THE UNITED REPUBLIC OF TANZANIA

MINISTRY OF WATER AND IRRIGATION

DESIGN MANUAL
FOR
WATER SUPPLY
AND
WASTE WATER DISPOSAL

Service or branch lines connect city water to plumbing systems

In large apartment buildings sewage lifts are used to raise the level of the waste from a building cellars to the street conduits.

Sewer manhole covers have vents in them to provide for ventilation of gas or odors building up underground.

Sewer manholes consist of a shaft, generally with built-in stairs, that widen from two to five feet at the bottom for cleaning the sewer lines.

To save energy and maintain a reliable flow, gravity is generally used to carry wastewater. Pump stations help lift it over the hills.

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CHAPTER NINE

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ABBREVIATIONS

AC	Asbestos Cement
BOD	Biochemical Oxygen Demand
BS CP	British Standard Code of Practice
CAESB	Water and Sewage Corporation of Brasília, Brazil
COD	Chemical Oxygen Demand
CCTV	Closed Circuit Television
DOL	Direct on Line
GRP	Glass Reinforced Plastic
KN	Kilo-Newton
MLHUD	Ministry of Lands, Housing and Urban Development
MPD	Modified Proctor Density
NEMC	National Environment Management Council
O&M	Operation and Maintenance
OD	Outside Diameter
OPC	Ordinary Portland Cement
PVCu	Unplasticised Poly Vinyl Chloride
SWA	Steel Wire Armoured
TAG	Technical Assistance Guidelines
TANESCO	Tanzania Electric Supply Company Limited
UNDP	United Nations Development Program
VIP	Ventilated Improved Pit
WC	Water Closet
WEDC	The Water Engineering Development Centre
WRc	UK Water Research Council

CHAPTER NINE – SEWAGE COLLECTION

9.1 INTRODUCTION

9.1.1 General

In this Chapter of the Design Manual, sewage collection, is taken to involve the collection of waste water from occupied areas and conveying them to some points of treatment or disposal, usually off-plot but in certain circumstances on-plot.

Sewerage is a term that can be applied to all procedures, pipes and structures required for the collection, treatment and disposal of liquid wastes. More specifically herein, it refers to a system of sewers that conveys wastewater from its sources to a treatment plant or disposal point. The term "sewerage" also includes all the manholes, pumps, rising mains, gravity mains, air release valves, screens, overflows and associated infrastructure.

This chapter has expanded by the addition of several sections covering survey techniques such as CCTV, on low cost (simplified and settled) sewerage, on hydrogen sulphide and an introductory section on low cost on-plot sanitation.

9.1.2 Definitions Used

In addition to the above definition of sewage collection and sewerage, the following are the meanings given to the terms used herein:

- Sewage is the liquid conveyed by a sewer. It is the liquid waste produced by humans, their households and from industry.
- Sanitary sewage also known as domestic sewage is that which originates in the sanitary conveyances or a dwelling, business building, factory or institutions. It typically contains washing water, faeces, urine, as well as laundry waste and other liquid or semi-liquid wastes from households
- Industrial waste is liquid waste from an industrial process such as dyeing, brewing etc. It may require pre-treatment on the industrial premises before it is acceptable for discharging into public sewers.
- Sewage collection implies the collection of waste water from occupied areas and conveying them to some points of disposal or treatment.
- A sewer is a pipe or conduit, generally closed but normally not flowing full, for carrying sewage.
- A house sewer is a pipe conveying sewage from the plumbing system of a building to a common sewer point of immediate disposal.
- A lateral sewer has no other common sewer discharging into it.
- A sub-main sewer is one that receives the discharge from a number of lateral sewers.
- A truck or main sewer receives the discharge of one or more sub-main sewers.
- A sewer outfall receives the discharge from the collecting system and conveys it to a treatment plant or point of final disposal.

- An intercepting sewer is one that cuts transversely a number of other sewers to intercept dry weather flow with or without a determined quantity of storm water in case of combined sewer system.
- A relief sewer is one that has been built to relieve an existing sewer of inadequate capacity.
- Sewage treatment covers any natural or artificial process to which sewage is subjected in order to remove or alter its objectionable constituents so as to render it less dangerous or inoffensive.
- Peak flow is the maximum flow expected in the sewer.
- Peak factor is the ratio between the maximum flow and average flow.

9.2. CONTROLLING FACTORS IN THE DESIGN OF SEWERS

9.2.1 Waste Water Projections

Domestic and Industrial waste water, obviously is estimated from water supplied. Studies have shown that depending on the water consumption pattern, different proportions of the water supplied is collected as waste water (Ref. Table 9.2)

9.2.2 Domestic (Sanitary) Waste Water

For design consideration the value of 60 to 85 percent of the per capital withdrawal (consumption) of water becomes waste water. The lower value (< 60%) may be adopted / applied to the semiarid region or where water supply is insufficient. Table 9.2 give the percentage of wastewater produced in different category.

9.2.3 Industrial Waste Water

Waste water in which industrial wastes are predominate. Industrial water use varies widely according to the nature of the manufacturing processes. In practical design work it is therefore desirable to inspect the plant, (industry) concerned and make careful estimates of the quantities of wastewater produced. This may as well be facilitated through questionnaires. Where the specific type of industry is unknown, (or not easy to get information) an allowance of $50m^3$ /ha.d can be used for design purposes. Effect of industrial wastes upon sewers and Treatment works is given in Appendix 9.

9.2.4 Infiltration

The extraneous water that enters the sewer system from the ground through sewer service connection, pipe joints, manholes etc., is termed infiltration. The rate and quantity of infiltration depend on the length of the sewers, the area to be sewered, the soil, topographic condition, characteristics and conditions of the sewer material. Normally, infiltration is estimated to vary from 35 to 115 m^3/km of sewer per day. Higher values can be assumed where the sewers are passing below the water table or water table is higher.

9.2.5 Storm Water Inflow

Water which enters the sewer either deliberately or inadvertently from surface run-off is termed storm water inflow. In sewers designed for sanitary waste only, this is a most unwelcome inflow.

However, it can occur through such things as vandalism to manhole covers or a failure to ensure they are properly in place during rainy seasons. It is best prevented by good routine inspection and routine maintenance.

9.2.6 Peak Flow Factor

Peak flow factor is the ration of peak flow to average flow. It is derived or established for each major establishment or for each category of flow in the system. Where no actual measurements are available, usually the peaking factor of 4.0 is used in lateral sewer design while main sewers are then designed for a peak factor of 2.5. The normal range is from 1.5 to 4.

In other case, peak flow factors are linked to the pipe sizes and the following peak factors have been in use.

- For sewers 500mm in diameter or less . 2.00
- For sewers exceeding 500mm in diameter. 1.75
- For final outfall sewer (truck main). 1.50

The peak flow factor can also be estimated from population (Refer to Table 9.2)

9.3 SEWERAGE

Conventional Sewerage is usually confined to Central Business Districts, densely populated formal housing areas and industrial and commercial areas. Elsewhere, on-plot sanitation predominates with the septic tank and soak-pit or soak-trench used in medium and high cost areas and the pit latrine in low cost and informal areas.

However, there is an alternative to conventional sewerage for planned low cost housing areas in particular, that is referred to as Low-Cost, that is Simplified and Settled Sewerage and these are discussed in Sections 9.12 and 9.13 respectively.

9.4 CONVENTIONAL SEWERAGE

9.4.1 Survey of Existing Sewers

Although the total extent of sewers in Tanzania is not large by international standards, sewerage dates back many years in the major urban centres and existing sewers are aging and in some instances need either major rehabilitation or replacement or duplication to cater for increased flows.

It is therefore increasingly necessary to survey existing sewers as part of a scheme expansion programme to decide on how best to deal with them, and whether to rehabilitate or replace. Several survey techniques are available for this and guidelines for these are presented briefly below.

9.4.1.1 CCTV Surveys

The use of a close circuit television to survey the inside of an existing sewer is probably the best way to determine its condition and decide on what measures, if any, are practicable and cost effective to extend its life. An example of this was some years ago in Tanga. It does however require the employment of a firm with specialist knowledge, be it a consultant or a contractor.

Where sewers are being surveyed, it is necessary to use trained skilled operatives who have successfully completed courses in Confined Space Entry, the use of breathing apparatus, signage, lighting and coning in accordance with any Road and Street Works Act, as appropriate and be required to show a working knowledge of local Health and Safety Acts and have undertaken a course in Sewer Condition Classification.

Where drains are being surveyed, it is necessary to use operatives trained in the safe use of the equipment and site working procedures, and the operative should have an understanding of sewer condition classification.

All equipment used must be safe for working in sewers and drains, and the survey cameras should have a manual feed, be self-propelled or winched and will have in-built distance recording as appropriate for the situation.

Once on site, unless otherwise agreed, the Company should complete the job except where work has to be abandoned. This may prove necessary if it is deemed that there is a risk to the operation due to unsafe conditions, for example, sewer, drain or manhole collapse etc., or the inability to survey due to flooding, blockage, etc.

A full report on the findings of the survey, including video recordings and still photographs, where appropriate, must be provided to the Client. For work carried out in sewers and where the duration of a CCTV inspection exceeds a working shift, the report and site documentation will be in accordance with an acceptable manual such as the UK Water Industry Manual for Sewer Condition Classification including computer data output. For jobs less than 50 metres the report should generally follow such a Manual where appropriate but be in textual form only. In any case the report should normally be delivered to the Client within 14 days of completion of the job.

9.4.1.2 Sewer Flow Surveys

The company retained must provide sufficient suitable flow survey monitors and a secure means of fixing the flow monitoring equipment in place, together with an adequate number of rain gauges for the survey.

Equipment should be re-calibrated and tested prior to the commencement of each survey and checked for reliability and consistency at each data retrieval visit.

The staff deployed should be fully trained in the installation of equipment and experienced in data retrieval and interpretation of results. They should have successfully completed courses in confined space entry, the use of breathing apparatus, and in signage, lighting and coning in accordance with any Road and Street Works Act, and be required to show a working knowledge of local Health and Safety Acts as appropriate.

Data retrieval should take place at regular, agreed, intervals and a full report on the findings should be provided to the Client within four weeks of completion or as specified.

Work should generally be undertaken in accordance with a Model Contract Document such as that from the UK for Short Term Flow Surveys unless otherwise specified.

It should be noted that in certain circumstances consistently low flows may give suspect readings.

9.4.1.3 Jetting of drains and sewers.

The Company retained should provide suitable water jetting equipment for the task of clearing or unblocking of sewers and drains and limit the water pressures and flow rates used to ensure no damage is caused to the pipe work.

It should use trained skilled operatives who have successfully completed a course in the use of high pressure water jetting equipment, Confined Space Entry, the use of breathing apparatus and in signage, lighting and coning in accordance with any Road and Street Works Act, and be required to show a working knowledge of local Health and Safety Acts as appropriate. They should also be aware of the risk of causing damage as described in the UK WRc paper on Damage to Sewers by High Pressure Water Jetting and their training should have been carried out to an acceptable Water Industry Training.

All equipment should be safe and serviced to carry out the works and the jet heads used for the appropriate service be in a good condition.

Once on site, unless otherwise agreed, the Company should complete the job except where work has to be abandoned. Abandonment may be considered in the following circumstances:

- Risk to personnel, public or the environment from flooding/contamination.
- Unable to clear the blockage within the parameters for either safe working or avoidance of damage to the pipe work.
- Collapse of manhole, drain or sewer.

In these cases the Company should inform the Client of the action proposed.

A report on the result of jetting and any works recommended should be provided to the Client and it is his prerogative to seek independent advice on these recommendations.

Charges for small domestic jobs are generally on a daily, half-daily or hourly all-inclusive rate. Larger jobs may be undertaken on an agreed cost per metre basis, on terms similar to the UK Water Industry Model Contracts.

9.4.1.4 Reference Documents

The Model Contract Documents referred to above can be purchased from the WRc, Medmenham, Buckinghamshire, UK, <www.wrcplc.co.uk>).

This and other relevant documents available include:

- Model Contract Document for Sewer Condition Inspection. 2nd Edition, WRc 2005
- Manual of Sewer Condition Classification - 4th Edition WRc, 2004
- Model Contract Document for Manhole Location Surveys and the Production of Record Maps. 2nd Edition. (photocopy only) WRc, 1993.
- Model Contract Document for short term sewer flow surveys. 2nd Edition. WRc, 1993.
- Sewerage Rehabilitation Manual 4th Edition – Book or CD ROM, WRc 2001.

9.4.2 Hydraulic Design of Sewers

Conventional sewerage comprises a system of relatively large bore sewers, manholes and other appurtenances that convey effluent from individual premises through a system of sewers that get progressively larger in diameter and lead to some type of sewage treatment works. As far as practicable, the system relies on gravity and sewers are designed on the basis of flowing no more than half-full. The sewers are laid down the sides of roads at depths usually in excess of 900 mm with manholes at sufficiently frequent intervals that they can be accessed for sewer cleaning as well as allowing for changes of direction and grade.

9.4.2.1 Design Calculations

For hydraulic design calculation, different methods have been in use for a long time, common formula used are the Colebrook Formula and the Crimp and Bruges Formula which is an adaptation of the Manning Formula. Table 9.1 illustrates the recommended hydraulic design criteria when adopting the Crimp and Bruges method.

Whilst design for small systems can be readily undertaken using a hand held calculator or spread sheet, for larger systems it may be desirable to use computer software, especially where there is a risk that surface flows may get into the system due to vandalism to manhole covers or where a dual system is opted for, although this type of combined storm-water and sanitary sewerage is not recommended.

One such software package is the ‘Hydra’ Software for the Analysis, Design and management of Storm, Sanitary and Combined Sewer Systems from Pizer Inc. of the USA. Their 28 page sanitary sewer user’s manual can be downloaded after free registration from < http://www.pizer.com/>. It also provides useful information on daily flow patterns, flow routing, how to consider land use areas, population based average daily flows, diurnal variations, and sanitary service areas and flows. The software (2007) costs between US$ 1250 for the 200 sewer pipe module up to US$ 4,500 for the unlimited sewer pipe module.

9.4.2.2 Relative Velocity and Discharge in Circular Conduits

The relative velocity and discharge in a circular conduit flowing less than full is illustrated in Figure 9.1 on the following page. The recommended procedure is to first determine the necessary diameter for a pipe flowing full and then to adjust this upwards for the design flow depth from the Figure.

9.4.2.3 Design Capacity

Sanitary sewers should be designed for a capacity equivalent to double the peak domestic flow plus the peak industrial flow plus infiltration; that is sewers will take the peak flow when running half full. These are indicated in Table 9.1 on the following page.

* NOTE: In the Table, the maximum gradient given is preferred only, but not limited to.

$$V \text{ value} = 1.31 \times 10^{0.6} \quad m^3/s$$

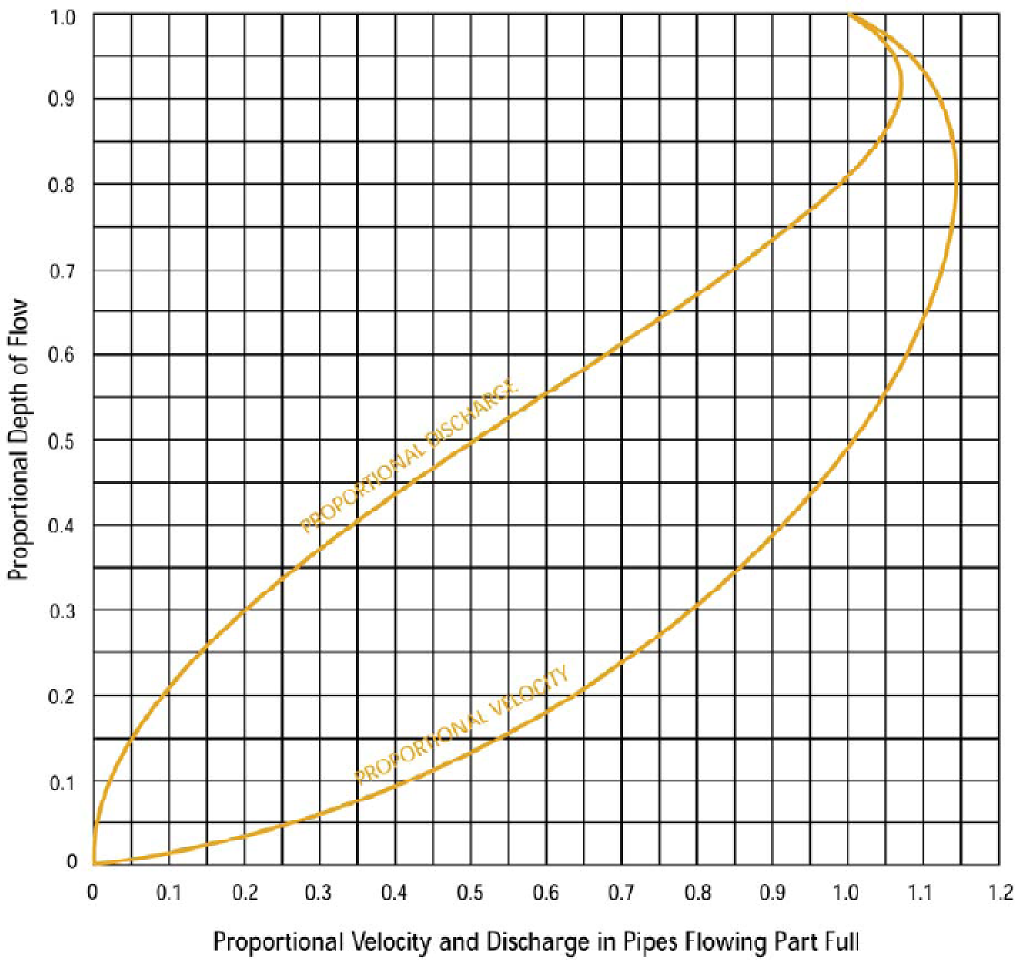


FIGURE 9.1: RELATIVE VELOCITY AND DISCHARGE IN CIRCULAR CONDUITS

TABLE 9.1 – HYDRAULIC DESIGN VALUES

DIAMETER mm	GRADIENT 1 in …		FLOW IN 1/sec		PIPE FULL VELOCITY IN m/ sec		PEAK FLOW FACTOR	PIPE HALF FULL
mm	MAX*	MIN	MAX	MIN	MAX	MIN		
200	20	130	75	30	2.4	0.95		
250	50	212	87	42	1.7	0.85		
300	50	250	140	60	1.9	0.85		
350	50	333	200	80	2.2	0.85	2.00	
400	70	400	250	100	2.0	0.85		
450	75	400	340	150	2.1	0.90		2.00
500	100	400	380	190	2.0	0.96	1.75	
600	100	450	600	300	2.2	1.05		
700	100	500	950	420	2.4	1.05		
800	100	500	1300	600	2.6	1.15	1.50	
900	100	500	1800	800	2.8	1.25		

Design Criteria are given in Table 9.2 below and overleaf.

TABLE 9.2: DESIGN CRITERIA

DESIGN FUNCTION	VALUE
FLOWS	
Discharge factors (% of water consumption)	75%
Low density 1600m^2 plots	80%
Medium density 800m^2 plots	65%
High density 400m^2 plots	35%
Communal ablutions	30%
City Centre, Institutional and Industrial	
Peak flow factors (Design peak to average)	4.00
Contributing population	3.50
Up to 20,000	3.00
20,000 - 60,000	2.00
Above - 60,000	1.00
City Centre and Industrial	
Infiltration	
SEWERS	200mm
Minimum diameter of main sewers	200mm
Commercial Institutional and Industrial areas	
Residential areas	100mm
Branch sewer diameter in Residential areas	150mm
Lateral connection diameter	0.2%
One or two properties	0.1%
More than two properties	3.0%
Minimum slope	0.75%
Absolute minimum slope	1m/s
Minimum slope for lateral connection	3m/s
Minimum flow velocity – full pipe condition	3.00mm
Target minimum flow velocity – full pipe condition	1.50mm
Maximum fowl velocity – full pipe condition	1.00m
Roughness coefficient (ks) Concrete pipes	
Roughness coefficient (ks) PVCu pipes	100m
Sewer depth (minimum cover)	
MANHOLES	
Maximum manhole spacing	
PUMPING STATIONS AND PUMPING MAINS	
Minimum diameter of main	150mm
Minimum flow velocity	0.75m/s
Maximum flow velocity	2.00m/s
Roughness coefficient (k)	0.6mm

Cont'd

DESIGN FUNCTION	VALUE
SEA OUTFALLS	
Minimum flow velocity	1.00 m/s
Absolute minimum flow velocity	0.75 m/s
Maximum flow velocity	2.00 m/s
Design peak flow factor (average flow)	6
Roughness coefficient (ks)	0.6mm
SEWAGE TREATMENT	
Pond Option	50 g/ head/d
Biochemical Oxygen Demand - Domestic	6 kg / ha / d
(5 days) Loading - Industrial	
Anaerobic Pond - Retention time	5 days
Depth	3-4m
BOD reduction at 5 days	55 – 70 %
Facultative Pond – Depth	> 2.0m
Temperature	20^{o}C
Volumetric loading	15 – 30 g BOD/m^3/d
Maturation Pond - Mini. Number in series	2
- Depth	1-1.5m
Final Effluent Standard – BODs	< 25 mg/1
Bacteriological quality	< 5000 E. Coli per 100 ml
Dilution factor (to be attained in receiving water wherever feasible)	8:1

9.4.2.4 Sewer Diameter

The recommended smallest sewer pipes range from 100 to 150 mm in diameter, these are usually of PVCu or ductile cast iron. For ease of cleaning and other maintenance works, the diameter should not be less than 200 mm for street sewers. If of PVC then suitable embedment and embedment compaction are important.

9.4.2.5 Gradient (Slope) in Sewer

In sewers the allowable minimum slope is 0.2%. Excessive slope may result in erosion of the channel bottom or sides. An absolute minimum slope of 0.1% can be adopted with caution, such that it may not lower the velocity to cause deposition or sedimentation in the sewer or favouring hydraulic inefficiency of the sewer hence corrosion.

9.4.2.6 Flow Velocity in Sewer

The velocity in sewers should vary from 0.6 to 3 m/s. To prevent the settlement of wastewater solids, the velocity in sewers flowing full should be not less than 0.75 m/s while for one – sixth full sewer the value 0.3 m/sec is reasonably adequate. Higher velocities should be avoided as they may cause sewer scouring.

9.4.2.7 Roughness (Friction Coefficients)

This coefficient depends upon the roughness of the pipe, pipe material or surface, and affects inversely as its value. For sewers of good construction methods, careful aligning of the pipe and smooth joints the value of **Ks** should be smaller and vice–versa, as shown in Table 9.3.

TABLE 9.3 – ROUGHNESS COEFFICIENTS IN SEWERS

SEWER PIPE	ROUGHNESS 'Ks' in mm (NORMAL)
New sewers (assumed clean)	
Asbestos cement	0.03
Clayware	0.06
Uncoated steel	0.06
PVCu	0.06
Concrete	0.15
Slimed sewers	
Asbestos cement	3.0
Clayware	3.0
Uncoated steel (moderate)	3.0
PVCu	1.5
Concrete	6.0

9.4.2.8 Lateral Connections

The diameter of lateral sewer connection should not be less than 100mm. When a connection is made to a sewer, a Y – branch should be inserted. The method of drilling a hole in the sewer and inserting the lateral pipe connection should be always avoided. It should be ensured that the lateral pipe does not protrude into the sewer, as this may interfere with normal cleaning (0&M).

9.5 LAYING OF SEWERS

9.5.1 Maximum and Minimum Cover to Sewer, Sewer Depth and Trench Width

The depth of a sewer should be sufficient to that all houses sewers connected to it will be drained by gravity. Minimum cover to sewer should not be less than 1m, while maximum cover can be as much as 5m, ensuring sufficient protection against most superimposed loads in either case. In no case should a sanitary sewer be placed above a nearby water main. The width of trenches for sewers is to be at least the diameter of the sewer pipe plus 400mm.

9.5.2 Pipe Bedding and Trench Backfill (for Rigid and Semi-rigid Pipes)

Rigid and semi-rigid pipes are those with a sufficiently thick wall that the exhibit no or little deflection such as concrete, vitrified clay, asbestos cement and ductile cast iron. For these the crushing strength is important as the first limit state reached is fracture rather than in buckling.

The trench must be excavated to invert level if the soil is decomposed and easily excavated by hand. If the bottom of the trench is of broken rock then excavation must be continued and select backfill material to be used and compacted. In the case of thermoplastic sewers such as PVCu and GRP sewers, and steel sewers without a concrete lining this should always be the case as these are flexible pipes which rely on good compaction for support to keep deflection within acceptable limits to prevent their first limit state which is buckling. In such a case, compaction should be to not less than 90% MPD and if necessary the trench width must be increased to ensure that this is achieved. For design of flexible sewer pipes, please refer to Chapter 4.

Any excavation more than 150mm below the design invert of the pipe must be backfilled with mass concrete to prevent undue settlement. Where practicable, minimum cover should be 1 m beneath roads.

Where the soffit of a sewer is less than 1.2 metres below the crown of a road or less than 0.6 m below ground level elsewhere, (0.9 m in the case of PVCu) then a concrete of a minimum of 150mm must be used to surround the sewer. When used under roads this surround should be extended out at least one metre beyond the road edge.

Some of the Sewer Bedding details are described below and all are shown in Figure 9.1 overleaf:

1. **Class A Bedding Concrete.** For all sewer types. Here, the concrete (reinforced or plain) should have a minimum cube strength of 20 N/mm^2 at 28 days and backfilling should not be done until at least 24 hours after placing the concrete. Heavy rammers should not be used nor heavy traffic allowed until at least 72 hours after concreting.
2. Class B Bedding. This requires granular embedment materials at least to the crown of the sewer and is suitable for both flexible and rigid walled sewers when as shown.
3. Granular bedding type A. Materials to pass 10-25mm sieves according to pipe size and be retained on a 5mm sieves for rock and coarse grained soils – ideally broken stones or gravels, but other similar uniform material available locally should be used, e.g. Crushed bricks or concrete. Sand containing an excess of fine particles should be avoided for this type a material since they are difficult to place and compact properly.
4. Selected fill type B. Uniform readily compatible material free from tree roots, vegetable matter and building rubbish and excluding large clay lumps (retained on a 75 mm sieve) and stones retained on a 25 mm sieve.

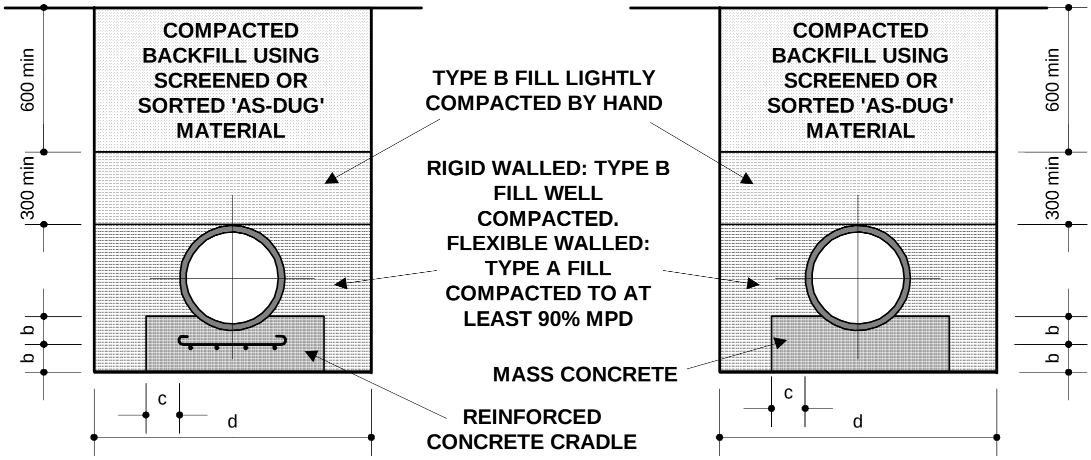
Key to Bedding Details shown

OD = outside diameter a = OD/2 b = OD/4 (150mm. minimum)
c = OD/3 (100mm minimum) d = OD + 400mm (minimum)

Notes: (a) Whenever rock is encountered in a line specified for class C bedding; then class B bedding should be used instead

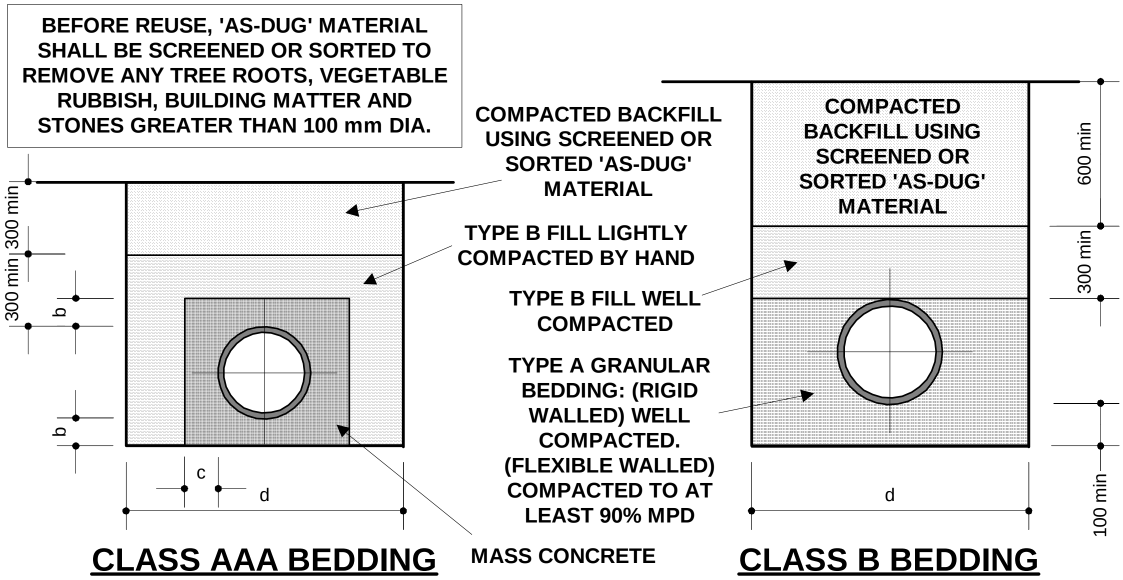
(b) At any road or railway crossing, bedding type AAA should be used.

It is also most important to note that Class C and D Beddings are unsuitable for flexible sewer pipes such as PVCu, and unlined, epoxy lined or cement mortar lined Steel and should only be used for sewer pipes that can be classified as rigid or semi-rigid.



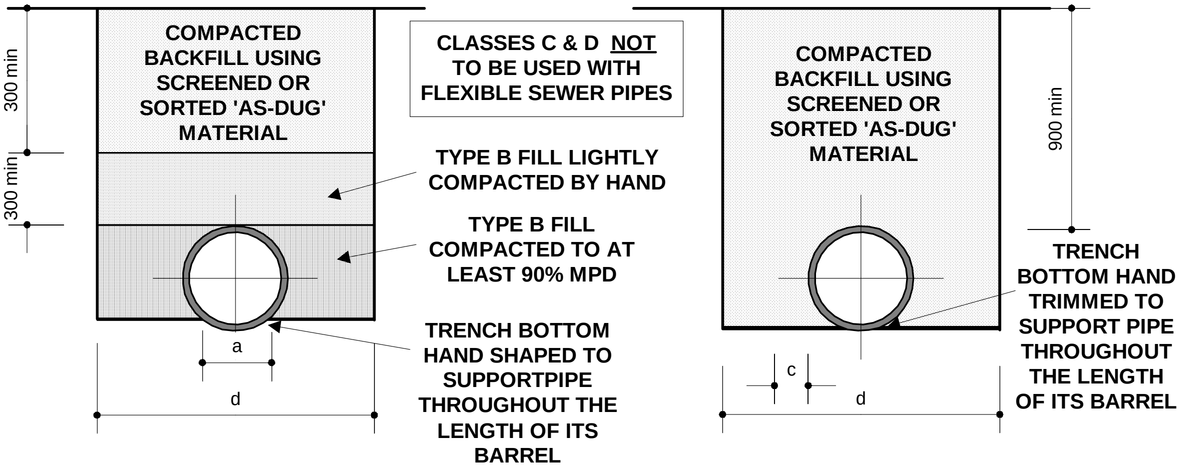
CLASS A BEDDING **CLASS AA BEDDING**

BEFORE REUSE, 'AS-DUG' MATERIAL SHALL BE SCREENED OR SORTED TO REMOVE ANY TREE ROOTS, VEGETABLE RUBBISH, BUILDING MATTER AND STONES GREATER THAN 100 mm DIA.



CLASS AAA BEDDING **CLASS B BEDDING**

CLASSES C & D NOT TO BE USED WITH FLEXIBLE SEWER PIPES



CLASS C BEDDING **CLASS D BEDDING**

FIGURE 9.2: STANDARD SEWER BEDDING DETAILS

To ensure a functioning sewer it is important that:

- The sewer pipe should be handled carefully, properly bedded and backfilled in such a manner that there is a minimum damage during and after construction.
- Joints should be made with sufficient care to eliminate excessive infiltration.
- The line and slope of the sewer should be free of irregularities that might favour the accumulation of solid wastes which results into clogging of the pipe and release of hydrogen sulphide, whilst changes of grade and alignment should only occur at manholes.

Standard bedding information, including the minimum crushing load for rigid and semi-rigid sewers in KN/m is given in Table 9.4 below:

TABLE 9.4: STANDARD BEDDING INFORMATION – MINIMUM CRUSHING LOADS

MINIMUM CRUSHING LOAD (KN/m^2) for RIGID PIPES NOMINAL BORE OF PIPE (mm)													
DEPTH OF COVER cm	**TYPE C BEDDING**			**TYPE B BEDDING**									
	200	**250**	**300**	**200**	**250**	**300**	**350**	**400**	**500**	**600**	**700**	**800**	**1000**
Not less than 900 mm	14	18	20	13	14	16	18	22	27	34	39	42	51
	16	20	22	15	16	17	22	24	30	38	44	45	57
	18	23	25	16	18	20	28	32	36	45	51	55	71
	21	25	26	18	20	22	32	38	42	53	59	65	85
	25	27	30	20	21	24	34	42	47	59	64	72	99
	27	28	33	21	22	26	36	45	51	66	68	79	114
DEPTH OF COVER cm				**TYPE A BEDDING**									
				200	**250**	**300**	**350**	**400**	**500**	**600**	**700**	**800**	**1000**
Not less than 900 mm				8	9	10	12	14	17	22	25	27	33
				9	10	11	14	15	19	24	28	29	39
				10	12	13	18	20	23	28	32	35	45
				12	13	14	20	24	27	32	38	40	54
				13	13	15	22	27	30	38	41	46	63
				13	14	16	23	29	33	42	43	50	73
Assumptions:	**Saturated density of trench fill is assumed to be 2000 kg/m^3. Concentrated surcharge load is taken as a group of two wheels spaced 0.9 m apart and each having a static weight of of 30 KN with a factor of 2.0, both wheels acting simultaneously.**												

9.6 SEWER PIPE CLASSIFICATIONS

The strength of rigid and semi-rigid walled sewer pipes installed must have a minimum crushing load capacity as specified by the pipe manufacturer, and greater than the values given in Table 9.4 above for the given size and depth or backfill. The minimum crushing load is computed by the following equation.

$$WT \geq (We \times Fs) / Fm \tag{9.1}$$

Where,

WT = Ultimate test strength of pipe in KN/m

We = External design load in KN/m

Fs = Factor of safety

F_s (ULT) = 1.25 9.2

Where,

Fm = Bedding factor depending on bedding class

Class A:	Fm = 3.0	Class B:	Fm = 1.9
Class C:	Fm = 1.5	Class D:	Fm = 1.1

9.7 SEWERAGE STRUCTURES

9.7.1 Manholes

For ease of maintenance and inspection manholes are provided at each intersection and every change in gradient, pipe diameter, direction of flow or level of the sewer and at all junctions. Manholes are usually installed at intervals ranging from 70 to 150m. For Tanzania where maintenance has traditionally been poor, and blockage problems tend to be frequent, in addition to this usual requirement, the distance between manholes should be restricted to:

Sewers, diameter:	100 – 500mm	Spacing:	70-80 m
Trunk sewers, diameter:	500 – 700mm	Spacing:	90 m
Trunk sewers, diameter:	> 700mm	Spacing:	100 m

9.7.2 Types and Dimensions of Manholes

Manholes are usually constructed of brick or concrete / concrete blocks. The general design varies from inside drop / outside drop to very large manholes for large pipes. The bottom part is usually of concrete with benching to give a half-round or U–shape to allow for smooth flow trough for the effluent. Circular manholes are preferred and usually 1.2 m in dia., but reducing to not less than 0.6 m dia. at the top. For square or rectangular manholes, dimensions should not be less than 0.6 m × 0.6 m (Ref. Figure 9.3 and 9.4). Normally manholes are centred over the pipe, but for large sewers it may spring from one wall of the sewer. The use of pre-cast concrete rings is often preferred as these can be cast in advance to a high standard and minimise site construction time.

The joining of manholes to flexible sewer pipes in general and thermoplastic pipes in particular needs considerable care given the rigidity of the manhole wall and the flexibility of the pipe.

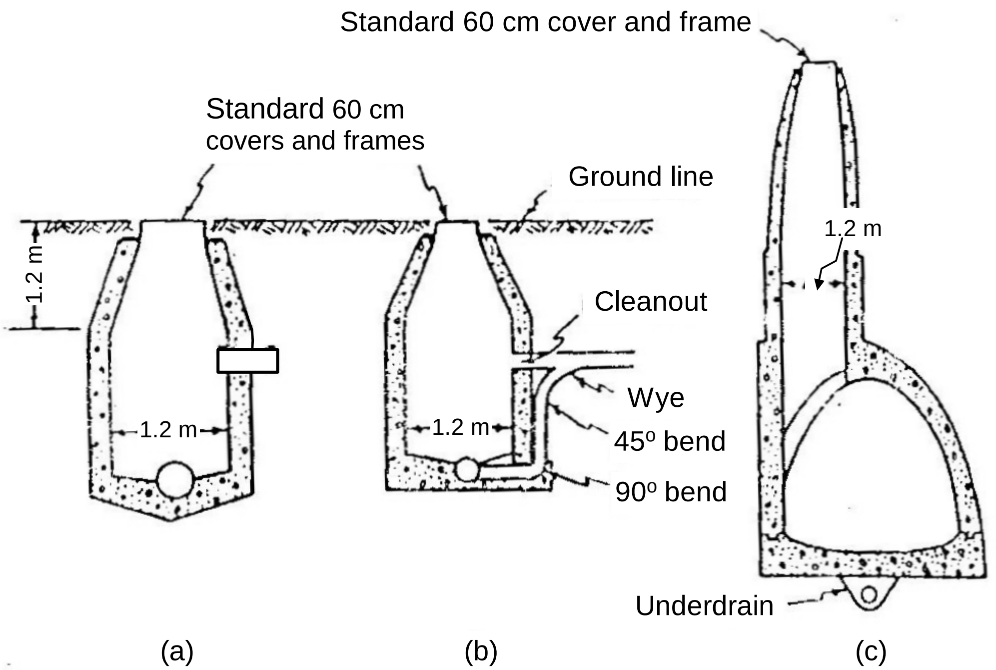
Manhole covers and cover frames are usually made of cast iron, lighter covers are used in places subjected to negligible traffic loads, but heavy duty covers should be employed on and adjacent to major highways. The risk of vandalism and theft should always be considered a possibility, especially for lighter covers and in areas close to informal housing areas.

There is always a risk of differential settlement between a manhole and the adjoining sewer, and short lengths of 'rocker' pipes with joints that can take deflection should be provided, especially on sewers of 200 mm dia. and above to cater for this.

9.7.3 Special Rodding Manholes

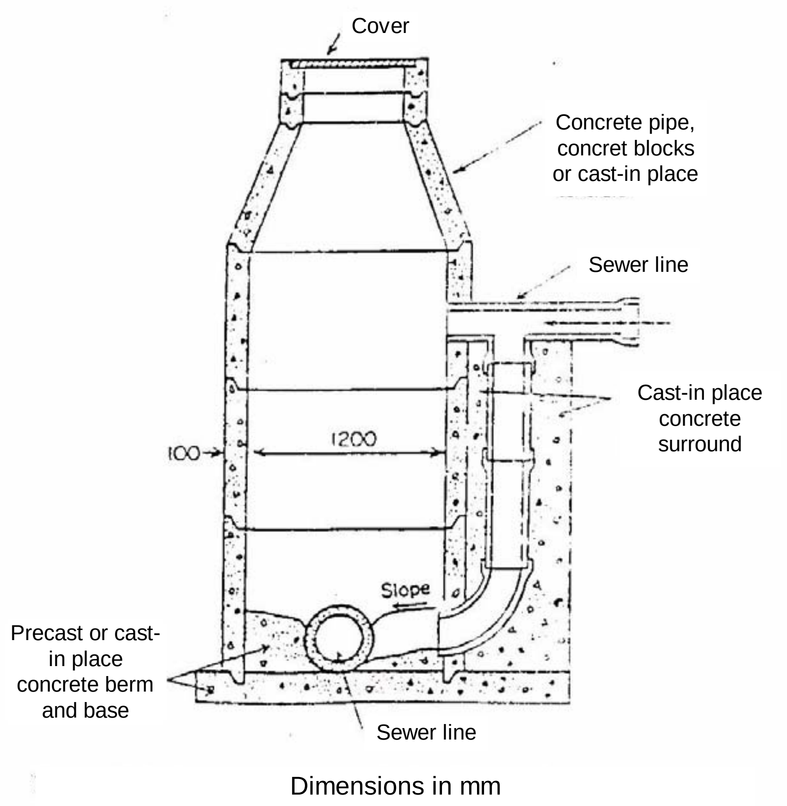
It has been found that the cost of laying approximately 20 metres of say 200mm diameter sewer is comparable to the cost of building a manhole.

At times the need for provision of an extra manhole may arise for example at road intersections, with one or both of the sewers spacing less than the standard required, in such situation instead of providing the normal type of manhole, this may be substituted by a small opening at the intersection which may be allow access to both lines during maintenance.



Some typical manholes: (a) inside drop; (b) outside drop; (c) manhole for large pipe

FIGURE 9.3: TYPICAL MANHOLE ARRANGEMENTS



URE 9.4: TYPICAL DROP MANHOLE ARRANGEMENT

9.7.4 Ventilation of Sewers

Ventilation of sewers is necessary and can be achieved by use of special manhole covers that can be provided upstream of every line and at every tenth manhole downstream. Ventilation pipes are to be used if the pipeline is not in a road or footpath. Vent stack normally are provided at the house end of every house connection.

In areas where there is heavy rainfall or risk of storm runoff waters covering the ground, it is not recommended to provide ventilation manhole covers. Instead it is recommended that ventilation columns be placed at the head of all branch sewers and at all points where pumping mains discharge into the sewerage system. Extra precautions are then required when entering manholes for routine inspection or to deal with blockages.

9.8 SEWER PIPE MATERIALS

Common materials for sewer pipes include: asbestos cement (AC) pipes, vitrified clay pipes, unplasticised polyvinychloride (PVCu) pipes, precast concrete products, ductile iron (DI) pipes, and to a lesser extent glass reinforced plastic (GRP) pipes and except in the USA, steel pipes.

9.8.1 Vitrified Clay Pipe

Manufactured to standard specification, in diameter from 100 to 1070 mm. Vitrified clay pipes are extensively used in Europe and the Middle East for sewers which convey corrosive liquid effluent since they are not subjected to mineral or bacterial corrosion. Their brittle characteristics make them unpopular where special shipping arrangements, e.g. Containerisation, are not employed as otherwise breakages can be very high.

The technology required is much more complex than that required for the production of concrete or asbestos cement pipes. There is no existing industry in Tanzania producing such pipes or a ceramics industry whose technology and experience could be exploited to form a manufacturing base for vitrified clay products.

During construction, concrete or mortar should be used around pipe joint to prevent weakness and leakage. In poor soil conditions (heavy clay), bedding is particularly critical. Trenches may require sheeting and flooring or even pile support to prevent excessive settling or damage to the pipe. They are not recommended to a depth of more than 4 m nor above 1.5m (to avoid severe cracking due to either loads imposed by backfilling or traffic load etc).

9.8.2 Reinforced concrete pipe

They are manufactured in sizes from 305 to 4570 mm. Though widely used, if unlined, they are susceptible to corrosion by sulphuric acid, where there is strong or stale sewage resulting in the production of hydrogen sulphide (areas where the slope of the sewer is small). To avoid this, reinforced concrete pipes may be lined using corrosion resistant material. The load bearing capacity is higher than for clay pipes.

9.8.3 Precast Concrete Products

The precasting of concrete products is a technique widely used for producing the standard requirements of the sewerage construction industry. Pipes are manufactured in diameter from 100 to 610 mm. The main advantage of the precasting method is a high standard of construction with significant time saving over in-situ construction. They are also easier to line as this can be done at the factory.

9.8.4 Unplasticised Polyvinyl Chloride (PVCu)

As flexible pipes, they must be properly designed to ensure an adequate wall thickness is specified.

PVc u is available in the range of sizes from 100 mm to 600 mm in diameter and in number of strength classes to cater for variations in pressure requirements, even for pumping mains application, although this is not recommended. A separate class is available for construction of gravity sewers, especially where class AAA bedding is proposed. Two types of joints are available, cemented or rubber ring. The latter is preferred and should normally be used.

Extreme lightness, long and high resistance to attack from acids and gases including methane and gases generated in sewers, the thin wall construction also means that considerable care is required during laying to ensure that embedment and bedding is of the correct quality and properly compacted.

Limited bending of pipes can be allowed whilst protection from the direct rays of the sun is required for outside storage. However, the point of entry and exit from manhole chambers requires particular care given the rigidity of the manhole walls and the flexibility in the sewer thermoplastic pipe.

9.8.5 Glass Reinforced Plastic (GRP) Pipes

Although their use in Tanzania is rare, GRP pipes can be used as sewer pipes as unlike water distribution mains, there should be no connections made into the sewer itself. Care at the manhole sewer interface is however crucial to ensure neither sewer wall cracking nor leakage occurs.

9.8.6 Asbestos Cement Pipes

Asbestos cement has been a common material in the manufacture of pipes for sewerage. The technology in the process is relatively simple, but high standards of quality control and testing are required to ensure a reliable product. In addition the high environmental health risks of inhalation of asbestos cement fibres requires that great care be taken.

For example, asbestos cement pipes were exclusively used on the city centre sewerage of Dar es Salaam constructed during the 1950's. Apart from attack by hydrogen sulphide in some locations these pipes when inspected were found to be in reasonable condition, although the sea outfall deteriorated considerably through the 1990s.

There is no existing industry in Tanzania producing asbestos cement pipes and all the asbestos cement pipes used for the city centre sewerage were imported.

For existing AC sewer pipes, their cutting, removal and disposal requires very great care to be taken and under no circumstances should this be practised without use of the proper protective breathing face masks and equipment. In some parts of the world, cutting and removal of asbestos cement products now requires the employment of specialist licensed contractors only.

9.8.6 Ferrous Pipes

Cast or ductile iron pipes and steel pipes, suitably coated and lined, the lining usually with sulphate resisting cement mortar or cement mortar and epoxy can be used, especially in force mains, and small outfall lines or where sewers are constructed above the ground surface and in inverted siphons.

Low pressure steel pipes, (8 bar) coated with fusion bonded epoxy and lined with either sewer grade fusion bonded epoxy or sulphate-resisting cement mortar is another possible sewer pipe that can now be manufactured in Dar es Salaam and a Specification sheet is available from the manufacturer. Again however, as a flexible pipe, both design as well as embedment and laying must be undertaken appropriately.

Corrugated metal pipes are used in storm sewers and twin thin-walled steel with the inner pipe smooth and the outer pipe corrugated to give the necessary strength are also used, but primarily in the USA.

9.9 SEWER APPURTENANCES

Sewer systems require a variety of appurtenances to ensure their proper operation. These include inlets, flushing devices, inverted siphons, regulators, sand, grease and oil traps.

9.9.1 Inlets

An inlet is an opening into a storm or combined sewer for entrance of storm run off, placed at the gutters. Combined sewers are both in uncommon and not recommended for Tanzania, hence this is not dealt with further.

9.9.2 Flushing Devices

Formerly it was a practice to place automatic flushing tanks at the upper ends of laterals where grades were low. However, due to maintenance problems these are now seldom used in present practice and not recommended unless a high level of maintenance can be assured. Instead, the use of manually operated flushing tanks with a fast opening flushing gate is recommended. A traditional automatic flushing tank is illustrated in Figure 9.5, and a tank with a HYDROSELF system from Germany with fast flushing gate in which the gate can be controlled either hydraulically or manually in Figure 9.6.

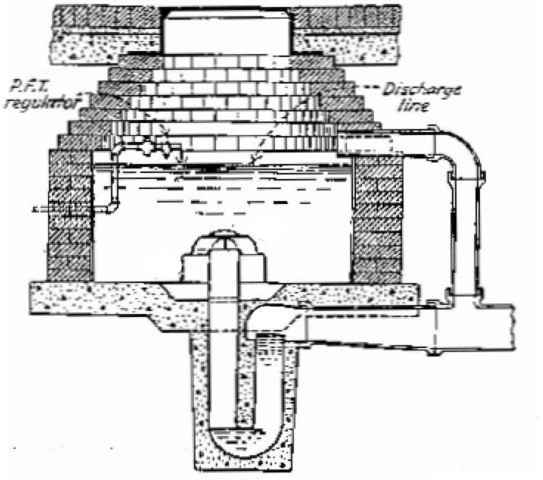


FIGURE 9.5: AUTOMATIC FLUSHING TANK

An alternative with an automatic tilting gate that operates when the tank is full is the Hydrass system from France.

Wherever a designer decides it is necessary to install a flushing tank, acceptable criteria has to be determined; in this case a relationship has been developed for a peak flow factor of 3 (small bore pipes) between the number of contributors to a length of 200 mm sewer and gradient for a minimum flow velocity of 0.75 m/sec.

A guide to this is given in Figure 9.7 on the following page.

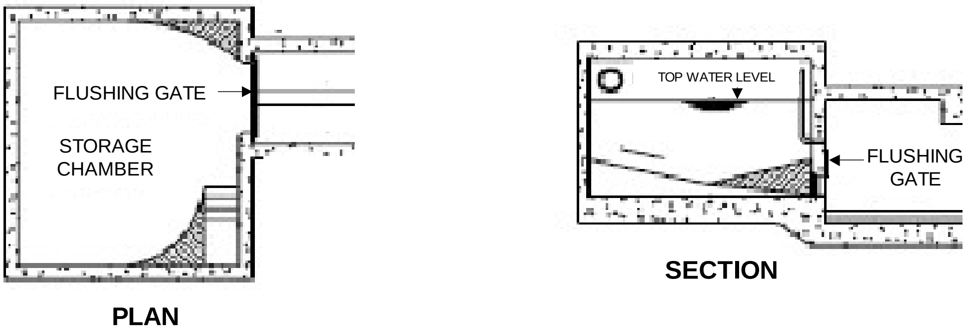


FIGURE 9.6: FLUSHING TANK WITH FAST OPERATING GATE

In Figure 9.7, the area between the x-axis and y-axis on the graph shows the minimum required number of contributors to achieve a minimum flow of 0.75 m/sec for various gradients of sewer, represents the section of sewer which needs to be flushed regularly.

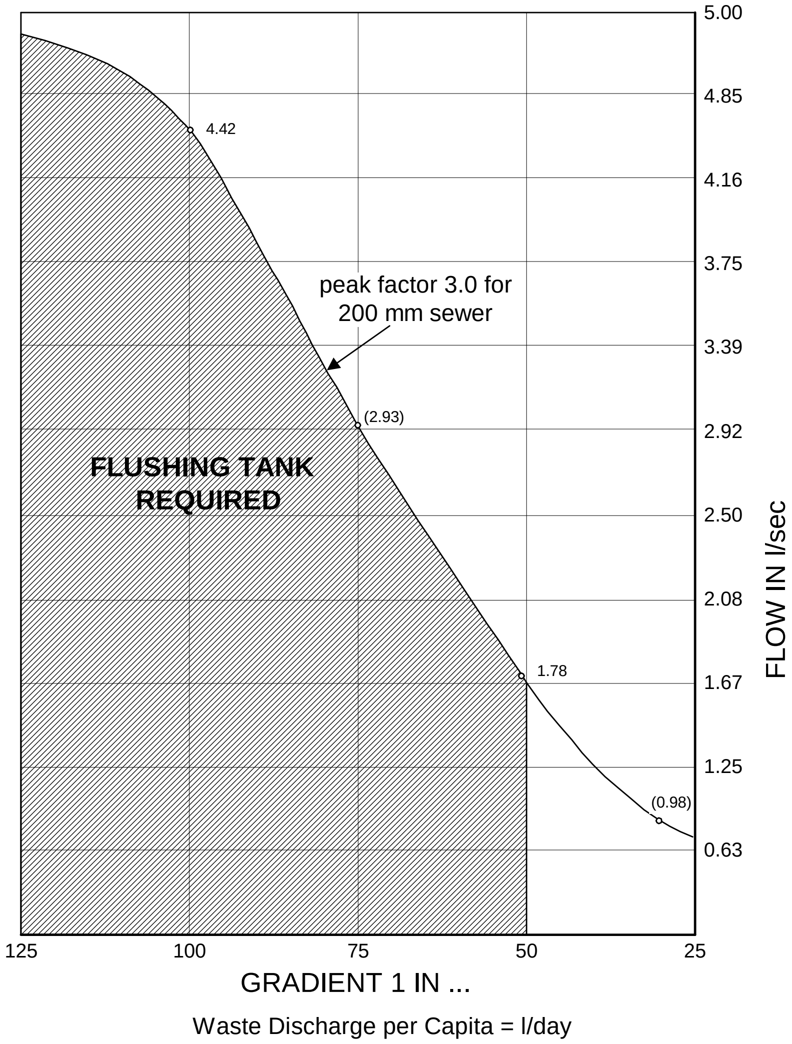


FIGURE 9.7: DETERMINATION OF FLUSHING TANK REQUIREMENTS

However any one single flushing of a toilet with a 10 litre cistern capacity into a 100 – 200 mm sewer under a gradient of 1:50 creates a self cleansing velocity. Flushing tanks are therefore only placed at the uppermost end of any sewer line where the combination of the number of contributors and the gradient of the sewer results in a velocity less than 0.75 m/sec as shown by the shaded area in the graph.

9.9.3 Sand, Grease and Oil Separator Traps

A very important but often overlooked factor is the need for sand, grease and oil separator traps for a number of industrial wastes prior to them entering the sewerage system. Otherwise sewers are liable to clogging and all biological sewage treatment processes are likely to be adversely affected.

The sewage from kitchens of hotels and restaurants contains grease which tends to accumulate on sewer walls and cause clogging.

This is often hot when discharged and the trap needs to be large enough to give time for cooling and rising to the surface. Likewise the sewage from garages contains mud, grease, sands and sometimes gasoline.

For places having sewage of that character it is strongly recommended to require such separator traps and for them to be cleaned regularly.

Usually, oil/sand separators are about 2/3rds the size of grease and fat separator traps, the latter usually being of a capacity not less than about 3 m^3 but dependant on the flow from the establishment.

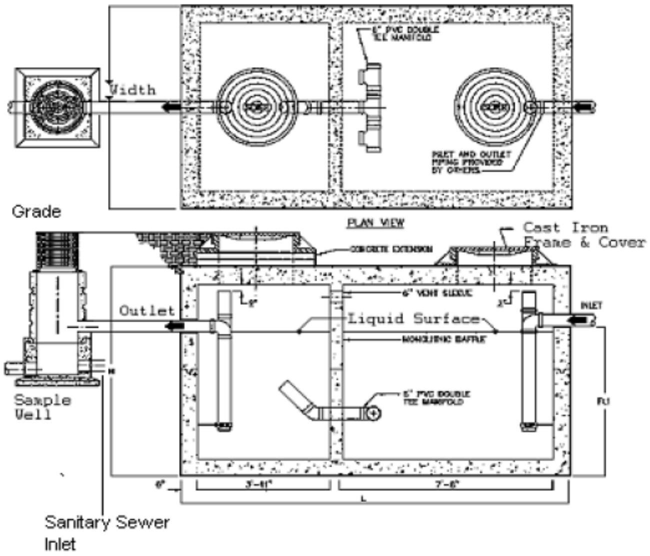


FIGURE 9.8: TYPICAL GREASE AND OIL SEPARATOR

The property owner should be required to pay for the cost of installation as part of his agreement when obtaining a sewer connection.

A decision is also necessary on who should be responsible for maintenance and cleaning. However, to avoid illegal dumping of the waste removed, it is usually better for the sanitation authority to be responsible for this and to charge for the service.

9.9.4 Inverted Siphons

An inverted siphon is used in a section of a gravity sewer which dips below the hydraulic gradeline so as to avoid such an obstruction as a railway cut, a subway or a stream. The sewer pipe used must be able to withstand the internal pressure in addition to the various imposed loads. The velocity should be not less than 0.9 m/s, and more than one pipe is desirable to overcome difficulties, say three pipes placed in parallel (se Fig. 9.9 overleaf)

When three are in use: Pipe ‘c’ – will carry the minimum flow
Pipe ‘b’ – will carry from minimum to average flow
Pipe ‘a’ – will carry all flows above the average

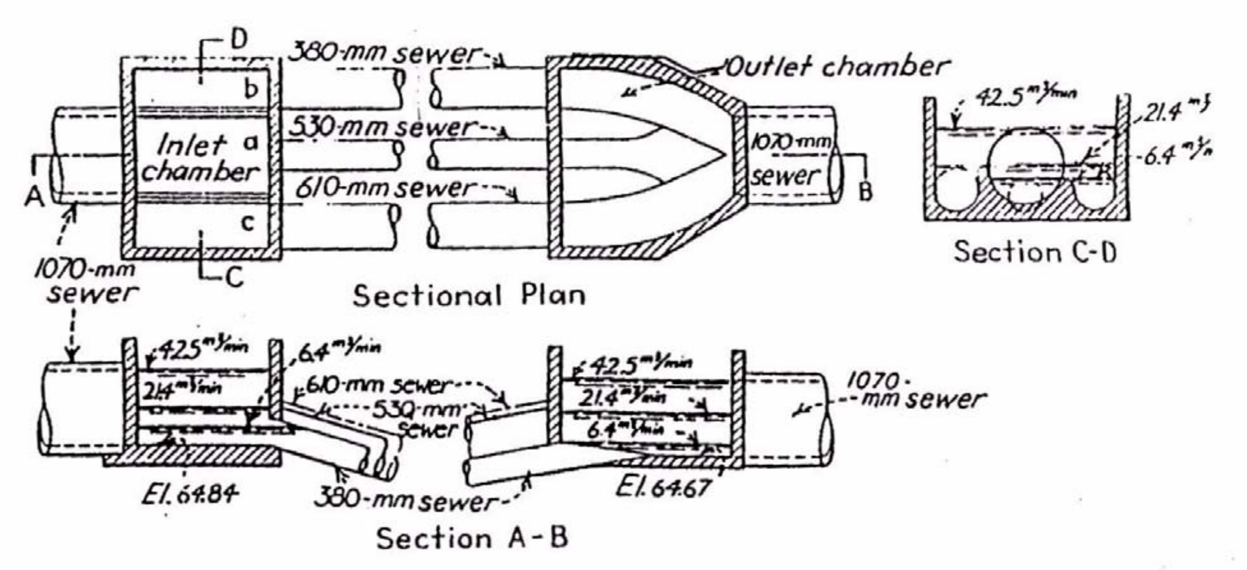


FIGURE 9.9: INVERTED SIPHON

Sometimes it is possible to cross depressions or small water courses without inverted siphons, using sewer pipes supported on piers. Cast or ductile iron pipe or steel, suitably lined should be used and provided with special couplings to avoid leakage.

Problems can be experienced with inverted siphons due to blockages as a result of the practice of some residents to dispose of their garbage in plastic bags into upstream manholes.

Where possible, a screened interceptor chamber needs to be built upstream of the siphon and such debris removed at frequent intervals. Where this is impracticable and notwithstanding the additional excavation and costs involved, if such blockages are likely, the best way to overcome the problem is to run the inverted siphon in a falling grade to a deep chamber at the downstream end of the section. This can then be periodically accessed for removal of such debris as it often floats to the surface in the chamber, or otherwise requires removal after onward pumping using a small portable submersible sludge pump into the next sewer section.

9.9.5 Regulators

A regulator is a device that diverts sewage flow from one sewer into another. It usually goes into action when the sewage flow reaches a predetermined amount. Regulators are mostly used where combined sewers discharge into interceptors. Usually the interceptors take the dry–weather flow, but the storm water is diverted into a sewer which flows to the nearest watercourse.

9.10 SEA OUTFALLS

Because the Indian Ocean is nutrient deficient off the coast of Tanzania, and the predominant current is northwards, sea outfalls, preferably for sewage after some form of primary treatment are often an acceptable means of final disposal for coastal towns, especially if most of the sewage is primarily of domestic and commercial origin.

Although it is easy to list reasons for undertaking a accurate assessment of the dynamic operation of a outfall it is not easy to provide rule of thumb solutions or generalized design criteria and parameters. However a description of the principal parameter will illustrate the complexity of outfall design and the need for detailed oceanographic data at each site to enable outline and final designs to be prepared.

9.10.1 Discharge Types

Basically there are two types of discharge, either pumped or gravity. In both cases the discharge can be continuous or intermittent depending upon the flow characteristics.

9.10.2 Dilution

Initial dilution rates are function of many factors including water depth, sea currents, diffusion rate, port size, discharge velocity, relative temperature, specific gravity of the effluent and ambient characteristics of sea water. The initial dilution criteria used in preliminary design is generally 100:1 but this will depend on the overall dilution factor specified which can range from 2,000 to 12,000 depending on distance of diffusers from the shore, tidal range and sea currents.

The effects of currents and a moving ambient fluid has a very pronounced effect on initial dilution hence detailed oceanographic data needs to determine the actual initial dilutions. Preliminary initial dilution calculations are frequently based on the assumption of still ambient water conditions.

9.10.3 Discharge Velocities

In both continuous and intermittent flow characteristics, velocities should be self cleansing and high enough not only to keep material in suspension during discharge but also to re-suspend material which may have deposited itself on the invert of the sewer pipe during times of no discharge. Minimum design velocities of 2.0 m/s and absolute minimum velocity of 0.75 m/s have been used in preliminary outfall design calculations. The capacity of outfalls has been based on a design peak flow of six times the average flow rate.

9.10.4 Diffusers

Diffusers are devices located at the discharge end of submarine sea outfall so as to achieve ejection of the effluent into the sea through a series of small apertures instead of a single open ended discharge through the main bore of the pipe.

The diameter and velocity of effluent through a diffuser port is determined by the degree of initial dilution required. For preliminary design, diameters between 100 mm and 150 mm are frequently used whereas velocity of discharge at a diffuser port is taken as 3 m/s.

9.10.5 Preliminary Design

With the oceanographic data often available it is not possible to determine whether or not diffusers will be required, the exact length required for the outfalls or their mode of operation.

Therefore for master planning, sea outfalls have been sized (diameter) from calculated flows to be discharged and their points of discharge have been taken to point at least 200 metres beyond the reef or into at least 13 metres depth of water at average high tide with a further allowance of 100 metres for the diffuser system.

9.10.6 Summary

There is no reason why a properly designed and scientifically located sea outfall with or without a diffuser system should not satisfy NEMC and other interested bodies. With few exceptions sea outfalls have proved to be the most economic solution for sewage disposal in a coastal town or city when compared with land based treatment methods.

For more information designers are recommended to consult the freely available Project Gutenberg E-Book entitled 'The Sewerage of Sea Coast Towns by Henry C. Adams.

9.11 PUMPING STATIONS AND PUMPING MAINS

Pumping stations should only the installed in new works where it is entirely impractical to effect drainage by gravity. However, to operate successfully there will be a minimum flow required to the station to keep retention times in the station's wet well and pumping main to within acceptable limits.

Once the need for a pumping station is established the design has to be such so as to optimise construction cost with ease of maintenance and operation.

However, and because such pumping stations are then the key to the successful conveyance of sewage from the areas of generation to the areas of treatment and disposal, it is essential that they incorporate pumping plant of the highest reliability that is appropriate and easily serviced and maintained.

Experience shows that especially in the local situation, submersible pumps although possibly the cheapest investment solution are not always in this category. Even the more expensive and well manufactured of submersible pumps require pre pump grinding or maceration of the sewage to deal with the foreign objects such as polythene bags containing household waste that these days get into sewers, whilst over time submersible pumps suffer from mechanical seal failure.

Given the nature of the environment in which they operate, namely raw sewage, there is naturally great temptation to only attend to this risk after actual failure occurs. Even equipping small sewage pumping stations with both operational and standby units or having standby units ready to hand to replace a failed unit does not altogether resolve this problem.

If submersible sewage pumps are to be used, one possible way would be to insist that the pump manufacturer have a locally based agent with all necessary maintenance personnel and facilities and for the Client to enter into a rigorous annual maintenance contract with that company.

Although the flows and head conditions at each station will differ it is sometimes possible to compromise and standardize on a limited number of station sizes and pump models. Variation in flow can be accommodated in a number of instances by changes of pump impeller with a particular pump model size. This can greatly simplify station maintenance and the stocking of spares. In many cases it also enables pumping capacities to be increased as flow builds up.

9.11.1 Pumping types

There are three basic types of sewage pumping arrangement:

- Submersible pumps
- Dry well Centrifugal Pumps
- Positive Displacement Pumps

9.11.1.1 Submersible Pumps

The use of submersible type pumping stations has increasingly become the most common type constructed. Exceptions tend to be in those circumstances where a sewage pumping station is required to be large and wet well / dry well construction may be warranted. The capital costs of construction of civil works and installation of machinery, are very much lower for a submersible sewage pump station than for a conventional wet well / dry well station. However, they are not without their problems as the routine inspection and attention to glands and power cable seals are most important to avoid deterioration and burning out of motors so that where this may be inadequate, the decision over type of pump is most important.

Submersible pumps are however easy to operate and relatively cheap to maintain provided strict adherence is made to the recommended operating and maintenance programme. This is essential to the successful operation of submersible pumping equipment since the pumps are normally out of sight and incipient defects often cannot be detected without lifting the pump and physically checking it.

9.11.1.2 Design Features for Submersible Pumping Stations.

The following features should be designed into all submersible pumping stations:-

1. Submersible pumping stations should be preceded by a screening chamber and by pump grinding or maceration of the sewage.
2. The pumping main should never be less than 150mm diameter
3. The velocity in the pumping main should preferably be of the order of 1.5 m/s. It should never be less than 0.75 m/s to ensure adequate scouring in the pumping main and in certain instances, depending on the levels of the main, e.g. if a long low section is unavoidable, should be higher.
4. The pumping main should be kept as short as possible to reduce the retention time in the main.
5. Multiple high point should be avoided in the main if at all possible since these required air valves which require maintenance. Also multiple high points imply intermediate low points where settlement and blockage may occur. A hatch box should be installed every kilometre.
6. The size of the pumping station will be governed by the invert of the incoming sewer, the number and size of pumps to be installed and the requirement for a minimum capacity between maximum and minimum water levels in the station which is a function of the number and size of pumps and the maximum permissible number of pump start-ups and working hours.
7. Maximum water level in the wet well should always be below the invert of the incoming sewer to obviate surcharge of the sewer.
8. The position of the incoming sewer in relation to the pumps must be carefully selected to ensure uniform flow distribution to the pumps if two or more are operating together, and to avoid undue turbulence in the wet well which could cause air entrainment in the liquid being pumped, and lead to cavitation in the pumps. In

some cases, particularly where the station is large or the inlet velocity is high, it may be necessary to build a wall or inlet chamber around the incoming sewer.

9. Allowance must be made for benching at the bottom of the wet well. This should be designed to direct flow to the pump suction and to prevent build up of solids. The pump manufacturer should be asked to confirm the suitability of the design before construction begins.
10. The station should have a valve chamber alongside the wet well. The depth of the chamber will be governed by the depth of the pumping main where it leaves the station.
11. The valve chamber should have drain connection into the wet well.
12. The valve chamber and wet well should have heavy duty covers capable of withstanding, without significant deflection, the heaviest load likely to be placed upon them. In the case of steel covers these should be heavily galvanized before being brought to site.
13. Keys should be provided for all covers and for valves where hand wheels are not fitted.
14. Step irons should be provided to the valve chamber where this is more than 0.6m deep.
15. All structures should be brought to at least 150 mm and preferably 300 mm above final ground level to prevent ingress of sand and rubbish when the covers are open.
16. Pumps should incorporate the following features:-
    - (i) The number of starts per hour shall be limited to less than 15 maximum for pumps up to 40 kVA rating. In practice design for 10-12 starts/hr. For larger pumps see manufacturers' recommendations.
    - (ii) The motors shall be capable of running submerged for considerable periods. Bottom water level shall be no less than the top of the impeller casing to minimize build up to floating matter in the wet well.
    - (iii) External motor cooling systems are not acceptable.
    - (iv) Impellers shall be of the non clog type. Where large quantities of solids or sludge are anticipated vortex type impellers shall be specified.
    - (v) Good solid passing capacity shall be specified. The size of solids to be passed will vary with the size of installation but handling capacity should never be less than minimum diameter.
    - (vi) The pump shall slide freely up and down the guide rails without snatching or jamming.
    - (vii) The pump delivery flange shall make a sliding contact with the fixed delivery pipe flange to ensure good contact. It should not be necessary to enter the wet well to locate or fix the pump.
    - (viii) The pumps shall have a heavily galvanized lifting chain brought up to a convenient hook, or similar, just inside the pump chamber.

(ix) The motor cable shall be sealed in the terminal housing and shall be brought to position outside the pump chamber without internal terminal or connection boxes.

17. The pump control equipment should be fully suited to local site conditions. It should be fully weather, dirt and vermin proof and be enclosed overall in a steel or GRP enclosure having a well sealed door and anti-humidity heaters.

18. Unless in a particular situation there is good reason to the contrary, the control equipment should be housed in a brick or similarly constructed kiosk measuring not less than 1.5 m^2 internally, which will also serve to store lifting equipment and other tools as required, a place for the keeping of station records and a shelter for attendants. The kiosk may in some cases be built over the wet well chamber and incorporate the pump lifting gear in the form of a rail and lifting block and tackle. Otherwise the kiosk should be located at some convenient location in the vicinity of the station. The control equipment should be mounted on the internal wall of the kiosk, as should also the isolator on the incoming electricity supply.

19. The Electricity Supply Authority (TANESCO) fuses and meters should be mounted at least 1 m clear of the ground on the wall of the kiosk or similar so that they are at all time accessible to the Authority's officials without the use of keys.

20. Control equipment shall be rated for site conditions and should incorporate at least the following features:-

(i) Suitably rated pump starters. Pumps may be started DOL up to 2.2 kW, but above this and up to 11.2 kW the starting current shall be limited to 4 times full load current and above 11.2 kW to 2 times full load current.

(ii) Automatic duty / standby changeover between pumps should be provided.

(iii) Hand off/automatic switch for pump operation.

(iv) Key operated spring loaded start control for manual operation.

(v) Under voltage protection.

(vi) Hours run counter for each pump.

(vii) Ammeter for each pump.

(viii) Pump running (red), pump available (green) and pump fault (amber) lights.

(ix) Power available (blue) lamp.

(x) Level controls shall be of the float switch type with integral box or an intermediate terminal box.

(xi) All external cabling shall be PVC SWA PVC and shall be suitably protected against mechanical damage where it runs at level or comes out of the ground.

(xii) Every installation shall incorporate weather-proof three phase and single phase switched socket outlets, with screwed weather caps and matching plugs for use with emergency lighting and pumping equipment.

21. Each pumping station should be provided with suitably related lifting equipment to lift the pumps out of the wet well to at least 1 metre clear of the ground and clear of

the wet well opening. The lifting gear may take the form of a fixed or portable davit or a fixed lifting beam or gantry depending on the size of the pumps and location of the station. If a portable davit is specified this shall be supplied with one or more sockets which shall be built into the pumping station structure.

22. Screening Chamber. Every pumping station should be protected by a coarse screen upstream of the wet well. The screen shall comprise mild steel bars of not less than 10 mm x 40 mm section, edge on to the flow with 40 mm gaps between bars. The bars shall be set at 60^o to the horizontal and shall be curved over at the top so that screenings may be raked up the bars and onto a perforated trough or slab for collection and draining. The screen assembly shall hook over a channel or bar set into the walls of the chamber such that the screen can be removed as a complete assembly if required.

    If the chamber is less than 2 m deep to the top of the screen it shall be covered by open steel flooring with a section easily removable so that top of the screen chamber may be covered by a roof slab with an access cover provided.

    Two rakes, with tines to suit the screen bars, should supplied at each screen for removal of the screenings, normally a daily operation.

    Depending on the depth of the sewer, and hence screening chamber a platform should be provided in the chamber for raking. Either step irons or a fixed vertical steel access ladder shall be provided in the chamber down to the platform. Full precautions in the form of handhold, safety chains etc., shall be provided for the safety of operatives. All steelwork shall be heavily galvanized before bringing to site.

    Consideration should be given to fitting the chamber with grinders (munchers) to break up material to a size readily pumpable.

23. A good access track should be provided to each pumping station from the nearest roadway so that maintenance vehicles may be driven right up to the station with ease.

24. Each station should be provided with a security fence and gates which have a 3 m wide opening.

9.11.2 Alternative to Submersible Pumps

The two alternatives to submersible sewage pumping stations are:

For large installations: Wet well / dry well pumping stations with the pump and possibly other in-line mechanical devices such as cutters mounted in the dry well for ease of access and maintenance. Again an inlet chamber is required and whilst generally similar to that described above for submersible pumps, should preferably incorporate twin screw rotating grinders so as to avoid the need for anything but very coarse screening. Motors are usually shaft-coupled each mounted vertically above its pump just above ground level on the floor directly above in proximity to their switchgear. The structure housing the motors and switchgear is thus constructed directly over the dry-well. Access and security arrangements are also generally similar.

The floor of the superstructure is provided with removable gratings to allow for removal and replacement of the pumps with a crane gantry rail running the length of the building and protruding out beyond the machinery access doors at a height that enables pumps and motors to be offloaded and loaded directly onto a lorry.

For low-lift small installations: Where flows are up to 110 l/s, and lifts are relatively low, consideration should be given to positive displacement sewage pumps, preceded by an in-line macerator.

The positive displacement action of the pump lifts the raw sewerage from the sump into the cutting chamber of the macerator. This enables pump and motor to be located above ground and outside the wet sump. Low suction velocities ensure that foreign object damage is eliminated, large objects remaining in the sump for periodic removal.

Such units can have low wear rates and optimise running time and have high energy efficiency and low rotating speed.

Such units can achieve very efficient disintegration of virtually any products in the inflowing sewage and finely macerate inflow, hence avoiding the need for screening, and allow routine maintenance to be carried out easily in a clean environment in-situ above ground with no need to haul sets out of a sewage sump. They are easily and speedily installed have a low noise level and are fully weather-proofed.

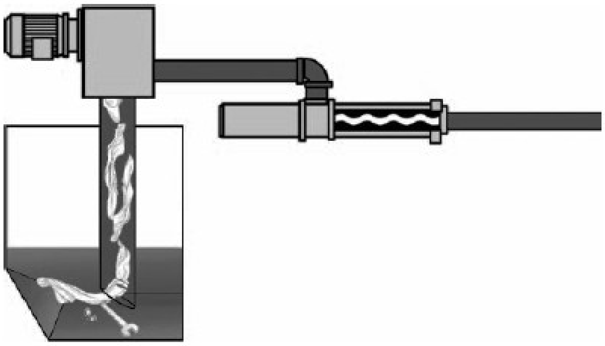


FIGURE 9.9: MACERATOR & POSITIVE DISPLACEMENT SEWAGE PUMP

As a result, they also allow for smaller diameter and hence less costly pumping mains than with conventional sewage pumping and hence reduce flow time and the risk of septicity.

A source for designers requiring more information is <www.mono-pumps.com>.

9.12 SIMPLIFIED SEWERAGE

Simplified sewerage is a possible sanitation option in urban unplanned settlements peri-urban areas of Tanzanian towns, especially as it is often the only technically feasible solution in these high-density areas. It is a sanitation technology widely known in Latin America, but it is much less well known in Africa. Originally developed to improve the health of poor communities, it is not just for peri-urban areas and can be successfully and appropriately used in middle-and upper-income areas as well.

Simplified sewerage is an off-site sanitation technology that removes all wastewater from the household environment. Conceptually it is similar to conventional sewerage, but with conscious efforts made to eliminate unnecessarily conservative design features and to match design standards to the local situation.

It collects all household wastewaters (WC wastes and sullage) in small-diameter pipes laid at fairly flat gradients—for example, a 100 mm diameter sewer laid at a depth of perhaps no more than 400 mm and at gradient of 1 in 200 (0.5 percent) will serve around 200 households of 5 people with a wastewater flow of 80 litres per person per day. It is suitable for existing unplanned low-income areas and new housing estates with a more regular layout as illustrated in the Figure below. The relatively shallow depth allows small access chambers to be used rather than large expensive manholes and these are best provided with a screen to prevent domestic rubbish in plastic bags being dumped in them.

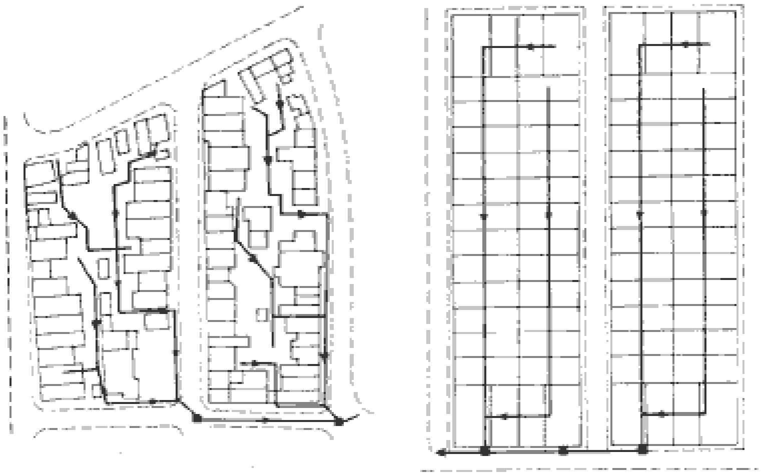


FIGURE 9.11: POSSIBLE LAYOUTS WITH SIMPLIFIED SEWERAGE

In-block sewerage, particularly back-yard sewerage, can significantly reduce the length of sewer required, thus reducing costs. Costs are further reduced by laying sewers at shallow depths away from heavy traffic loads. As a result, as the population density increases, simplified sewerage can become cheaper than on-site sanitation systems.

The fact that simplified sewerage is low-cost does not mean that it can only be used in low-income peri-urban areas. CAESB, the water and sewerage company of Brasília and the Federal District in Brazil, now regards simplified sewerage as its standard solution for sanitation in rich and poor areas alike.

A design manual and computer software is available for those designers interested from www.efm.leeds.ac.uk/CIVE/Sewerage/download.html

9.13 SETTLED SEWERAGE

Settled sewerage is a means of conveying domestic sewage which has been settled in a septic tank (sometimes referred to, in this context, as a solids interceptor tank). It was developed in Northern Rhodesia (now Zambia) in about 1960 to remove the settled wastewater from aqua-privy tanks. It is therefore of considerable interest in formal housing areas where septic tanks predominate and where for whatever reason, upgrading of the disposal system from on-plot to sewage treatment works is envisaged be it for environmental or economies-of-scale as part of a larger development project.

It is now most common in Australia and the United States, with over 300 schemes installed but has been used successfully elsewhere.

The early Zambian settled sewerage schemes were designed on the basis of 100 mm diameter pipes laid at a minimum gradient of 1 in 200 to achieve a velocity at peak flow of 0.3 m/s. This was the general basis for design until the development of the "inflective gradient" design approach in the United States in the late 1970s.

In inflective gradient hydraulic design, the sewer roughly follows ground contours and the flow in the sewer is allowed to vary between open channel flow and pressure (full-bore) flow; precautions are taken to ensure that in pressure flow sections there is no flow from the sewer to an interceptor tank. There must be an overall fall from the upstream end of the sewer to its downstream end. The sewer is divided into sections over which the flow is of the same type (i.e. open channel or pressure flow) and reasonably uniform (i.e. the sewer can be laid at a more or less constant gradient). Sewer diameters are at least 75 mm, and the actual peak flow in each section must be less than the "just full" flow (if it is not, the next larger sewer diameter is selected). In sections where there is pressure flow, the hydraulic gradient cannot rise above the level of the invert of any interceptor tank outlet (if it does, then either select the next larger pipe diameter or increase the depth at which the sewer is laid).

This design approach is more economical than the earlier design which required the achievement of a given velocity at peak flow. Consideration of self-cleansing (or other) velocities is not necessary with settled sewerage since all the solids which would block the sewer are retained in the interceptor tank.

Given that existing septic tanks are often at the rear of properties, the settled sewer can be laid there, rather than in the road verge (as in normal with conventional sewerage), and this will result in considerable cost savings (and is in fact analogous to the backyard or condominal variant of simplified sewerage). Manholes are not required at every junction or change of direction; simple cleanouts suffice. Lift stations are only required in very flat areas, but these are simple structures often using a raw water pump, rather than a more expensive sewage pump since there are no solids to be pumped.

The sewerage authority has to ensure that only connections from septic tanks are made to the settled sewer, and preferably also has to become responsible for desludging the septic tanks although this can be contracted to a private firm. Experience has shown that this simply cannot be left to the householders as they just do not do it and eventually settleable solids pass through the tank into the sewer which becomes blocked as a result. Thus at the start of the scheme the sewerage authority should arrange for desludging and, if necessary, renovate of the existing septic tanks, and then annually or biennially, as required, arrange for them to be desludged. Desludging costs can be recovered from the householders through the billing arrangement.

9.14 HYDROGEN SULPHIDE

9.14.1 Introduction

Because it is a potential killer in sewerage systems, and can also significantly affect the life of concrete and masonry structures and unlined ferrous sewers, this subject is considered to be of sufficient importance to cover in some detail to ensure that the designer has a full understanding of the potential problem.

Hydrogen sulphide, H_2S, is a gas that is widespread in nature, and well-known because of its odour. It can arise from the decay of some kinds of organic matter, especially albumins. An example is the white of an egg, an albumin that can release large amounts of H_2S. The odour of H_2S is most commonly described as the odour of rotten eggs. H_2S also occurs in many ground waters. Its presence in such waters is due not so much to breakdown of organic matter as to the bacterial reduction of sulphate. By this it is meant that certain bacteria are able to split oxygen from the sulphate ion, $SO_4^=$, a common constituent of natural waters, and use it to oxidize organic matter. The sulphur is then left in the form of the sulphide ion, $S^=$, which immediately changes by reaction with water to a mixture of H_2S and HS^-.

H_2S is a gas slightly heavier than air. It condenses to a liquid only at the low temperature of -62° C. It is fairly soluble in water. At 20° C, it can dissolve in pure water to the extent of 3,850 mg/l, or 2.7 litres of H_2S gas per litre of water. The solubility decreases about 2.5 % for each degree increase of temperature. The stated solubility is the amount that will dissolve when the pure gas is brought into contact with pure water. From H_2S diluted with air, it will dissolve only in proportion to its concentration in the gas mixture. Thus, for example, air in which the concentration of H_2S is 0.1 % (1,000 mg/l) by volume of H_2S will, if brought to equilibrium with pure water at 20° C, produce a solution containing 3.85 mg/l. One mg/l in solution can produce a concentration of about 260 mg/l by volume in the air if the temperature is 20° C, or 330 mg/l by volume if the temperature is 30° C.

When dissolved in water, hydrogen sulphide is partially ionized, so that it exists as a mixture of H_2S and HS^-. The proportions depend principally upon the pH of the solution. In a typical natural water at a temperature of 20° C, and at pH 7.0, it is just 50 % ionized; that is, half of it is present as HS^- and half as un-ionized H_2S. Temperature and mineral content of the water affect the degree of ionization, but only by a small amount. The sulphide ion, $S^=$, also exists in water, but not in appreciable amounts except in solutions in which the pH is above 12. The solubility data given in the previous paragraph applies only to the equilibrium between the gas and the slightly acidic (low-pH) solution produced when it dissolves in pure water or between the gas and the unionized H_2S in waters where the pH is not low.

Because everyone is familiar with the odour of H_2S in its natural occurrences, this familiarity has led to a lack of appreciation of its toxic character, and many deaths have resulted from carelessness in dealing with it. The threshold odour concentration of H_2S is very low - between 1 and 10 ng/l. It is potentially very dangerous because its smell is quickly lost as the concentration increases. As a result, there have been many deaths in sewers on this account. Even the H_2S from swamps and from natural hot springs can be deadly. There is evidence that a concentration of 0.03 % (300 mg/l) of H_2S in the air has caused death. It should be noted that this is the concentration that could arise from water containing 1 mg/l of unionized H_2S. Fortunately these hazards are now more widely recognised, and the frequency of fatal accidents has been greatly reduced.

The above discussion has been about hydrogen sulphide and its ionized form, HS^-. Sulphur combines with metals too, producing compounds which are generally insoluble, such as zinc sulphide, ZnS, two copper sulphides, CuS and Cu_2S, several iron sulphides, etc. In all such combinations, as well as in H_2S and HS^-, sulphur is in an electro-negative state. In this state it is simply called sulphide.

In waste waters of normal pH values (6.5 to 8), sulphide may be present partly in solution as a mixture of H_2S and HS^-, and partly as insoluble metallic sulphides carried along as part of the suspended solids. In analyses of waste waters, a distinction is made between dissolved sulphide and insoluble sulphide. The sum of these forms is called total sulphide. The concentrations are normally expressed in terms of the sulphur content. The amount of insoluble metallic sulphide does not ordinarily exceed 0.2 to 0.3 mg/l if the sewage is of residential origin, but the amount may be larger in sewers containing trade wastes.

Sulphide in waste waters reacts with dissolved oxygen, mostly by biological processes.

Under the conditions prevailing in sewers, the principal biological oxidation product is thiosulphate. If oxidizing bacteria are abundant in the waste water, and dissolved oxygen is also present, sulphide may be oxidized at a rate of 1 mg/l in five minutes, but in less active sewage, as for example fresh domestic sewage, the same reaction may take an hour. Sulphide can also react chemically with dissolved oxygen, that is, without the intervention of bacteria. This reaction is slow, producing a variety of products, including sulphur, thiosulphfate, sulphite, sulphate, and others. The rate of reaction depends greatly on the presence of catalysts such as iron ions and the products produced are influenced by the pH value.

H_2S that escapes as a gas from solution in a sewer may be oxidized on exposed surfaces. If the surfaces are quite dry, free sulphur may be formed, but under moist conditions a species of bacteria named *Thiobacillus concretivorus* oxidizes it to sulphuric acid by the reaction:

$$H_2S + 2O_2 \rightarrow H_2SO_4$$

The acid causes corrosive damage to vulnerable materials. The process of oxidation of hydrogen sulphide is a complex series of reactions involving many members of the species *Thiobacilli*, each with its own optimum growth rate at a given pH value. Some of the *Thiobacilli* can remain active in solutions containing up to 7% of H_2SO_4 (pH about 0.2). The whole process of oxidation of hydrogen sulphide by bacteria and the factors which influence the bacterial corrosion of concrete in water are complex.

9.14.2 The Occurrence of Sulphide in Sewage

Sewage contains bacteria, sulphate, and organic matter, so it has the elements required for sulphide generation. One further condition is necessary. The reduction of sulphate to sulphide can occur only under anaerobic conditions. In the absence of dissolved oxygen, nitrate can provide oxygen for bacteria and can thus prevent septic conditions developing. The conditions will become strictly anaerobic when all the ‘oxygen’ provided by the nitrate anions, has been consumed by the facultative anaerobic bacteria. This is a state that can develop in sewage, because ‘many kinds of bacteria are present that rapidly consume dissolved oxygen and "oxygen’ from nitrate. However, if the sewer is partly filled, the water surface exposed to the air absorbs oxygen. The rate of absorption is slow, and the bacterial action may deplete it to concentrations of a few tenths of a mg/l, or sometimes only a few hundredths. Still, where any dissolved oxygen or nitrate at all is present there can be no reduction of sulphate, as for example in a blocked sewer or in a pumping sewer.

A layer of slime builds up on the submerged pipe wall in a sewer, very thin where the stream is swift, but a millimetre or more in thickness where it is slow. The slime layer is the site of intense micro-biological action, and it is here that anaerobic conditions develop, and that sulphate reduction and sulphide generation can take place.

There is frequently an aerobic (oxygen containing) zone in the slime layer where it is in contact with the flowing stream. In a typical case the aerobic zone may extend into the slime layer to a depth of only 0.1mm, but it may be deeper if the stream carries several mg/l of dissolved oxygen. Sulphate and part of the organic nutrients diffuse through the aerobic zone and into deeper layers, thus supplying the requirements of bacteria that produce sulphide, and so it comes about that sulphide generation can occur even when the stream contains dissolved oxygen, but is unlikely to occur if nitrate were present as it will diffuse into the lower layers of the slime and provide a source of oxygen to prevent septicity. The zone where sulphide is produced is generally only a few tenths of a millimetre in thickness. The sulphate or the organic nutrients are used up in that distance and unless the slime layer is quite thin, there is a deeper layer that is relatively inactive.

Sulphide diffusing out of the zone where it is produced is at least in part oxidized to thiosulphate in the aerobic zone. If much oxygen is present, the sulphide will all be oxidized there, but if the oxygen condition is low, then part of the sulphide will escape from the slime layer into the stream. When this condition prevails, the sewer may show ‘sulphide build-up’, meaning that the concentration in the stream will progressively increase as the sewage moves down the sewer. However, oxidation occurs to some extent in the stream, and some H_2S escapes to the atmosphere, so that in free-flowing sewage in larger diameter sewers, the concentration tends to approach a steady state condition where the losses are equal to the rate that sulphide is produced.

Figure 9.12 shows an enlarged scale cross section view of the slime layer of a sewer. Oxygen, organic nutrients and sulphate are seen to be diffusing into the slime layer. Oxygen and part of the organic nutrients are used up in the aerobic zone.

Sulfate and the remainder of the organic nutrients are diffusing farther, reaching the anaerobic zone. The dense population of anaerobic bacteria found there, especially the species *Desulfovibrio desulfuricans*, are bringing about the reaction that produces sulphide, at a rate determined by the rate that the nutrients can diffuse into that zone. Sulphide is diffusing outward from the slime layer, part of it being oxidized in the aerobic zone and part escaping into the stream.

(Note: The direction of diffusion of nutrients, oxygen, and sulphate in the slime layer is perpendicular to the sewer wall. The lines are shown as oblique to lessen confusion in the representation.)

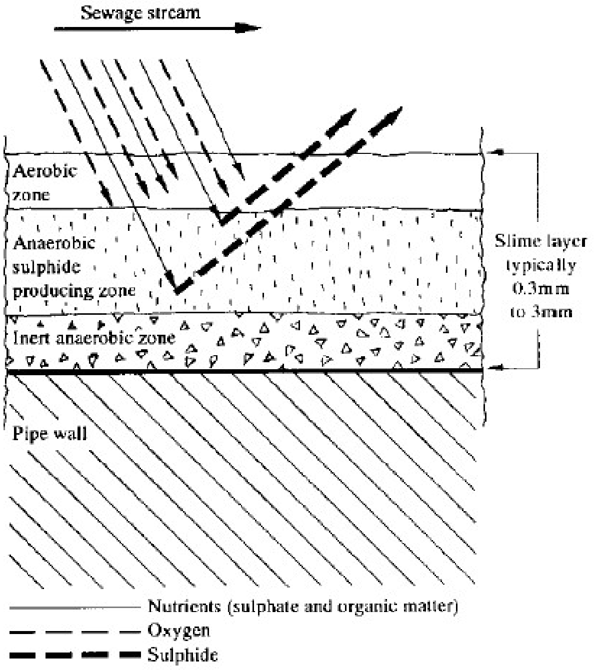


FIGURE 9.12: MAGNIFIED CROSS-SECTION OF SLIME LAYER

The concentration of oxygen necessary to prevent any sulphide build-up may vary widely, depending upon a number of conditions. The velocity of the stream is one factor. At low velocity, the motion of the sewage is not very efficient in carrying oxygen to the slime layer, and under these conditions a higher oxygen concentration is necessary if sulphide is to be barred from the stream than when the stream is swift. In a typical case it may require 0.5 mg/l of dissolved oxygen to prevent sulphide build-up, but under some conditions as much as 1.0 mg/l, or even more, may be required.

9.14.3 Forecasting sulphide build-up

A characteristic of the generation of sulphide in sewers is its sporadic occurrence. A major determining factor is the amount of oxygen (both dissolved and available from nitrate) in the sewage stream. If the oxygen concentration is high, there will be no sulphide build-up; if it is low, then sulphide build-up can be expected.

The rate of sulphide production is influenced not only by oxygen concentration, but by other factors as well. The rate increases with increase of temperature, and it depends in a complex way on the concentrations of organic nutrients and of sulphate. The rate of sulphide production can be limited by a scarcity of either sulphate or organic matter. Since both are consumed in the biological reactions that produce sulphide, they are required in a certain ratio. If there is an excess of organic nutrients, then the rate is limited by the amount of sulphate and if there is an excess of sulphate it is limited by the amount of organic nutrients.

The organic nutrients available for sulphide production in sewers is not clear, but they must be in solution, since they must diffuse to the sulphide producing zone. It is often assumed that in typical municipal sewage the organic nutrients for sulphide generation are proportional to the biochemical oxygen demand or BOD or to the chemical oxygen demand or COD.

The effects of velocity on sulphide build-up are complex. At low velocity, solids may settle and move slowly and intermittently along the bottom. The loosely deposited solids quickly become depleted of oxygen, and sulphide generation proceeds until the depletion of sulphate or organic nutrients. If the solids are then disturbed by the motion of the sewage, sulphide is released into the stream in greater amounts than would result from the process depicted in Figure 9.x. Higher velocities prevent this from happening, and also increase oxygen absorption into the stream, increase the rate of oxygen transfer to the slime layer, and shorten the time that the sewage spends in transit, all of which lead to lower sulphide concentrations. On the other hand, at low velocities, and especially if the sewage is intermittently stationary, as is usually the case in pumping sewers from pumping stations, nutrients may become depleted in the water adjacent to the slime layer, thus retarding sulphide generation. An increase of velocity in a completely filled sewer will, up to a point, increase sulphide generation.

The rate of sulphide build-up is a function of the various factors that influence generation by the slime layer and the losses by oxidation and escape to the air. However, even if an equation to represent this could be written, it would not be very useful, because of the difficulty of securing the input information that would be required. Most important would be the dissolved oxygen concentration. An accurate prediction of dissolved oxygen would require a detailed history of the sewage for an hour or so upstream from a point where a prediction of sulphide build-up would be attempted. Absorption of oxygen at the surface of the stream can be predicted if slope, sewer diameter and flow quantity are known, but extra oxygen will be added at junctions, drops, and other points of turbulence, and it is difficult to predict the rate at which oxygen will be consumed.

The only practical approach to the problem of predictions is to limit such attempts to the restricted case that the unpredictable factors are favourable for build-up. That is to say, it is assumed that sufficient sulphate is present so that it is not limiting, that oxygen concentration is low, that no nitrate is present either derived from the water supply or from industrial discharges, and that there is no toxic condition or other factor that inhibits the action of the slime layer.

Quantitative forecasts have been attempted for the restricted case of sewage in pumping mains and other completely filled sewers, where it is denied any contact with air. Sewage pumped into a pumping main often contains dissolved oxygen which may result from its fall into the wet well or from other causes, and on this account there may be no sulphide build-up initially. However, after a time the dissolved oxygen and nitrate 'oxygen' will become completely depleted and then the maximum sulphide producing capability of the slime layer will be displayed.

When the sewage becomes completely anaerobic, generation occurs not only at the sewer wall but also in the stream. The amount produced in the stream, however, is small in comparison with the output by the slime layer except in very large sewers.

In a small sewers of, say, 100 mm diameter, troublesome sulphide concentrations may arise even where the retention time of the sewage in the sewer is as little as ten minutes. In larger mains the build-up rate is slower, but significant amounts are likely to be produced within 20 to 30 minutes in a sewer of one metre diameter.

9.14.4 Forecasting sulphide conditions

Formulae that have been proposed for predicting rates of sulphide build-up in gravity sewers are complicated, but there is a rather simple qualitative indicator that will aid in foreseeing future sulphide conditions. It is called the 'Z formula', and is as follows:

$$Z = (3[EBOD] \times P) / (S^{1/2} \times Q^{1/3} \times b) \qquad 9.3$$

Where, EBOD = effective BOD, which is defined as the standard 5-day, 20°C biochemical oxygen demand multiplied by the temperature factor $1.07 \times (T-20)$

Where,

T = Sewage temperature, ° C

S = slope of the sewer, m/100 m

Q = sewage flow, litres/sec.

P/b = ratio of wetted perimeter (P) of the pipe wall to surface width (b) of the stream.

Before interpreting the meaning of the 'Z' quantity, it is necessary to emphasize that neither the Z formula nor any other equation can, when applied only to a particular reach of sewer, provide an answer as to what the sulphide conditions will be in that reach, because upstream contributions cannot be ignored. Upstream conditions may include pumping mains in which sulphide build-up is probable, gravity sewers having flow conditions that allow build-up, or discharges of sulphide-bearing industrial wastes. What the equations do indicate is whether there is likely to be a tendency for build-up in the reach for which the calculations are made.

With these important warnings as to the limited application of the formula, it may be said that where a certain 'Z' value is characteristic of conditions existing for two or three km upstream from a point of interest, and there is not an upstream sulphide source such as a pumping main, the conditions described in Table 9.4 may be reasonably expected.

TABLE 9.5: Z VALUES AND CHARACTERISTIC CONDITIONS FOR H_2S FORMATION

Z VALUE	CONDITIONS LIKELY TO BE OBSERVED
below 5,000	Sulphide rarely present or only in very small concentrations
around 7,500	Peak concentrations of a few tenths of a mg/l of dissolved sulphide may be reached; slight corrosion of concrete and masonry in structures may occur. Substantial corrosion may sometimes be observed in the vicinity of points of turbulence.
around 10,000	Sulphide sometimes may develop in sufficient proportion materially to increase odours, and concrete and masonry structures may suffer substantial damage, especially near points of turbulence.
around 15,000	Odour of sewage will increase markedly at times. Rapid attack of concrete structures is to be expected at points of turbulence, with significant attack elsewhere. With concrete sewers of 25mm wall thickness, and unlined ferrous sewers, there is a strong possibility of failure within 25 years.
at or above 25,000	Dissolved sulphide will be present most of the time, and small concrete and unlined ferrous sewers possibly will fail in 5-10 years.

The 'Z' formula is limited in its range of application. In large flows, generally above 2000 l/sec, there may be sulphide build-up even when 'Z' is as low as 5000, but only at a very slow rate. On the other hand, with flows below 3 l/sec there may be no build-up even at relatively high 'Z' values. In small sewers, the principal determining factor is the accumulation of debris in the bottom of the sewer. Such accumulations retard the flow until velocities are much lower than assumed in deriving the equations. The ability of the sewer to keep itself free from such accumulations must not be judged by the flow velocity that would prevail when the pipe flows half full, but by the peak velocities that will be reached at least once each day under the actual operating conditions.

A further complication in the application of the equation is the fact that the various quantities in the equation, with the exception of the slope of the pipe, are variable. In addition to random fluctuations, there are seasonal temperature changes and diurnal changes of flow and sewage strength. It is recommended that the average temperature for the warmest quarter of the year and the average sewage strength for the highest six hours of the day, with the corresponding flow, be used in developing a climatic 'Z' value. If the formula then indicates that sulphide problems are likely, this should be taken as a warning that the system is at risk and judge the suitability of construction materials from the standpoint of corrosion resistance.

It may be noted that 'Z' becomes infinity in a completely filled pipe. This is because filled pipes allow no exposure of the wastewater to oxygen, and sulphide build-up can proceed at a rate determined by the temperature and nutrient supply to the sulphide-producing bacteria. Even a relatively small pumping main can produce enough sulphide to cause damaging concentrations in a much larger flow to which it is a tributary, unless sulphide control measures are applied. Many of the very serious sulphide conditions that have been encountered in sewers have been due to sulphide produced in pumping mains.

9.14.5 Sulphide build-up rates in Pumping Mains

In pumping mains where detention times are longer than, say 10 minutes, there can be considerable sulphide build-up, as strictly anaerobic conditions are most likely to prevail. This can sometimes also occur where unduly large wet wells retain sewage for long periods of time.

When the pump begins to operate, the heavy sulphide concentration is discharged, usually into a gravity sewer, where serious corrosion can take place if acid susceptible materials are used for the pipeline. These sources of trouble have often disregarded in the past when designing pumping stations and pumping mains.

Since the conditions in many pumping mains do not conform to the limitations under which the Z equation is applicable, many such mains produce less sulphide than the amount expected and where detention times are short, less than, say, 10 minutes, there is often little or no sulphide build-up, since a strictly anaerobic condition is not likely to be attained.

9.15 ON-PLOT SANITATION

9.15.1 Introduction

On-plot sanitation is essentially by some form of pit or composting latrine in poorer formal and informal urban areas and by septic tank followed by infiltration tank or ditch depending on soil conditions and area available in richer formal areas.

Whilst most Tanzanian households now have a sanitary facility, the vast majority rely on unimproved pit latrines without adjacent hand washing facilities. As a result the overall level of health and hygiene amongst most of the population remains poor.

Because of the wealth of published information on basic sanitation, the topic of latrines is only touched on briefly in this Design Manual and designers should refer to the many sources of available information, some of which are suggested herein.

9.15.2 Septic Tanks

9.15.2.1 Septic Tanks – Design Criteria

Septic tanks are used principally for the treatment of wastes from individual residences. In other areas they are used for establishments such as schools, hotels and institutions. Septic tanks designed for residential use generally have a 24 hrs detention period. For larger installations serving multiple families or institutions a shorter detention period may be permissible. Sludge should normally be removed every 2 to 3 yrs although if the septage is periodically disturbed to break up the crust longer periods have been found practicable as a considerable proportion of the small fibrous waste tends to be carried over. Sludge pumped from septic tanks should be discharged to nearby wastewater-treatment plants or specially designed collecting stations for treatment. The septic tank has four functions:

- Removal of solids from sewage by settlement and flotation.

- Storage of settled sludge and floating scrum.
- Biochemical decomposition of settled and floating solids with carbon dioxide, water and methane as the main end products.
- Partial treatment of the liquid fraction of sewage prior to further treatment and disposal, normally by infiltration into the ground.

9.15.2.2 Septic Tank Capacity

The capacity of a septic tank should be sufficient for the settlement / floatation on the rate of flow of liquid through the tank and this is related to the retention time. Storage space required for the sludge and scum is largely a function of the time interval between desludging.

Several rules of thumb have been published for tank capacity; of these the simplest is that included in the BSCP 302, which gives the volume below maximum water or scum level as $2000 + X \times p$ litres. Where p is the contribution population, and X is the water consumption per person per day.

In other words it allows for one day retention and gives a constant volume of 2,000 litres (2 m^3) for storage of sludge and scrum, irrespective of the size of the contributing population (assuming the sludge is removed every 12 months).

Thus formula is not commonly used in Tanzania, and instead the data in Table 9.4 has widely been used for several years in Tanzania.

TABLE 9.6: SEPTIC TANK SIZES

SEPTIC TANK SIZE (Depth is from top water level)						
TYPE	**ALL WASTES No. OF USERS**	**SOLID WASTES ONLY No. OF USERS**	**DIMENSIONS**			**VOLUME**
			LENGTH (cm)	**WIDTH (cm)**	**DEPTH (cm)**	**V (m^3)**
1	1 to 6	10	210	60	150	
2	7	20	260	75	170	
3	15	30	300	90	170	
4	30	45	350	105	180	
5	40	60	400	120	180	

Effluent disposal by infiltration is not applicable where soils are non–porous (e.g. clay or black cotton soil) or standard percolation rates are in excess of 60 1/min/25 m^2 (refer MLHUD).

9.15.2.3 Calculation of Soak Trench

Assumptions:

150 1 per day per capita in residential buildings

40 1 per day capita for and day time occupants

Required length of trench in metres for loamy soil = Flow in l/d) / 25

9.15.2.4 Specification for Septic Tanks

The following specification are often applied in the construction of septic tank:

- Reinforced Concrete: Grade 20 according to BSCP 110; Minimum Cement Ratio OPC Cement Content 300 Kg/m^3
- Formwork: Plain Boards –according to BSCP 110, Type B
- Reinforcement Bars: Bars Prefixed "Y" are High Yield Steel in accordance with BS 449; Minimum Characteristic Yield Stress 410 N/mm^2 and minimum diameter of former (BR) "Y" Bars 6D
- Cover: Minimum 30 mm
- Mortar: Cement / Sand 1:3 by Volume
- Rendering: Cement / Sand 1:2½ by volume
- Blinding: Mix 1: 4:7

9.15.3 Low Cost on-plot Sanitation – The Latrine

The basic unit of improved sanitation remains the ventilated improved pit latrine (VIP), notwithstanding the many variants of this that have been proposed over the years. Probably the best known reference work for the design of VIPs remains the UNDP / World Bank TAG Technical Assistance Note TAG 13 which despite the date of issuance (1984) is an excellent starting point for the designer new to the topic.

Another useful starting reference work is TAG 15 (1985) for the design of pour flush latrines.

Over the intervening years in particular, many alternatives have been proposed including composting toilets, and more recently ecological sanitation units that separate urine and faeces. Here the best starting point for those interested is <www.ecosan.org>. However, except in circumstances where shallow groundwater pollution from pit latrines is a serious health hazard, the capital cost and need for a significant change in peoples sanitation practices makes this an unlikely contender, at least at present.

Hence the VIP latrine seems to have retained its place as the most popular choice, possibly because it is an improved version of the most commonly used latrine worldwide, and often requires but a limited modification to an existing latrine to construct.

It is however noticeable that in many publications on low-cost sanitation, the need to be able to wash hands after defecation has been inadequately addressed. This is particularly the case when it comes to institutional facilities in such places as schools and public facilities in local markets and eating places.

The importance of hygiene in the matter of sanitary practices cannot be over-stressed and for primary schools in particular. When coupled with hygiene education, it gets back to the family and can be a major way of improving the health and well being of whole communities. Good latrine design for schools is also a very important topic and there is an excellent web based toolkit for this obtainable from <schoolsanitation.org> entitled Toolkit on Hygiene, Sanitation and Water in Schools.

Another useful information source is the Loughborough University, WEDC Website which can be accessed on <www/wedc.lboro.ac.uk/publications/>. By registering, one can have free pdf download access to up to 100 of many of their publications, including such reports as ‘On-plot Sanitation Guidelines’, ‘On-plot Sanitation – A Literature Review’, and ‘Designing Water Supply and Sanitation Projects’.

CHAPTER NINE

APPENDIX 9

EFFECTS OF INDUSTRIAL WASTES UPON SEWERS AND TREATMENT WORKS

Characteristics	**Effects**
PH value	Less than 6.5 will corrode concrete and metals, greater than 11.0 will upset operation of treatment plant, attack sealants causing leakage.
Temperature	High temperature may soften bituminous joints, may be deleterious to pipe materials and may induce premature digestion.
Salinity	High salinity causes corrosion of concrete and steel: sulphate (SO_4) > 300 mg/1 corrodes concrete and affect digestion processes. Chlorides are noxious in concentrations > 500 mg/1. Ferrous Sulphate liberate Sulphuric acid upon hydrolysis. Magnesium salts and iron chloride have leaching effect on lime therefore concrete.
Organic Pollutants	Shock leads affect treatment plants. High BOD and SS affect capacity of municipal treatment plants.
Toxic components	(i) Heavy metals inhibit biological treatment processes e.g Sludge digestion becomes difficult in presence of 100mg/1 copper, 200 mg/1 nickel, and trivalent chrome ($CR3_{+}$). Mercury (Hg) is toxic for all biological processes above trace level. Copper at 1 mg/1 inhibits nitrification Hexavalent chrome (CR 6+) at 2 mg/1 is harmful to activated sludge and 1 mg/1 is harmful to biological filters. In addition: Zinc, sodium, lead, manganese, cadmium and iron can all be toxic above trace level depending on the toxic threshold of micro-organisms in the process under consideration.
	(ii) Poisonous and explosive substance. Cyanide, HCN, is toxic at 1 mg / 1 for all biological processes. Generally a low toxicity threshold exists for phenols. In addition: Acetylene, alcohol, benzene, petrol, methane, chorine, hydrogen sulphide, ether, calcium carbide and CO_2 are toxic and or corrosive in sufficient quantities.
	(iii) Oils and fats corrode on formation of free fatty acids, clog sewers and introduce difficulties in operation of treatment plants.

(iv) Radioactive wastes must be avoided by containment and separate disposal or in certain cases predetermined dilution should be ensured for safe discharge to sewerage system.