Part 1

SEWERAGE MANUAL

(with Eurocodes incorporated)

contents related to Eurocodes highlighted in green

Key Planning Issues and Gravity Collection System

Third Edition, May 2013

DRAINAGE SERVICES DEPARTMENT

Government of the Hong Kong
Special Administrative Region

CONTENTS

1. INTRODUCTION

1.1 SCOPE

Part 1 of this Manual offers guidance on the planning, design, construction, operation and maintenance of public gravity sewerage systems in Hong Kong. For guidance on sewage pumping stations & rising mains, please refer to Part 2 of this Manual. DSD has also promulgated Practice Note No. 1/2011 "Design Checklists on Operation & Maintenance Requirements" and Practice Note No. 3/2010 "Design Consideration for Large Deep Gravity Sewers" which can be reached on DSD's internet home page : www.dsd.gov.hk. Readers are requested to go through the Practice Notes, or their latest versions, when designing sewers 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 1:

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
CEDD	Civil Engineering and Development Department
CIRIA	Construction Industry Research and Information Association
DSD	Drainage Services Department
DWF	Dry Weather Flow
DWFI	Dry Weather Flow Interceptor
E&M	Electrical & Mechanical
EMSD	Electrical and Mechanical Services Department
EC	Eurocodes (i.e. European Standards EN1990 to EN1999)
EN	European Standard
EPD	Environmental Protection Department
EIAO	Environmental Impact Assessment Ordinance
FRP	Fibreglass Reinforced Plastic
GEO	Geotechnical Engineering Office
GRP	Glass Reinforced Plastic
HATS	Harbour Area Treatment Scheme
HDPE	High Density Polyethylene
HyD	Highways Department
ISO	International Organisation for Standardisation
IWA	International Water Association
MDPE	Medium Density Polyethylene
NCO	Noise Control Ordinance

SCA	Sewerage Catchment Area
SMP	Sewerage Master Plan
SMPR	Sewerage Master Plan Review
SSDS	Strategic Sewage Disposal Scheme subsequently renamed as HATS
SSS	Sewage Strategy Study
STW	Sewage Treatment Works
UK NA	United Kingdom National Annexes to Eurocodes
uPVC	Unplasticized Polyvinyl Chloride
WCZ	Water Control Zones
WPCO	Water Pollution Control Ordinance
WPCR	Water Pollution Control Regulation
WSD	Water Supplies Department

1.3 DESIGN STANDARDS

1.3.1 Planning, Investigation and Materials of Sewerage System

The following design standards, or their latest versions, are to be adopted, except otherwise stated in this Part 1:

Design Elements	Design Standards
Planning and investigation of drainage and sewerage system	BS EN 752
Self cleansing velocity of sewer	BS EN 752
Head loss coefficient K	BS EN 752
Plain/reinforced concrete pipe	BS 5911-1
Prestressed concrete pipe	BS 5911-5 and BS EN 639 & 642
Vitrified clay pipe	BS 65 and BS EN 295
Mild steel pipe	BS EN 10224, 10311, 10220, 10216-1 & 10217-1
Ductile iron pipe	BS EN 598
Cast iron pipe	BS 437, 416-1, 1211, 4622
Stainless steel pipe	BS EN 6362, 10217-7 & 10312
GRP pipe	BS EN 14364
uPVC pipe	BS 3506 and BS EN 1401-1, 1452-1 to 5, 13598-1
MDPE/HSPE pipe	BS EN 12201-1, 2 & 5

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 this Part 1, or sewage pumping stations in Part 2). 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)	- 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 15.

1.4 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 sewer is not only a pipe 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 pipe, the use of inverted siphon, envisaged development phasing and the alignment of the sewer are common factors that have an impact on energy requirement for conveying sewage.

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

1. 5 HARBOURFRONT ENHANCEMENT REQUIREMENTS

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 requirement 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. SEWERAGE IN HONG KONG

2.1 THE HONG KONG SITUATION

Drainage and sewerage have always been part of the essential infrastructure of a modern city. In Hong Kong, separate systems are provided for the collection and disposal of stormwater and sewage.

Currently over 93% of the sewage produced from residential, commercial and industrial premises in Hong Kong is being collected and properly treated in various treatment works prior to disposal to sea for dilution and dispersion through outfalls. Latest technologies on trenchless pipelaying, septicity control and odour control are adopted in some sewerage works in order to improve the quality of service.

In Hong Kong, sewers have been installed incrementally over the past decades as development has progressed.

In 1971, a consultancy was commissioned "to investigate the state of the waters of Hong Kong and to recommend a programme of improvement works". The recommendations of this study have since formed the blue print for the sewage treatment and disposal strategy which is to fully utilize the natural assimilative capacity of the sea. In the past, this strategy together with ad hoc additions to the sewerage system had been successful in mitigating serious deterioration of most of Hong Kong's waters.

However, in the 1980's, it was recognised that these sewerage arrangements were not adequate to contain the increasing threat of pollution. The White Paper "Pollution in Hong Kong - A Time to Act" of 1989 assessed the adequacy of current programmes and outlined a comprehensive plan to tackle pollution. Moreover, in the Chief Executive's 1999 Policy Address: Quality People, Quality Home – Positioning Hong Kong for the 21st Century, the policy of sustainable development and the need to provide adequate sewerage facilities for further planning scenarios formed a key element. Assessment of sewerage infrastructure needs in order to cater for housing demands and new developments was carried out under the Sewerage Master Plans plus their associated reviews. This was complemented by the control of wastewater discharges through the Water Pollution Control Ordinance and Environmental Impact Assessment Ordinance. A new sewage strategy has then been formulated and the following actions are now in hand to reduce the water pollution problem:-

(a) Continued implementation of "existing schemes" which have been in the public works programme and which are compatible with other proposed new measures to satisfy new water quality standards. Examples are new and improved sewage treatment and disposal facilities in the North West Kowloon, Tsuen Wan/Kwai Chung and the North West New Territories.

(b) In order to identify specific sewerage problems in various districts of Hong Kong and to propose improvements to the sewerage system, a series of "Sewerage Master Plans" (SMP) and Sewerage Master Plan Reviews (SMPR) have been or are being prepared. As resources permit, the recommendations of SMP and SMPR will be implemented in a prioritised manner which will greatly improve the effectiveness of the sewerage system.

(c) To improve the arrangements for sewage disposal, a "Strategic Sewage Disposal Scheme (SSDS)" which was subsequently renamed as Harbour Area Treatment Scheme [HATS] combining elements of land based sewage treatment with the natural self-purification capacity of the ocean has been endorsed. It consists of a deep tunnel system to collect all sewage in the most densely populated urban areas on both sides of the Victoria Harbour. With the completion of HATS Stage 1 in 2001, over 1.4 million cubic metres of sewage is receiving Chemically Enhanced Primary Treatment every day at Stonecutters Island Sewage Treatment Works. Preliminarily treated effluent now only accounts for less than 30% of the total volume of sewage treated every year. Various sewage treatment upgrading works including HATS Stage 2 are under design or construction to further treat the preliminary effluent.

(d) To improve the environment and sanitary conditions of village areas and the water quality of nearby streams and waters, DSD is gradually implementing village sewerage programmes to provide proper public sewerage networks for collection and conveyance of sewage from unsewered village areas in the New Territories for centralized treatment and disposal at suitable locations without detriment to the environment or public health.

3. GENERAL PLANNING AND INVESTIGATION

3.1 INTRODUCTION

A sewerage system should be designed to collect all wastewater generated within a catchment area and to convey it to a sewage treatment works for treatment prior to discharge into the receiving watercourse or the sea via the outfall facilities. General information on the planning and investigation required for sewerage is given in BS EN 752: 2008. This Chapter gives further guidance on this subject.

3.2 INFORMATION FOR SYSTEM PLANNING

3.2.1 Previous Studies

In planning a sewerage system, the following documents should be referred to ensure compatibility with the overall strategic plan and master plans:

(a) the Sewage Strategy Study (SSS) for Hong Kong and the Strategic Sewage Disposal Scheme (SSDS) now renamed as Habour Area Treatment Scheme (HATS);

(b) the appropriate Sewerage Master Plan (SMP) Study and Sewerage Master Plan Review (SMPR) Study.

The SSS was endorsed by the Government in 1989. It set out water quality objectives to protect the coastal waters of Hong Kong, and developed a long term strategy for sewage collection, treatment and disposal to meet these objectives.

The study recommended the construction of a central urban area sewerage network known as the Habour Area Treatment Scheme (HATS). The HATS consists of a deep tunnel system to collect all sewage in the urban area and to convey it to the Stonecutters Island Sewage Treatment Works (SCISTW) for treatment.

A typical SMP Study consists of the following :

(a) an investigation of the existing condition of the sewerage system;

(b) an assessment of flow and pollution loads within the sewerage system under existing and future/ultimate development conditions;

(c) an analysis of the hydraulic capacity of sewerage system - generally on computerized models;

(d) the recommendation of measures to mitigate pollution problems or shortfalls in the existing sewerage system;

(e) recommendation for the provision or upgrading of sewage treatment works and sewerage systems;

(f) the preparation of the cost estimate for carrying out the recommendations in (d) and (e), and the recommendation of an implementation programme.

Depending on the scope of work in hand and the information available from the SSS, SMPs and SMPRs, collection of further data may be necessary, including :

(a) location, level and size of existing sewers;

(b) details (including as-built records and operation data) of any existing sewage handling installations such as pumping stations, sewage treatment works, dry weather flow interceptors and outfalls;

(c) data on sewage flows including infiltration and/or leakage;

(d) any other relevant information such as utility plans and traffic studies.

3.2.2 Planning of Sewerage Catchment Areas

The designer should relate the design work to the sewerage catchment areas (SCA) defined in the appropriate SMP, making adjustments to the SCA, if necessary. Once the SCA is finalized, the designer may need to estimate the flow and pollution loads for the following:

(a) existing development conditions (estimate should be compared with existing data);

(b) interim development conditions, if any;

(c) ultimate development conditions.

Further guidance on the estimation of the flows and loads is given in Chapter 4 of this Manual.

A preliminary hydraulic check should then be carried out to assess if the existing sewerage system is adequate under the various development conditions, and if necessary to come up with a preliminary improvement or extension proposal. At this stage, consideration should also be given to see if redefinition of the SCA can better meet the objectives. The preliminary proposal shall then be used as a framework for detailed design.

3.2.3 Maps, Town Plans and Drainage Records

Government regularly publishes maps and town plans from which information can be extracted on land use and the topography of catchment areas. For large scale works, aerial photographs may provide an additional source of reference. Reference should also be made to

Drainage Services Department's drainage records for information on the existing sewerage system.

3.2.4 Location of Utilities

(a) General

Utility companies and the appropriate Government authorities should be consulted regarding the effect of the project on their existing and proposed services and regarding any facilities required for the project. Please refer to Section 2.5.2 of Chapter 4 of the Project Administration Handbook for Civil Engineering Works for circulation to utility companies.

The installation of utility services by utility companies on Government land is in general governed by block licences, permits etc. Under the block licences, Government can order the utility companies to carry out any diversion works without any charge. The diversion or resiting of tram tracks and the associated posts and cables is an exception to this general rule.

(b) Existing Utility Services

The procedure for obtaining approval for the removal or diversion of existing services belonging to utility companies can be lengthy and may require the sanction of the Chief Executive-in-Council. Engineers should therefore apply for such approval at the earliest possible stage. Relevant Ordinances, block licences and permits should be referred to if necessary.

3.3 IMPLEMENTATION PROGRAMMES

For a scheme with large catchments and where the design horizon extends over 10 years, consideration should be given to implement the project in phases so as to avoid (i) a prolonged period of low flows after commissioning and (ii) an under-utilized facility should the programme of development or the expected build-up of flows fail to materialise. This would also help to optimise the utilization of resources for competing projects.

It is important to draw up an implementation programme so as to ensure the timely provision of sewerage, sewage treatment and disposal facilities to match new town development and environmental improvement programmes. The programme shall include key activities, contract packages, important milestone dates, phasing of works and cost estimates. In the formulation of the implementation programmes, reference should be made to the design life of the sewerage, sewage treatment and disposal facilities.

Projection of flow over time must be carefully studied during the planning stage. Consideration should also be given for staged increase in the capacity of E&M equipment for each phase as idling of E&M equipment would involve additional costs for routine servicing, checking and maintenance.

3.4 DESIGN LIFE

For the design life of sewage installations, reference should be made to the recommendations of the Study of Asset Inventory, Montgomery Watson (1994), details of which are summarised in Table 1.

3.5 LAND

In order to minimise land resumption, sewerage, sewage treatment and disposal facilities should be located on Government Land as far as possible. For sewerage works necessitating the resumption and creation of rights on private lands, please refer to Section 4.16 of Chapter 3 of the Project Administration Handbook for Civil Engineering Works for detailed procedures. In undeveloped areas, all sewers, rising mains and associated chambers should be located either in road reserves or specially designated drainage reserves, which should be non-building areas. Such reserves are essential in order to ensure that there is free and unrestricted access at all times for construction, repair, operation and maintenance.

Drainage reserves should be included on the various statutory and town plans. The width of a reserve should be determined from the requirements for working space, vehicular access for construction plant, depth of the sewer and clearance from adjacent structures and foundations. In general, it is recommended that the width of a drainage reserve should be 3 m from both sides of the pipeline or box culverts Should the size of the pipeline or box culvert is equal or smaller than 600mm diameter/wide, consideration might be given to reducing the overall drainage reserve width requirements provided that adequate working space can be provided for future maintenance or replacement.

The land required for a sewage pumping station or a sewage treatment plant is highly variable. It depends on many factors including the designed capacity, the site configuration, the level of treatment, the type of treatment process, the standby capacity, and the type and nature of the ancillary facilities required. Sites for sewage pumping stations and sewage treatment works should be included on the various statutory or town plans. For the preliminary estimation of land requirements for pumping stations, please refer to Part 2 of this Manual.

3.6 ENVIRONMENTAL CONSIDERATIONS

3.6.1 Environmental Standard and Legislative Control

The Environmental Chapter of the 'Hong Kong Planning Standards and Guidelines' provides guidance to planners, engineers and architects on air quality, water quality, waste management, noise, rural environment and urban landscape.

The control of water quality in Hong Kong is governed by the Water Pollution Control Ordinance (WPCO) which was enacted in 1980. The WPCO enables the Government to establish Water Control Zones (WCZ) within which the discharge of pollutants is controlled. All sewerage works shall comply with the requirements under Water Pollution Control (Sewerage) Regulation.

Other legislative control of environment standards is stipulated in the Air Pollution Control Ordinance, Noise Control Ordinance, Environmental Impact Assessment Ordinance and the relevant Technical Memoranda.

3.6.2 Environmental Assessment

In planning, design and construction of sewerage projects, considerations should be given to the impacts on air, noise and water pollution and appropriate mitigation measures should be devised. Furthermore, for sewerage projects that are classified as Designated Projects under the Environmental Impact Assessment Ordinance, an Environmental Permit shall be obtained from the Director of Environmental Protection for their construction and operation.

3.6.3 Mitigation Measures

Mitigation measures, which include alternatives to a proposed project or action, are important in the environmental assessment process.

(1) *Noise*. A number of options that can reduce noise levels are:-

(i) provision of acoustic screens or enclosures;

(ii) acoustic shielding of plant to reduce noise at source;

(iii) use of silenced plant;

(iv) schedule works to reduce number and usage time of noisy plant; and

(v) physical separation of the source and the receiver.

(2) *Air Quality*. To improve the air quality near construction sites, watering of exposed surfaces can reduce dust problems. Common control methods employed for controlling dust from unpaved site roads include watering and speed control of vehicles.

For sewage treatment works and pumping stations, the odour nuisance is a major factor. Consideration should be given to covering odour sources and providing deodorization units.

(3) *Water Quality*. To minimise the impact to receiving water quality during construction, it is recommended that surface runoff from construction sites should be discharged into stormwater drain via suitable sediment removal facilities. Good practice for dealing with other types of discharges from construction sites is provided in the “Practice Note for Professional Persons on Construction Site Drainage” published by EPD.

(4) *Visual and Landscape Impact*. Generally, mitigation measures include:

(i) screen planting and landscaping;

(ii) rearrangement of structures;

(iii) high standard of external design/finish for main structures; and

(iv) perimeter fences and walls.

For other recommendations on environmental mitigation measures, please refer to the Environmental Standards & Guidelines promulgated at the EPD's website.

3.7 SITE INVESTIGATIONS

Reference should be made to the Guide to Site Investigation (GEO, 2000) for guidance on good site investigation practice and Guide to Rock and Soil Description (GEO,2000) for guidance on the description of rocks and soils in Hong Kong.

3.8 HYDROGRAPHIC STUDIES

Hydrographic studies should be carried out to provide information for the determination of submarine sewage outfall locations and the design of diffusers. These comprise the collection of data on water depths, tides, current, salinity and the temperature gradient of the water column.

Information on water depth is readily available from Admiralty Charts or sounding surveys. Further details can be obtained by echo sounding or chain sounding surveys. Tide tables are published annually by the Hong Kong Observatory. Although the Admiralty Charts may indicate generalised current direction and speed, detailed information for design purposes at specific sites should be obtained through on-site measurements.

A hydrographic study comprises both fixed station measurements and float tracking. It is usual to obtain fixed station measurements over a typical spring and neap tidal cycle. To maximise data quality, it is necessary to calibrate the instruments before deployment, followed by a check calibration after recovery. Detailed profiles of current speed, direction, water temperature, salinity, etc. are usually obtained from a moored vessel using a single direct reading current meter fitted with appropriate additional sensors. Such measurements are taken at a number of chosen locations of the proposed diffuser.

Profiles are taken at regular time intervals and at regular depth increments. The number of depth increments depends on the water depth. A minimum of four readings are required to be taken near surface, at one-third and two-third of the water depth and near seabed.

4. FLOW AND LOAD ESTIMATION

4.1 FLOW ESTIMATION

With effect from 2008, DSD has adopted Technical Paper Report No. EPD/TP1/05 - Guidelines for Estimating Sewage Flows for Sewage Infrastructure Planning (GESF) issued by EPD for sewage flows estimation. Flow components and data, population and employment forecasts, methodology of flow estimation, flow parameters and factors are given in the GESF. The full report is available for downloading from EPD's website:

http://www.epd.gov.hk/epd/english/environmentinhk/water/guide_ref/gesf.html

Should the designers wish to adopt other methodology and parameters for estimating sewage flows for the design of sewerage and sewage treatment projects, the designers shall submit their detailed justifications to EPD for approval.

4.2 LOAD ESTIMATION

4.2.1 Loads

The most important loads to be taken into account in the design of sewage treatment works are as follows :-

Suspended Solids (SS);
Biochemical Oxygen Demand (BOD);
Chemical Oxygen Demand (COD);
Total Kjeldahl Nitrogen (TKN);
Ammoniacal Nitrogen (NH_3N);
Escherichia coli (E. coli).

Loads are normally determined on a per capita basis except for industrial loads which must be determined according to the industrial process involved.

4.2.2 Existing Data Sources

Load data for existing sewage treatment works are available from Sewage Treatment Divisions of Drainage Services Department. Some load survey data are also available from the following sources :

Sewage Strategy Study

Domestic	-	Long Ping, Yuen Long (Low Cost Rental)
	-	Ma On Shan (Low Cost Rental + Private R2)
Commercial	-	South Kowloon

Industrial - Kwai Chung/Tsuen Wan

Sewerage Master Plan Studies

Aberdeen, Ap Lei Chau and Pok Fu Lam
Central, Western and Wanchai West
Chai Wan and Shau Kei Wan
East Kowloon
Hong Kong Island South
North and South Kowloon
North District
North West Kowloon
Outlying Islands
Port Shelter
Tolo Harbour
Tsuen Wan, Kwai Chung and Tsing Yi
Tuen Mun
Wanchai East and North Point
Tseung Kwan O
Yuen Long and Kam Tin

Sewerage Master Plan Reviews

Review of Yuen Long and Kam Tin Sewerage and Sewage Treatment Requirements
Review of Central and East Kowloon Sewerage Master Plans
Review of Tuen Mun and Tsing Yi Sewerage Master Plans
Review of Outlying Islands Sewerage Master Plan
Review of Hong Kong Island Sewerage Master Plans
Review of North District and Tolo Harbour Sewerage Master Plans
Review of Tsuen Wan and West Kowloon Sewerage Master Plans

4.2.3 Load Estimation

The methodology for load estimation is given below:-

(a) Field surveys to establish existing loads;

(b) Separate identification of industrial loads;

(c) Correlation with global load parameters in conjunction with population data;

(d) Load estimates for new development from global load parameters.

4.2.4 Unit Load Factors

The recommended unit load factors for use in design are shown in Table 4. These are based on the values derived for the SSS.

5. DESIGN OF SEWERS

5.1 DESIGN CRITERIA

5.1.1 Capacity (gravity pipelines)

A sewer is subjected to a wide range of flow conditions. It must have sufficient capacity to cater for the designed peak flow. On the other hand it must also minimise the deposition of solids under low flow conditions. Small sized sewers are prone to blockage by grease and silt. To reduce the chance of blockage and to facilitate cleansing, the minimum size for public sewers should be 200 mm diameter. However, under special circumstances, smaller diameter pipes may be adopted subject to agreement of the maintenance party.

The maximum discharge at a circular pipe occurs when the flow depth is about 0.95 of the pipe diameter. Since any slight increase in depth will cause a reduction in flow velocity, it is usual to design on the assumption that the circular pipe will run full, which attains about 93% of the maximum discharge. The full bore flow shall be taken as the design capacity of a sewer. No additional factor of safety is necessary on top of those associated with flow estimation.

Sewers under surcharge are not desirable because:

(a) The environmental nuisance associated with a sewage overflow is enormous, bearing in mind that the peak flow is expected to occur on a daily basis;

(b) Grease content of sewage in Hong Kong is high, and it tends to accumulate at the top of the sewage flow. Under submerged condition, the grease will accumulate at the manhole and will easily clog the sewer when the flow rate is reduced during off peak conditions;

(c) Uncertainty associated with flow assessment and hydraulic modeling e.g. siltation and grease accumulation, head losses, pipe defects, infiltration and so on;

(d) Difficulty in inspecting a surcharged sewer and in carrying out maintenance operations.

Checks on flows in an existing sewerage system may reveal that some sewers are surcharged but with some freeboard, i.e. overflow will not occur at peak flow. These sewers should be considered as under capacity. Improvement proposals shall be drawn up to eliminate the surcharged condition. Implementation of these proposals, however, will not be accorded a high priority if, at peak flow, the following is satisfied:

(a) a minimum freeboard of 1 m ; and

(b) a minimum factor of safety against overflowing of 1.15, ie overflow will not occur at a flow rate of (1.15 times peak flow).

Such improvement proposals, even if not accorded a high priority, should still be carried out when the opportunity arises e.g. in conjunction with road works and/or nearby sewerage projects.

5.1.2 Minimum Velocity

A minimum velocity enables the sewage flow to self-cleanse the nominal amount of silt carried through the sewers, and helps to minimize sewer chokage as a result of siltation and grease accumulation. Subsequent maintenance costs and environmental nuisance are reduced. The self-cleansing can also relieve the problems of septicity due to siltation.

It has been established that self-cleansing velocities vary with the particle sizes of sediments and sizes of sewers. It is not easy to determine the particle sizes of silt in the sewerage system because both the range of sizes and the variation of sizes are great.

According to BS EN 752: 2008, self cleansing for small diameter sewers of diameter less than 300mm can generally be achieved by ensuring either that a velocity of at least 0.7m/s occurred daily, or that a gradient of at least 1: DN (i.e. Nominal diameter of the sewer in mm) is specified, provided that a flow of 2 ADWF is assumed to occur at least once daily. Strict requirements for bedding and accurate laying of the pipes are essential to achieve self-cleansing conditions in sewers with low gradient.

For larger diameter sewers, higher minimum velocities should be used particularly if relatively coarse sediment is expected to be present. For sewers of diameter up to 900mm, it should be designed to achieve a self-cleansing velocity of 1.0m/s in full pipe condition. Currently, there are references regarding the application of sediment transport theory to the design of sewers and the design guideline for various sewer sizes and various sediment loads, e.g. CIRIA (1996), "Solids in Sewers - Characteristics, Effects and Control of Sewer Solids and Associated Pollutants" published by IWA in 2004, etc. However, such information should be supplemented by local project experiences. Their applicability on local sewerage system should also be verified.

It is advisable to have self-cleansing conditions attained at least at times of daily peak flow. Controlling ingress of sediment to the sewer and other sediment management options should also be considered. Special maintenance provisions may be required to ensure frequent cleaning operation on sewers where it is impractical to achieve self-cleansing conditions. Where a system is to be developed in phases, considerations should be given to the likely lower flow than design flow, which may happen at the initial stage of commissioning. The minimum velocity shall be determined to avoid the septic and odour problems.

5.1.3 Maximum Velocity

Very fast flow is not desirable because:

(a) Very fast flow is not stable and will give rise to scouring and cavitation especially when the pipe surface is not smooth, and if the sewer contains junctions, bends, manholes. The usual hydraulic equations for flow prediction may not be applicable. More importantly, severe erosion causes damage to the sewerage system;

(b) Very fast flow occurs when the sewer is laid at steep gradient and the flow becomes supercritical. When the gradient eventually flattens, the flow may become subcritical and a hydraulic jump will occur. The potential damage associated with the uncontrolled energy dissipation is substantial; and

(c) Inspection and maintenance of sewers with fast flowing sewage are unsafe, usually difficult and sometimes impossible.

The maximum velocity at peak flow shall be limited to 3 m/s but this can be relaxed to 6 m/s provided that:

(a) a continuous, smooth, durable, and abrasion resistant pipe (e.g. ductile iron) or internal lining is chosen; and

(b) all junctions, bends, manholes or other appurtenances are designed with appropriate erosion protection measures.

Sometimes, sewers with steep gradient are unavoidable due to the topography of the area. Measures to reduce the maximum velocity generally include:

(a) laying the sewer at flatter gradient with the installation of backdrop manholes in the system to dissipate excessive static head in a controlled manner;

(b) providing steps at manholes to dissipate energy; and

(c) using specially designed energy dissipators.

For the sewage flow conditions commonly encountered in Hong Kong, a combination of measures (a) and (b) is adequate. The application of measure (c) is more common in stormwater drainage systems where the flow rate is much higher.

5.1.4 Levels

Apart from the hydraulic performance, the depth of sewers should be designed in conjunction with other factors such as

(a) topography of the ground and subsoil conditions;

(b) proximity of foundations of adjacent structures;

(c) proximity of utilities services;

(d) proximity of trees or heavy root growth;

(e) minimum cover required;

(f) method of construction; and

(g) life cycle cost.

As the size of a sewer increases downstream, it is normal practice to align the soffits at the same level at the manhole. This is to prevent the sewer being surcharged by back water effect when the downstream sewer is flowing full. Similarly when a lateral sewer joins a main sewer, the soffit of the lateral sewer shall not be lower than that of the main sewer. If the situation allows, it is preferable to have the lateral at equal soffits to minimize possible surcharge of the lateral sewer.

5.1.5 Alignment

The designer should check carefully whether the alignment of sewer will be obstructed by other utilities. Utility plans should be referred to, and in case of doubt, trial holes should be dug to ascertain any possible conflict. Utility diversions should be carried out in advance of the sewer construction if necessary.

Special attention shall also be paid to possible traffic disruption during construction and during future maintenance operation. This is especially important if the sewer is deep, or is to be laid along a steep carriageway, a heavily trafficked carriageway, a single-lane one way carriageway, and so on. The traffic authority shall be consulted to ensure that an acceptable traffic scheme for sewerage construction can be worked out.

In choosing the alignment of a sewerage system, the following factors shall also be considered:

(a) the objectives to serve all existing and future land development;

(b) the topography where the system is located;

(c) availability, location and level of existing or planned sewerage facilities for connection;

(d) the hydraulic performance;

(e) the soil condition;

(f) site constraints;

(g) access for inspection, operation and maintenance;

(h) need of land resumption;

(i) proximity of trees and other vegetation;

(j) life cycle cost;

(k) groundwater levels and effects of tides, waves and currents; and

(l) social and economic impact

5.1.6 Minimum Pipes Size

To facilitate inspection and cleaning, pipes of diameter less than 200mm should normally not be used as sewers unless agreed by the operation and maintenance agents.

5.1.7 Septicity

Septicity occurs when the residence time of sewage is long, the temperature is high and there is a lack of air exchange. The deposition of sediments in sewers also facilitates the formation of sulphide. This frequently occurs in gentle gravity sewers in which the flow is too slow. In addition, sulphide formation will be more serious with saline sewage as seawater contains a high level of sulphate.

The accumulation of hydrogen sulphide is known to cause at least three detrimental effects. Firstly, it is odorous and is a hazard to people who work in the vicinity and can be fatal at high concentration. Secondly, it is flammable and explosive. Last but not least, it is acidic and can cause corrosion problem in sewers and sewage treatment works.

The adverse effects of septicity in gravity sewers can be mitigated by suitable design to shorten residence time, minimize sediments deposition and adopt corrosion resistant construction materials.

5.1.8 Large Deep Sewer

Difficulties are frequently encountered in the inspection, maintenance and repair of large deep gravity sewers, which is defined as gravity sewers of diameters not less than 675mm and invert levels exceeding 6m below ground level. Laying of large deep gravity sewers should be avoided as far as possible. However, if it cannot be avoided, the designer should consider the following:

(a) In the design of sewerage facilities, evaluation of various alternatives, including the adoption of shallower sewers by the provision of intermediate pumping stations and localized sewage treatment plants if necessary, should be carried out.

(b) To facilitate inspection and maintenance of surcharged large deep sewer, over pumping is usually required to draw down the sewage level in the sewer.

(c) If over pumping is not practically feasible, the designer should consider a twin line design.

(d) The designer should work out and agree with DSD on other maintenance requirements for large deep gravity sewers and make reference to DSD Practice Note no. 3/2010, or its latest version.

5.1.9 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 sewers 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 sewers.

(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 including the associated site formation work and 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.

5.1.10 Sewerage Works in Conjunction with Roadworks

The following should be considered for planning of sewerage works:

(a) Newly constructed or resurfaced roads are normally subject to a road opening restriction extending over several years and it is essential that any sewerage works beneath the roads are done prior to or in conjunction with the roadworks.

(b) Details of proposed roadworks are normally circulated to the relevant DSD divisions for comments.

(c) When sewers are proposed to be laid in future road carriageways/verges or in existing roads 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 the proposed roadworks.

5.2 HYDRAULICS OF GRAVITY PIPELINES

5.2.1 Basic Equations

In hydraulic design or analysis, both the Colebrook-White equation and the Manning's equation are most commonly used.

(1) *Colebrook-White Equation.* The Colebrook-White equation can be applied to analyze a wide range of flow conditions. The Colebrook-White equation is

(i) for circular pipes flowing full,

$$V = -\sqrt{(8gDs)}\,\log\left(\frac{ks}{3.7D} + \frac{2.51v}{D\sqrt{(2gDs)}}\right)$$

(ii) for partially full pipes or pipes with non-circular cross-sections,

$$V = -\sqrt{(32gRs)}\,\log\left(\frac{ks}{14.8R} + \frac{1.255v}{R\sqrt{(32gRs)}}\right)$$

where

V = mean velocity (m/s)
g = gravitational acceleration (m/s2)
R = hydraulic radius (m)
D = internal pipe diameter (m)
ks = hydraulic pipeline roughness (m)
v = kinematic viscosity of fluid (m2/s)
s = hydraulic gradient (energy loss per unit length due to friction)

Design charts and tables are available for the Colebrook-White Equation in HR Wallingford et. al. (2006).

The roughness value is, in theory, related to the height of roughness element of the pipe wall. In practice, it is also influenced by the joints, discontinuities, slime growth on the wall, grease build-up and sediment on the invert.

The slime that grows on the pipe surface below the maximum water level may increase the roughness value to a certain extent which depends on pipe material and the flow velocity.

Most common roughness values for various pipe materials are listed in the Table 5[1]. The roughness value for slimed sewers should be used for designing sewerage. The usual range of roughness value for common pipe materials lies between 0.6 mm and 6 mm. The designer shall use his or her own judgement to select an appropriate roughness value compatible with pipe material and its condition.

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1 H.R. Wallingford Ltd., Barr, D.I.H. and Thomas Telford Ltd. are acknowledged for their consent to the reproduction of the Table on Recommended Roughness Values in the publication "Table for the Hydraulic Design of Pipes, Sewers and Channels, 8th Edition (2006)" in Table 5 of this Manual.

(2) *Manning's Equation*. Although the Manning's equation was originally developed for the analysis of flow in open channels, it is now widely used to analyze flow in both open channels and closed conduits. The Manning's equation is

$$V = \frac{R^{2/3} s^{1/2}}{n}$$

where
V = mean velocity (m/s)
s = hydraulic gradient (energy loss per unit length)
n = Manning's roughness coefficient
R = hydraulic radius (m)

Typical values of Manning's roughness coefficient for pipes in good and poor conditions are listed in Table 6.

5.2.2 Local Losses

In order to minimize the head losses in pipe flow, the selection of the pipe materials and the joint details are very important. The resistance in pipes will be influenced by the pipe material but will be primarily dependent on the slime that grows on the pipe surface. Other factors such as the discontinuities at the pipe joints, the number of manholes, the number of branch pipes at manholes and their directions of inflow will all affect the head losses. Proper benching with smooth curves should be provided to accommodate the changes in pipe direction.

The hydraulic pipeline roughness (ks) in Colebrook-White equation or the roughness coefficient (n) in Manning's equation allows for head losses due to pipe material and slime growth on the pipe surface below the water level. Local head losses arisen at inlets, outlets, bends, elbows, joints, valves, manholes and other fittings are usually small in relation to the pipeline head losses and are not normally considered. Nonetheless, if total head loss including local head losses is required, two methods of calculation can be adopted:

(1) Assuming a higher value of hydraulic pipeline roughness (ks) or roughness coefficient (n) in the calculation of pipeline head loss;

(2) Adding the local head losses calculated by the following formula to the pipeline head losses:

$$h_f = K \frac{V^2}{2g}$$

in which K may refer to one type of head loss or to the sum of several head losses.

The head loss coefficient K can be found in literature on hydraulics. Table 7 contains some of the most commonly used head loss coefficients as abstracted from the Preliminary

Design Manual for the Strategic Sewage Disposal Scheme prepared by AB2H Consultants in June 1992. Reference should also be made to D S Miller (1990), Streeter and Wylie (1985), BS EN 752:2008 and Chow (1959).

5.2.3 Water Surface Profiles

In the design of sewer sometimes it is inadequate to assume uniform flow to determine pipe sizes and invert levels.

The most common water profiles are the backwater and drawdown curves. The flow of sewage may occur under partial flow or surcharged conditions. Partial flow usually occurs where the hydraulic grade line lies on the surface of the flowing sewage; and surcharge occurs when the hydraulic grade line rises above the soffit of the sewer. In general, inlet pumping at the treatment works, discharging through seawall overflows or bypasses, abrupt change in pipe size or flow gradient and the presence of overflow weirs or orifices may all affect the hydraulic grade line.

It is essential that all hydraulic control structures are identified. A control structure has two effects. First there is a local effect resulting in a significant change in flow regime at the control structure. This causes a local energy loss and subsequent change in the hydraulic grade line. Second, there are upstream and downstream effects. Upstream, the control may cause a drawdown curve. Downstream, it may cause a hydraulic jump.

The water profiles (including backwater and drawdown curves) representing the hydraulic grade line of the flow in a sewer can be determined by a number of different methods (e.g. Direct integration, graphical integration and direct step method). Reference can be made to the various hydraulic textbooks.

When checking backwater profile in a sewerage system discharging effluent into the sea, an appropriate tide level should be chosen. Reference should be made to the Stormwater Drainage Manual which provides further details on the tide levels at various locations. The return period chosen should not be less than two years.

5.2.4 Design Tools

Sophisticated computer software packages (e.g. InfoWorks) have been developed for the hydraulic design of new sewerage systems and the analysis of existing systems. The use of computer models will facilitate the ease of updating and managing the existing system to cope with the demands from new developments and to identify deficiencies in the network for improvement work.

In the use of computerized design and analysis packages, attention should be paid to the theory behind and the assumptions and limitations of such models. Common areas of concern may include whether backwater effects are considered; whether assumptions regarding flooding and overflow are correct; whether downstream tidal effects can be catered for; whether the model can be applicable to looped sewer networks; whether the model can cater for such facilities as pumps, storage tanks, overflow devices and the various head losses in a system. It is common that a package will consist of different analysis models for different applications. In choosing between the models, the limitations involved in each of them should be clearly identified such that the applicability of a model will not be compromised by simplifying the analysis.

Another important area in the use of computerized models is validation, particularly where stormwater flow is present. The data related to catchment characteristics such as surface runoff coefficients built-in in the models developed overseas may not be applicable to Hong Kong. The designer should not overlook the physical meanings of the parameters to be input into the models and should check that the parameters are applicable for the Hong Kong situation.

The calibration and validation of these computer models are important and very time consuming processes. On-site flow survey and monitoring schemes have to be devised to verify these models.

5.3 PIPELINE MATERIALS

5.3.1 Choice of Pipe Material

The following factors should be taken into account in selecting the type of pipe for a project:

(a) hydraulic design: gravity or pressure flows;

(b) structural design: crushing test strengths (and pressure ratings in the case of pressure pipelines) that are available;

(c) nature of the fluid to be conveyed;

(d) nature of ground water and external environment;

(e) cost considerations: capital and maintenance costs;

(f) pipe jointing system: ease of installation, past performance;

(g) durability: resistance to corrosion and abrasion;

(h) availability of pipe sizes, fittings and lengths in the market for construction and subsequent maintenance;

(i) ease of cutting and branch connections;

(j) length and weight of individual pipes in relation to transportation and handling; and

(k) future operating procedure and system development.

Table 8 summarizes typical pipe materials currently available, range of size, appropriate British Standard etc., and provides a brief comparison of their properties and uses.

5.3.2 Corrosion Protection

In general, most of the pipes and fittings are susceptible to both internal and external attack by corrosion unless appropriate protective measures are adopted. The degree of attack depends upon the nature of the soils, the characteristics of the fluid being conveyed and the type of pipe protection used.

Metallic corrosion, in the presence of water, is a chemical reaction accompanied by the passage of an electric current similar to that which takes place in a battery cell except that in the case of a pipe, the metal surface acts as both the anode and cathode, with corrosion pits developing at anodic sites.

As sulphate-reducing bacteria can assist the cathodic reaction in certain anaerobic environments, corrosion can also take place in anaerobic conditions. The deposition of sediment and slime on internal metal pipe surfaces are conducive to microbiological activity which tends to deplete oxygen levels, thus stimulating localized corrosion.

To protect the pipe from corrosion, pipes made of corrosion resistant material or coated with inert protective materials should be considered. For concrete pipes with protective liners, the pipe joints should also be covered by linings and the lining must be subsequently jointed after installation if the pipe diameter is large enough for man access. If the diameter is too small, the pipes should be supplied with joint surfaces already safeguarded with lining.

A summary of typical corrosion protection measures suitable for mild steel, ductile iron and concrete pipelines is given in Table 9.

5.3.3 Pipe Joints

Most of the pipes supplied by the manufacturer have their own design of joint. In the past many pipe joints were welded, bolted or made by caulking with cement mortar or run lead. These joints allowed no movement of the pipes after laying. Any movement of the pipeline resulting from ground settlement, or of differential settlement between the pipelines and the structure, highly stresses the pipe and joints, leading to fracture and joint leakage.

Nowadays, flexible joints are generally used. This reduces settlement problems and speeds up the pipe laying work.

At reclamation area or areas where differential settlement between the pipeline and the structure is anticipated, designer shall critically review if the allowable angular deflection at the flexible pipe joint could sustain the predicted deflection. If required, addition of large displacement expansion joint at appropriate locations of pipeline can be considered, in conjunction with the associated cost implication.

Table 10 summarizes common types of pipe-joints and provides a brief comparison of their characteristics and uses.

6. STRUCTURAL DESIGN OF GRAVITY PIPELINES

6.1 INTRODUCTION

Pipes can be categorised into rigid, flexible and intermediate pipes as follows:

(a) Rigid pipes support loads in the ground by virtue of resistance of the pipe wall as a ring in bending.

(b) Flexible pipes rely on the horizontal thrust from the surrounding soil to enable them to resist vertical load without excessive deformation.

(c) Intermediate pipes are those pipes which exhibit behaviour between those in (a) and (b). They are also called semi-rigid pipes.

Concrete pipes and vitrified clay pipes are examples of rigid pipes while steel, ductile iron, UPVC, MDPE and HDPE pipes may be classified as flexible or intermediate pipes, depending on their wall thickness and stiffness of pipe material.

The load on rigid pipes is concentrated at the top and bottom of the pipe, thus creating bending moments. Flexible pipes may change shape by deflection and transfer part of the vertical load into horizontal or radial thrusts which are resisted by passive pressure of the surrounding soil. The load on flexible pipes is mainly compressive force which is resisted by arch action rather than ring bending.

The loads on buried gravity pipelines are as follows:

(a) The first type comprises loading due to the fill in which the pipeline is buried, static and moving traffic loads superimposed on the surface of the fill, and water load in the pipeline.

(b) The second type of load includes those loads due to relative movements of pipes and soil caused by seasonal ground water variations, ground subsidence, temperature change and differential settlement along the pipeline.

Loads of the first type should be considered in the design of both the longitudinal section and cross section of the pipeline. Provided the longitudinal support is continuous and of uniform quality, and the pipes are properly laid and jointed, it is sufficient to design for the cross section of the pipeline.

In general, loads of the second type are not readily calculable and they only affect the longitudinal integrity of the pipeline. Differential settlement is of primary concern especially for pipelines to be laid in newly reclaimed areas. The effect of differential settlement can be catered for by using either flexible joints (which permit angular deflection and telescopic movement) or piled foundations (which are very expensive). If the pipeline is partly or wholly submerged, there is also a need to check the effect of flotation of the empty pipeline.

The design criteria for the structural design of rigid pipes is the maximum load at which failure occurs while those for flexible pipes are the maximum acceptable deformation and/or the buckling load. The approach for designing rigid pipes as mentioned in this chapter is not applicable to flexible pipes, deeply laid pipes or pipes laid by tunnelling methods. For the structural design of flexible pipes, deeply laid pipes or pipes laid by tunnelling methods, it is necessary to refer to relevant literature such as manufacturers' catalogue and/or technical information on material properties and allowable deformations for different types of coatings, details of joints etc.

6.2 DESIGN PROCEDURES FOR RIGID PIPES

The design procedures for rigid pipes are outlined as follows:

(a) Determine the total design load due to:

(i) the fill load, which is influenced by the conditions under which the pipe is installed, i.e. narrow trench or embankment conditions;

(ii) the superimposed load which can be uniformly distributed or concentrated traffic loads; and

(iii) the water load in the pipe.

(b) Choose the type of bedding (whether granular, plain or reinforced concrete) on which the pipe will rest. Apply the appropriate bedding factor and determine the minimum ultimate strength of the pipe to take the total design load.

(c) Select a pipe of appropriate grade or strength.

Specific guidance on the design calculations is given in Sections 6.3 to 6.8.

6.3 FILL LOADS

6.3.1 Narrow trench condition

When a pipe is laid in a relatively narrow trench in undisturbed ground and the backfill is properly compacted, the backfill will settle relative to the undisturbed ground and the weight of fill is jointly supported by the pipe and the shearing friction forces acting upwards along the trench walls. The load on the pipe would be less than the weight of the backfill on it and is considered under 'narrow trench' condition by the theory and experimental work of Marston:

$$W_c = C_d \quad w \quad B_d^{\,2}$$

$$C_d = \frac{1}{2k\mu'}[1\text{-}\exp(\text{-}2k\mu'\frac{H}{B_d})]$$

$$k = \frac{\sqrt{(\mu^2+1)}-\mu}{\sqrt{(\mu^2+1)}+\mu}$$

where W_c = fill load on pipe in kN/m,
w = unit weight of fill in kN/m^3,
B_d = the width of trench in metre measured at the top level of the pipe (as shown on the relevant DSD Standard Drawing),
C_d = narrow trench coefficient,
k = Rankine's ratio of lateral earth pressure to vertical earth pressure,
μ, μ'= coefficient of friction of backfill material and that between backfill and trench side respectively,
H = actual height of fill above the top of pipe in metres.

For practical applications, take μ = μ' , and use Figure 4 to obtain values of C_d.

6.3.2 Embankment condition

When the pipe is laid on a firm surface and then covered with fill, the fill directly above the pipe yields less than the fill on the sides. Shearing friction forces acting downwards are set up, resulting in the vertical load transmitted to the pipe being in excess of that due to the weight of the fill directly above the fill. The load on the pipe will then be determined as in the 'embankment' condition (also known as 'wide trench' condition). The equation for the embankment condition as proposed by Marston is as below:

$$W_c = C_c \quad w \quad B_c^2$$

$$C_c = \frac{\exp(\frac{2k\mu H_e}{Bc})-1}{2k\mu} + \left(\frac{H-H_e}{Bc}\right)\exp(\frac{2k\mu H_e}{Bc})$$

H_e is given by:

$$\left[\frac{\exp(\frac{2k\mu H_e}{Bc})-1}{2k\mu}\right]\left[\frac{1}{2k\mu}+\frac{H-H_e}{Bc}+\frac{r_{sd}\,p}{3}\right] + \frac{1}{2}\left(\frac{H_e}{Bc}\right)^2 + \frac{r_{sd}\,p}{3}\left(\frac{H}{B_c} - \frac{H_e}{B_c}\right)\exp\frac{2k\mu H_e}{Bc}$$

$$- \frac{H_e}{2k\mu B_c} - \frac{H H_e}{B_c^2} = r_{sd}\; p\frac{H}{B_c}$$

where W_c = fill load on pipe in kN/m,
w = unit weight of fill in kN/m^3,
B_c = external diameter of pipe in metres,
C_c = load coefficient under embankment condition,
H_e = height of plane of equal settlement above the top of pipe in metres,
H = actual height of fill above the top of pipe in metres,
r_{sd} = settlement ratio,
p = ratio of projection of pipe's crown above firm surface to the external pipe diameter,
k = Rankine's ratio of lateral earth pressure to horizontal earth pressure,
μ = coefficient of internal friction of backfill material.

For practical applications, values of C_c can be obtained from Figure 5.

Use r_{sd} = 1.0 for rock or unyielding foundation
= 0.5 ~ 0.8 for ordinary foundation
= 0.0 ~ 0.5 for yielding foundation

Narrow trench and embankment conditions are the lower and upper limiting conditions of loading for buried rigid pipes. Other intermediate loading conditions are not very often used in design.

One method for deciding whether the narrow trench condition or embankment condition of the Marston equations is to be used to determine the fill load on pipes was proposed by Schlick. Calculations are carried out for both conditions. The lower of the two calculation results is suggested to be adopted in design. Method of construction will be specified in accordance with the designed trench conditions if necessary.

Under certain site conditions, when restricting the trench width is not practical because of the presence of underground utilities, consideration should be given to design the pipe for fill loads under the worse scenario of narrow trench and embankment conditions.

If the width of the trench, B_d, and external diameter of the pipe, B_c, are fixed, there is a unique value of cover depth at which the embankment or narrow trench calculations indicate the same load on the pipe. This value of cover depth is termed the ‘transition depth’ T_d, for this trench width and external diameter of pipe.

At depths less than the transition depth, the pipe is in the ‘embankment’ condition and the fill load will be dependent on the external diameter of the pipe. No restriction to trench width is required. In other cases, when the depth is greater than the transition depth, the fill load is dependent on the assumed trench width. The tabulated fill load on the pipe in Table 11 will be exceeded unless the trench width is restricted to the assumed value in order that the pipe is in the ‘narrow trench’ condition.

The fill load on a pipe and value of transition depth, assuming a saturated soil density of 2000 kg/m^3, are shown in Table 11. If the actual soil density $\boldsymbol{\sigma}$ differs from 2000 kg/m^3, the fill load may be adjusted by a multiplying factor of $\boldsymbol{\sigma}/2000$. The values of $k\mu$ assumed in deriving this table are 0.13 for narrow trench condition and 0.19 for embankment condition. $r_{sd}\,p$ for embankment condition is taken as 0.7 for pipes up to 300 mm nominal diameter and 0.5 for larger pipes.

6.4 SUPERIMPOSED LOADS

The equivalent external load per metre of pipe transmitted from superimposed traffic loads can be calculated by the Boussinesq Equation, by assuming the distribution of stress within a semi-infinite homogeneous, elastic mass:

$$p = \left(\frac{3L}{2\pi}\right)\left(\frac{H^3}{H_s^{\,5}}\right)\alpha$$

where
- L = concentrated load applied at surface of fill in kN,
- p = unit vertical pressure at a specific point within the fill in kN/m²,
- H = depth of such point below the surface in metres,
- H_s = slant distance of such point from the point of application of concentrated load at surface in metres,
- α = impact factor.

The traffic load will be calculated as below:

$$W_p = \sum pB_c$$

where
- W_p = design traffic load in kN/m,
- Σp = unit vertical pressure due to the various concentrated loads in kN/m²,
- B_c = external diameter of pipe in metres.

Values of traffic loads for design are shown in Table 12 with the following assumptions:

Main road: pipelines laid under main traffic routes and under roads to be used for temporary diversion of heavy traffic, where provision is made for eight wheels loads, each of 90 kN acting simultaneously with an impact factor of 1.3 and arranged as in BS 5400 Part 2: 2006 Type HB Loading.

Light road: pipelines laid under roads except those referred in main roads, where provision is made for two wheel loads, each of 70 kN static weight, spaced 0.9 m apart, acting simultaneously with an impact factor of 1.5.

6.5 WATER LOAD

The weight of water in a pipe running full generates an additional load, the equivalent external load on the pipe can be calculated from the following equation:

$$W_w = 9.81 \left(\frac{3\pi}{4}\right) \left(\frac{D^2}{4}\right)$$

where W_w is the equivalent water load in kN/m,
D is the internal diameter of pipe in metres.

In general, the water load is not significant for small pipes of less than 600 mm diameter. The equivalent water load of pipes of 600 mm to 1800 mm diameter are as below:

Nominal Diameter (mm)	*Equivalent Water Load (kN/m)*
600	2.1
750	3.3
900	4.7
1050	6.4
1200	8.3
1350	10.6
1500	13.0
1650	15.8
1800	18.8

6.6 BEDDING FACTORS

The strength of a precast concrete or vitrified clay pipe is given by the standard crushing test. When the pipe is installed under fill and supported on a bedding, the distribution of loads is different from that of the standard crushing test. The load required to produce failure of a pipe in the ground is higher than the load required to produce failure in the standard crushing test. The ratio of the maximum effective uniformly distributed load to the test load is known as the 'bedding factor', which varies with the types of bedding materials under the pipe and depends to a considerable extent on the efficiency of their construction and on the degree of compaction of the side fill.

The various methods of bedding used with precast concrete pipes are shown on the relevant DSD Standard Drawing. The values of the bedding factors below are average experimental values and are recommended for general purposes: -

(a)	granular bedding	1.9
(b)	120° plain concrete bedding	2.6
(c)	120° reinforced concrete bedding with minimum transverse steel area equal to 0.4% of the area of concrete bedding	3.4
(d)	concrete surround	4.5

On the basis of the experimental and numerical modelling work carried out, bedding factors used with vitrified clay pipes for class F, B and S bedding are shown in Figure 6.

6.7 DESIGN STRENGTH

For design, it is required that the total external load on the pipe will not exceed the ultimate strength of the pipe multiplied by an appropriate bedding factor and divided by a factor of safety.

The design formula is as follows:

$$W_e \leq \frac{W_t F_m}{F_s}$$

where W_e = total external load on pipe,
W_t = ultimate strength of pipe,
F_m = bedding factor,
F_s = design safety factor of 1.25 for ultimate strength of pipe.

Based on the assumed design parameters in Sections 6.3, 6.4, 6.5 and 6.6, values of the total external design loads in main roads and light roads are shown in Table 13.

Alternatively, Table 14 may be used for direct evaluation of the minimum crushing strength or grade of precast concrete or vitrified clay pipes using different bedding factors in main roads.

Worked Example: -

Given: Nominal pipe size 375 mm (outside diameter 500mm)
Class B bedding (bedding factor = 1.9)
Cover depth range 1.8 m to 4.6 m
Pipe to be laid in main road

To determine strength of concrete pipe required.

Solution:

From Table 11,

as transition depths vary from 2.4 to 3.0 m, which is less than 4.6m, assume wide trench condition

maximum design load, W_e = 66 kN/m

Required W_t = 66 x 1.25 / 1.9 = 43.4 kN/m

Based on BS 5911, Class H Pipe with ultimate strength of 45 kN/m is required.

6.8 EFFECT OF VARIATION IN PIPE OUTSIDE DIAMETERS

The outside diameters in Table 13 are the general maxima for the majority of pipes, a few pipes may be encountered, outside diameters of which would exceed the tabulated dimensions. Provided the excess is not greater than 5% the effect can be ignored. If the pipes employed have an outside diameter less than that being assumed, the load in Table 13 will then err on the safe side. It may be worthwhile making a more accurate computation of the design load by means of Sections 6.3 and 6.4 with a view to achieving economy where the difference in outside diameter is considerable.

7. MANHOLES AND SPECIAL STRUCTURES

7.1 MANHOLES

7.1.1 Location

Manholes should be provided at :

(a) intersection of sewers;

(b) junction between different size/gradient of sewers;

(c) location where the sewer changes direction; and

(d) on long straight lengths at the following intervals :

Diameter of Pipe (mm)	Maximum Intervals (m)
≦675	80#
>675 and ≦1050	100
>1050	120

For pipe of size smaller than or equal to 675mm, the maximum interval should be reduced to 60m if:

- the flow carried by the pipe may cause difficult chokages;
- the manhole covers of the pipes are located on busy road such that opening 2 adjacent manhole covers at the same time may involve difficult traffic arrangement; or
- the pipe is located in a village with narrow roads which are inaccessible to large-sized water-jetting units.

A narrower spacing may be required to facilitate operation and maintenance of large deep sewers, i.e. sewer with 675mm or above in diameter and the invert level is more than 6m below. Should there be any doubt on the maximum interval to be adopted for any special circumstances, the relevant operation and maintenance divisions should be consulted at the design stage.

In addition, manholes should, wherever possible, be positioned such that the disruption to the traffic will be minimum when their covers are lifted under normal maintenance operations.

7.1.2 Access Openings

Access openings are generally of two types, one for man access and the other for desilting purposes. Desilting openings should not be smaller than 750 mm by 900 mm, and should be placed along the centre line of the sewer to facilitate desilting. Man access opening should not be smaller than 675 mm by 675 mm. If ladders are installed in the manhole, minimum clear opening should be 750 mm by 900 mm. Man access openings should be placed off the centre line of the sewer for deep manholes and along the centre line of the sewer for manholes shallower than 1.2 m.

7.1.3 Access Shafts

Access shafts should be sufficiently large for persons to be able to go down in comfort and yet small enough that one can reach the shaft walls by hand while climbing down for feeling a sense of security. Minimum size of access shaft should be 750 mm by 900 mm. The access shaft should be orientated such that the step irons are provided on the side with the smaller dimension. The access openings should be confined to one traffic lane.

7.1.4 Working Chambers

Usually, for manholes less than 1.2 m deep, works can be performed from ground level. Workers standing on the ground can reach the invert of the sewers without great difficulty. Working chambers are generally not required for this type of manhole.

For manholes deeper than 1.2 m, works inside generally cannot be easily carried out from ground level. Manholes of this type should be provided with working chambers with access shafts, if necessary, leading from ground level. The working chambers should enable persons to work inside.

7.1.5 Intermediate Platform

Where the invert of a manhole is more than 4.25 m from the cover level, intermediate platforms should be provided at regular intervals. Headroom between platforms should not be less than 2 m and not greater than 4 m. The size of the platform should not be smaller than 800 mm by 1350 mm. The platform should be fitted with handrailing and safety chains at the edge to protect persons from falling.

In order to facilitate rescue operation in case an accident occurred, designers are advised to provide an additional manhole opening where space permits.

7.1.6 Inverts and Benching

Inverts and benching in manholes should be neatly formed. The ends of pipes should be cut off and should not project into the manholes. The channel inverts should be curved to that of the associated pipes and carried up in flat vertical faces, and should match the cross-sections, levels and gradients of their respective sewers. The benching should be formed from plane surfaces sloping gently downward toward the sewers and should not be too steep to cause persons to slip into the sewer nor too flat so as to accumulate sediment. A suitable gradient of the benching is 1 in 12.

7.1.7 Covers

Manhole covers should be sufficiently strong to take the live load of the heaviest vehicle likely to pass over them, and should remain durable in a damp atmosphere. Heavy duty manhole covers should be used when traffic or heavy loading is anticipated, otherwise medium duty covers can be used.

Manhole covers should not rock when initially placed in position, or develop a rock with wear. Split triangular manhole covers supported at three corners are commonly used to reduce rocking. The two pieces of triangular cover should be bolted together to avoid a single piece of the cover being accidentally dropped into a manhole.

Sewer and stormwater drain manhole covers should use the appropriate grid patterns, which are shown on the DSD Standard Drawings, to allow easy identification.

7.1.8 Step-irons and Ladders

Step-irons should be securely fixed in position in manholes, and should be equally spaced and staggered about a vertical line at 300 mm centres. Ladders should be used in manholes deeper than 4.25 m or which are entered frequently. It is safer and easier to go down a ladder when carrying tools or equipment.

Step-irons and ladders should start within 600 mm of the cover level and continue to the platform or benching.

Step-irons and ladders, being constantly in a damp atmosphere and prone to corrosion, should be made of or protected with corrosion resistant materials, e.g. galvanized iron, glass-fibre reinforced plastic, plastic-coated steel, or stainless steel to suit the actual site conditions.

7.1.9 Backdrop Manholes

Backdrop manholes are used to connect sewers at significantly different levels, and should be used where the level difference is greater than 600 mm.

The backdrop can be provided by means of :

(a) a vertical drop in the form of a downpipe constructed inside/outside the wall of a manhole; and

(b) a gradual drop in the form of cascade.

A cascade is preferred for sewers larger than 450 mm diameter. Downpipes are suitable for sewers less than 450 mm in diameter and should not be used for sewers larger than 675 mm diameter. When downpipes are used, the following is recommended:

(a) proper anchoring of the backdrop at the bottom either in the form of a duckfoot bend or a 90 degree pipe bend surrounded by concrete; and

(b) a T-branch at the top fitted with flap valve inside the manhole to avoid splashing.

7.2 INVERTED SIPHONS

An inverted siphon is a depressed sewer that drops below the hydraulic gradient to avoid an obstruction. It is always surcharged. The system normally includes an inlet chamber, a group of depressed sewers and an outlet chamber. High velocity of flow in the depressed sewer should be maintained, with 1.5 m/s as the minimum to avoid sedimentation. Furthermore, to maintain favourable velocities at all times, multiple parallel pipes (normally 3) should be arranged at increasing level so that additional pipes are brought into service progressively as flows increase.

Desilting openings should be provided for both the inlet and the outlet chambers. Depending on the sizes of the incoming sewer and the depressed sewers, penstocks or at least grooves for shut-off boards should be provided. The inlet chamber should be constructed so that the lower level of the sewers is accessible for carrying out a flushing operation. The addition of a grit chamber is also desirable to avoid the deposition of grit in the siphon.

An inverted siphon requires considerable maintenance and its use is not recommended unless other means of passing an obstacle are not practicable.

7.3 MULTIPLE PIPE CROSSINGS

7.3.1 Introduction

Multiple pipe crossings have been used in Hong Kong in the past to overcome problems where sewers may be intersected and obstructed by obstacles such as storm water drains, utilities and other sewers. They usually consist of several smaller diameter pipes at the intersection to provide adequate clearance between the sewers and the obstacles, while maintaining the sewer capacity.

There are many problems with the existing multiple pipe crossings, and they include:

(a) head loss to the flow;

(b) flow disturbance;

(c) silt/grease or rubbish accumulation;

(d) frequent chokage; and

(e) adverse effect on the hydraulics of the stormwater drainage system which is to be crossed.

As in the case of inverted siphons, multiple pipe crossings should not be adopted for permanent sewers unless there is no practical alternative. When obstacles are encountered, which cannot be avoided by changes of sewer alignment or level, the diversion of the obstacle is the preferred option. Multiple pipe crossings may be used as a temporary works before diversion of the concerned obstacles are completed, and should satisfy the criteria below.

7.3.2 Number of Pipe Crossings and Size

The total flow capacity of the multiple pipe crossing should not be less than the original sewer and no pipe smaller than 300 mm diameter should be adopted. Hydraulic analysis should be carried out for the system with the pipe crossing to show that the headloss is not excessive.

Hydraulic analysis and model test, if appropriate, should also be carried out for the stormwater drainage system which is affected by the multiple pipe crossing to ensure that the risk of flooding is not increased to an unacceptable degree.

7.3.3 Control Structures

Control structures should be provided at the junctions of the original sewers and the multiple pipe crossing. The structures should have access to permit regular inspection, clearing, and the removal of obstructions from the pipes. They should be designed to avoid rubbish or grit from blocking the sewers or accumulating at the entrance of the pipe crossing. Desilting openings should be provided.

7.3.4 Level of Pipe Crossings

The maintenance problems resulting from sewer pipe crossing within the stormwater drainage system should not be overlooked. The sewer pipe crossing should be placed at least 900 mm above the inverts of the stormwater drainage system to allow the normal low flow during dry weather period or light rains. If sufficient headroom cannot be maintained, consideration should be given to the options of embedding the sewer pipe crossing in the base slab of the stormwater drain or adopting a better solution such as re-routing. If the sewer pipe crossing inside a stormwater drain cannot be avoided, the hydraulic impact to the stormwater drainage system should be assessed and mitigated.

7.4 DRY WEATHER FLOW INTERCEPTION

7.4.1 Pollution Sources

The pollution loads in the flow of the surface water course and the stormwater drainage system are due to the following :

(a) The poor operation and lack of maintenance of private treatment facilities resulting in sub-standard effluent being discharged into the stormwater system.

(b) The illegal discharge of industrial wastes, agricultural waste or both.

(c) The discharge into stream courses from squatter areas where no sewerage system is provided.

(d) Expedient cross connections between sewers and stormwater drains.

7.4.2 Abatement of Pollution Problems

The following three measures help to mitigate pollution in the coastal waters from polluted water courses and stormwater drains :

(a) Control at source

This is the least expensive option in terms of works but may not be easy to implement because of the enforcement problems arising from lack of staff, non-availability of appropriate legislation etc.

(b) Separate system

This option involves the provision of a comprehensive separate system for all unsewered areas and proper re-connection works for the existing sewerage. This is the most expensive solution and will take considerable time to implement.

(c) Dry weather flow (DWF) interceptor

This is often used as an interim or first aid measure. It is relatively inexpensive and can be carried out quickly. However, its proper functioning requires intensive and regular maintenance.

7.4.3 Design Considerations for DWF interceptors

The design considerations for DWF interceptors are:

(a) The rate of interception must be controlled so as not to overload the sewerage system but be sufficient to remove the major portion of polluted flows. Flow gauging should be carried out to estimate the quantity of polluted flows.

(b) It should be located downstream of the pollution sources but the intrusion of seawater into the sewer at the tidal zone must be guarded against.

(c) The hydraulics of the stormwater system must be checked so as not to increase the risk of flooding.

(d) Proper vehicular access should be provided.

(e) Degritting and screening devices must be provided to reduce the likelihood of blockage.

(f) The ease of operation and maintenance of DWF interceptors must not be compromised by other constraints.

Please also refer to DSD Technical Circular No. 4/99 (or its latest version) for other design considerations for DWF interceptor.

8. OPERATION AND MAINTENANCE OF SEWERAGE SYSTEMS

8.1 GENERAL

The proper maintenance and operation of the sewerage system is essential if the systems are to achieve their designed objectives. This Chapter provides some good practice and guidance to assist those who are involved in the day-to-day operation and maintenance of the sewerage system.

8.1.1 Maintenance Objectives

The objectives for proper maintenance and operation include :

(a) to offer a quality of service that is acceptable, having regard to costs and to effects on the environment, and to remedy recognised deficiencies;

(b) to monitor the capacity of the system and to restore the flow capacity by removal of excessive accumulation of silt and grease;

(c) to monitor and maintain the structural integrity of the system;

(d) to prevent excessive infiltration and inflow;

(e) to attend to complaints of blockage, flooding and damage to sewerage systems; and

(f) to provide feedback on the need for planning and implementation of improvement and upgrading works.

8.2 TAKING OVER OF COMPLETED WORKS

8.2.1 Procedures for Handing Over

To ensure that the works can be readily handed over to the maintenance authorities on completion, the standard of design and maintenance requirements laid down in this Manual must be fully complied with. Additionally, close consultation and liaison should be maintained between the design office and the maintenance authorities at each stage of the project. During the planning and design stages of a project, a design memorandum should be prepared so that the design parameters, handing over requirements or phased handing over arrangement of large project can be agreed by the maintenance authority. For non-standard sewerage items, detailed consultation is required such that the operation and maintenance requirements can be incorporated into the design. If unforeseen problems are encountered during construction and changes have to be made, the maintenance authority must be consulted as soon as possible so that the changes can be accepted. On completion, any changes made should be incorporated in the design memorandum before handing over of the completed works to the maintenance authorities.

Prior to handing over of the works, joint inspection must be carried out and any outstanding works agreed. Completion certificate should be issued together with the agreed list of outstanding works. Within 3 months of issuing the completion certificate, the final operation and maintenance (O&M) manual for Civil Engineering Works, as-built drawings and calculations should be submitted. Prior to the end of the Maintenance Period, a joint inspection should again be carried out to check if further works are required and that all outstanding or remedial works have been completed. For E&M works, relevant O&M training should be conducted and the O&M manuals for Electrical and Mechanical (E&M) Works, as-built drawings and design calculations should also be submitted. Prior to the end of the Defects Liability Period (DLP), a joint inspection should again be carried out to check if further works are required and that all outstanding works have been completed and defects rectified.

Reference should be made to the Project Administration Handbook and the relevant technical memoranda/circulars for details of handing over and taking over procedures.

8.2.2 Handing Over in Dry Conditions

Where possible, all pipes and culverts to be handed over should be inspected in dry conditions. When the pipes or culverts have to be commissioned prior to handing over (e.g. due to the requirement to maintain the existing flow or staged completion) and a temporary diversion of flow is not feasible, an additional inspection should be arranged prior to the commissioning. In certain circumstances and with the prior agreement of DSD, a closed circuit television (CCTV) survey of the pipe before commissioning can be adopted as an alternative to the joint inspection but prior agreement with the respective operation and maintenance division of DSD should be sought.

8.2.3 Documents to be Submitted

Usually, `as-built' drawings are unavailable for the handing over inspection. Marked-up prints of the working drawings showing the latest amendments and the extent of works to be handed over should be provided. Records of material quality and acceptance tests should also be available for scrutiny.

After the handing over inspection, the following documents should be submitted :

(a) as-built drawings, in hard-copy and electronic format if applicable;

(b) hydraulic and structural design calculations, in electronic format if available;

(c) construction records including major acceptance tests and material quality records, product specifications and warranties;

(d) O&M manual and system manual, where appropriate; and

(e) other maintenance manuals where appropriate.

In order to allow the project office to prepare the records (in particular the as-built drawings), it is usually acceptable that the records can be submitted some time after the handing over inspection but the records must be submitted before the expiry of the Maintenance Period of the Contract.

8.3 INSPECTION AND GENERAL MAINTENANCE OPERATIONS

8.3.1 Inspection Programmes

Inspection of all existing sewerage systems should be carried out regularly to ensure that the system is functioning properly. The frequency of inspection should be determined principally from the nature and importance of the installations, the likely consequences of malfunction, the frequency of complaints received in the vicinity and the resources available. Priority should be given to those installations where the result of failure would be serious or the remedial works particularly expensive.

The recommended frequency of inspections of sewers is shown in the following table. However, some locations may require a more frequent rate of inspection and each case should be considered individually.

Component	Frequency
Complaint black-spots	1 month to 6 months depending on location
Sewers within red routes, pink routes and expressways	1 year
Other sewers	1 - 5 years

8.3.2 Closed Circuit Television Surveys

Apart from visual inspections, closed circuit television (CCTV) surveys can also be used to investigate the condition and the structural integrity of the sewers.

It is essential that CCTV surveys are conducted during low flow conditions. If the flow quantity is high, the sewer upstream should be temporarily blocked and the flow diverted. An adequate lighting system should also be adopted so as to produce a clear picture of the sewer. Pipes should be cleaned prior to the survey.

The defect coding and structural assessment of culvert or pipeline with CCTV results should be made in accordance with the “Manual of Sewer Condition Classification” and “Sewerage Rehabilitation Manual” published by Water Research Centre.

8.3.3 Inspection within Red Routes, Pink Routes and Expressways

"Red" and "Pink" Routes are classified by Highways Department as the major road network in Hong Kong. The Red Routes and Pink Routes are sections of the major road network where the capacity and nature of the alternative routes are limited and the potential impact is very high if these routes are either partially or totally closed. The details of the Red and Pink Routes are shown in the relevant Highways Department Circular No. 5/2001 and 8/2003.

In order to minimize the adverse effect on traffic from urgent sewerage repair works and clearance works, regular inspections of the sewerage system within the Red and Pink routes should be given a high priority, so that preventive maintenance can be well planned and performed outside the peak traffic hours.

For works in expressways, the requirements stipulated in the Road Traffic Ordinance, and in particular the safety requirements, must be observed. It should be noted that all expressways are either Red Routes or Pink Routes and allowable working time may be restricted. The inspection programmes should preferably be carried out in conjunction with Highways Department's cyclic lane programmes. Reference should also be made to the relevant Highways Department Technical Circular.

8.3.4 Inspection of Drains behind Slopes

Persistent leakage of water from sewers and stormwater drains (including gravity pipes, channels, tunnels and rising mains) not only causes nuisance, but can also be a serious risk to the stability of slopes and retaining walls. Such leakage can deliver a significant amount of water into the ground and its potential effect on the stability of the slope or retaining wall should not be disregarded. Preventive measures in the form of regular inspection and maintenance should be carried out with reference to "Code of Practice on Monitoring and Maintenance of Water-carrying Services Affecting Slopes" (ETWB (2006)) and the latest Geoguide requirements. Where defective drains are found, repairs should be carried out immediately.

As a minimum, sewers and drains located within a distance of 'H' from the crest of a man-made slope/retaining wall, where 'H' is the maximum vertical height of the slope/retaining wall, should be inspected at the frequency in accordance with "Code of Practice on Monitoring and Maintenance of Water-carrying Services Affecting Slopes" (ETWB (2006)). The distance from the crest of the slope should be further extended where the sewers and drains are known to be leakage prone. Particular attention should be paid to pressurized rising mains as their leakage or bursting may lead to severe damage. More frequent leakage detection may be desirable for those rising mains behind slopes and retaining walls in the high Risk-to-Life (i.e. Consequence-to-Life) Category as classified by GEO Technical Guidance Note No. 15 (GCO (2004)). The frequency shall be decided based on the prevailing conditions of the slopes/retaining walls and the rising mains. Records of inspections should be sent to the maintenance agent of the slope likely to be affected by the sewers or drains.

8.3.5 Desilting Programmes

Desilting of pipes and culverts is required so as to maintain the flow capacity. The frequency of desilting varies from pipe to pipe and depends on the pipe size, gradient, flow condition, type of sewage, the pipe capacity etc. subject to the verification of inspection results. Experience indicates that regular desilting at complaint black spots can reduce the complaint frequency. It is important to identify the causes of complaints. If they are attributed to the capacity of the system, consideration should be given to other long term solutions including improvement or modification to the existing systems.

8.3.6 Methods for Desilting/Cleansing

Manual rodding and scooping is the simplest method used in cleansing blockages. A rod with a hook or spike is driven manually into the pipe to pierce through the blockage. Solids produced will be collected at the downstream manhole and removed by scoops. This method requires the least equipment. The set-up time is minimal and it is very effective in clearing local chokage caused by refuse or debris. However, sometimes only a small hole is made in the chokage and the pipe is not cleaned thoroughly and chokage tends to recur. When the manhole is deep, length of the pipe is long and the pipe size is large, rodding is not effective.

Water jetting is a common method for pipe cleansing. A hose is led into the pipe, usually from downstream end, and water under high pressure of 300 Bar or higher pushes the hose forward while at the same time washing away the substances accumulated inside the pipe. This method is particularly effective in clearing blockages caused by oil and grease. It is also very effective in clearing the grease stuck onto the pipe wall enabling the inspection of the pipe surface condition. However, the effectiveness of water jetting decreases with the increase in pipe diameter and is seldom used for pipes greater than 900mm diameter. Water jetting is also not effective for pipes of length exceeding 100m due to the handling difficulty of the hose.

Apart from normal cleansing, there are proprietary products available in the market for mounting onto the head of the water jetting hose for breaking through hard material.

Winching is another commonly used method for the thorough cleansing of pipes. A `ball' or bucket is towed to and fro along a section of sewer between two manholes several times by a pair of winches. The silt and debris inside the pipe can be scraped out. This method can be used for various sizes of pipes and is very effective in removing silt and semi-large particles inside the pipe. Some specially made `balls' can also be used for breaking hard material.

8.4 SEWERAGE REHABILITATION

8.4.1 Pipe Replacement

When pipes are found to be damaged, repair work should be carried out as soon as possible before the situation gets worse. In most cases, replacement of the damaged pipes by open excavation is the cheapest method and is the most effective way to make the repairs.

When replacing defective pipes by open excavation method, attention should be drawn to the following :

(a) maintenance of the existing flow;

(b) the traffic conditions;

(c) the presence of underground utilities;

(d) nuisance and inconvenience to the public;

(e) excavation dewatering; and

(f) working area and shoring requirements.

Close liaison with the utility undertakings and traffic authorities is required before the replacement work is carried out so that suitable construction methods and temporary work requirements can be determined.

Open excavation may occupy road space for long period of time. The public is becoming less tolerant of traffic disruption, and trenchless methods for pipe rehabilitation should be considered as an alternative to open excavation.

Many of the defective sewers in the urbanized area have become undersized because of city expansion and redevelopment, and if feasible the chance should be taken during the remedial works to replace them with larger pipes.

8.4.2 Trenchless Methods for Repairing Pipes

Several trenchless rehabilitation methods are described in the following paragraphs. It should be noted that the list is not exhaustive and there may be some other methods which would be applicable.

(1) *Joint Grouting*. This method is used where sewers are leaking through the joints, but are otherwise structurally sound. Chemical grout is pumped into the pipe joint and fills up the void surrounding the leaking joint to seal it. For small sewers the chemical grout is internally applied by an inflatable packer guided by a CCTV camera and the same packer is used to test for air tightness of the grouted joint. For large pipes it may be more convenient to send people into the sewer to carry out the grouting directly.

The method has also been used to repair leaking joints inside submarine outfalls and inverted siphons. Equipment involved is generally simple, and the cost of remedial works is low when compared with the traditional replacement of sewers. Its applicability, however, is limited to sewers suffering from open joints without other structural defects.

(2) *Relining Using Epoxy Impregnated Liner*. This method uses a factory fabricated lining tube to form a continuous solid pipe inside the original sewer to be rehabilitated. The polyester lining is firstly impregnated with specially formulated resin in the factory. When delivered to site and installed in position, the liner is expanded so that it makes contact with the interior of the defective sewer. The temperature is increased inside the liner to cure and harden the resin. Any branch connections can be restored with a remotely controlled hole cutting machine.

The method is generally applicable for small to large size pipes, including oval and egg shaped sewer. It can negotiate smooth bends, but wrinkles may develop at sharp bends. It adds extra structural strength to the original pipe and offers good chemical and corrosion protection for all sort of environment. The internal diameter of the pipe is slightly reduced by the thickness of the liner, but the liner provides a smooth surface to the pipe which may improve the flow capacity.

The equipment required for the method is sophisticated. Special equipment is required to ensure proper and even impregnation and to remove the air inside the polyester felt. Proper use of inhibitors and control of surrounding temperature are important to prevent premature curing before insertion. The set up for insertion and heating is also demanding. The method is therefore expensive, especially if only short lengths are to be lined.

(3) *Relining Using Pre-deformed Polyethylene Liner*. This method involves placing a factory made polyethylene liner inside the defective sewer. The liner is first deformed and pulled through the existing sewer by winches. Water at high temperature and pressure is then used to cure and to restore the circular shape so that the liner fits snugly inside the old pipe.

The method is applicable for sewer ranging in size from 100 to 450mm diameter. It can only negotiate large radius bends, and is not as flexible as the epoxy impregnated liner. It can be used to seal joints and cracks, and to improve the flow characteristics and chemical resistance. However, the interior of the old pipe must be smooth, and without serious obstructions. The working space within the manholes must be quite large also.

(4) *Relining Using Smaller Pipes*. This method involves pulling or pushing a thin walled pipe made from steel , GRP, HDPE or other materials, through a defective sewer. The size of the new pipe is smaller than the old pipe. The pipes are generally jointed by welding as they are pushed. The annular space between the new and the old pipes is grouted.

The main disadvantage of this method is the large reduction in size, and that a large space is generally required at the inlet. It cannot go through even large radius bends. It works better for large diameter pipes where the reduction in size is less significant. Branch connections are also quite difficult unless the sewer is large enough for human access.

(5) *Pipe Bursting.* This method, sometimes called the pipe eating system, employs a powerful hydraulic expander which progressively destroys and expands the old pipe as it advances itself through the pipe. The replacement pipe, generally of larger size, is pulled in behind the bursters. The method has been used overseas, but potential applicability in Hong Kong is rather limited because of the close proximity of other utilities which may be damaged easily.

8.5 DRY WEATHER FLOW INTERCEPTORS

8.5.1 Inspection

The objectives of inspection are :

(a) to reveal clogging and blockage in pipes, screens, and associated sewers and stormwater drains so that remedial action can be taken;

(b) to monitor the performance of the control devices/mechanism and to check the rate of flow intercepted and diverted; and

(c) to examine the condition of the structures and mechanical installations such as pumps, flap valves etc.

Experience shows that the frequency of inspections required for dry weather flow interceptors ranges from fortnightly to yearly and the frequency depends on the performance of individual components. For interceptors located in stormwater drains or open nullahs, where the flow is known to carry a large amount of silt and rubbish, more frequent inspection is normally required. In addition, it is advisable to carry out an inspection after the first heavy rain of each year and after each severe rainstorm.

The frequency should be adjusted in the light of experience on the performance of the interceptor.

8.5.2 Cleansing

Together with the inspection, the dry weather flow interceptors should be desilted and cleaned to remove rubbish, grit, and sludge. A regular cleansing schedule should be drawn up for the silt traps, and screen chambers.

8.6 INVERTED SIPHONS

8.6.1 Flushing

As inverted siphons are operated under submerged flow conditions, the chance of silt accumulation is much higher than normal. Even though inverted siphons are usually designed such that a self-cleansing velocity can be maintained during very low flow conditions, siltation can still occur.

To reduce the accumulation of silt, it is advisable to carry out regular flushing. This is particularly important for inverted siphons spanning over 100 m, because of the difficulty in carrying out desilting. The frequency of flushing can range from weekly to quarterly and depends very much on the configuration and flow in the inverted siphons. The frequency should be adjusted in the light of experience.

8.6.2 Inspection and Desilting

The frequency of inspection for inverted siphons is normally higher than that for normal sewers. Under normal circumstances, inspection should be carried out not less than twice per year. Cleaning and desilting should be taken place, if required, after the inspection.

8.7 CONNECTIONS TO EXISTING SEWERAGE SYSTEM

8.7.1 Existing Capacity

When a connection to the existing sewerage system is required, the capacity of the existing system should be checked to see whether it has adequate spare capacity to accommodate the flow from the proposed connections and whether enlargement or duplication work is required.

8.7.2 Terminal Manholes

For every sewer connection from a private development, government building, park or housing estate, a terminal manhole in accordance with DSD Standard Drawings should be provided and positioned within the lot as near to the site boundary as possible. The terminal manhole is designed to form a demarcation of maintenance responsibility and to protect the public sewerage system from damage or blockage due to the indiscriminate discharge of sewage by the occupants of the land served by the connection. The terminal manhole also acts as a seal to stop passage of gases from the public sewer to the internal sewerage system creating a nuisance.

8.7.3 Provision of Manholes

Direct connection by Y-junction to existing pipes should be avoided and manholes should always be provided for connections to existing pipes. For existing pipes larger than 900 mm in diameter, where the construction of new manholes would be difficult, connections should always be made to existing manholes.

8.8 DRAINAGE RECORDS

The existing drainage records should be updated to include all newly constructed sewers and installations.

For all new works handed over to DSD for maintenance, as-constructed drawings and documents as specified in para. 8.2.3, in hard copy and electronic format, containing the geographical and topographical data should be passed to the drawing office for retention and incorporation into the existing drainage record drawings as soon as possible. All manhole positions with details of cover levels, invert levels, diameters and the directions of all the connecting pipes should be given in the drawings. For all other special installations and special manholes, as-constructed drawings showing the details are required. The hydraulic and structural calculations, in hard copy and electronic format containing the hydraulic models if available, should also be provided to supplement the drawings.

For all repair works, sewer connections and minor improvement works carried out during the maintenance operations, the as-constructed survey should be made on completion of the work. All changes in levels, positions and sizes should be surveyed and the results should be incorporated into the drainage records.

8.9 SAFETY PROCEDURES

8.9.1 General

It must be emphasized that working in a confined space such as an underground sewer, is a very dangerous task. Great attention should also be paid to safety whenever working under adverse weather conditions.

8.9.2 Working in Sewers

Working within the confined spaces associated with sewers is dangerous. The gases emitted by sewage may be lethal. Sewers may contain industrial waste making it impossible to predict what gases are present. Injuries may occur by falling, slipping or misuse of tools and equipment. Sewer workers are also subject to the additional hazard of the sudden in-rush of high flows or a sudden release of toxic, corrosive or hot liquid.

8.9.3 Safety Requirements for Working in Confined Space

Working in a confined space such as an underground drain, box culvert, tanks, etc., is potentially dangerous. Great care must be taken at all times, particularly when working under adverse weather conditions. The legislative requirements of the Factories and Industrial Undertaking (Confined Spaces) Regulation have to be followed. Reference should be made to Labour Department Code of Practice : Safety and Health at Work in Confined Space, DSD Practice Note No. 3/2012 and DSD Safety Manual (2010) or their latest versions, for the legislative requirements and good safety practice for working in confined space. The essential elements of which include:

(a) Appoint a "competent person" to carry out a risk assessment and make recommendations on safety and health measures before undertaking work in confined space.

(b) Allow only "certified workers" to work in the confined space.

(c) Operate a "permit-to-work" system.

(d) Conduct atmospheric testing of the confined space before entry.

(e) Provide adequate ventilation.

(f) Isolate the confined space.

(g) Monitor the air quality throughout the entire working period by means of a gas detection device.

(h) Ensure a "standby person" is stationed outside the confined space to monitor the weather condition and maintain communication with the workers inside.

(i) Ensure the use of approved breathing apparatus (if recommended in the risk assessment report) and other necessary personal protective equipment by workers inside the confined space.

(j) Formulate and implement appropriate emergency procedures to deal with serious or imminent danger to workers inside the confined space.

(k) Provide necessary instructions, training and advice to all workers to be working within a confined space or assisting with such works from immediately outside the confined space.

Based on experience, it is considered necessary to add a second line of defence to enable an early warning signal to be given out so as to increase the possibility of escape or being rescued when the prescribed safety measures fail. The following enhanced safety measures are introduced for DSD confined space work, unless the risk assessment demonstrates that such measures produce no added benefit to safety at work:

(a) Continuous Gas Monitoring: The person entering a confined space shall bring along a gas detector, which can give out warning signals of the sudden presence of dangerous gases or oxygen deficiency, to continuously monitor the atmosphere so as to enable immediate evacuation; and

(b) Personal Alarm: A personal alarm of dead-man type, which is able to give out signals soon after a person loses his mobility (commonly 20 seconds), shall be worn by all persons entering a confined space to facilitate early rescue.

8.9.4 Working under Adverse Weather Conditions and during Flooding

Officers should always take note of the prevailing warning messages issued by the Hong Kong Observatory, in particular the following:

(a) Thunderstorm Warning;

(b) Rainstorm Warning Signals;

(c) Tropical Cyclone Warning Signals;

(d) Landslip Warning;

(e) Strong Monsoon Signal;

(f) Special Announcement on Flooding in the Northern New Territories;

(g) Very Hot Weather Warning;

(h) Cold Weather Warning; and

(i) Rain Alert.

Some safety guidelines for working under adverse weather conditions are given in DSD Safety Manual (2010) or its latest version.

9. TUNNEL SEWERS

9.1 GENERAL

The tunnel sewers described in Section 9.2 refer to those which operate under partial flow conditions or where the sewage/treated effluent can be temporarily diverted and the tunnel sewers can be inspected under dry conditions. Deep tunnel sewers which operate under submerged flow conditions, such as tunnel sewers well below sea level constructed under the HATS, are included in Section 9.3.

9.2 TUNNEL SEWERS

9.2.1 Introduction

As access to tunnel sewers is not easy, the normal maintenance operations for ordinary sewers are not applicable. Sewer tunnels are normally very long and inspections have to be carried out using specialised plant and equipment. Tunnel inspection vehicle should be spark proof. Special arrangement has also to be made to temporarily divert the sewage/treated effluent flow and to ventilate the tunnels prior to the carrying out of inspections or other maintenance operations.

A comprehensive and fully detailed operation and maintenance manual should be prepared at the design stage of each tunnel such that the maintenance procedures can be fully agreed and appropriate provision made in the design.

9.2.2 Flow Control in Tunnel Sewers

Tunnel sewers should be designed so that the sewage/treated effluent flow can be controlled upstream at the inlet chamber or upstream treatment plant. During inspection and maintenance, sewage/treated effluent flow has to be stopped from entering the tunnel and diverted by penstocks or similar control installations.

9.2.3 Monitoring of Hydraulic Performance

As inspection of tunnel sewers is difficult, the monitoring of hydraulic performance will be a good indicator of the tunnel conditions in respect of siltation, structural damage or other defects. The head loss of the sewage/treated effluent flow through the tunnel should be monitored. If there is an increase in the head required, this may be a sign that there are some problems and that a detailed inspection is required.

9.2.4 Inspections

Inspections should be conducted on a regular basis in accordance with the operation and maintenance manual to be provided for each individual tunnel. An inspection frequency of between 2 and 5 years would be quite typical. Inspection should also be carried out if there are any signs of defects as revealed from the hydraulic performance. The inspection should identify the presence of any spalling, cracking, leakage, or cavities behind the lining and accumulation of deposits.

Inside tunnel sewers are confined space and safety supervision of tunnel sewers inspection should follow the DSD Practice Note No. 3/2012 – "Safety Supervision of Work in Confined Space", or its latest version. This Practice Note should be read in conjunction with the Factories and Industrial Undertakings (Confined Space) Regulation; Code of Practice for Safety and Health at Work in Confined Space; and DSD Safety Manual.

As tunnel sewers are usually very long, the inspection team may require tunnel inspection vehicle for transport of staff and equipment. The following steps and precautions should be observed prior to and during inspection:

(a) the tunnel should be drained and ventilated prior to entry and adequate ventilation should be maintained throughout the inspection;

(b) breathing apparatus must always be readily available;

(c) the team must be provided with gas detectors capable of detecting the level of oxygen, methane and inflammable gases, hydrogen sulphide, carbon monoxide and other toxic gases which are likely to be present;

(d) if at any time the gas detectors show that toxic or explosive gases are present, the inspection team should use the breathing apparatus and evacuate the tunnel as soon as possible;

(e) protective clothing must be worn and personal alarm (dead-man type) must be equipped;

(f) risk assessment and permit-to-work system must be implemented;

(g) a rescue team should be set up to deal with emergencies; and

(h) communication between the inspection team and the rescue team must be established and maintained throughout the inspection.

9.2.5 Maintenance

If maintenance work is required, the tunnel must be ventilated and a continual supply of fresh air provided. Petrol or diesel engines should not be used. Procedures for maintenance works shall generally follow those required for inspections of tunnels in Section 9.2.4 and the Operation and Maintenance Manuals prepared for the sewage tunnels.

The O&M Manual shall include, amongst other essential information the following:

(a) items to be inspected, possible defects, repair methods with labour, materials and plants specified;

(b) regular maintenance works required such as desilting with detailed method statements, labour, materials and plants specified;

(c) a maintenance schedule with frequency of inspection, proposed structural inspection by Registered Structural Engineer or engineer with tunnel design/construction experience with scope and frequency given;

(d) authorities to be notified such as FSD, EPD, etc. before and after inspection, operation or maintenance works;

(e) arrangement for flow bypass, diversion or temporary storage;

(f) temporary traffic arrangement with approved traffic diversion plan;

(g) safety procedures; and

(h) emergency contingency plans, escape routes, and agreed rescue procedures etc.

Project team may be required to demonstrate successful inspection and maintenance operations before handover to O&M team.

9.2.6 Potential Problems and Remedial Actions

(1) *Spalling or Deterioration of Concrete*. The main causes of concrete deterioration are corrosion of reinforcing steel, sulphate attack, carbonation and alkali-silica reaction. If severe deterioration is observed, the concrete in the affected area should be hacked off until sound concrete is exposed. Any exposed reinforcement should be cleaned and additional reinforcement should be provided if necessary. The affected area should then be cleaned and filled with cement rich mortar or sprayed concrete. In highly corrosive environments, special protective coatings should be applied to the concrete surface.

(2) *Cracks in the Lining*. Transverse cracks are likely to develop with changes in the external loads or in the lining thickness. They may be caused by variation in the properties of the ground and abrupt changes in overburden depths. Longitudinal cracks, which usually appear along the crown or the spring line, will develop as a result of inadequate load-carrying capacity of the tunnel section. Diagonal cracks may appear as a result of uneven vertical movements. Short cracks are caused by local overstress or flaws in the lining material or poor workmanship.

The cause of cracks should be investigated so that appropriate remedial measures can be taken accordingly.

(3) *Leakage*. The watertightness of the tunnel lining is important, but absolute watertightness is very difficult to achieve. If the volume of flow is significant, or the water carries silt or the surrounding ground is loosened, the leaks should be sealed by pressure grouting.

(4) *Cavities behind Lining*. Cavities behind the lining are detrimental, not only because of the loss of composite action with the surrounding ground, but also because of the erosive action of groundwater, which may cause blocks of rock to separate and add to the loads on the lining. The detection of cavities behind the lining can be achieved by means of dynamic, electronic instruments or radioactive isotopes. Any cavity so discovered should be marked on the lining for further observations or repair.

(5) *Accumulation of Deposits on the Tunnel Invert*. Normally, tunnel sewers are designed with self-cleansing velocities at low flow. Therefore, the problem of heavy solid matter settling in the tunnel is rare. However, in the event that accumulation of deposits does occur, the deposits should be removed by the most appropriate means.

9.3 DEEP SEWAGE TUNNEL SYSTEM

9.3.1 Introduction

This Chapter addresses the considerations relating to the planning and design of deep sewage tunnel system. Deep sewage tunnels refer to deep sub-sea or underground tunnels for the conveyance of sewage. They are designed to mainly operate either as inverted siphons or rising mains under submerged flow conditions. Intermediate transfer pumping stations may be required to maintain flow at sufficient hydraulic heads.

9.3.2 Choice of Deep Sewage Tunnel System

A deep sewage tunnel system normally forms the trunk sewer network for sewage collection. If properly designed, it can have the following advantages:

(a) to avoid road opening work, minimizing disruption to traffic and environmental nuisances to the public;

(b) to avoid conflicts with existing and planned underground utilities and underground infrastructure; and

(c) to provide flexibility in adopting a relatively straight alignment by avoiding building foundations and not be restricted by existing road configurations as for shallow pipe system.

Before a decision is made to adopt a deep sewage tunnel system, designers should assess the merits and demerits of adopting such a system as compared with a shallow sewer system. Different construction forms of the shallow sewer system such as trenched pipelines, pipe jacking or shallow tunnelling should be evaluated for comparison with the deep sewage tunnel system. This assessment should be conducted for all individual sections of the sewer system. The assessment should compare the pros and cons of the various aspects of the different systems including the following:-

(a) Constructability: Geological and hydrogeological conditions along the tunnel alignment should be properly studied with specialist's assistance to assess matters that would affect the constructability of the tunnel at different depths. The extent of weak and/or permeable ground such as fault zone, fractured rock or soft soil stratum and their effects on the method of construction should be assessed. It is important to study carefully these aspects during the planning and design stages. However, constructing a tunnel in the hard rock stratum may not necessarily get rid of the difficult geological problems associated with tunnel construction.

(b) Cost and Programme: The assessment should include a comparison of the cost and programme associated with the different construction schemes. The availability of intermediate access to the tunnel and the length of individual tunnel sections may have important bearing on the cost and programme of the tunnel system. The operating cost to cater for the lifting of sewage conveyed through the deep sewage tunnels should be given careful consideration.

(c) Environmental and Social Impacts: A shallow pipeline constructed using conventional trenching may cause serious environmental and social impacts during construction. Construction of shallow or deep tunnels using tunnel boring machines or the drill and blast method may have comparatively lesser environmental and social impacts during construction.

(d) Risks: The construction of deep sewage tunnel system involves high risks that need to be managed by well-planned ground investigation, careful selection of the alignment and the construction method, contractual measures and other risk mitigation measures.

(e) Operation and Maintenance: The concern about effective operation and maintenance of deep sewage tunnels should be addressed. Reference could be made to Sections 9.2.5 and 9.3.10.

9.3.3 Tunnel Construction Methods

Tunnel Boring Machines (TBM) and Drill and Blast Method (D&B) are the most common methods to construct deep tunnels. The aspects mentioned in (a) to (d) in the lower part of Section 9.3.2 should be evaluated before a decision is made on the construction method for the individual sections of tunnels. For procurement by D&B Method, it is worth noting that prior consultation to the public, the utility undertakers and the authorities are essential in order to address the major concerns associated with the vibration caused by blasting and the logistics of delivery of explosives.

9.3.4 Site Investigation (SI)

Reference should be made to existing geotechnical information such as those documents available in Geotechnical Information Unit of the Civil Engineering and Development Department in working out the SI plan to determine the alignment and the level of the deep sewage tunnels. In addition to drilling boreholes and carrying out in-situ tests, designers should consider the need to conduct further SI by the application of state-of-the-art technology such as various kinds of geophysical surveying methods and horizontal directional coring (HDC) which is a technique used to collect continuous samples and conduct in-situ testing along or close to the proposed tunnel alignment.

9.3.5 Land Requirements

Designers should identify suitable sites for the construction of the deep tunnels and associated shafts. They should also make reference to the Sewage Tunnels (Statutory Easements) Ordinance which provides for the creation of easements and other rights over land in favour of Government for the purpose of the construction, maintenance and operation of sewage tunnels and for connected matters. Sufficient time should be allowed for land search and subsequent procedures to complete the gazetting, resolution of objections, amendments and authorization before construction commences.

9.3.6 Protection of Deep Sewage Tunnels

Consideration should be given to protect the completed deep tunnel system and associated structures against damage caused by construction works or ground investigation works in the vicinity[2].

9.3.7 Geotechnical Control for Tunnel Works

There is a need to deploy geotechnical expertise during the planning, design and construction of the deep tunnel system. Designers should refer to the relevant technical circulars or the Project Administration Handbook for Civil Engineering Works on geotechnical control for tunnel works.

9.3.8 Sizing of Deep Sewage Tunnels

Deep sewage tunnels are in general more difficult to maintain than the shallow sewers and hence designers should consider whether the deep sewage tunnels need to be designed and sized to achieve a certain minimum flow velocity so as to adequately scour the grit particles and other suspended solids to prevent accumulation of sediment along the tunnels. Reference could be made to the relevant available results of recognized research works, e.g. research done by CIRIA (Construction Industry Research and Information Association, London, UK). Designers should also consider if a sampling and testing plan needs to be devised to investigate the characteristics of the sewage to be conveyed in the sewage tunnel system in order to better estimate the minimum flow velocity required. There may be cases where it is necessary to add flows, e.g. by adding seawater, to achieve the minimum flow velocity.

9.3.9 Gradient of Deep Sewage Tunnels

Designers should consider the need to avoid possible accumulation of air pockets in the deep sewage tunnels which could cause corrosion to the surrounding materials. If such

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2 Reference can be made to the protection mechanism for the existing HATS Stage I Sewage Tunnels.

air pockets are released, they will expand significantly on reaching the surface due to the significant reduction in pressure and this significant air volume may blow out almost explosively, if uncontrolled. The gradient of the sewage tunnels is a major factor that governs the move of an air bubble. Both upward and downward sloping deep tunnels have been constructed either locally or overseas. Designers should evaluate the pros and cons when choosing the tunnel gradient which may have an impact to other considerations such as the construction method.

9.3.10 Operation and Maintenance Considerations

During the planning and design of a deep sewage tunnel system, designers should properly address operation and maintenance issues which may include:-

(a) Scum Removal: Accumulation of scum, especially in the upstream shafts, may cause operation and maintenance problems.

(b) Release of air in Drop Shaft: The drop shaft should be designed to include features to effectively dissipate excessive energy and to minimize air entrapment in the flow entering into it.

(c) Tunnel and Shaft Lining: For deep sewage tunnels and associated shafts, lining should be designed to withstand the expected conditions of exposures. Additional corrosion protection to the wetting zone of the surface of the structures should be considered.

(d) Deodourization: Designers should check for the generation of odour during operation of the deep sewage tunnel system and devise appropriate mitigation measures.

(e) Stagnant sewage: Designers should consider the possibility of long stoppage of the system and the need to dilute the stagnant sewage during the stoppage.

10. TRENCHLESS CONSTRUCTION

10.1 INTRODUCTION

Trenchless (no-dig) construction methods have been used in various DSD projects and some of the successful applications were presented in the technical papers identified in the reference list. Trenchless construction method in this chapter refers to means for laying of pipeline (or construction of culvert) of less than 3 metres in diameter without opening up the ground surface above, which might be a more cost-effective alternative if it is at all allowed or permissible. The difficulties for opening up the ground surface in Hong Kong especially in the vicinity to the heavily inhabited area are various such as unbearable disruption to traffic or business activities, physical obstructions (above or below ground), prolonged construction period, construction problems and adverse factors on environmental & other technical grounds.

Trenchless construction methods can be classified based on whether man-entry would be permitted for the normal excavation operation along the alignment of pipeline (or culvert). In this regard, they are broadly classified into two main types, namely 'man-entry' type and 'non-man-entry' type for the context of this Manual. The main reason for such classification is safety orientated as the safety concern and requirements would be more stringent for former type.

For the avoidance of doubt, if some smaller diameter inner pipelines are to be laid within a larger sleeve pipe or lining pre-formed beforehand, only the operation for constructing the sleeve pipe or lining is to be governed by this classification. The safety measures or requirements for subsequent laying of the inner pipelines especially when such operation might render health or safety hazards to workers such as difficulties to swift evacuation should be dealt with by other provisions under the construction contract.

Similar to other confined space work under DSD's jurisdiction, contractor's workers who need to participate in the trenchless construction would need to comply with the competence enhancement training requirements stipulated in DSD Technical Circular No. 3/2012, or its latest version, as appropriate.

10.2 NON-MAN-ENTRY TYPE

The usual conditions associated with ordering this type of trenchless method includes pipeline at considerable depth, long distance between adjacent access shafts and susceptible ground conditions. After stipulating this type of trenchless method in the construction contract, strictly no man-entry for normal excavation operation of pipeline (or culvert) should be allowed for unless the Engineer is satisfied that the risks perceived at the planning and design stages have all been cleared or for performing rescue operation for the malfunctioning tunnel boring machine or other essential equipment trapped below ground.

Under this type of trenchless method, those types of tunnel boring machine (TBM) equipped with a remote-control for normal excavation operation can usually be adopted. However, some models of TBM which require frequent manual removal of foreseeable obstruction such as hard strata or rock are unlikely to meet the said 'non-man-entry' requirements in this connection. In addition, other means known as hand-dug tunnels, headings and hand shield methods that require constant manual input for normal excavation operation obviously cannot meet such requirements.

Some basic information in respect of these methods that can meet the 'non-man-entry' requirements are highlighted below which are by no means exhaustive. Project engineers and designers are to satisfy themselves that any particular method accepted can really perform the required functions.

10.2.1 Slurry Pressure Balance Method

It is a TBM with a bulkhead located behind the face to form a pressure chamber. Bentonite slurry or other medium is introduced into the chamber under appropriate pressure to equalise ground pressure and to be mixed with material excavated by rotary cutterwheel. The bentonite slurry forms a temporary filter cake on the tunnel face which the slurry exerts pressure to support the ground. The continuously forming filter cake will be cut away by the rotary cutterwheel as the TBM advances. The excavated spoil will be removed from the pressure chamber by the slurry circulation system.

10.2.2 Earth Pressure Balance (EPB) Method

The EPB method consists of a cutting chamber located behind the cutterhead. This chamber is used to mix the soil with water foam/soil conditioner. It is maintained under pressure by the screw mucking system. The ground at the cutting face is supported by the resultant pressure balancing the increase in pressure due to advancement of the TBM and the reduction in pressure due to discharge of the excavated spoil.

The underlying principle of the EPB method is that the excavated soil itself is used to provide continuous support to the tunnel face by balancing earth pressure against the forward pressure of the machine. The thrust forces generated from rear section of TBM is transferred to the earth in the cutterhead chamber so as to prevent uncontrolled intrusion of excavated materials into the chamber. When the shield advances, the excavated soil is mixed with the injected special foam/soil conditioner material which changes the viscosity/plasticity of the spoil and transforms it into a flowing material. With careful control of the advance thrust force of the TBM and the rate of discharge of the spoil, adequate pressure could be maintained in the pressure chamber for supporting the tunnel face during the excavation process.

10.3 MAN-ENTRY TYPE

As indicated by the category name, man-entry would be permitted under this type of trenchless construction. Thus, adequate underground working space should have been ascertained by the designer at the pre-contract stage. Thorough study on the record drawings of the existing structures and utilities for the entire alignment along with any necessary ground investigation (including geophysical survey) should be conducted prior to allowing this type of trenchless method in the construction contract. According to the current safety standards, underground access to workers should be of 1.2m diameter minimum. Besides, sufficient area at the access shafts should also be obtained as back-up area to cater for emergency.

Some basic information in respect of these methods that can meet the 'man-entry' requirements are highlighted below which are by no means exhaustive. Project engineers and designers are to satisfy themselves that any particular method accepted can really perform the required function.

10.3.1 Heading Method

Heading method is a simple form of constructing hand-dug tunnel using structural frame as ground support during manual excavation. Minimum excavation dimensions of at least 1.5m x 1.5m are typically required for installing usually short-length pipelines crossing underneath road junctions, underground utilities and services and entrance to car parks in shallow depth. The completed works have demonstrated its effectiveness due to fast mobilization of plant, simple set-up on site, and flexibility in construction method to suit the limited space available.

Safety and ground condition risks must be carefully considered for this form of construction. Designers shall exercise reasonable skills and care to check that no other form of construction is appropriate and the ground conditions that are expected to be encountered during excavation are unlikely to impose unacceptable safety risks to the workers before deciding to adopt heading construction.

10.3.2 Hand-dug Tunnel Method

Hand-dug tunnel (i.e. open mode) is the technique of installing pipes by forming a tunnel with manual excavation inside the handshield from the entry pits to the end pits. The excavated materials are transported to the ground level through a trolley system and lifted up by lifting gantry installed at entry pit. Segments of tunnel frames are constructed one after the other until reaching the end pits. It is effective when the alignment of a pipeline (or culvert) has to pass through mechanical obstructions like walls and artificial hard materials which can be removed by manual means. However, emphasis has to be placed on pre-treatment to the ground prior to excavation to avoid instability of tunnelling soil face. Excavation at tunnel face could be accelerated by using pneumatic tools or by mini-backhoe if the size of tunnels allows.

10.4 MAJOR CONSIDERATIONS

10.4.1 Planning & Design Stage

(a) Existing Underground Conditions

The roads in the urban areas of Hong Kong are generally congested with underground utilities and services of different types and sizes at different depths. When planning a pipeline using trenchless construction, the level and alignment shall be designed to avoid diversion of existing utilities and services as it involves open excavation. Sufficient information shall be obtained and trial pits or other means shall be carried out to verify the depth and locations of all underground utilities in the vicinity of the proposed alignment & level of trenchless pipeline.

(b) Alignment & Level

Construction of a pipeline (or culvert) normally follows the alignment of the road. Pipe jacking is well applicable for straight driving, though slightly curved driving is possible with the latest technology; therefore, pipe jacking is not feasible in areas that require sharp bends unless additional intermediate jacking/receiving shafts are constructed.

Trenchless construction is often applicable for deep pipes in order to avoid underground utilities, felling of valuable trees and unacceptable ground movement. Hence, it is not suitable for very shallow pipe installation. Construction of deep pipelines may encounter bedrock or boulder which presents difficulty in pipe jacking. Hand-dug tunnel construction would be an alternative in such scenario while microtunnelling could also drill through rock and artificial hard material. Comprehensive planning and implementation of site investigation would help to reduce the risk of unexpected ground conditions. It may not be practical to carry out thorough drilling along the whole alignment of the pipeline. In most circumstances, directional coring and geophysical methods should be considered along the whole alignment of the proposed trenchless pipeline.

For pipeline (or culvert) construction in long length, it may be worthwhile to consider adopting different forms of construction for different sections of the pipeline between intermediate temporary shafts to suit changing conditions along the pipe alignment.

(c) Locations of Jacking/Launching and Receiving Shafts

Jacking shaft and receiving shaft between a pipeline (or culvert) should be selected to avoid conflicting with traffic and major utilities or minimize their diversions. The choice of the locations of the launching shaft and the receiving shaft depends on a number of factors such as the positions of permanent manholes, the hydraulic design of water flow, the maximum length of pipelines for the ease of future maintenance and the required working space. Substantial working space is required for launching shaft, receiving shaft and slurry treatment plant (for slurry operated TBM method). Thus, the area occupied by the shafts and slurry plant shall be considered in space limited works fronts during design stage. Due consideration should be given to temporary traffic arrangement schemes and application of Excavation Permits in stages.

The underground condition generally governs the geometry of the shaft. Rectangular shaft is usually constructed because it can be modified without much difficulty to accommodate existing utilities and services. However, at locations where these features are absent, circular shaft is used due to the smaller member size of temporary works required.

The shape and size of a shaft need to be tailor-made to suit utility constraint, resulting in the possible use of a combination of sheetpiles and pipe-piles to overcome the problem. For deep shaft, grouting is always required along the perimeter to ensure watertightness and hydraulic failure at the base of the shaft, before excavation is to commence.

(d) Site Investigation and Design

Thorough site investigation shall be carried out at the design stage. The site investigation result is essential to the design and procurement of machine for trenchless construction. Designers shall take into account the tunnel face stability, face support pressure, dewatering effects, ground loss and ground movement estimation, etc in the design. With regard to ground control slurry TBM method, guidelines for design calculations and work procedures shall be made reference to GEO Report No. 249.

10.4.2 Construction Stage

(a) Alignment & Level Control

The pipe jacking works in Hong Kong using TBMs generally shall follow the "Specification for Tunnelling (BTS and ICE, 2010)" as guideline for controlling tunnel alignment, in that a tolerance of 50mm is specified for line. However, deviation in more than the tolerance may occur at locations with unfavourable ground conditions. The tunnel alignment is corrected by suitable extension or retraction of the steering cylinders installed in the TBM. The use of TBM with 4 nos. steering cylinders offers better control in alignment than that with 3 nos. It requires a long period of time to correct any out-of-tolerance in alignment in order to avoid causing damage to the jacking pipes. However, allowance has to be made to account for the irregular profile of the tunnel, due to different ground conditions encountered during excavation, which could affect installation of the permanent pipeline therein to the required alignment.

The level control shall also follow the "Specification for Tunnelling (BTS and ICE, 2010)", in that a tolerance of 35mm is specified for level. In case of the pipeline exceeded the tolerated 0.5 degree angular deflection at pipe joint, there is a need to carry out a detailed inspection to ensure that there is no dislocation thereat. To better control the hydraulic performance of a pipeline (or culvert), tighter tolerance on invert level in the order of few millimeters may be adopted. For excessive opening in pipe joint, remedial measures have to be carried out. This can be achieved by locally trimming the concrete at the pipe end for better bonding before applying non-shrinkage epoxy, with a strength equivalent to the pipe, to fill up the problematic location for prevention of ingress of water.

(b) Safety Concerns

(i) Working under compressed air

The adoption of compressed air hand-dug tunnelling method would face a problem associated with air loss in porous ground, giving rise to the necessity of carrying out ground treatment to safeguard the tunnel and the personnel working inside. The switch-on of compressors and generators round–the-clock to maintain the pressure in tunnel also causes noise problem. Although high cost and relative low production rate make this method only applicable to short drives, the removal of artificial obstructions can be warranted. However, following the rapid development of TBM technology which allows pipe jacking drives in curved alignment and detects obstructions ahead of TBM advancement, personnel working under compressed air shall be avoided as far as practicable due to the risk involved and the reasons stated above. In case working under compressed air is found essential, detailed justifications and risk assessment should be prepared before construction.

Compressed-air tunnel will be adopted for high groundwater table condition. Depending on depth, an air pressure of 1 to 2 bars is required to balance the water head in the excavation face and be maintained inside the tunnel round-the-clock to avoid flooding which may in turn affect tunnel stability. To ensure constant supply of air, a standby compressor is provided for emergency situations. Pressurization and depressurization process is required in the air-lock installed on top of an air deck erected in the jacking shaft, for personnel entering and leaving the tunnel respectively. A medical lock needs to be provided at the shaft location when the applied compressed-air pressure exceeds 1 bar.

(ii) Working in confined space

Workplaces for trenchless construction including shaft and tunnel are always enclosed nature and there are reasonably foreseeable risks such as sudden ingress of water and collapse of tunnel. Procedures for working in confined space shall be strictly followed including assessment on the tunnel face stability and ingress of groundwater. Reference shall be made to DSD Practice Note No. 3/2012 "Safety Supervision of Work in Confined Space", or its latest version, DSD Safety Manual on "Use of Headings" and relevant regulations.

When working in confined space under compressed air condition, there have been some cases that air was found leaking through the porous ground during tunnel excavation, resulting in inflow of groundwater. This entails horizontal and vertical grouting from inside the shield to stabilize the ground before further excavation could be proceeded with.

Flooding of the heading and the access shaft can occur as a consequence of sudden inrush of water from exposed faces due to bursting of nearby watermains, heavy rainfall, etc. In the risk assessment, suitable measures to ensure the heading works watertightness to prevent flooding should be considered.

(c) Ground Movement Monitoring

Tunnelling and pipe jacking would induce settlement in surrounding ground. The magnitude of settlement is greatly affected by ground conditions, type of tunneling method, control of inflow of groundwater, depth of tunnel and jacking speed. The presence of underground utilities and services above the jacked pipeline would lead to under-measurement of surface ground settlement due to their rigidity. It is necessary to estimate the settlement influence zone and to assess its effect on nearby roads, structures and utility installations such that they can be safeguarded during the operation and remedial measures taken, if necessary. Maximum ground settlement occurs at the centre line of the pipeline and diminishes to zero at a distance from its two sides. Most settlements occur during and immediately after completion of tunneling and pipe jacking works. Further settlement would continue, and its stoppage depends on the ground and groundwater conditions above the jacked pipeline, for a few weeks to a few months.

In many cases, ground settlement is associated with change in groundwater level due to dewatering or groundwater inflow in the tunnel. The Contractor shall closely monitor the standpipe and piezometer readings with reference to the baseline record. If there is significant drawdown of groundwater level, assessment to the effect of settlement and subsequent remedial measures shall be carried out.

For monitoring settlement, sub-surface settlement markers, in the form of a steel rod, by coring through rigid pavement, are generally adopted, with their installation at suitable intervals along the alignment of the pipeline and with sufficient number offset at both sides, prior to commencement of a pipe jacking drive. In flexible pavement, nail markers are used. This is supplemented by visual inspection that if settlement occurs, cracks would develop in pavement. For structures sitting on shallow foundation, their condition has to be assessed before commencement of tunneling and pipe jacking such that suitable monitoring devices such as tilt markers and settlement markers can be installed to monitor the ground behavior during the course of works. If the measured ground settlement exceeds the predicted value, the tunneling and pipe jacking works have to stop and an investigation on the cause, and the damage, if any, carried out, with remedial measures such as ground treatment implemented, as necessary, prior to resumption of works.

10.4.3 Environmental Issue

Slurry pressure balance method using TBM requires a large amount of bentonite based slurry during the course of driving. Proper consideration should be made to recycle and dispose of the bentonite slurry after use to minimize the impact to the environment.

The bentonite based slurry of slurry shield TBM is mixed at the slurry tank and pumped to the work face through the cutterhead of the shield under a recycling system. The spoil excavated by the slurry shield machine is pumped to the slurry tank for separation and disposal. Proper monitoring system should be set up to avoid overflow of slurry from the recycle tank in case the outflow slurry pipe is clogged with spoil. The slurry tank should also be designed with sufficient free board to avoid the bentonite based slurry spilling out on public roads and drains.

10.4.4 Cost Consideration

Pipeline (or culvert) laid using trenchless construction method are usually of higher construction cost than those laid using open trench construction method. Thus, consideration shall be made on the cost-effectiveness of trenchless construction method and the benefits that may be brought to the public before adopting trenchless construction method instead of open trench construction method. However, for case of deep sewer, great difficulty in utility diversion or temporary traffic arrangement, trenchless construction method may prevail in terms of cost and constructability.

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TABLES

CONTENTS

Table No.

Table 1 : Design Life

Sewage Installations	**Design Life (in years)**
Tunnel Sewers	100
Sewers	40
Outfalls	50
Sewage Treatment Works	
Civil/Building Works	50
Electrical & Mechanical Equipment	15
Pumping Stations	
Civil/Building Works	50
Electrical & Mechanical Works	25
Rising Mains	25

(source: Study of Asset Inventory by Montgomery Watson)

Table 2 (Note Used)

Table 3 (Not Used)

Table 4 : Global Unit Load Factors

	Unit	**SS (kg/d)**	**BOD (kg/d)**	**COD (kg/d)**	**TKN (kg/d)**	**NH_3N (kg/d)**	**E. Coli. (no./d)**
Domestic							
Residential	person	0.040	0.042	0.090	0.0085	0.0050	$4.3x10^{10}$
Commercial							
Employed Population	employee	0.034	0.034	0.070	0.0067	0.0040	$3.5x10^{10}$
Commercial Activities	employee	0.025	0.053	0.103	0.0025	0.0008	
Industrial Process							
Food	employee	0.632	0.898	1.663	0.044	-	-
Textiles	employee	2.095	3.680	8.757	0.067	-	-
Leather	employee	0.432	0.288	0.853	0.044	0.011	-
Paper	employee	2.228	2.150	5.454	0.033	-	-
Manufacturing	employee	0.355	0.931	2.250	-	-	-
Machinery	employee	0.089	0.133	0.587	0.033	0.022	-
Others							
Beach Users	person	0.0012	0.0012	0.0025	0.0014	0.0009	$1.9x10^{10}$

(source: Review of Flows and Loads by AB_2H Consultants)

Table 5 : Recommended Roughness Values k_s

Source : HR Wallingford et. al. (2006)

Classification (see note 1)	**Suitable values of k_s (mm)**		
	Good	Normal	Poor
Smooth Materials (Pipes)			
Drawn non-ferrous pipes of aluminium, brass, copper, lead, etc. and non-metallic pipes of Alkathene, glass, perspex, uPVC, etc.	-	0.003	-
Asbestos Cement	0.015	0.03	0.06
Metal			
Spun bitumen or concrete lined	-	0.03	-
Cast iron, epoxy lining, coupling joints	-	0.015	0.03
Ductile iron, polyethylene lining, push-fit joints	-	0.06	0.15
Ductile iron, polyurethane lining, push-fit joints	0.015	0.03	0.06
Wrought iron	0.03	0.06	0.15
Rusty wrought iron	0.15	0.6	3.0
Uncoated steel	0.015	0.03	0.06
Rusty steel	-	0.15	0.3
Steel, epoxy lining, push-fit joints	0.03	0.06	0.15
Galvanised iron, coated cast iron generally	0.06	0.15	0.3
Uncoated cast iron	0.15	0.3	0.6
Tate relined pipes	0.15	0.3	0.6
152mm x 51mm corrugated plate, unpaved circular pipe, running full	50	60	-
76mm x 25mm corrugated plate, unpaved circular pipe, running full	25	30	-
Old tuberculated water mains as follows :			
Slight degree of attack	0.6	1.5	3.0
Moderate degree of attack	1.5	3.0	6.0
Appreciable degree of attack	6.0	15	30
Severe degree of attack	15	30	60
(Good: up to 20 years use; Normal: 40 to 50 years use; Poor : 80 to 100 years use)			
Wood			
Wood stave pipes, planed plank conduits	0.3	0.6	1.5
Concrete			
Prestressed	0.03	0.06	0.15
Precast concrete pipes with 'O' ring joints	0.06	0.15	0.6
Spun precast concrete pipes with 'O' ring joints	0.06	0.15	0.3
Monolithic construction against steel forms	0.3	0.6	1.5
Monolithic construction against rough forms	0.6	1.5	-

Table 5 (Cont'd)

Classification (see note 1)	**Suitable values of k_s (mm)**		
	Good	Normal	Poor
Clayware			
Glazed or unglazed pipe:			
With sleeve joints	0.03	0.06	0.15
With spigot and socket joints and 'O' ring seals dia < 150mm	-	0.03	-
With spigot and socket joints and 'O' ring seals dia > 150mm	-	0.06	-
Pitch Fibre (lower value refers to full bore flow)	0.003	0.03	-
Glass Reinforced Plastic (GRP)	0.03	0.06	-
uPVC			
Twin-walled, with coupling joint	0.003	0.006	
Standard, with chemically cemented joints	-	0.03	-
Standard, with spigot and socket joints, 'O' ring seals at 6 m to 9 m intervals	-	0.06	-
New Relining of Sewers/Drains			
Factory manufactured GRP	0.03	-	-
Brickworks			
Glazed	0.6	1.5	3.0
Well pointed	1.5	3.0	6.0
Old, in need of pointing	-	15	30
Slimed Sewers/Drains (see note 3)			
Sewers/drains slimed to about half depth; velocity, when flowing half full, approximately 0.75 m/s:			
Concrete, spun or vertically cast	-	3.0	6.0
Asbestos cement	-	3.0	6.0
Clayware	-	1.5	3.0
uPVC	-	0.6	1.5
Sewers/drains slimed to about half depth; velocity, when flowing half full, approximately 1.2 m/s :			
Concrete, spun or vertically cast	-	1.5	3.0
Asbestos cement	-	0.6	1.5
Clayware	-	0.3	0.6
uPVC	-	0.15	0.3

Table 5 (Cont'd)

Classification (see note 1)	**Suitable values of k_s (mm)**		
	Good	Normal	Poor
Sewer Rising Mains (see note 4)			
All materials, operating as follows:			
Mean velocity 0.5 m/s	0.3	3.0	30
Mean velocity 0.75 m/s	0.15	1.5	15
Mean velocity 1 m/s	0.06	0.6	6.0
Mean velocity 1.5 m/s	0.03	0.3	1.5
Mean velocity 2 m/s	0.015	0.15	1.5
Concrete Channels			
Trowel finish	0.5	1.5	3.3
Float finish	1.5	3.3	5.0
Finished with gravel on bottom	3.3	7.0	18
Unfinished	2.0	7.0	18
Shotcrete, or Gunite, good section	5.0	14	43
Shotcrete, or Gunite, wavy section	10	33	70
Unlined Rock Tunnels			
Granite and other homogeneous rocks	60	150	300
Diagonally bedded slates	-	300	600
Earth Channels			
Straight uniform artificial channels	15	60	150
Straight natural channels, free from shoals, boulders and weeds	150	300	600

Notes :

1. The classifications ‘Good’, ‘Normal’ and ‘Poor’ refer to good,, normal and poor examples of their respective categories unless otherwise stated. Classifications ‘Good’ and ‘Normal’ are for new and clean pipelines. The range of roughness takes account not only of the quality of the jointing but also the variation in surface roughness to be found in pipes that are normally of the same material.

2. Figures in bold print are the values particularly recommended for general design purposes.

3. The hydraulic roughness of slimed sewers/drains vary considerably during any year. The ‘Normal’ value is that roughness which is exceeded for approximately half of the time. The ‘Poor’ value is that which is exceeded, generally on a continuous basis, for one month of the year. The value of ks should be interpolated for velocities between 0.75 m/s and 1.2 m/s.

4. The hydraulic roughness of sewer rising mains varies principally with the amount of slime that builds up inside the pipe and is normally not significantly affected by factors such as the jointing or the construction. Primarily, the increasing roughness values are intended to cover for the loss of flow area. The ‘Normal’ value represents the mean value of the measured hydraulic roughness while the ‘Good’ and ‘Poor’ values represent the values which are two standard deviations on each side of the ‘Normal’ value.

Table 6 : Values of n to be used with the Manning's equation

Surface	Best	Good	Fair	Bad
Uncoated cast-iron pipe	0.012	0.013	0.014	0.015
Coated cast-iron pipe	0.011	0.012[a]	0.013[a]	
Commercial wrought-iron pipe, black	0.012	0.013	0.014	0.015
Commercial wrought-iron pipe, galvanized	0.013	0.014	0.015	0.017
Smooth brass and glass pipe	0.009	0.010	0.011	0.013
Smooth lockbar and welded "OD" pipe	0.010	0.011[a]	0.013[a]	
Riveted and spiral steel pipe	0.013	0.015[a]	0.017[a]	
Vitrified sewer pipe	0.010 0.011	0.013[a]	0.015	0.017
Common clay drainage tile	0.011	0.012[a]	0.014[a]	0.017
Glazed brickwork	0.011	0.012	0.013[a]	0.015
Brick in cement mortar; brick sewers	0.012	0.013	0.015[a]	0.017
Neat cement surfaces	0.010	0.011	0.012	0.013
Cement mortar surfaces	0.011	0.012	0.013[a]	0.015
Concrete pipe	0.012	0.013	0.015[a]	0.016
Wood stave pipe	0.010	0.011[a]	0.012	0.013
Plank flumes				
Planed	0.010	0.012[a]	0.013	0.014
Unplaned	0.011	0.013[a]	0.014	0.015
With battens	0.012	0.015[a]	0.016	
Concrete-lined channels	0.012	0.014[a]	0.016[a]	0.018
Cement-rubble surface	0.017	0.020	0.025	0.030
Dry-rubble surface	0.025	0.030	0.033	0.035
Dressed-ashlar surface	0.013	0.014	0.015	0.017
Semicircular metal flumes, smooth	0.011	0.012	0.013	0.015
Semicircular metal flumes, corrugated	0.0225	0.025	0.0275	0.030
Canals and ditches				
Earth, straight and uniform	0.017	0.020	0.0225[a]	0.025
Rock cuts, smooth and uniform	0.025	0.030	0.033[a]	0.035
Rock cuts, jagged and irregular	0.035	0.040	0.045	
Winding sluggish canals	0.0225	0.025[a]	0.0275	0.030
Dredged-earth channels	0.025	0.0275[a]	0.030	0.033

Table 6 (Cont'd)

Surface	**Best**	**Good**	**Fair**	**Bad**
Canals with rough stony beds, weeds on earth banks	0.025	0.030	0.035[a]	0.040
Earth bottom, rubble sides	0.028	0.030[a]	0.033[a]	0.035
Natural-stream channels				
1. Clean, straight bank, full stage, no rifts or deep pools	0.025	0.0275	0.030	0.033
2. Same as (1) but some weeds and stones	0.030	0.033	0.035	0.040
3. Winding some pools and shoals, clean	0.033	0.035	0.040	0.045
4. Same as (3), lower stages, more ineffective slope and sections	0.040	0.045	0.050	0.055
5. Same as (3) some weeds and stones	0.035	0.040	0.045	0.050
6. Same as (4) story sections	0.045	0.050	0.055	0.060
7. Sluggish river reach, rather weedy or with very deep pools	0.050	0.060	0.070	0.080
8. Very weedy reaches	0.075	0.100	0.125	0.150
[a]Values commonly used designing				

(source: Brater & King, 1976. Handbook of Hydraulics)

Table 7 : Head Losses Coefficient, K

	Entry Losses		K
	Sharp-edged entrance		0.50
	Re-entrant entrance		0.80
	Slightly rounded entrance		0.25
	Bellmouthed entrance		0.05
	Footvalve and strainer		2.50
	Intermediate Losses		K
(i)	Elbows		
	(R/D = 1/2 approx)	22.5°	0.20
		46°	0.40
		90°	1.00
(ii)	Close Radius Bends		
	(R/D = 1 approx)	22.5°	0.15
		25°	0.30
		90°	0.50**
(iii)	Long Radius Bends		
	(R/D = 2 to 7)	22.5°	0.10
		45°	0.20
		90°	0.40
(iv)	Sweeps		
	(R/D = 8 to 50)	22.5°	0.05
		45°	0.10
		90°	0.20
(v)	Mitre Elbows		
	22.5°	-2 piece	0.15
	30°	-2 piece	0.20
	45°	-2 or 3	0.30
	piece		0.65
	60°	-2 piece	0.25
		-3 piece	1.25
	90°	-2 piece	0.50
		-3 piece	0.30
		-4 piece	
(vi)			
	Tees		0.35
	Flow in line		
	Line to branch or		
	branch to line :		1.20
	Sharp-edged		0.80
	radiused		
(vii)			
	Angle Branches		0.35
	Flow in line		

	Intermediate Losses(cont'd)		**K**
	Line to branch or		
	branch to line:		
	30° angle		0.40
	45° angle		0.60
	90° angle		0.80
(viii)	Sudden Enlargements*		
	Inlet dia: Outlet dia.		
	4:5		0.15
			0.20
	3:4		0.35
			0.60
	2:3		0.80
			1.00
	1:2		
(ix)			
	1:3		
			0.15
	1:5 and over		0.20
			0.30
	Sudden Contractions*		0.35
	Inlet dia: Outlet dia.		0.45
	5:4		0.50
	4:3		
(x)	3:2		
	2:1		negligible
	3:1		
	5:1 and over		0.03
			0.04
	B.S. Tapers*		0.12
	Flow to small end		
(xi)	Flow to large end		
	Inlet dia.	4:5	0.12
	to	3:4	1.00
			6.00
	Outlet dia.	1:2	24.00
			10.00
			5.00
	Valves		1.00
	Gate Valve-fully open		0.30
	1/4 closed		**K**
	1/2 closed		
	3/4 closed		1.00
	Globe valve		1.00**
	Right angle valve		
	Reflux valve		
	Butterfly valve		
	Exit Losses		
	Sudden Enlargement		
	Bellmouthed Outlet		

Notes :

* Figure for enlargements, contractions and B.S. Tapers apply to smaller diameter
** Value modified

$$K = \frac{\text{Head Loss}}{V^2/2g} = \frac{\text{Head Loss}}{\text{Velocity Head}}$$

(Source: Preliminary Design Manual for the SSDS by AB_2H Consultants)

Table 8 (a) - Typical Pipe Materials and Their Characteristics

Material	Concrete - Plain/ Reinforced	Concrete - Prestressed	Vitrified Clay
British Standard	BS 5911	BS 5178 (gravity flow) BS 4625 (pressure flow)	BS EN 295
Size Range	DN 150 - DN 3000	DN 450 - DN 3000 (gravity flow) DN 400 - DN 1800 (pressure flow)	DN 150 - DN 1200
Normal Working Pressure	Atmospheric pressure	4 - 12 bars	Atmospheric pressure
Standard Lengths	a) In general: 0.45 m - 5 m b) For DN 600 or less, 3 m (max)	2.5 m - 6.5 m	600 mm - 3 m
Strength	Strong, high resistance to external load	Strong, high resistance to external load	High structural strength
Impact Load	Good impact resistance	Good impact resistance	Good impact resistance
Usual Jointing Methods	a) Flexible spigot and socket joints with rubber gasket ring; b) Flexible rebated joint	a) Flexible spigot and socket joints with rubber gasket ring; b) Flexible rebated joint	Flexible mechanical joint
Resistance To Corrosion	a) Resistant to attack by sea water or marine organisms; b) Cement subject to corrosion attack in acidic and septic sewage conditions, and in high sulphate environment	Similar to Concrete - plain/steel reinforced	Resistant to corrosion attack by: a) acids and alkalies; b) damage from hydrogen sulphide; c) microbiological induced corrosion; d) erosion and scour
Ease of Handling	Heavy, mechanised equipment required in handling and jointing	Heavy, mechanised equipment required in handling and jointing	Heavy, mechanised equipment required in handling and jointing
Availability	Readily available locally	Imported from overseas	Readily available DN 150 - DN 700
Application	Wide range of sizes and strengths is available, widely used in gravity sewers DN 600 - DN 2100	Can withstand high internal pressure, so cost competitive with other pipe materials such as steel, mainly used in large diameter pressure sewers and potable water mains	Used in small to medium size sewers carrying gravity flows

Table 8 (b) - Typical Pipe Materials and Their Characteristics

Material	Mild Steel	Ductile Iron(Spheroidal graphite iron)	Cast Iron	Stainless Steel
British Standard	BS 534, BS 3600, BS 3601	BS EN 598	BS 437, BS 416-1, BS 1211, 4622	BS EN 10312 BS EN 10217 - 7 BS EN 6362
Size Range	DN 60.3 - DN 2200	DN 80 - DN 1600	DN 50 - DN 225	DN 15 - DN 600,
Normal Working Pressure	9 - 15 bars	16 - 40 bars	6 - 12 bars	6 - 25 bars
Standard Lengths	8 m & 9 m	a) Flexible joints: 5.5 m (up to DN 800), and 8 m (greater than DN 800); b) Flanged joints: 5 m and 6 m	a) Flexible joint: 1.83 m - 5.5 m b) Flanged joint: 4.0 m	6 m (most common)
Strength	Mechanically very strong, high structural strength/weight ratio	High structural strength, high resistance to external load	Can withstand high external load	Not strong as steel, but have favourable strength to weight ratio
Impact Load	High impact resistance	High impact resistance, good in ductility, machinability and toughness	Brittle, subject to damage during handling and laying operation	Vulnerable to impact damage, must be carefully handled, bedded and backfilled to prevent damage by sharp objects
Usual Jointing Methods	a) Welded sleeve joint and butt welded joint; b) Flexible connection with slip-on type coupling; c) Flanged joint or stepped coupling	a) Flexible push-in spigot and socket joints with rubber gasket ring; b) Flanged joint; c) Flexible mechanical joint; d) Slip-on type coupling	a) Flexible spigot and socket joints with rubber gasket ring; b) Flexible mechanical joint; c) Flanged joint	a) Push-in joints with silicon gasket ring; b) Groove Coupling Jointing method
Resistance To Corrosion	Subject to corrosion attack due to: a) acidic environment and corrosive soils; b) septic sewage - hydrogen sulphide attack; c) microbiological induced corrosion	Subject to same kinds of corrosion as mild steel, but resistance superior to cast iron	Subject to same kinds of corrosion as mild steel, but comparatively more corrosive resistant	Good in stress corrosion in acidic and chloride environment
Ease of Handling	Heavy, mechanised equipment required in handling/jointing; stability when pipe empty or subject to negative gauge pressure to be checked	Heavy, mechanised equipment required in handling and jointing	Heavy, mechanised equipment required in handling and jointing	Heavy, mechanised equipment required in handling and jointing
Availability	Readily available locally or imported from overseas	Imported from overseas	Pipe manufacture largely superseded by ductile iron pipe, local availability to be checked	Imported from overseas and mainland
Application	Wide range of sizes and strengths is available, used in pressure sewers and mains, stream and bridge crossings, pumping station and treatment plant piping, submarine pipelines and outfalls	Availability of a complete range of standard fittings simplifies design/construction exercises, widely used in sewers, pressure mains and tidal outfalls	Pipe uses largely superseded by ductile iron pipes, now mainly used in surface water drains, non-pressure pipes for rainwater	Uses in potable water and sewage application working under gravity or pressure flows

Table 8 (c) - Typical Pipe Materials and Their Characteristics

Material	Glass-reinforced Plastics (GRP)	Unplasticized Polyvinyl Chloride (uPVC)	Medium/High Density Polyethylene (MDPE/HDPE)
British Standard	BS 5480	Gravity sewage/surface water: DN 110 - DN 630 BS 4660, BS 5481 Pressure flows: DN 10 - DN 610 BS 3505, BS 3506	BS 3284, BS 6437, BS 6572, BS 6730
Size Range	DN 100 - DN 4000,(DN 300 - DN 2500 most common)	DN 10 - DN 630	DN 16 - DN 2000
Normal Working Pressure	6 - 25 bars	Atmospheric pressure (gravity flow)9 - 12 bars (pressure flow)	2.5 - 10 bars
Standard Lengths	3 m, 6 m, 12 m (6 m most common)	6 m, 9 m, 12 m	10 - 12 m
Strength	Not strong as steel, but have favourable strength to weight ratio	Low structural strength	a) Low strength, reinforced or unreinforced; b) Strength: time- and temperature-dependent
Impact Load	Vulnerable to impact damage, must be carefully handled, bedded and backfilled to prevent damage by sharp objects	Low impact resistance, susceptible to damage due to impact, point loading, must be carefully bedded and backfilled to prevent damage by sharp objects; embrittlement with age	Susceptible to damage due to impact and point loads, must be carefully bedded and backfilled to prevent damage by sharp objects
Usual Jointing Methods	a) Push-in flexible spigot and socket joints with rubber gasket ring; b) Sealed collar joints; c) Mechanically coupled joints; d) Flanged joint; e) Butt welded joint	a) Push-in flexible spigot and socket joint with rubber gasket ring; b) Sleeve type joints; c) Rigid solvent welded spigot and socket joint	a) Butt or sleeve welded joints; b) Mechanical jointing (specially designed compression joints)
Resistance To Corrosion	Good in salt water/domestic sewage environment; however, it may be susceptible to stress corrosion in acidic environment	a) Highly resistant to corrosion attack in naturally occurring soils and water, unaffected by domestic sewage effluent and sea water	Unaffected in acidic conditions, by hydrogen sulphide attack associated with septic sewage, and chloride and sulphate ions
Ease of Handling	Light, flexible, easy to handle and joint	Light, flexible, easy to handle and joint	Light, flexible, easy to handle and joint
Availability	Imported from overseas	Available locally or imported from overseas	Imported from overseas
Application	Increased uses in potable water and sewage application (particular in large diameter pipe size) working under gravity or pressure flows, also in outfalls and diffuser domes	Usually used in sewers and low-pressure mains, chemical transfer lines in treatment works	Used in gravity and pressure sewerage application working at low to medium temperature, small diameter submarine pipelines/outfalls

Table 9 : Typical Corrosion Protection Measures and their uses

Pipe Material	Welded Steel	Ductile Iron	Concrete
Primary Protection - External	a) Bitumen sheathing; b) Reinforced bitumen sheathing - For pipelines subject to mild environment such as land mains; c) Bitumen enamel wrapping - Ditto; d) Reinforced bitumen enamel wrapping - Ditto; e) Coal tar enamel wrapping - For pipelines within splash and submerged zones such as submarine pipelines/outfalls, pipelines exposed to saline environment within surf zone; f) Plastics cladding (eg. fusion bonded epoxy and polyethylene coating) - Ditto; g) Paints and multi-component coatings (eg. chlorinated rubber and epoxy resins) - Ditto	a) Sprayed metallic zinc coating and a finishing coat of bitumen-based material; b) Zinc primer and coal tar epoxy resin coating	a) Sacrificial lining thickness; b) Use of calcareous aggregate - Increase overall alkalinity of concrete; c) Surface coating of bitumen, coal tar enamel and coal tar epoxy, vinyl and epoxy resins and paints - For pipes exposed to very corrosive environment; d) Cement replacement materials such as PFA - Improve durability and sulphate attack resistance
Primary Protection - Internal	a) OPC mortar/concrete lining b) SRC mortar/concrete lining - Sewage, treated effluent, salt water; c) Bitumen lining - Potable water; d) Coal tar enamel - For submarine pipelines and outfalls conveying sewage/treated effluent; e) Fusion bonded epoxy coating - Ditto; f) Coal tar epoxy resin - Ditto	a) Bitumen-based coating; b) OPC mortar lining - Surface water; c) SRC mortar lining - Potable water, sewage, treated effluent; d) PFAC/PBFC mortar lining	Types a) to d) as above; e) Use of protective layers such as modified PVC and HDPE liners for septic sewage, acids/alkalies
Secondary Protection	a) Petrolatum or bituminous anti-corrosion tape of proprietary types - for protection of buried pipes and those exposed to the sea within surf zone b) Cathodic protection: - Impressed current; - Sacrificial anodes of magnesium, zinc, aluminium	a) Bituminous tape - buried pipework; b) Polyethylene (PE) sleeving c) Spray or brush painted mortar lining with bitumen	a) Corrosion inhibitors - Neutralise rusting inducting effects of chloride ions; b) Hyperphobic poreblocking ingredient (PHI) - For use in aggressive chemical environment; c) Polythene (PE) sleeving
Remark	Choices on coatings and linings depend on their material costs and susceptibility to damage during handling and working environment	Polyethylene sleeving is an economical and effective method of providing additional protection	Characteristics of some commonly used coatings and materials: a) Epoxy - good durability and chemical resistance, but chalks in sunlight; b) Vinyl - good durability, easily touched up; c) Coal tar - resistant to moisture penetration

Table 10 (a) : Common Pipe Joints and Their Characteristics

Type of Joint	Flexible O-ring type push-in spigot and socket joints	Flexible type double collar type or double bell coupling joints	Flexible O-ring type Tyton joints	Flexible type bolted (mechanical) or screwed gland joints
Pipe Material	Concrete - plain/steel reinforced, prestressed, vitrified clay, PVC	Glass-reinforced Plastics (GRP), polyvinyl chloride (PVC)	Ductile iron, cast iron, uPVC	Ductile iron, cast iron
Mechanism	Forced insertion of spigot into socket causing the rubber gasket to roll or slide and be compressed sufficiently to effect a seal	A short sleeve with rubber gaskets at both ends which are compressed with insertion of spigots	Forced insertion of spigot into socket or sleeve causing the rubber gasket ring to be compressed sufficiently to effect a seal	Similar to Tyton joints, except that the gasket is clamped in place by means of a gland ring bolted or screwed to the socket
Axial Movement	10 - 25 mm (with joint in the undeflected position)	20 - 50 mm (with joint in the undeflected position)	38 - 85 mm (with joint in the undeflected position)	35 - 65 mm (with joint in the undeflected position)
Angular Flexure	0.5^o to 3^o (depending on pipe size and manufacturer's design)	1^o to 6^o (depending on pipe size and manufacturer's design)	2^o to 5^o (depending on pipe size and manufacturer's design)	1^o to 6^o (depending on pipe size and manufacturer's design)
Usages	Non-pressure pipelines to permit angular deflection in any direction and axial movements to compensate for ground movement, thermal expansion and contraction	Pressure and non-pressure pipelines to permit angular deflection in any direction and axial movements to compensate for ground movement, thermal expansion and contraction	Pressure pipelines to permit angular deflection in any direction and axial movements to compensate for ground movement, thermal expansion and contraction	High pressure pipelines to permit angular deflection in any direction and axial movements to compensate for ground movement, thermal expansion and contraction
Remarks	Simple and tight, ease of jointing reduces installation time;	Simple and tight, ease of jointing reduces installation time	Simple and easy to joint, mainly used in smaller diameter pipelines	More expensive than Tyton joints, mostly used in larger diameter pipelines, skilled personnel required in jointing

Table 10 (b) : Common Pipe Joints and Their Characteristics

Type of Joint	Flanged Joints	Welded Joints	Slip-on type or Viking Johnson type couplings	Flange adaptors
Pipe Material	Ductile Iron, Steel, Cast Iron, GRP	Steel, HDPE	Steel, Ductile Iron, uPVC, GRP, Concrete	Steel, Ductile Iron, uPVC, GRP
Mechanism	Clamping of sealing rubber gasket by means of bolts tightening	Fusion jointing of pipe material	Similar to a double collar joint, except that the rubber gasket rings are clamped in position by bolted gland rings.	A flanged collar joint with the gaskets clamped by bolts tightening at flanged end and by a bolted gland ring at other end.
Axial Movement	Not allowed	Not allowed	8 - 10 mm (depending on pipe size and manufacturer's design)	4 - 5 mm (depending on pipe size and manufacturer's design)
Angular Flexure	Not allowed	Not allowed	1^{o} to 6^{o} (depending on pipe size and manufacturer's design)	0.5^{o} to 3^{o} (depending on pipe size and manufacturer's design)
Usages	a) Above ground installation in pumping stations and treatment plants; b) Used to facilitate the installation and removal of valves or flanged fittings in flexibly jointed pipes; c) Connect pipes of different materials; d) Used in valve-bypass arrangement	a) Butt welded joints - for fabricating specials from straight lengths of pipes; b) Sleeve welding joints (parallel, taper or collar sleeve, spherical joint) - for jointing plain ended pipes	a) Provide a flexible joint between 2 plain ended sections of pipe allowing differential movement; b) Connect 2 pipes of same nominal diameter but of different materials and O.D.s; c) Allow axial movement caused by thermal expansion and contraction in exposed welded steel pipelines.	Forming a detachable flange onto a plain ended ductile iron or steel pipe, on the downstream side of valves, fitting or sections of pipe, which in conjunction with detachable coupling, facilitate removal for maintenance purpose
Remarks	Expensive jointing method, correct pressure rating to be specified; used wherever rigidity, strength and joint tightness required	Expensive, jointing by site welding must be carefully checked	Also known as Dresser type coupling and Gibrault joint; design requirements of the couplings to be defined in the specification.	Design requirements of the adaptors to be defined in the specification.

Table 11 - Narrow and Wide Trench Fill Load

Nominal Pipe Dia. **DN** (mm)	Assumed Outside Dia. B_c (mm)	Type of Load	Assumed Trench Width B_d (m)	T_d (m)	Fill load in kN/m of pipe length for cover depth in metres						
					0.9	1.2	1.5	1.8	2.4	3.0	4.6
150	190	Narrow Wide	0.60 -	3.7 -	- 5.4	- 7.1	13.4 9.0	15.1 10.8	18.1 14.4	20.4 18.1	24.0 27.1
225	280	Narrow Wide	0.70 -	2.4 -	- 7.9	- 10.5	15.6 13.1	17.8 15.7	21.4 21.1	24.2 26.4	29.2 39.7
300	380	Narrow Narrow Wide	0.75 0.85 -	1.5 2.4 -	- - 10.6	- - 14.3	17.8 19.8 17.9	20.3 23.2 21.6	24.6 28.4 28.7	28.3 32.6 36.0	34.6 40.4 54.1
375	500	Narrow Narrow Wide	1.00 1.05	2.4 3.0 -	- - 12.8	- - 17.5	24.3 26.5 21.9	27.8 30.8 26.4	35.3 38.4 35.2	40.2 44.9 44.0	52.6 57.6 66.4
450	580	Narrow Wide	1.15 -	2.4 -	- 14.3	- 20.6	28.9 25.8	33.5 30.9	41.9 41.4	49.3 51.9	63.6 78.2
600	790	Narrow Wide	1.35 -	1.8 -	- 17.8	- 25.7	35.6 34.4	41.5 41.5	52.5 55.7	62.3 69.7	82.0 105
750	950	Narrow Narrow Wide	1.50 1.60 -	1.5 1.8 -	- - 20.6	- - 29.3	40.1 41.2 39.2	47.0 50.2 50.0	59.5 62.8 67.0	71.0 74.3 84.1	94.6 102 127
900	1120	Narrow Wide	1.90 -	2.1 -	- 23.5	- 33.1	51.3 43.8	60.4 55.5	77.5 78.5	93.0 98.6	127 149
1050	1300	Narrow Wide	2.05 -	2.1 -	- 26.7	- 37.4	55.9 48.9	65.8 61.5	84.6 90.6	102 114	140 172
1200	1490	Narrow Wide	2.30 -	2.1 -	- 30.0	- 41.7	62.7 54.4	74.0 68.0	95.3 98.8	115 130	159 197
1350	1650	Narrow Wide	2.45 -	2.1 -	- 33.0	- 45.6	67.2 59.3	79.2 73.6	102 106	124 143	173 219
1500	1830	Narrow Wide	2.60 -	2.1 -	- 36.2	- 49.7	71.8 64.4	84.7 80.0	110 114	133 153	187 242
1650	2010	Narrow Wide	2.80 -	2.4 -	- 39.4	- 54.0	78.5 69.6	93.0 86.0	121 122	147 162	206 264
1800	2240	Narrow Wide	3.05 -	2.4 -	- 43.5	- 59.4	85.4 76.3	101 94.1	131 132	160 175	226 295

Table 12 - Traffic Loads

Nominal Pipe Dia. **DN** (mm)	Assumed Outside Dia. **B_c** (mm)	Type of Load	Traffic load in kN/m of pipe length for cover depth in metres						
			0.9	1.2	1.5	1.8	2.4	3.0	4.6
150	190	Main road	16.8	12.8	10.4	8.9	6.7	5.2	3.2
		Light road	13.6	9.2	6.4	4.8	2.9	2.0	1.0
225	280	Main road	24.5	18.6	15.3	13.0	9.9	7.7	4.4
		Light road	19.7	13.2	9.5	7.0	4.2	2.9	2.3
300	380	Main road	33.3	25.4	20.7	17.6	13.6	10.5	6.1
		Light road	26.8	18.1	12.8	9.6	5.8	3.9	1.7
375	500	Main road	42.9	32.7	26.7	23.0	17.5	13.7	7.9
		Light road	34.4	23.2	16.6	12.4	7.6	5.0	2.3
450	580	Main road	50.0	38.2	31.5	27.1	20.7	16.2	9.3
		Light road	40.1	27.0	19.4	14.6	8.9	6.0	2.8
600	790	Main road	66.6	51.5	42.3	36.5	27.7	21.7	12.5
		Light road	53.0	36.2	26.0	19.3	11.8	7.9	3.6
750	950	Main road	80.2	62.0	51.0	43.9	33.4	26.1	15.0
		Light road	63.5	43.2	31.2	23.3	14.1	9.5	4.4
900	1120	Main road	93.2	72.6	60.0	51.3	39.1	30.5	18
		Light road	73.3	50.2	36.2	27.1	16.8	11.1	5
1050	1300	Main road	106	84.3	69.5	59.8	45.2	35	20
		Light road	82.7	57.6	41.5	31.1	19.2	13	6
1200	1490	Main road	120	96.6	80.4	68.2	51.8	40	23
		Light road	92	65.0	47.2	35.6	22.0	15	7
1350	1650	Main road	131	107	89.4	76.4	58	45	26
		Light road	99.5	71.0	51.7	39.4	24	16	8
1500	1830	Main road	143	118	99.1	85.0	64	49	28
		Light road	107	77.0	56.6	43.1	27	18	8
1650	2010	Main road	154	129	109	93.8	70	54	31
		Light road	114	82.7	61.0	46.8	29	20	9
1800	2240	Main road	172	144	122	104	79	61	35
		Light road	122	89.4	66.6	51.0	32	22	10

Table 13 - Design Loads for Rigid Pipelines

(a) Design Load for Main Roads :

Nominal Pipe Dia. **DN** (mm)	Assumed Outside Dia. **B_c** (mm)	Assumed Trench Width **B_d** (m)	Total Design Load in kN/m of Pipe Length for Cover Depth **H** in metres						
			H=0.9	1.2	1.5	1.8	2.4	3.0	4.6
150	190	0.60	22	19.5	19.5	19.5	21	23	27
225	280	0.70	32	29	28	28	31	32	34
300	380	0.75	44	40	39	38	38	39	41
375	500	1.05	55	50	48	50	53	58	66
450	580	1.15	64	58	57	58	63	68	73
600	790	1.35	86	79	79	80	83	86	96
750	950	1.50	105	95	93	95	96	100	115
900	1120	1.90	120	110	110	110	120	130	150
1050	1300	2.05	140	130	125	130	135	145	170
1200	1490	2.30	160	145	145	145	155	165	190

(b) Design Load for Light Roads :

Nominal Pipe Dia. **DN** (mm)	Assumed Outside Dia. **B_c** (mm)	Assumed Trench Width **B_d** (m)	Total Design Load in kN/m of Pipe Length for Cover Depth **H** in metres						
			H=0.9	1.2	1.5	1.8	2.4	3.0	4.6
150	190	0.60	19	16	15.5	15.5	17.5	20	25
225	280	0.70	28	24	23	23	25	27	31
300	380	0.75	38	32	31	30	31	32	36
375	500	1.05	47	41	38	39	42	50	60
450	580	1.15	54	48	45	45	51	55	67
600	790	1.35	73	64	63	63	67	73	87
750	950	1.50	87	76	74	74	77	85	100
900	1120	1.90	100	88	85	87	99	110	135
1050	1300	2.05	115	100	98	99	110	120	155
1200	1490	2.30	130	115	110	110	125	140	175

Table 14 - Minimum Strength or Class of Pipes in Main Roads

(a) Class of Precast Concrete Pipes

Nominal Pipe Dia. **DN** (mm)	Assumed Outside Dia. **B**$_c$ (mm)	Assumed Trench Width **B**$_d$ (mm)	Bedding Factor **F**$_m$	Class of Precast Concrete pipes to BS 5911:Part 100:1988 for Cover Depth in metres						
				0.9	1.2	1.5	1.8	2.4	3.0	4.6
150	190	600	1.9	L	L	L	L	L	L	L
			2.6	L	L	L	L	L	L	L
			3.4	L	L	L	L	L	L	L
225	280	670	1.9	L	L	L	L	L	L	L
			2.6	L	L	L	L	L	L	L
			3.4	L	L	L	L	L	L	L
300	380	750	1.9	M	M	M	L	L	M	M
			2.6	L	L	L	L	L	L	L
			3.4	L	L	L	L	L	L	L
375	500	1050	1.9	M	M	M	M	M	M	H
			2.6	M	L	L	L	M	M	M
			3.4	L	L	L	L	L	L	L
450	580	1150	1.9	M	M	M	M	M	H	H
			2.6	M	M	M	M	M	M	M
			3.4	L	L	L	L	L	L	M
600	790	1350	1.9	M	M	M	M	M	M	H
			2.6	M	M	M	M	M	M	M
			3.4	M	M	M	M	M	M	M
750	950	1500	1.9	H	M	M	M	M	M	H
			2.6	M	L	L	L	L	M	M
			3.4	L	L	L	L	L	L	L
900	1120	1900	1.9	M	M	M	M	M	H	H
			2.6	L	L	L	L	L	M	M
			3.4	L	L	L	L	L	L	L
1050	1300	2050	1.9	M	M	M	M	M	H	H
			2.6	M	L	L	L	M	M	M
			3.4	L	L	L	L	L	L	L
1200	1490	2300	1.9	M	M	M	M	M	M	H
			2.6	M	L	L	L	M	M	M
			3.4	L	L	L	L	L	L	L

Table 14 (cont'd)

(b) Class of Vitrified Clay Pipes										
Nominal Pipe Dia. **DN** (mm)	Assumed Outside Dia. B_c (mm)	Assumed Trench Width B_d (mm)	Bedding Factor F_m	Class of Vitrified Clay Pipes to BS 65:1988 for Cover Depth in metres						
				0.9	1.2	1.5	1.8	2.4	3.0	4.6
100	130	600	1.9	F	F	F	F	F	F	F
			2.5	F	F	F	F	F	F	F
150	190	600	1.9	F	F	F	F	F	F	F
			2.5	F	F	F	F	F	F	F
200 & 225	245 & 280	700	1.9	F	F	F	F	F	F	F
			2.5	F	F	F	F	F	F	F
300	370	800	1.9	F	F	F	F	F	F	B
			2.5	F	F	F	F	F	F	F
375 & 400	460 & 500	1100	1.9	F	F	F	F	F	F	F
			2.5	F	F	F	F	F	F	F
450	550	1200	1.9	F	F	F	F	F	F	B
			2.5	F	F	F	F	F	F	F
500	615	1300	1.9	F	F	F	F	F	F	B
			2.5	F	F	F	F	F	F	F
600	730	1400	1.9	B	F	F	F	F	B	B
			2.5	F	F	F	F	F	F	F

Note :

1.L, M, H denote class of concrete pipes in Table 7 of BS 5911:Part100:1988.

2.F and B denote Standard and Extra Strength respectively of vitrified clay pipes in Table 3 of
BS 65:1991.

3.For vitrified clay pipes of diameter above DN 150, class 120 to BS EN 295:1991 can substitute either vitrified clay pipes of class F or class B. For DN 100 - DN 150, vitrified clay pipes to BS EN 295:1991 can substitute class F.

Table 15 – 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 and pumping station Tightness Class 0 : superstructure of pumping station Tunnel : 0.25 mm (maximum permissible crack width)

Parameter	Recommended Value
Stress-strain curve	Figure 3.8 of BD (2013) or its latest version
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

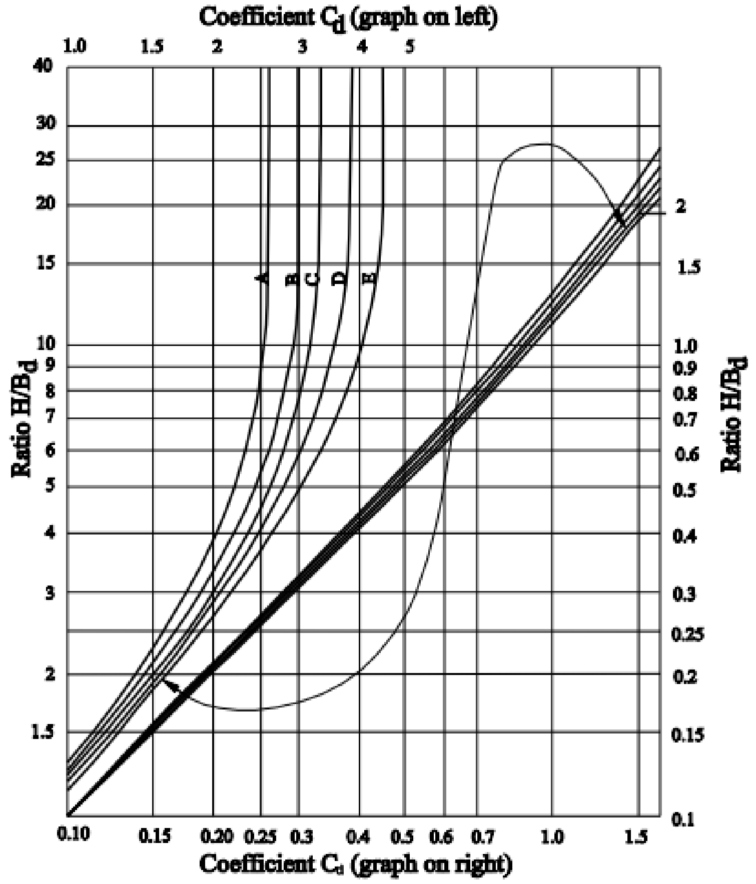
LIST OF FIGURES

Figure No.

Figure 1 (Not Used)

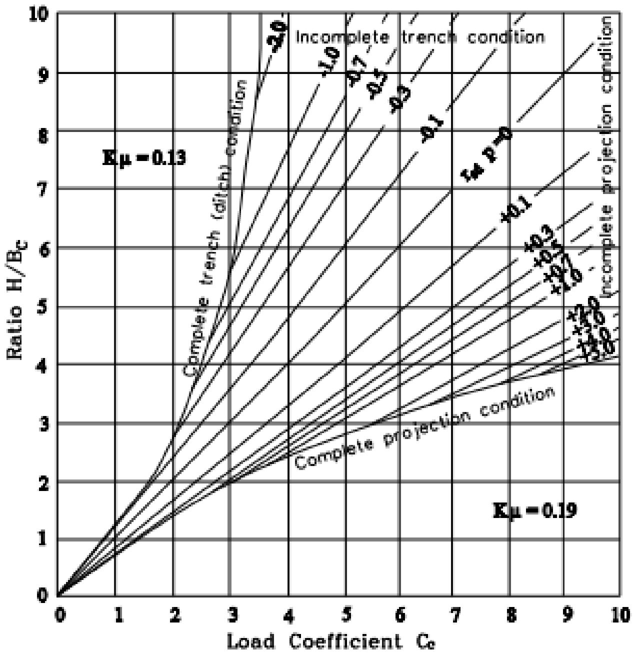
Figure 2 (Not Used)

Figure 3 (Not Used)



A = C_d for $K\mu$ and $K\mu'$ = 0.19 for granular materials without cohesion
B = C_d for $K\mu$ and $K\mu'$ = 0.165 max for sand and gravel
C = C_d for $K\mu$ and $K\mu'$ = 0.150 max for saturated top soil
D = C_d for $K\mu$ and $K\mu'$ = 0.130 ordinary max for soil
E = C_d for $K\mu$ and $K\mu'$ = 0.110 max for saturated clay

Figure 4. Values of Narrow Trench Coefficients C_d



To extrapolate values of C_c for higher values of H/B use the following equations		
Condition	$r_{sd}p$	Equation of curve
Incomplete trench Kμ = 0.13	- 0.1	Cc = 0.82 (H/Bc) + 0.05
	- 0.3	Cc = 0.69 (H/Bc) + 0.11
	- 0.5	Cc = 0.61 (H/Bc) + 0.20
	- 0.7	Cc = 0.55 (H/Bc) + 0.25
	- 1.0	Cc = 0.47 (H/Bc) + 0.40
	- 2.0	Cc = 0.30 (H/Bc) + 0.91
Incomplete projection Kμ = 0.19	0	Cc = H/B
	+ 0.1	Cc = 1.23 (H/Bc) - 0.02
	+ 0.3	Cc = 1.39 (H/Bc) - 0.05
	+ 0.5	Cc = 1.50 (H/Bc) - 0.07
	+ 0.7	Cc = 1.59 (H/Bc) - 0.09
	+ 1.0	Cc = 1.69 (H/Bc) - 0.12
	+ 2.0	Cc = 1.93 (H/Bc) - 0.17
	+ 3.0	Cc = 2.06 (H/Bc) - 0.20
	+ 4.0	Cc = 2.19 (H/Bc) - 0.21
	+ 5.0	Cc = 2.28 (H/Bc) - 0.22
Complete trench	use the formula $C_c = C_d = \frac{1 - \exp(-2K\mu\ H/B_c)}{2K\mu}$ and Kμ = 0.13	
Complete projection	use the formula $C_c = \frac{\exp(-2K\mu\ H/B_c) - 1}{2K\mu}$ and Kμ = 0.19	

Figure 5 Values of Embankment Coefficients C_c

Figure 1
Class F
Bedding Factor 1.9

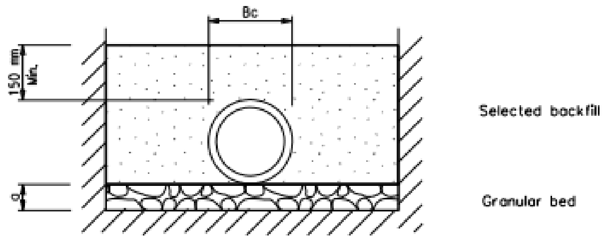


Figure 2
Class B
Bedding Factor 2.5

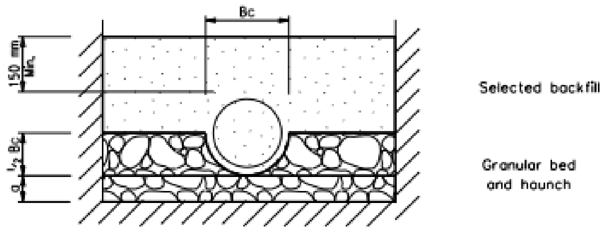
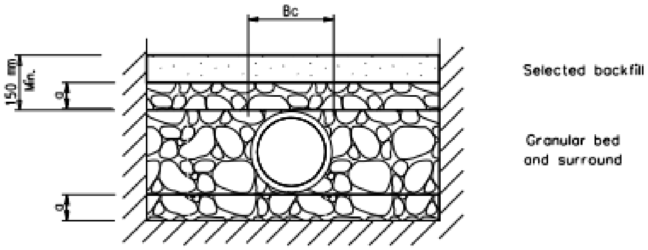


Figure 3
Class S
Bedding Factor 2.5



Normal bore of pipe (mm)	Size (mm)	
	singled-mixed	graded
100 - 125	10	-
150 - 200	10 or 14	14 to 5
225 - 300	10, 14 or 20	14 to 5 or 20 to 5
375 - 500	14 or 20	14 to 5 or 20 to 5
exceeding 500	14, 20 or 40	14 to 5 20 to 5 or 40 to 5

All granular material to be sized or graded in accordance with the adjacent table. Aggregates to BS 882, sintered pulverized-fuel ash to BS3797 and air-cooled blast furnace slags to BS 1047 are suitable.

Dimension a = for sleeve jointed pipes, a minimum of 50mm or 1/6 Bc, whichever is the greater. For socketed pipes a min. of 100mm or 1/6 Bc, whichever is the greater, under barrels and not less than 50mm under sockets

In rock or material containing hard spots :

a = for sleeve jointed pipes, a minimum of 150mm or 1/4 Bc, whichever is the greater. For socketed pipes a min. of 200mm or 1/4 Bc, whichever is the greater, under barrels and not less than 150mm under sockets

Bc = outside pipe diameter

Figure 6. Bedding Factors for Vitrified Clay Pipes