficiency for specific odour substances under specific conditions.

The absorption systems have the merit of relatively small foot print and the ability to handle variable loading. However the operating costs may be high as compared to biological methods. Suitable choice of the contact scheme and absorbents, analysis of composition and concentration of odorous gases, cost analysis and operation problems are key considerations in selecting a proper absorption system.

10.3.3 Biological Methods

The most commonly adopted forms of biological odour control by the DSD are the biotrickling filter and the bioscrubber which are described below. Removal efficiencies of 95 to 99% of hydrogen sulphide have been reported for both types of biological odour control methods. Biological methods present an economically attractive and more environmentally friendly means of control, providing effective treatment of odours with minimal operation and maintenance requirements.

The most important step in an air scrubber or filter is to create sufficient gas-liquid interface for the odorous gas to dissolve. To do this requires provision of large surface area thus large foot print. The oxidation of sulphur containing compounds in sewer usually takes place in one of the two pathways depending on the environment (pH and supply of dissolved oxygen) that favors the formation of special types of sulphur-oxidizing bacteria. When air supply is limited as in non forced ventilated system (bio-filters), the biological species formed usually favors a pH neutral environment and the end product is usually the formation of elemental sulphur. The oxidation of sulphide (acidic) to elemental sulphur represents an increase in alkalinity and no pH adjustment is required.

On the other hand, when forced ventilation is practiced (as in wet bio-scrubbers) where supply of dissolved oxygen is plentiful, the bacteria so formed is usually favored by an acidic environment with formation of sulphate as the end product , thus sulphuric acid. To prevent further pH drop, alkalinity replenishment is required and the optimum pH range for the acid -loving bacteria is usually around pH 4.

The use of any biological system for odour removal depends on the growth of bacteria which obtains energy by the oxidation of the odorous compounds. To support their growth, other nutrients (N and P) are required and become critical for system where the amount of biomass is of considerable size (as in wet scrubbers) and addition of nutrient is usually required.

(i) Biofilters

A biofilter comprises a biologically active media for the growth of micro-organisms. It requires an adequate supply of oxygen for aerobic conditions (which can be found in the foul air), sufficient moisture content and a supply of nutrients. A sprinkler system is required if the moisture content is too low. The gaseous stream will have a low BOD concentration which necessitates a high volumetric loading which in turn demands a high surface area. Thus, the land requirements of a biofilter can be substantial.

Filter media with a high surface area of both natural and synthetic nature have been used. The most common examples of natural filter media are peat, heather. Synthetic filter media, for example, shredded plastic, require inoculation with suitable micro-organisms.

The most important consideration in the design of a biofilter is to maintain an even distribution of the airstream throughout the filter bed. It is essential to avoid excessive increase in the pressure difference across the bed which would result in the formation of voids and channels in the media. Biofilters are able to cope with a variety of odorous compounds and good performance can be maintained with minimal attention. Biofilter is not well suited to treatment of very high concentration of sulphide or to the treatment of very large volumes of dilute odour. Biofilters will remove fairly low levels of hydrogen sulphide (< 50 ppm). Estimates of lifetime of the filter media ranges from 18 months to 5 years.

One advantage of biofilter is it is non-specific. A biofilter can remove different types of odour at the same time while biotrickling filter and bio-scrubber depends on the absorption process. The properties of the absorbent are adjusted for the target pollutants.

(ii) Bioscrubbers

The bioscrubbers works on a similar basis to biofilters. Therefore they have similar requirements for oxygen, moisture and nutrients. However, in contrary to the biofilters, the bioscrubbers use a microbial culture immobilised on man-made packing with a downward flow of liquid, for example, water or sewage effluent. The packing is usually of a plastic material similar to that used in a chemical scrubber. It is necessary to add a microbial culture of sufficient diversity to oxidise the odorous compounds. The odorous gas to be treated is passed upwards through the packing and the micro-organisms with the biofilm, and within the liquid itself, absorb and oxidise the odorous compounds. A proportion of the liquid flow must be wasted in order to remove the oxidation products away. The capital costs of bio-scrubbers are higher than biofilters due to the standard of technical control required. Land requirements of a bioscrubber are much lower than those of a biofilter.

Bioscrubbers are particularly suitable for the treatment of odorous gas with high levels of sulphide (between 100 to 500 ppm).

Design of such system must be based on trial plant studies. The actions of the micro-organisms on the odourants are slow compared with other odour control methods such as adsorption and absorption, thus a longer retention time is required.

10.4 NOISE CONTROL

10.4.1 Legislation in noise

During the design of a pumping station or sewage treatment work, the following legislation concerning about noise generation should be observed:

(a) Noise Control Ordinance (Chapter 400) and associated EIAO Technical Memorandum, and

(b) the Factories and Industrial Undertakings Ordinance (Chapter 59), and their subsidiary legislation.

According to the Factories and Industrial Undertakings (Noise at Work) Regulations (Chapter 59T) ear protection equipment is to be provided to the workers as appropriate.

10.4.2 Common Sources of Noise in Sewerage Works

Common sources of noise in sewerage works include the pump, motor, gearbox, internal combustion engine, generator, air compressor, and the ventilation system. Detailed design of noise control for these equipment items shall be carried out with reference to the recommendation of the equipment manufacturer and the acoustic control equipment manufacturers.

To reduce the noise level, the following measures should be considered:

(a) select a quieter machine;

(b) use of acoustic enclosure;

(c) use of vibration absorber to isolate the noisy machine or pipework from structure;

(d) use of acoustic absorber on the wall or solid walls for;

(e) siting the noisy equipment so that the transmission path of the noise is blocked or the equipment is far from the receiver;

(f) increase the wall thickness; and

(g) using acoustic louvers to stop noise emission from the fans.

Normally sound power level could be provided by the equipment manufacturer. By using the appropriate formula, the sound energy level at specific location from the source can be estimated based on the geometry of the building, location of the machines and position of the receiver.

Useful publication materials in noise control include:

(a) EPD, A practical guide for the reduction of industrial noise;

(b) Woods of Colchester Limited, Woods practical guide to noise control;

(c) Bruel & Kjaer, Acoustic noise measurements;

(d) EPD, Technical Memorandum for the Assessment of Noise from Places Other Than Domestic Premises, Public Places or Construction Sites;

(e) EPD, Technical Memorandum on Noise from Construction Work Other Than Percussive Piling;

(f) EPD, Good practices on Pumping System Noise Control; and

(g) EPD, Good practices on Ventilation System Noise Control.

11. FLOW MEASUREMENT AND VENTILATION

11.1 FLOW MEASUREMENT

The quantity of flow is an important parameter for both the design of sewerage facilities and the subsequent stage of operation. Unless there are special site constraints, flow measurement device should be provided. Considerations for the choice of device include the land uptake, the associated head loss, reliability, operational and maintenance aspects. Common types of flow measurement device are described below.

Electromagnetic flowmeter and flumes are the most common water flow measuring devices in DSD.

11.1.1 Electromagnetic Flowmeter

The operation of an electromagnetic flowmeter is based on electromagnetic induction. The voltage is directly proportional to the volumetric flow rate. Electromagnetic flowmeter is widely used in sewage pumping stations.

An advantage of electromagnetic flowmeter is their minimum exposure of system components to the actual liquid. The only exposed parts are the electrodes and the liner or unlined plastic tube. This minimizes corrosion and/or erosion from problem fluids and liquids containing appreciable suspended solids. Magnetic flow systems feature low power consumption.

Sufficient length of straight pipe run must be allowed upstream and downstream of the magnetic flowmeter for accurate measurement. Designers should follow the recommendations in the manufacturers' catalogues.

11.1.2 Open Channel and Partial Pipe Flow Measurement

Venturi flumes are commonly used for measuring rates of flow of water or sewage in open channels and partial pipe flow. Flumes and weirs are primary devices for measuring rates of flow of water or sewage in open channels. These devices operate on the principle that a rise in upstream liquid level will result which is a function of the rate of flow through a restricted section of a channel. Care should be taken to check whether the downstream section is submerged or not because the formula for calculating the rate of flow will be different.

The two most common types of venturi flumes are Parshall and Palmer-Bowlus flumes which are described below.

Parshall flume consists of a converging upstream section, a downward sloping throat and an upward sloping, diverging downstream section. The most popular material of construction are reinforced concrete cast in-situ and moulded fibreglass plastic (prefabricated liner) with concrete support walls.

Palmer Bowlus flume is available in one-piece construction or in field assembled panel design. It is small and portable. It is commonly used to measure sewage flows in sewers.

Of the various types of weirs, the 3 most commonly used are the V-notch, rectangular, and Cipolletti. V-notch weir is suitable for measuring flow which is changing slowly. The rectangular weir is capable of high capacity metering. It is simple and inexpensive to construct. The Cipolletti weir is similar to the rectangular weir except for sloping sides (1 horizontal to 4 vertical) of the notch. This design had the advantage of a simple discharge formula which is more convenient to work with than that for the rectangular weir. It has the disadvantage of complicated calibration procedures.

11.1.3 Doppler Transducer Flow Measurement

The Doppler transducer flow meters use sound pulse reflection principle to measure liquid flow rates. The transmitted and reflected signals are compared and the frequency shift is proportional to flow velocity. The sensor is mounted on the outside of the pipe.

11.1.4 Venturi and flow Tubes

The venturi meter system is commonly used for measuring rates of flow of water or sewage in open channels. It utilizes the basic engineering principle of the Bernoulli principle. Fluid passing through the reduced area of the venturi throat increases in velocity creating a pressure differential between the inlet and throat areas. The differential pressure across the throat of the venturi can be read directly or easily translated into actual flow by use of various types of differential pressure meters and capacity curves.

11.2 VENTILATION

11.2.1 General

Mechanical ventilation is a practical (and often a legal) requirement for:

(a) provision of a continuous supply of oxygen for breathing;

(b) removal of products of respiration and occupation;

(c) removal of artificial contaminants produced within the ventilated space by process work and cooking etc.; and

(d) heat dissipation.

Ventilation should be considered together with odour control in sewage pumping station and treatment plants. Noise could be a concern for rural areas.

11.2.2 Ventilation rates

Recommended ventilation rates are as follows:-

Air changes per hour	Typical situation
1-2	storage areas
4-6	offices and laboratories
6-8	lavatories and bathrooms
6-10	pump rooms, motor halls, dry wells, storerooms, workshops
8-12	pantries
15-30	generator rooms

For unmanned pump rooms, motor halls and dry wells, the ventilation rates should be selectable for reduction to 3 to 5 air changes per hour, e.g. a dual speed system.

This is a guide to the number of air changes generally recommended. If air inlets and outlets are properly located, the tabulated values will be sufficient for air movement, heat, pollution and moisture removal.

Air conditioning system is normally required for offices, control rooms and switchrooms.

11.2.3 Types of fans

The following fans are commonly used in the sewage pumping stations and sewage treatment works in DSD.

(a) Axial flow fans;

(b) Centrifugal or radial-flow fans;

(c) Propeller fans; and

(d) Mixed-flow fans.

Axial flow fans are widely used for both air intake and exhaust as it is suitable for installing in any position in run of ducting. Mixed flow fans are commonly used for roof extraction.

12. OPERATION AND MAINTENANCE ASPECTS

12.1 RISING MAINS

12.1.1 Spare Parts

Rising mains are usually made of steel or ductile iron pipes which are seldom used for gravity sewers and drains. It is necessary to keep sufficient spare parts for important unit and component so that any emergency repair can be carried out immediately.

The spare parts should be properly stored in a sheltered and secure place which can be readily accessible. Regular inspection is required to check the conditions of the spare parts. Whenever spare parts have been used, supply of replacement must be arranged as soon as possible.

12.1.2 Inspection

The air valves, isolating valves, access hatches and wash-outs installations should be inspected regularly and preferably not less than twice a year. The valves should be lubricated if required so that they are functioning properly. The outlet pipe of the wash-out should also be checked whether it would be blocked.

Inspection of the pipe itself can be at a much less frequency. If leakage is suspected, there are some proprietary products available that can identify the location of major leakage without excavation required. However, the use of these products may be affected by other underground installations, such as watermains, presented nearby. The sensitivity of the equipment may also be not adequate to detect minor leakage. These products have not been used in Hong Kong for rising mains and their application should be subject to further verification.

12.2 SEWAGE PUMPING STATIONS

12.2.1 Operation Activities

The operation of the pumping station should be controlled and monitored through the SCADA system (referred to Chapter 5) and regular inspection on the pumping station should be conducted. Depending on the criticality of the pumping station, inspection frequency should not be less than once per week. Regular inspection should cover the essential equipment in the pumping station, such as switchboard, pump and motor. Through regular inspection, abnormality of the equipment should be identified for remedial action to be taken before failure.

12.2.2 Data Collection

The following operation data should be gathered through the SCADA system or from inspection:

- equipment running hours
- energy consumption of the pumping station and individual equipment items which have power rating higher than 50kW
- accumulated flow and instantaneous flow rate
- running conditions of major equipment items (e.g. bearing temperature, vibration level, suction and delivery pressure of centrifugal pump for condition and efficiency monitoring)
- trash/grit amount
- odour performance monitoring figures of deodorizers, if applicable

12.2.3 Maintenance

Maintenance of the pumping equipment is of prime importance. To assure maximum reliability of operation and maximum efficiency in performance, the maintenance procedures outlined in the O&M manuals for each specific station should be performed as scheduled. The maintenance should be flexible and preferably condition-based. Adequate spare parts should be stocked for planned maintenance and urgent repair. Sufficient space, access and maintenance platform at high level should be provided for maintenance.

12.2.4 Contingency Plan

Contingency plan for each pumping station should be ready when the pumping station is commissioned. The contingency plan should cater for emergency scenarios such as power supply failure, total breakdown of pumps, bursting/major leakage of rising mains and flooding of pumping station etc.. The plan should be updated regularly to match the change in legislation and administration requirements. Drills on the critical activities, e.g. deployment of emergency genset should be performed regularly.

REFERENCES

Anderson, R. (1981). *Odour Problems and Solution*, Effluent and Water Treatment Journal, March, 1981.

BD (2004/1). *Code of Practice on Foundations*. Buildings Department, The Government of the Hong Kong Special Administrative Region.

BD (2004/2). *Code of Practice on Wind Effects in Hong Kong 2004.* Buildings Department, The Government of the Hong Kong Special Administrative Region.

BD (2011). *Code of Practice on Dead and Imposed Loads 2011*. Buildings Department, The Government of the Hong Kong Special Administrative Region.

BD (2013). *Code of Practice for Structural Use of Concrete 2013*. Buildings Department, The Government of the Hong Kong Special Administrative Region.

BSI (2002). *BS EN 1990 – Eurocode – Basic of Structural Design and its respective UK National Annex*. British Standards Institution, London.

BSI (2004). *BS EN 1992 – Eurocode 2 – Design of Concrete Structures – Part 1-1: General Rules and Rules for Buildings and its respective UK National Annex*. British Standards Institution, London.

BSI (2006). *BS EN 1992 – Eurocode 2 – Design of Concrete Structures – Part 3: Liquid Retaining and Containment Structures and its respective UK National Annex*. British Standards Institution, London.

DSD (2013). *Sewerage Manual Part 1 : Key Planning Issues and Gravity Collection System*. Drainage Services Department, The Government of the Hong Kong Special Administrative Region.

EIAO (1997). *Environmental Impact Assessment Ordinance*. Hong Kong Government.

GEO (1993). *Geoguide 1 - Guide to Retaining Wall Design.* Geotechnical Engineering Office, Hong Kong Government.

GEO (2006). *GEO Publication No. 1/2006 – Foundation Design and Construction.* Geotechnical Engineering Office, The Government of the Hong Kong Special Administrative Region.

Linsley, R.K. & Franzini, J.B., Inc. (1972). *Water-Resources Engineering* (Second Edition). McGraw-Hill, Inc., International Edition.

Linton P, edited by Enever, K J (1972). *Note on Pressure Surge Calculations by the Graphical Method, Pump stoppage after power failure*, BHRA Fluid Engineering, TN 447.

Masch.-Ing (grad.) Gerhard Nagel (1968). *Archimedian Screw Pump Handbook*, RITZ Pumpenfabrik OHG Schwabisch Gmund.

Metcalf & Eddy, Inc. (1981). *Wastewater Engineering: Collection and Pumping of Wastewater*. McGraw-Hill, Inc., International Edition.

Metcalf & Eddy, Inc. (1991). *Wastewater Engineering, Treatment, Disposal, Reuse*, third edition, McGraw Hill Book Company.

Palmer, R.D. *Beyond the Bend - Allen Gwynnes Sewage Pumps*. A.P.E. Engineering Nos. 19, 20 and 21.

Palmer,R.D. *A Wet Well or a Dry Well Arrangement for Pumping Stations*, A.P.E. Engineering No. 12.

Parmakian, J. (1963). *Waterhammer Analysis*, Dover Publications, Inc., New York.

Parthum C. A. and Leffel R. E.(1979). *Odour Control for Wastewater Facilities*, Manual of Practice No 22, Water Pollution Control Federation.

Peavy, H.S., Rowe, D.R. and Tchobanoglous, G (1986). *Environmental Engineering*, McGraw Hill Book Company.

Pomeroy (1977). *The problem of hydrogen sulphide in sewers*, Clay Pipe Development Associations Ltd.

Sawyer, C.N. and McCarty, P.L. (1978) *Chemistry for Environmental Engineering*, third edition, McGraw Hill Book Company.

Schroeder, E. D. (1977). *Water and Wastewater Treatment*, McGraw Hill Book Company.

Stern, A. C. (1968). *Air Pollution*, Volume III, second edition, Academic Press, Inc., 1968.

Summer, W. (1971). *Odour Pollution of Air, Cause and Control*, Leonard Hill Books.

Thorley, A.R.D. & Enever K. J. (1979). *Control and Suppression of Pressure Surges in Pipelines and Tunnels*, CIRIA, Report 84.

Turk, A. (1991). *Applications of Activated Carbon to Air Pollution Control*, Department of Chemistry, the City College of City University of New York, New York, NY 10031, 1991.

Turk A., Sakalis, E., Lessuck, Karamitsos, H. and Rage, O. (1989). *Ammonia Injection Enhances Capacity of Activated Carbon for Hydrogen Sulfide and Methyl Mercaptan*, Environ Sci and Tech, 23.

Turk, A., Sakalis, E., Rage, O. and Karamitsos (1991), *Activated Carbon Systems for Removal of Light Gases*, Annals N Y Academy of Sciences.

Water Research Centre (1989). *Odour Nuisance in Wastewater Treatment, Cause and Control*, Report No UM 1025, Water Research Centre.

WSD (2004). *Civil Engineering Design Manual*. Water Supplies Department, Hong Kong Government.

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Table 1 : Land Requirement for Pumping Station with Centrifugal Pumps

Wet Well/Dry Well Arrangement

Pumping Capacity (m^3/s)	Area (m^2)
Not exceeding 0.15	400
0.15 - 0.35	400 - 900
0.35 - 1.00	900 - 1400
1.00 - 4.50	1400 - 2500
4.50 - 7.50	2500 - 4000

Wet Well Arrangement

Pumping Capacity (m^3/s)	Area (m^2)
Not exceeding 0.15	300
0.15 - 0.35	300 - 800
0.35 - 1.00	800 - 1200

Table 2 : Typical Strength of Hydrogen Sulphide and Recommended Air Volume Changes at Various Locations of a Sewage Treatment Works

Location	Typical H_2S Emission Level in ppm	Recommended Air-change Per Hour [note 1]
Pump Stations	0-50	5-10
Lift Stations	0-50	5-10
Screening Chambers	50-500	15-30
Grit Chambers	50-500	15-30
Primary Sedimentation Tanks	50-500	15-30
Final Sedimentation Tanks	0-10	1-5
Sludge Holding Tanks	100-1000	5-10
Sludge Thickeners	100-1000	5-10
Sludge Conveying Systems	0-10	Hood design
Sludge Dewatering Areas	0-50	5-10
Control/Switchgear Rooms	0-5	4-6

Note 1 : The recommended air change per hour is given by a U.K. principal, as in the local condition where it has a much higher summer temperature, the applicable rate should preferably be 1.5 or 2 times the recommended figure.

Table 3 : Recommended Design Parameters for Concrete and Steel Reinforcement

Parameter	**Recommended Value**
Concrete	
Compressive strength	Design equations based on cylinder strength (f_{ck}), with its equivalent cube strength ($f_{ck,cube}$) given in Table 3.1 of BSI (2004) or its latest version
Exposure condition	Sewage Pumping Station - XC3 (superstructure) - XA (substructure) *(N.B. XC4 if suitable protective measures provided to concrete surface)* Manhole (other than standard manholes in DSD standard drawings) - XA - XC4 (with suitable protective measures provided to concrete surface) Tunnel XA (with suitable protective measures provided to concrete surface)
Concrete grade	$f_{ck,cube}$ = 40 MPa (XC3 / XC4) $f_{ck,cube}$ = 45 MPa (XA)
Concrete cover	Sewage pumping station XC3 / XC4 : 35 mm XA : 50 mm Manhole (other than standard manholes in DSD standard drawings) XC4 : 35 mm XA: 50 mm Tunnel XA: 50 mm
Design crack width	Section 7.3 of BSI (2006) or its latest version Tightness Class 1 : manhole, chamber and pumping station Tightness Class 0 : superstructure of pumping station Tunnel : 0.25 mm (maximum permissible crack width)
Stress-strain curve	Figure 3.8 of BD (2013) or its latest version

Parameter	Recommended Value
Modulus of elasticity	Table 3.2 of BD (2013) or its latest version
Coefficient of thermal expansion	Section 3.1.9 of BD (2013) or its latest version
Drying shrinkage	Section 3.1.8 of BD (2013) or its latest version
Creep	Section 3.1.7 of BD (2013) or its latest version
Steel Reinforcement	
Yield strength	500 MPa
Modulus of elasticity	200 GPa

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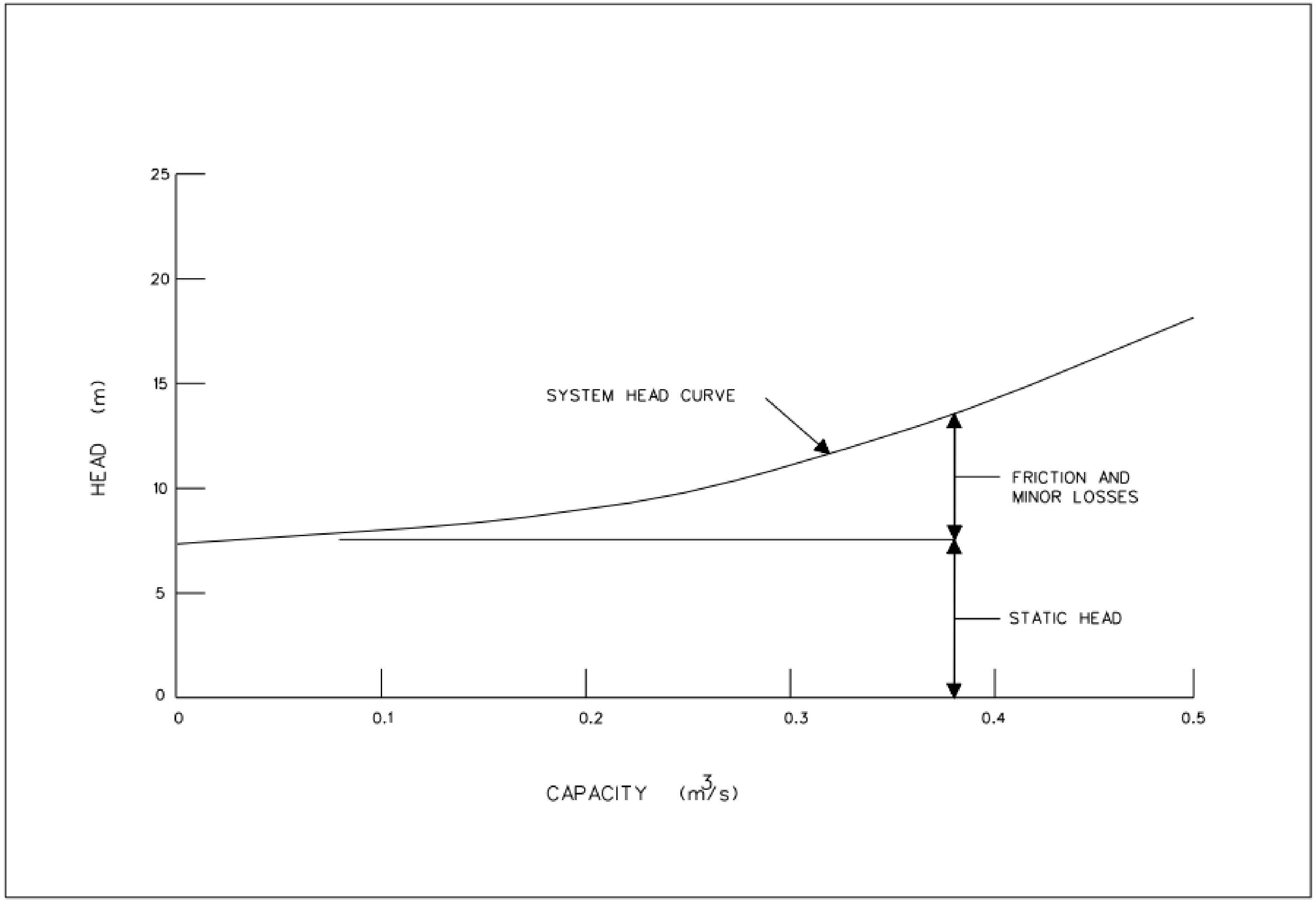


Figure 1 Typical System Head Curve

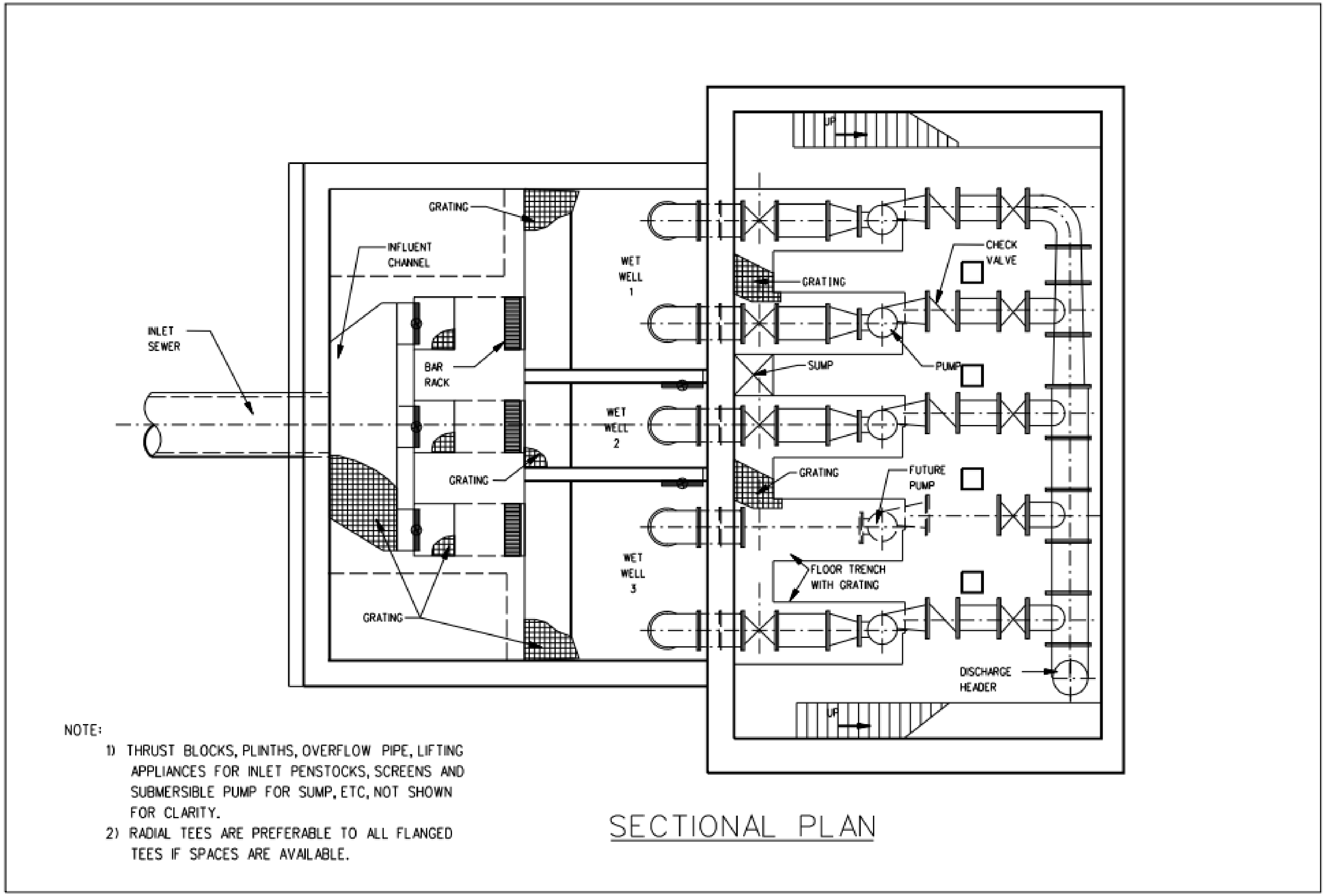


Figure 2a. Typical Arrangement of Large Conventional Dry Well/Wet Well Sewage Pumping Station

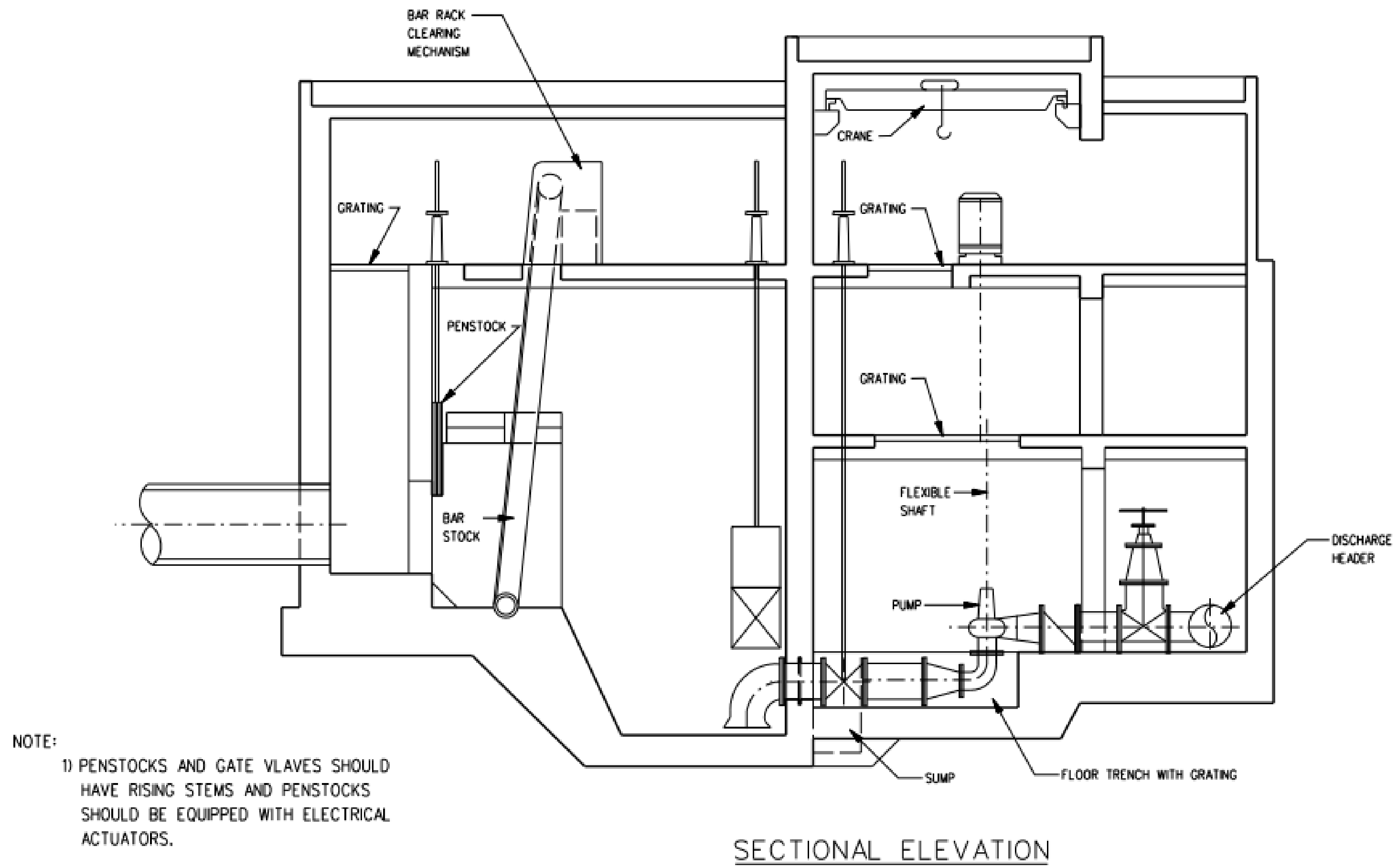


Figure 2b. Typical Arrangement of Large Conventional Dry Well/Wet Well Sewage Pumping Station

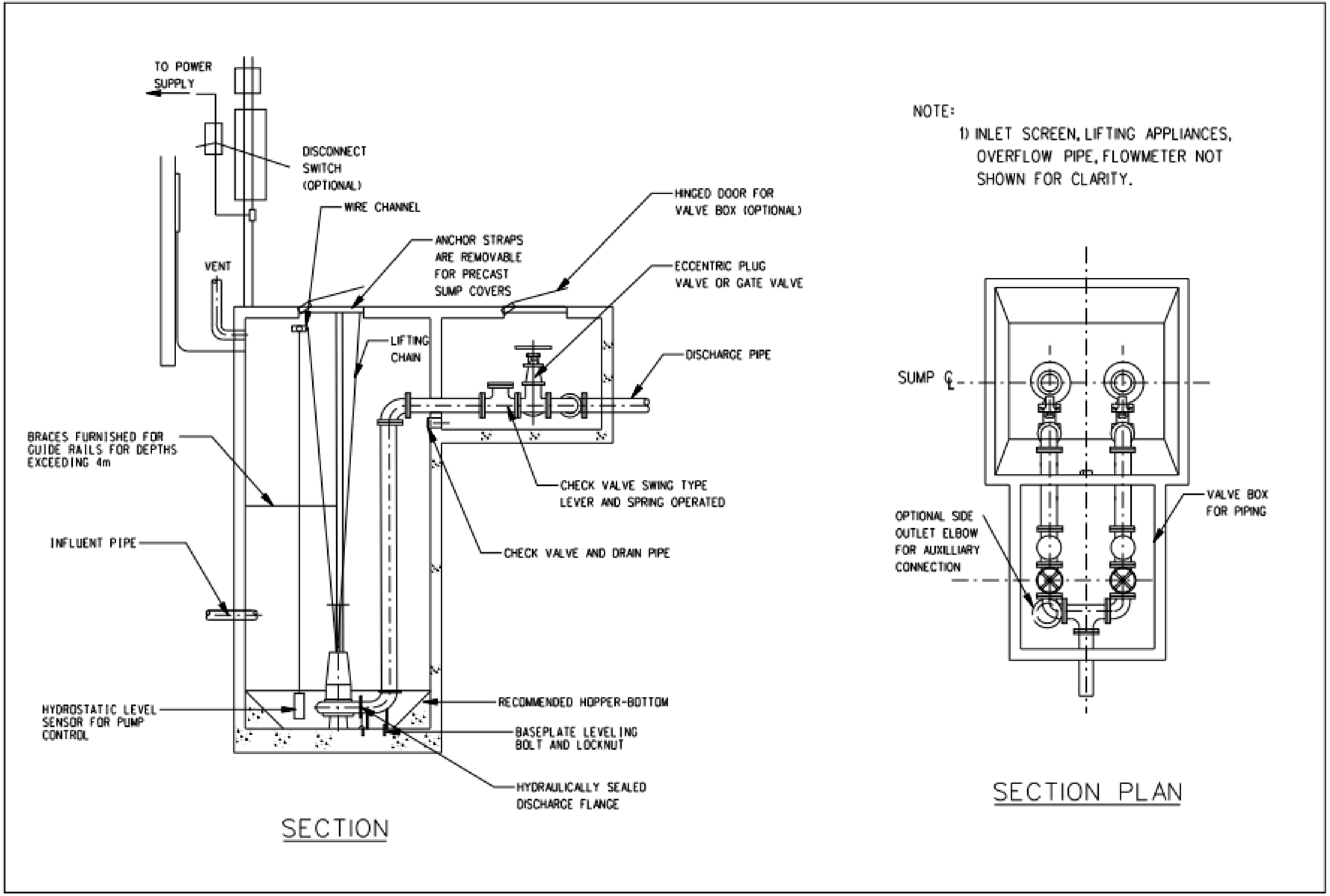


Figure 3. Typical Arrangement of Submersible Pumping Station

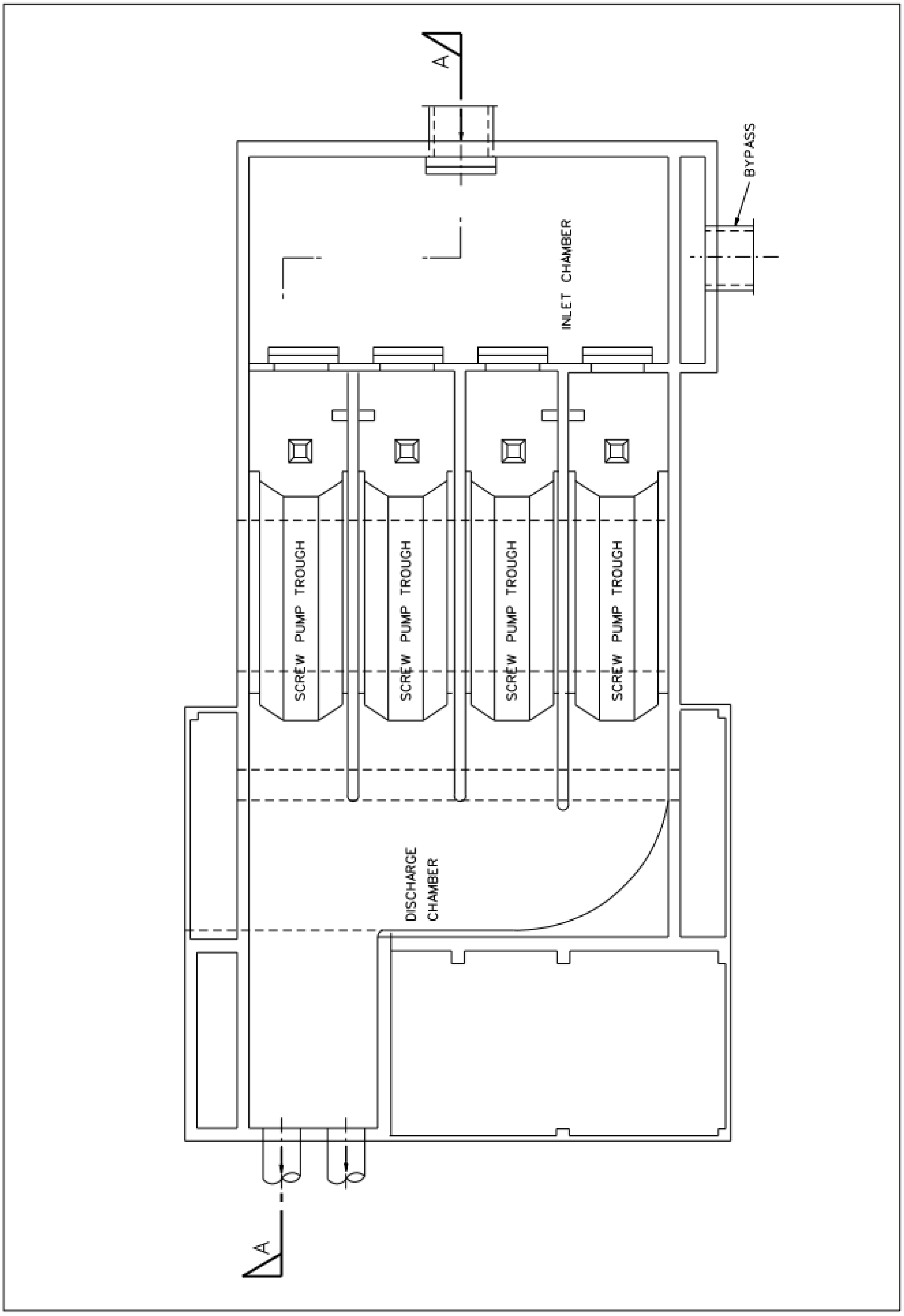


Figure 4a. Typical Arrangement of Screw Pumping Station (Civil Works Layout)

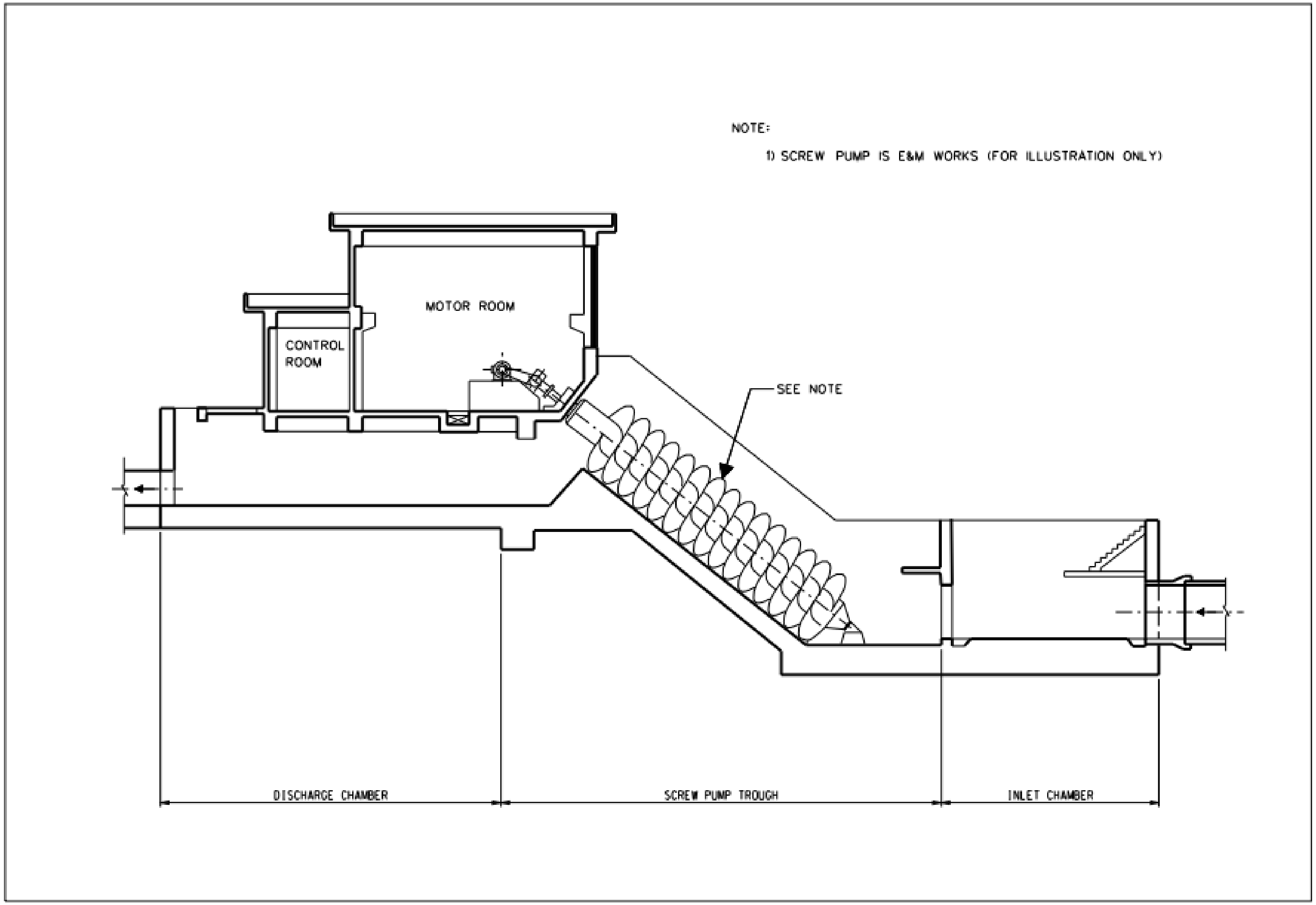
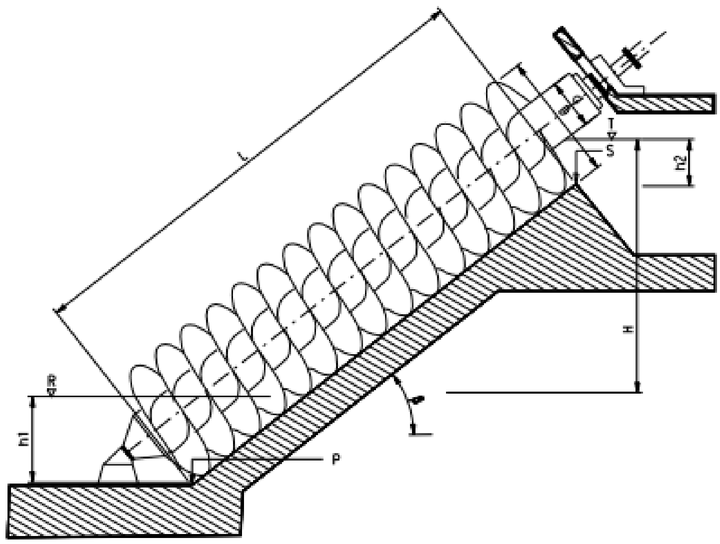


Figure 4b. Section A-A of Screw Pumping Station (Civil Works Layout)



Q : Capacity
β : Angle of Inclination
D : Screw Diameter
d : Shaft Diameter
H : Static Lift
L : Length of Screw
P : Touch Point
R : Filling Point Level
S : Chute Point
T : Max. Pumping Level
h1 : Depth % Filling Point Level and Suction Point Level
h2 : Depth % Max. Pumping Level and Discharge Point Level

Figure 5. Typical Characteristics of Screw Pump

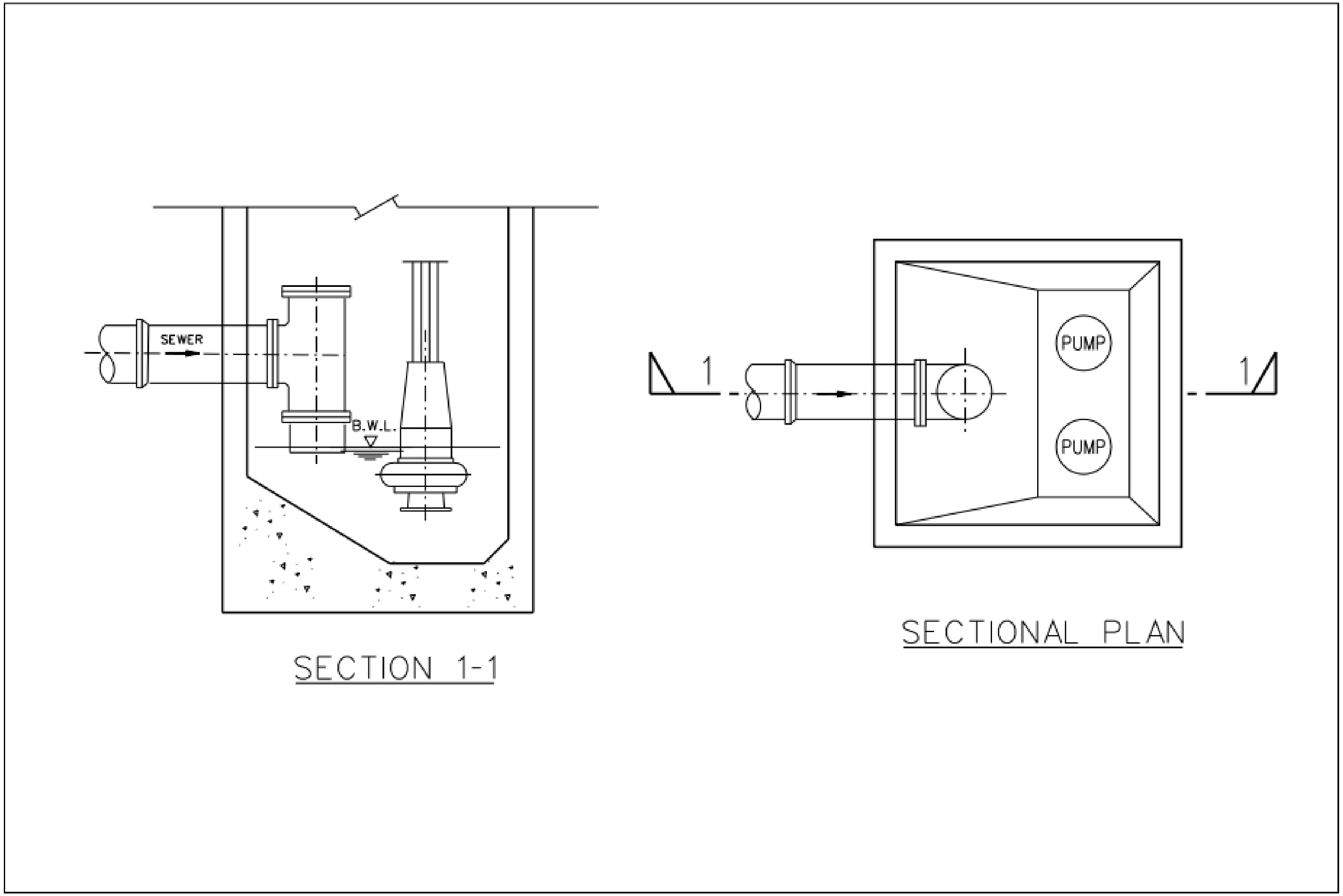


Figure 6. Typical Arrangement of Drop Tube in Small Station

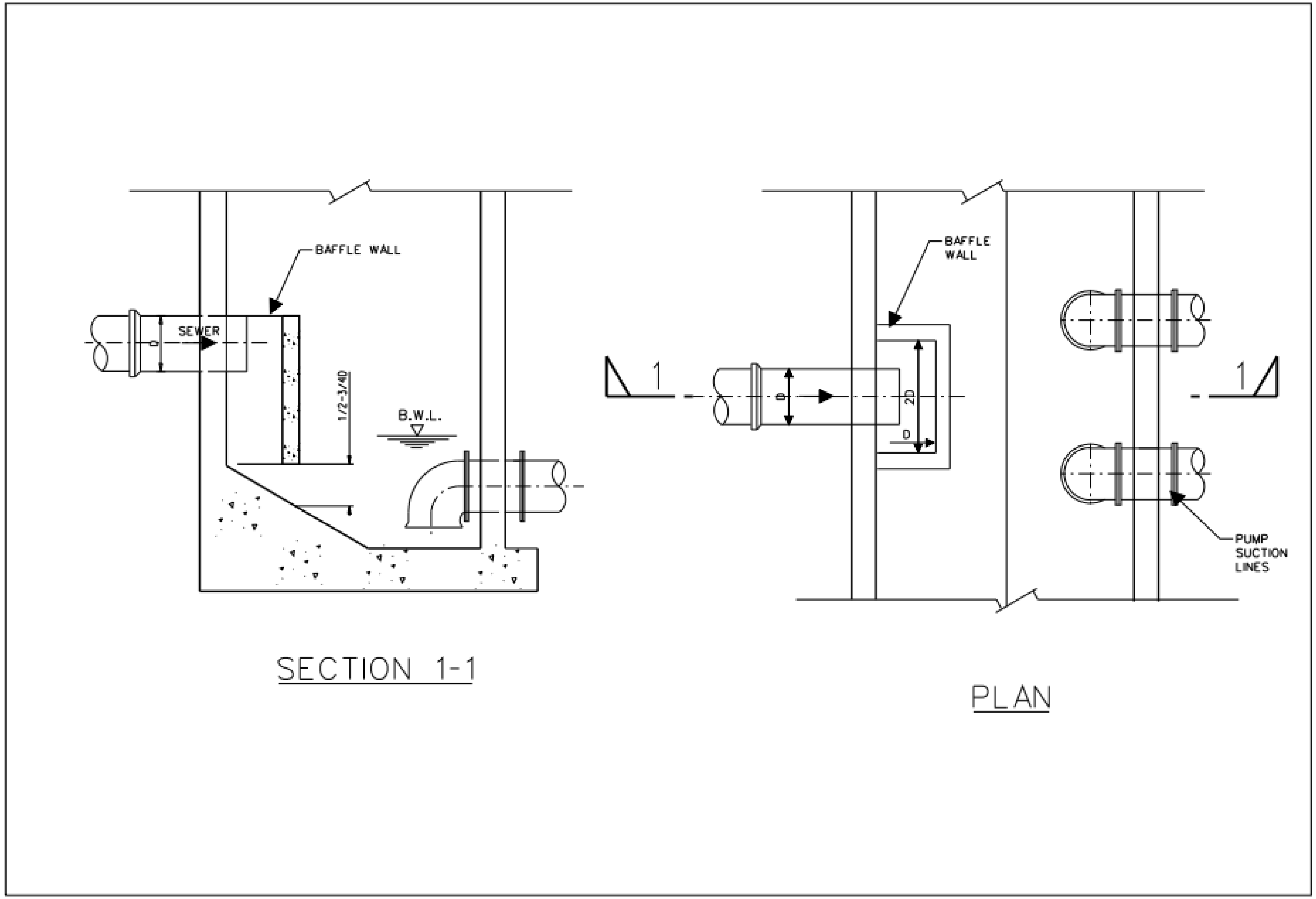


Figure 7. Typical Arrangement of Baffle Wall in Large Station

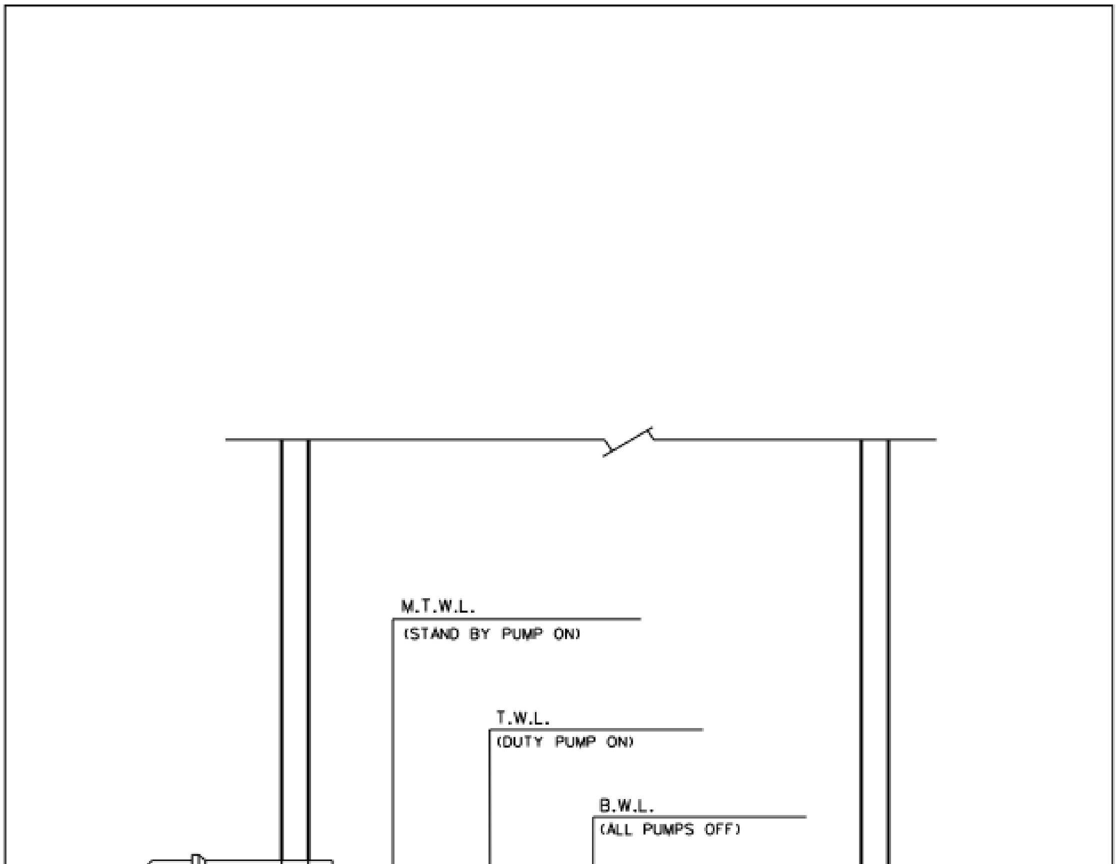


Figure 8. Simple Switching Arrangement in Small Station

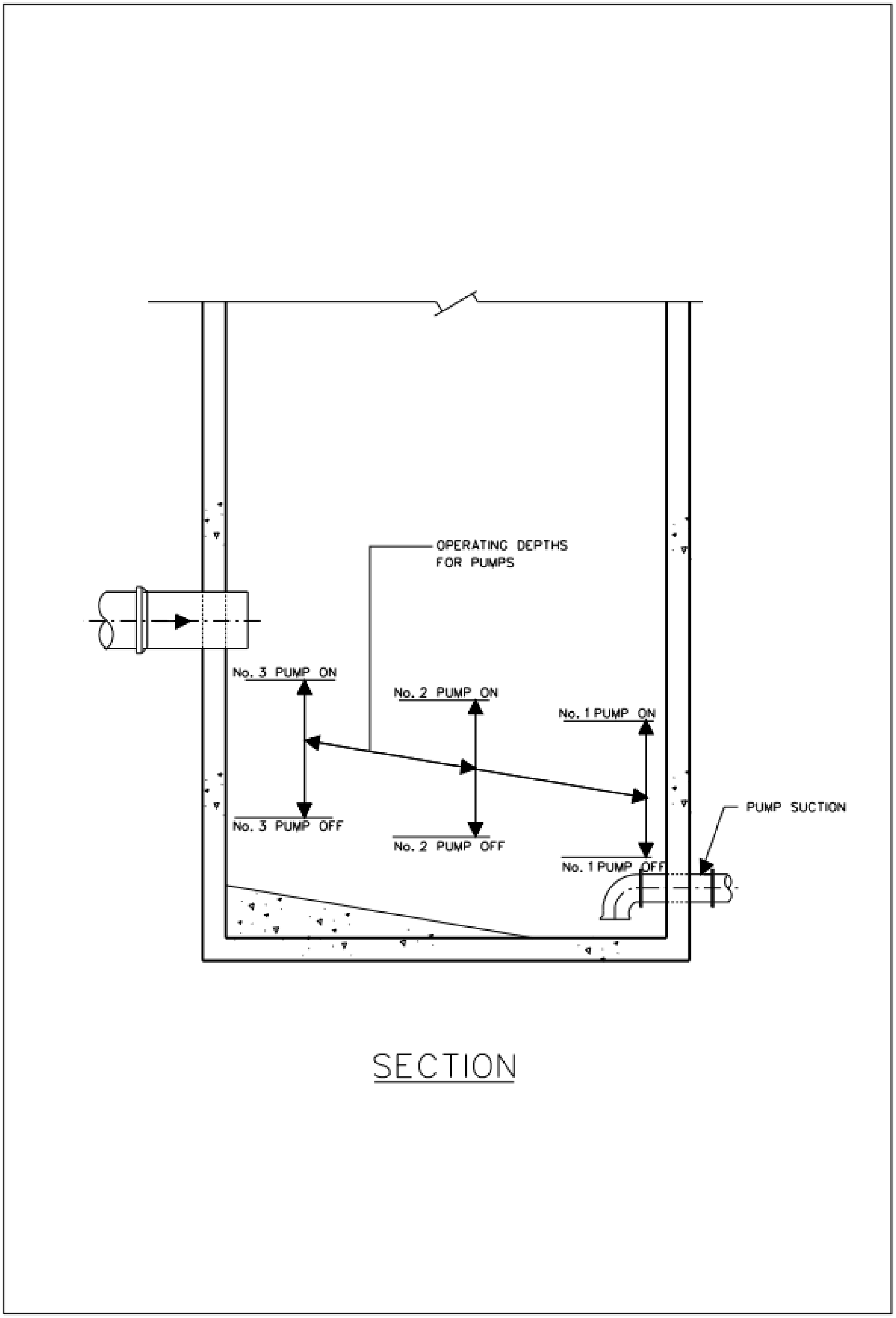


Figure 9. Staged Switching Arrangement in Large Station

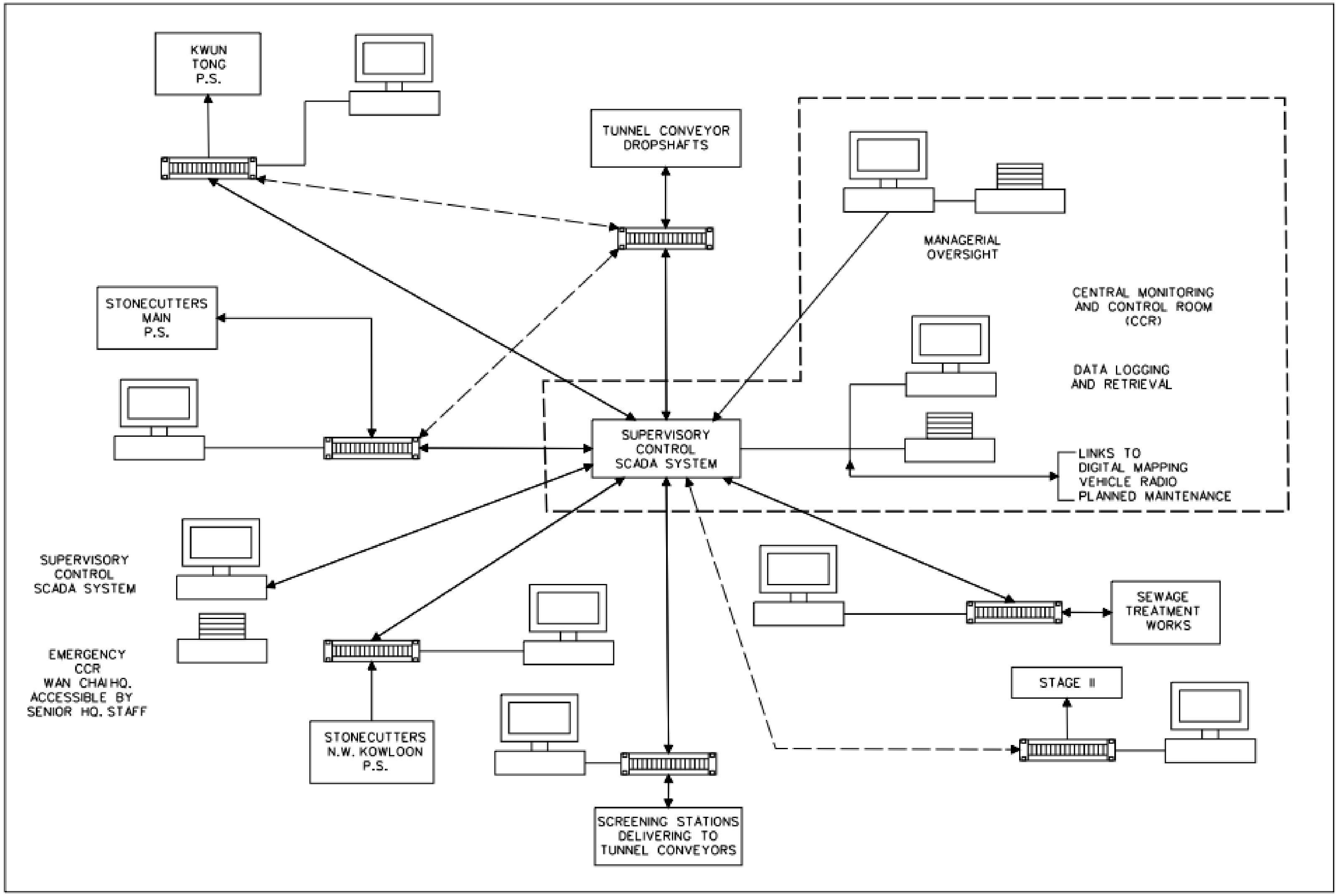


Figure 10. Typical Schematic of Monitoring and Control System

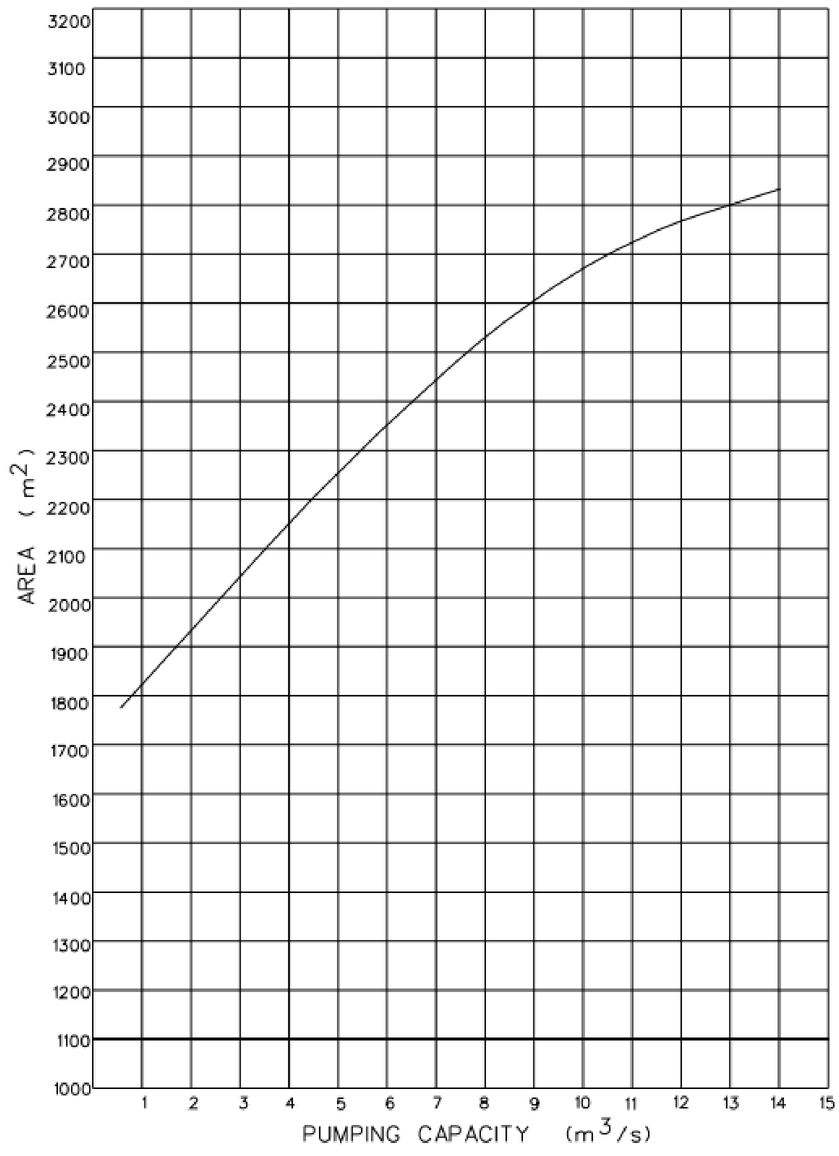
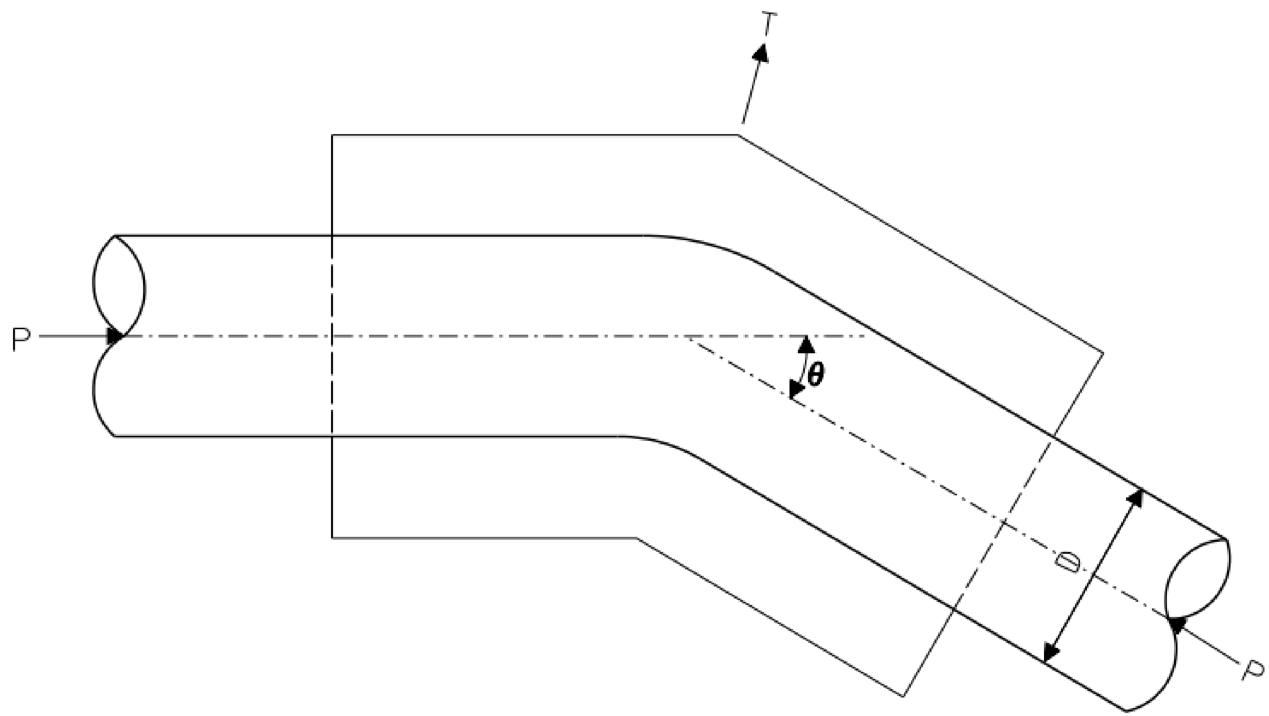


Figure 11. Area Requirements for Screw Pumping Station



T = 2P($\pi\theta^2$/4) SIN(θ/2)

T = THRUST (kN)

P = INTERNAL PRESSURE (kN/mm^2)

D = INTERNAL DIAMETER OF PIPE (mm)

θ = BEND ANGLE

Figure 12. Thrust Block For Horizontal Pipe Bend