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A Tutorial on the Design of Building Sewage Systems for Developing Environments

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Abstract- The paper highlights the salient aspects of the design of sewage drainage, treatment, and disposal for buildings and makes recommendations on the design practice that would improve system reliability for developing environments. An actual case of a 10- occupant residential building project is used to illustrate the recommended design guidelines.

Keywords*- Sewage Systems, Developing Environments*

I. INTRODUCTION

The design of sewage drainage systems for buildings entails the design of the drainage system within the building (which is usually above ground) and that outside the building (which is underground). This requires determining an appropriate pipe system (i.e. either a one-pipe or two-pipe system (Institute of Plumbing (IOP), 1977)), sizing the drainage pipes, determining pipe gradients, specifying appropriate pipe fittings, as well as determining the inverts of manholes or inspection chambers in line with the specified gradients.

Sewage treatment and disposal design entail determining the capacities and dimensions of sewage treatment units and disposal pits or trenches.

In carrying out the afore-mentioned exercises consideration must be given to the prevalent low literacy level in sanitation matters in developing environments. For instance, sewage systems are very much abused and ill-maintained.

Furthermore, relatively easy construction techniques need to be designed for in developing environments.

This paper highlights, by means of an actual building project, some of the ways in which these objectives can be achieved.

II. DESIGN METHODS AND SUGGESTIONS

A. Waste Drainage

In waste drainage design, the objective is to quickly and quietly convey the sewage to a treatment unit and to subsequently convey treated effluent to a disposal unit.

All horizontal piping should therefore be adequately sloped to ensure flow by gravity. This is particularly important in developing environments so as to avoid the use of sewage lift pumps, which may require periodic maintenance if installed, since many maintenance-related problems abound.

Also, the proper ventilation of drainage systems is known to reduce the objectionable phenomenon of air entrapment and the nuisance of discharge noise in sanitary installations; and this should be given due attention. Methods of designing ventilation piping are given in available literature (IOP, 1977 and Nielsen, 1982).

Furthermore, the drainage system should be water-tight in order to avoid leakages. Trap seals should also be installed at all suitable points on drain lines of sanitary appliances in order to prevent a back-flow of air, from the sewer into the building, which might generate a foul smell. The choice of an appropriate pipe system is an important aspect of system design.

In the one-pipe system, all appliances located on upper floors above the ground floor are connected to a common discharge stack; whereas in the two-pipe system, soil appliances (water closets, urinals, and the like) located above the ground floor are connected to a common soil stack while culinary and ablutionary appliances (sinks, wash basins, baths, and the like) located on the upper floors are connected to a separate waste stack. There are, however, modifications of these two basic systems. In general, the two-pipe system is recommended for buildings in developing environments, one advantage of this system being the segregation of the piping installation, which aids installation, fault diagnosis, and maintenance.

A common approach to system pipe sizing is to assign discharge units (D.U.) to each appliance and to aggregate these units to obtain the total for the various appliances connected to a particular pipe section. These totals are then used with the recommended pipe gradients to obtain pipe sizes from tables and graphs.

The underground drainage design additionally requires planning the pipe routes, and specifying the inverts of pipework and inspection chambers in line with the specified gradients.

Design codes which guide waste drainage design such as the Code of Practice (CP) 301(British Standards Institution (BSI),1971), CP 304 (BSI, 1968), and CP 305(BSI, 1974) should be consulted to achieve a functional system design.

B. *Sewage Treatment*

Excluding the mechanized methods of sewage treatment (such as the activated sludge and the aerated lagoon systems), which are utilized as central treatment plants serving groups of houses or entire settlements, the most common sewage treatment method is the septic tank. There are several variations of septic tank construction but the basic configuration is an underground covered tank with an inlet from the building drainage system and an outlet to a soakaway pit or trench (Figure 1). In order to achieve proper settling of the sludge, the tank is divided into two compartments, the first from the inlet end being larger than the other (Mueller, 1987).

The heavier solids settle at the bottom of the tank to form a sludge, a fraction of which digests by the action of anaerobic bacteria. Lighter solids and grease, which result from the bacterial action, float on the surface to form a scum. The liquid which remains between the scum and sludge, after the settling process, constitutes the effluent which is piped away for disposal in a soakaway pit or drainage trench. In order to reactivate it, the tank needs to be cleaned (or de-sludged) periodically.

Even though the septic tank is widely utilized in developing countries, its design, construction, operation, and maintenance are not given due attention as a consequence of the prevalent low level of sanitation literacy. This results in frequent system failure and poor performance, with attendant nuisance and health hazards.

In realization of such neglect and abuse, it is suggested that septic tanks utilized in developing environments should have larger capacities than those utilized in the more developed countries. Following from this reasoning, a comparison had been made of the several equations normally utilized in sizing tanks (Sodiki, 1995), and a recommendation made that the Chartered Institution of Building Services Engineers (CIBSE) equation (CIBSE, 1977)

$$C = 250N + 2000 \quad (1)$$

where C = tank capacity in litres

and N = number of persons in full-time residence be applied to obtain the minimum septic tank capacity for developing environments. For part-time occupancy, say for buildings used as offices, proportionate values of N need to be applied in Equation 1.

Also, working equations had been derived from existing codes and guidelines for calculating the relative dimensions of the septic tank (Figure 2), namely(Sodiki, 1995)

$$C = \frac{1}{1000}(250N + 2000)\, in\, m^3$$

$$= L \times W \times D \quad (2)$$

where L = Length of tank

W = Width of tank

D = Depth of liquid in the tank

Also $L = \sqrt[3]{6C}$ in m (3)

$W = \frac{L}{3}$ in m (4)

$D = \frac{L}{2}$ in m (5)

Furthermore, D_{tot} = Depth of tank below ground level

$$= \frac{L}{2} + A \quad (6)$$

where A = Invert of the inlet inspection chamber of the tank

P_{Pat} =Position of the divider partition of the tank, measured from the inlet end (Figure 2)

$$= \frac{2L}{3} \quad (7)$$

$D_{Pat,\,tot}$ = Depth of the pass-through opening in the divider partition (Figure 2)

$$= \frac{2D}{3} + A$$

$$= \frac{2}{3} x \frac{L}{2} + A = \frac{L}{3} + A \quad (8)$$

and B = Invert of the outlet inspection chamber

$$= A + 0.1 \quad (9)$$

C. *Effluent Disposal*

Effluent disposal following from treatment is usually by means of land drainage (using pits and trenches) or by discharge into water courses. As an environmental protection measure, several countries stipulate limits for the concentration of pollutants in effluents to be discharged into receiving waters as well as those for land application; the limits for the latter being generally less stringent and easier to comply with.

As it has been observed that the theoretical maximum amount of digestion of domestic sewage in septic tanks is in the region of 33% in terms of reduction in Biochemical Oxygen Demand (Escritt, 1972), a figure which is low in comparison with that (in the region of 90%) attainable by mechanized central sewage systems (Fair, Geyer and Okun,1968), the tank effluent is not expected to meet high statutory requirements in its quality.

It is therefore suggested, especially for developing environments, that septic tank effluents be disposed of by means of land drainage systems only. In this regard, the soakaway pit is more commonly used.

In soils that are firm and pervious, such as chalk, the pit may be constructed by merely digging the ground and covering the resulting pit with a concrete slab.

When constructed in loose soil, the pit is lined with hollow concrete blocks to maintain its sides, the blocks being laid normal and on their sides in alternate layers as shown in Figure 3. This arrangement creates adequate perforations that enable the water to percolate into the surrounding soil. Hardcore, such as broken stones are usually placed in the immediate surroundings of the pit to ensure that the surrounding soil does not collapse through the perforations and enter the pit.

In siting a soakaway pit, there needs to be ample clearance in every direction from any underground wall or barrier that might impede effluent seepage or might itself get structurally weakened due to the presence of excess moisture. A distance of at least 3m away from any building is recommended in this respect (Barry,1984). To avoid underground pollution, soakaway pits must be far away from water wells.

A prerequisite to sizing and dimensioning soakaway pits is the performance of a site seepage test or the obtaining of such test results for a representative site within the same locality. This is important as the soil characteristics determine how fast a given amount of effluent contained in the pit would be percolated. The procedures employed in such tests are elaborated in available literature (Mueller, 1987and Klargester, 1991) and basically involve determining the time taken for water to percolate down a given depth in a hole of standard dimensions on the site under consideration.

By reasoning that only a fraction of the daily wastewater volume (which is determined by the daily water demand) would remain unpercolated in the pit over the day, a rational approach had been suggested, namely(Sodiki,1995)

$$C_{pit} = N \times WD \times FR \quad (10)$$

where C_{pit} = Capacity of soakaway pit
N = Number of full-time residents
WD = Daily water demand per person (as per the design code in use)
FR = A fraction (obtained from seepage tests conducted on the site)

Another approach to soakaway pit sizing is the use of the empirical formula (Klargester,1991)

$$A_t = 0.25NV_p \quad (11)$$

where A_t = Floor area (in m^2) of the soakaway pit or drainage trench
V_p = Percolation rate (in s/mm) at the site and N is as defined earlier.

Furthermore, a reasonably shallow pit (in relation to the depth of the subsoil water table) needs to be constructed since a very deep pit would result in poor soil seepage qualities as the soil tends to be saturated with moisture at greater depths. It is yet important to provide an adequate ground cover over the effluent so as to eliminate any possible nuisance therefrom, such as a foul smell.

III. A PRACTICAL DESIGN EXAMPLE

The design methods and suggestions are illustrated with an actual project, which is a 10 occupant residential building project, whose sewage drainage and disposal system is shown in the isometric sketch of Figure 4. The project consists of two building units within the premises: a 5-bedroom unit having two floors and a 2 bedroom unit on a ground floor.

A. Waste drainage above ground

The necessary computations are summarized in Table 1, which should be read in conjunction with Figure 4. The appliance discharge units are taken from Table 2 (IOP, 1977) while the corresponding pipe sizes are read off from Tables 3 and 4(IOP, 1977), for the vertical stacks and horizontal runs respectively. A convenient fall of 1:50 (0.02) is chosen for all horizontal runs.

It is observed from Figure 4 and Table 1 that the largest cumulative D.U. occurs on stack no. 1 for soil stacks and on stack no. 2 for waste stacks.

To provide an ample safety margin the drainage pipes are sized on the basis of being a quarter full when discharging.

Maximum soil stack D. U. (stack no. 1) = 24
But there are 2 water closets on the stack
∴ corresponding stack diameter (quarter full) from Table 3
= 90mm
Corresponding horizontal soil pipe diameter from Table 4
= 65mm

However, since water closets are usually manufactured with 100mm outlets (i.e. larger than the sizes of 90mm and 65mm obtained from the tables), this size is specified for all soil stacks and horizontal runs.

Now, maximum waste stack D.U. (stack no.2) = 14

Corresponding stack diameter (quarter full) from Table 3 = 50mm

But there are 2 wash basins on this stack.

∴ corresponding horizontal waste pipe diameter (from Table 4) = 38mm

To provide a safety factor and to achieve pipe size uniformity the 50mm size is specified for all waste pipes.

In order to properly ventilate the sewage drainage system of this project all stacks discharging from the upper floor are raised up to roof level and cowled as shown in Figure 4.

B. Waste drainage below ground

In Figure 4, each underground drainage section is specified by means of numbers indicated at each inspection chamber. Table 5 summarizes the drainage calculations utilizing values of D.U. obtained from Table 6 (for underground drainage systems) .The design process results in a 65mm pipe size being the largest pipe size i.e. that for sections 7-8 and 8-12. However, to ensure pipe size uniformity and to provide a safety margin, a 100mm size is specified throughout the underground drainage pipework, this size being the normal outlet pipe size from water closets.

A convenient drainage slope of 1:50 (0.02) is utilized in the calculation of invert levels, which is illustrated as follows for pipe sections 1-2, 2-4, and 3-4:

Measured length of section 1-2 = 4m
Fall = 0.02 x 4 = 0.08m

The high point invert is that of the inspection chamber located at the beginning of the particular pipe section. For the section 1-2 it is the invert of the chamber into which the waste and soil stacks directly discharge, and which should therefore, be the shallowest invert. A convenient value of 0.45m is taken for it in consideration of utilizing two layers of 0.225m high hollow concrete blocks.

Low point invert = High point invert + fall =0.45 + 0.08 = 0.53m
Measured length of section 2-4 = 3m
Fall = 0.02 x 3 = 0.06m
High point invert = Invert of chamber no.2 = 0.53m
Low point invert = 0.53 + 0.06 = 0.59m
Measured length of section 3-4 = 6m
Fall = 0.02 x 6 = 0.12m

The high point invert is again taken as 0.45m for this section since chamber no.3, like chamber no. 1, receives discharges directly from the stacks, and should therefore have the shallowest invert.

Low point invert = 0.45 + 0.12 = 0.57m

This invert being shallower than that obtained for section 2-4 needs to be revised (or dropped) to 0.59m to equalize the depths of the inlet pipes to chamber no.4. To achieve this, the fall is recalculated.

Thus, final fall required for section 3-4= 0.59 - 0.45= 0.14m

The slope of this pipe section should therefore be $\frac{0.14}{6} = 0.233$

There is thus a back-drop of 0. 14- 0.12 = 0.02m for this section.

Depths and slopes of other pipe sections are calculated in a similar manner.

C. Sewage treatment: the septic tank

Building occupancy, N = 10
Septic tank capacity, C (from equation 1)

$$= \frac{1}{1000}(250N + 2000)$$
$$= \frac{1}{1000}(250 \times 10 + 2000)$$
$$= 4.5m^3$$

L (Equation 3) $= \sqrt[3]{6 \times 4.5}$
$= 3.0m$

W (Equation 4) $= \frac{3.0}{3}$
$= 1.0m$

D (Equation 5) $= \frac{3.0}{2}$
$= 1.5m$

Now, the invert A of the inlet inspection chamber of the septic tank is the low point invert of pipe section 11-12 as obtained from the drainage calculations

= 0.94m

$\therefore D_{\mathrm{Tot}}$ (Equation 6) $= 1.5 + 0.94$
$= 2.44m$

P_{pat} (Equation 7) $= \frac{2 \times 3.0}{3}$
= 2.0m

$D_{\mathrm{pat\ Tot}}$ (Equation 8) $= \frac{3.0}{3} + 0.94$
= 1.94m

B (Equation 9) = 0.94 + 0.1
= 1.04m

To facilitate site measurements $A, D_{tot}, D_{pat,\ tot}$ and B are respectively approximated as 1.0m, 2.5m, 2.0m and 1.1m.

D. Effluent disposal: the soakway pit

At the site under consideration V_P was measured as equal to 2.5 s/mm

$\therefore A_t$ (Equation 11) = 10 x 2.5 x 0.25 = $6.25m^2$

Considering land area constraints, a square area plan is utilized, and the length of each side, S, is given as

$S = \sqrt{6.25}$
= 2.5m

A depth of 1.8m is chosen for the soakaway pit (i.e. 0.7m deeper than the outlet chamber of the septic tank), located 3m away from the septic tank. Utilizing the 0.02 general slope for the effluent discharge pipe from the septic tank to the soakaway pit,

Fall = 0.02 x 3 = 0.06m

$\therefore$ Depth of inlet pipe at soakaway pit
= B + 0.06
= 1.1 + 0.06 = 1.16m (say 1.2m)

IV. Recommendations and Conclusion

As a way of minimizing the incidence of nuisance and environmental pollution resulting from faulty design, construction and operation of sewage drainage, treatment, and disposal systems for buildings in developing environments, the following recommendations are made to complement existing codes and design guides:

a. All horizontal piping should be adequately sloped to ensure flow by gravity and to minimize the use of sewage lift pumps.
b. Drainage systems should be properly ventilated, be water-tight, and trap seals be installed therein.
c. Ample safety margins should be provided in drainage pipe sizing.
d. The two-pipe stack system should be utilized in preference to the one-pipe system.
e. Septic tanks should have larger capacities than those utilized in developed environments. As a minimum requirement, the Chartered Institution of Building Services Engineers equation given should be used in sizing tanks.
f. The simple equations given, which had been derived from existing codes of practice and design guides, should be utilized to facilitate the dimensioning of tanks.

g. Disposal of treated effluent should be by means of land drainage using soakaway pits and trenches in preference to discharge into watercourses.
h. Site seepage tests (to determine percolation rates) should be conducted as a prerequisite to the sizing and dimensioning of soakaway pits, this practice being presently very rare in developing environment.

The paper has thus highlighted the design methods for sewage drainage, treatment, and disposal using the septic tank and soakaway pit systems. The case of a residential building project is used for illustrations. Ways of improving the design practice for developing environments have also been recommended.

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TABLE I. CALCULATIONS FOR SEWAGE DRAINAGE ABOVE GROUND

Stack No	Appliances	Cumulative Discharge Units (Table 2)	Corresponding Stack Diameter (Table 3)(mm)	Corresponding Horizontal Pipe Diameter (Table 4) (mm)
1	2 water closets	24	90	65
2	2 wash basins and 2 bath tubs	14	50	38

TABLE II. (IOP, 1977): DISCHARGE UNITS FOR SANITARY APPLIANCES CONNECTED TO SANITARY PIPEWORK ABOVE GROUND

Appliance	Flow Rate (L/s)	Discharge Units
Water closet (with High Level Cistern)	2.27	12
Wash Basin (Domestic)	0.34	1
Sink (Domestic)	0.75	3
Bath (Domestic)	0.06	6
Shower (Domestic)	0.08	1

TABLE III. (IOP, 1977): MAXIMUM CAPACITIES OF STACKS FLOWING QUARTER FULL

Stack Diameter (mm)	Stack Capacity (L/s)	Discharge Units
50	1.10	70
65	2.00	175
75	3.25	375*
90	5.00	700
100	7.10	1200
125	12.30	2800
150	20.60	6000

* Not more than 1 water closet

TABLE IV. (IOP, 1977) : MAXIMUM NUMBER OF DISCHARGE UNITS TO BE ALLOWED ON HORIZONTAL BRANCHES AT A FALL OF 1 IN 50

Diameter of Pipe (mm)	Discharge Units
32	Not more than 1 basin
38	18
50	40
65	100
75	200
90	350
100	650
125	1500
150	3000

TABLE V. CALCULATIONS FOR UNDERGROUND SEWAGE DRAINAGE

Pipe Section	Discharge Units	Horizontal Pipe Size (m)	Slope	Measured Pipe Length (m)	Fall (m)	Invert Level (m)		Back-Drop (m)	Revised Low point Invert (m)
						High Point	Low Point		
1 – 2	3	38	0.0200	4	0.08	0.45	0.53	-	-
2 – 4	8	38	0.0200	3	0.06	0.53	0.59	-	-
3 – 4	20	50	0.0233	6	0.14	0.45	0.59	0.02	0.59
4 – 5	28	50	0.0200	2.5	0.05	0.59	0.64	-	-
5 – 6	34	50	0.0200	3	0.06	0.64	0.70	-	-
6 – 7	40	50	0.0200	4	0.08	0.70	0.78	-	-
7 – 8	45	65	0.0200	2	0.04	.078	0.82	-	-
8 – 12	55	65	0.0200	6	0.12	0.82	0.94	-	-
9 – 10	15	38	0.0200	5	0.10	0.45	.055	-	-
10 – 11	15	38	0.0200	8.5	0.17	0.55	0.72	-	-
11 – 12	15	38	0.0367	6	0.22	0.72	0.94	0.10	0.94

TABLE VI. (IOP, 1977): DISCHARGE UNITS FOR SANITARY APPLIANCES CONNECTED TO UNDERGROUND DRAINAGE

Appliance	Flow Rate (L/s)	Discharge Units
Water Closet (with High Level Cistern	1.51	7
Wash Basin (Domestic)	0.34	1
Sink (Domestic)	0.75	3
Bath (Domestic)	1.06	6
Shower (Domestic)	1.08	1

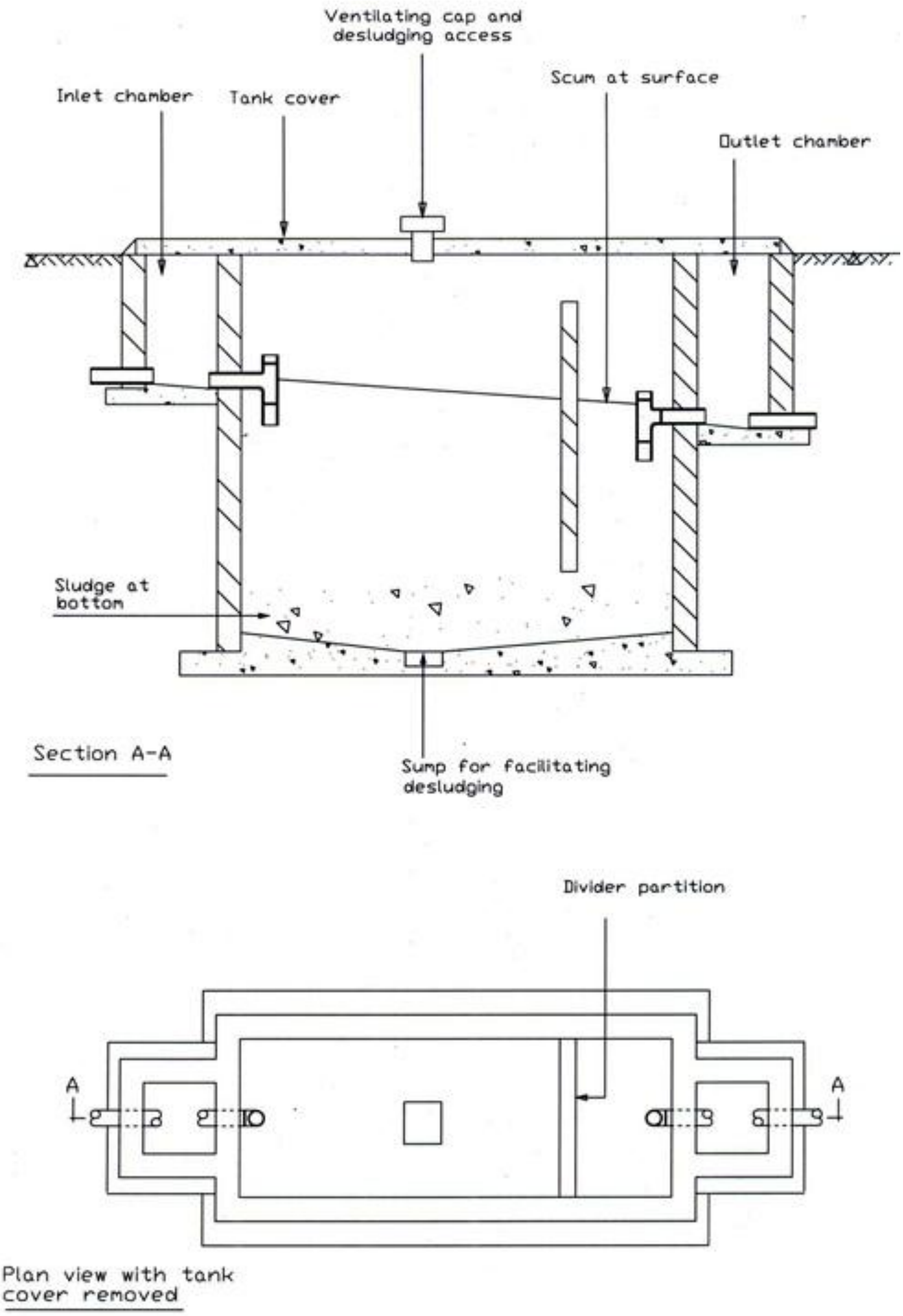

Figure 1. A typical septic tank

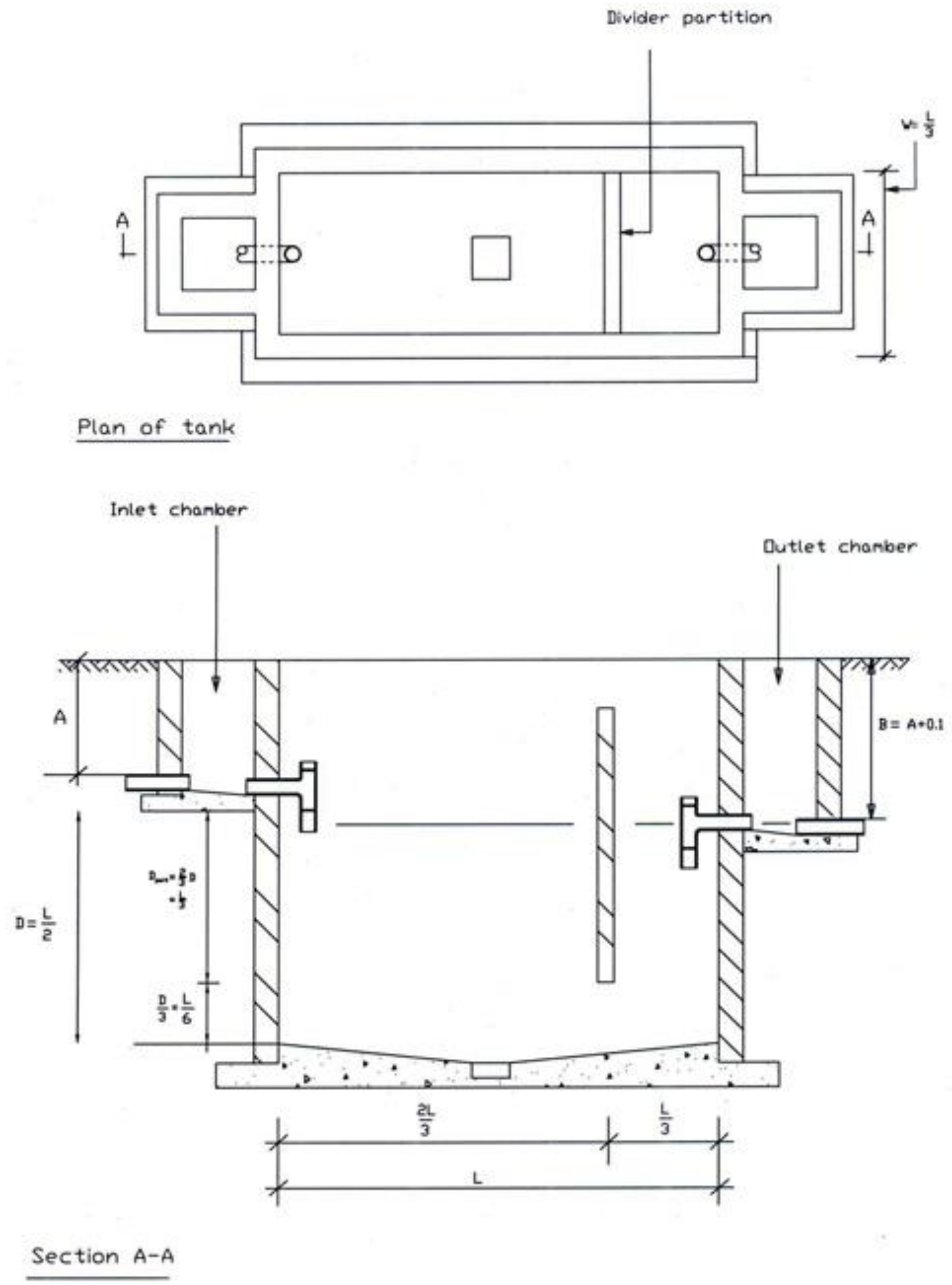

Figure 2. Dimensions on septic tank

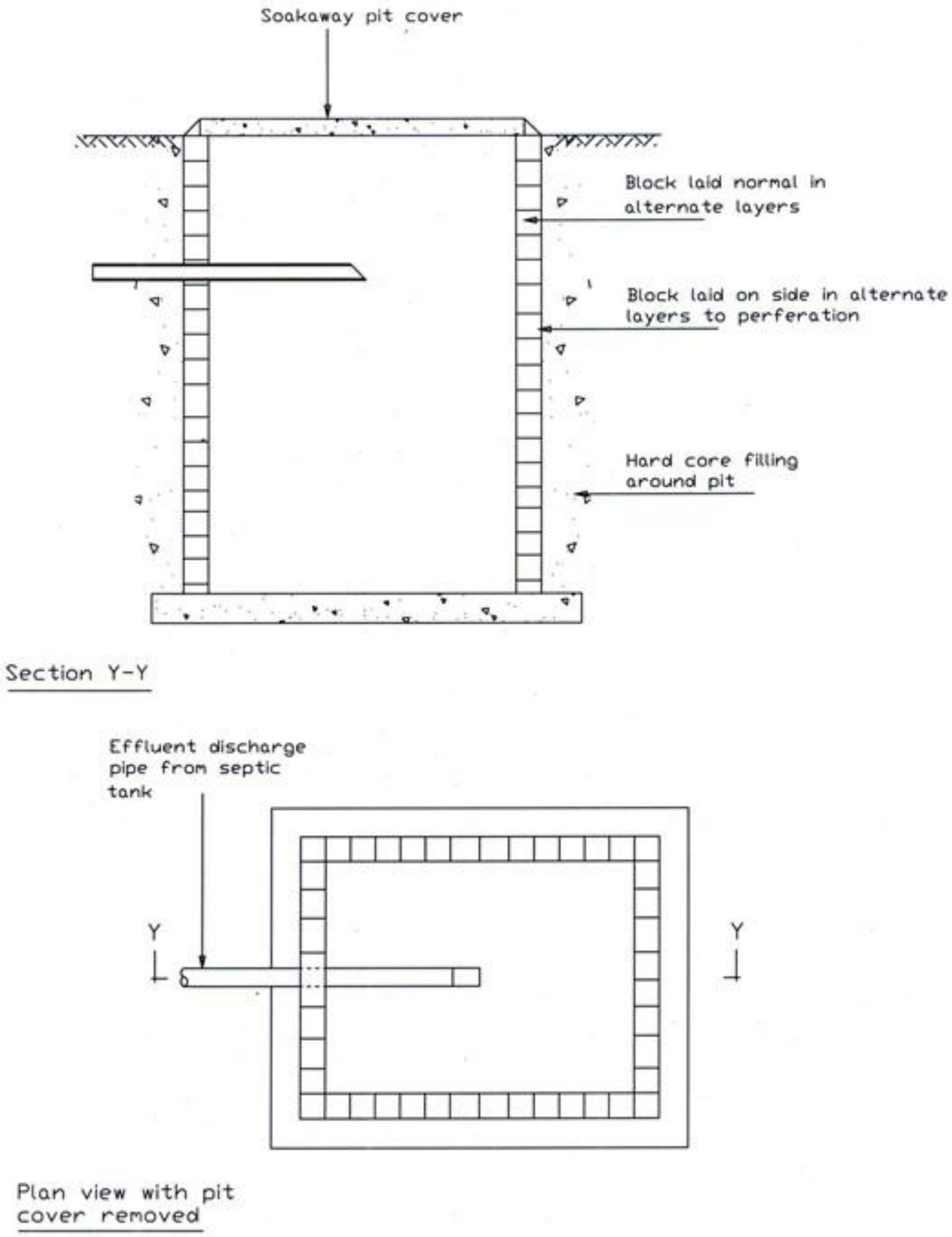

Figure 3. A typical soakawaypit constructed in loose soi

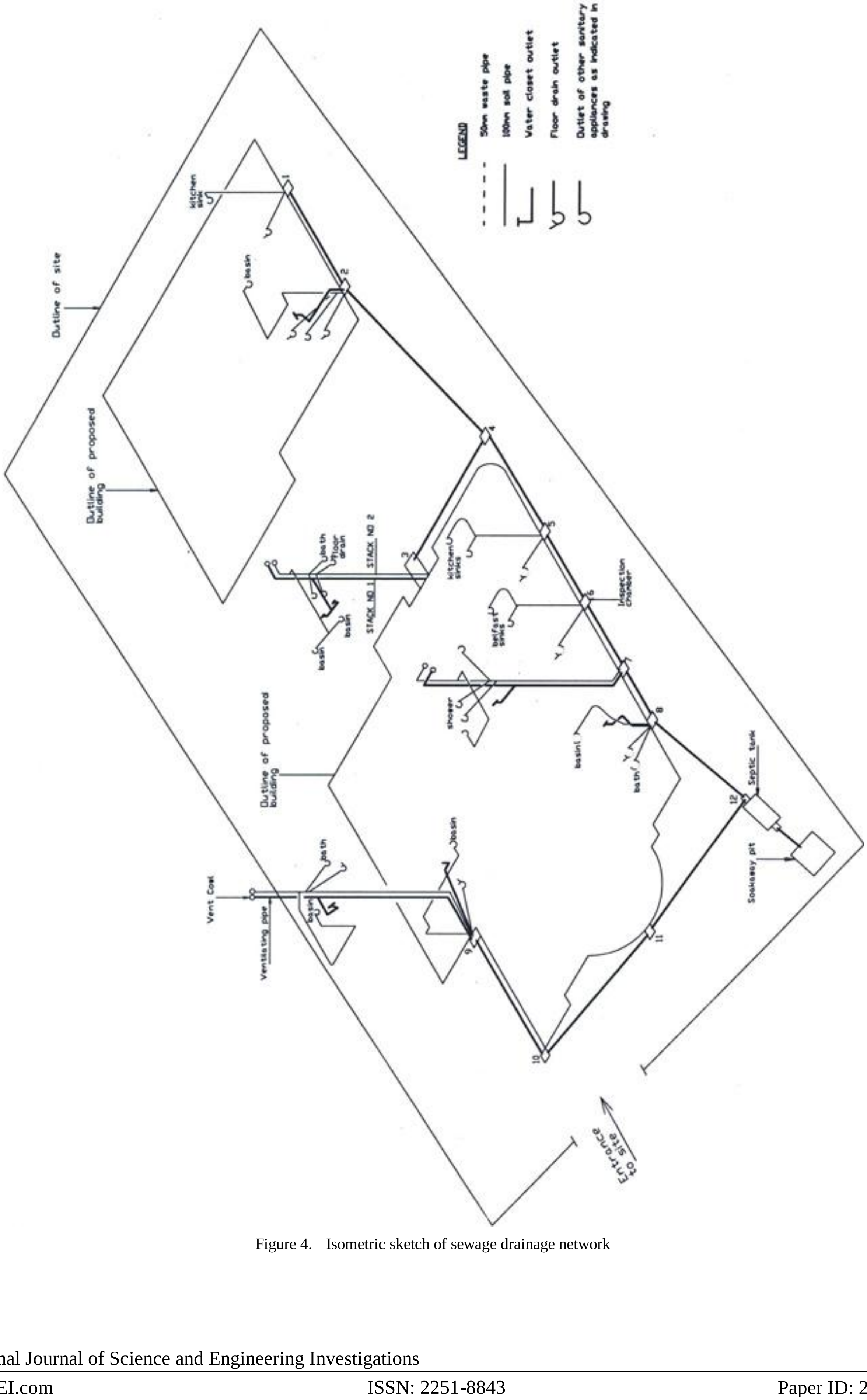

Figure 4. Isometric sketch of sewage drainage network