

TAG Technical Note No. 15

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Executing Agency: World Bank

The Design of Pour-Flush Latrines

by D. Duncan Mara,
Technology Advisory Group (TAG)



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A joint United Nations Development Programme
and World Bank Contribution to the International
Drinking Water Supply and Sanitation Decade

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PREFACE

This Technical Note by D. Duncan Mara, **The Design of Pour-flush Latrines**, is one of a series of informal Technical Notes prepared by TAG^{1/} on various aspects of water supply and sanitation programs in developing countries. The initial emphasis of TAG was on the promotion of policy shifts from high-cost to low-cost, on-site sanitation technologies. This emphasis is now being directed progressively to a focus on institutional development for on-site, low-cost sanitation program delivery.

The present note sets out guidelines for the design of pour-flush latrines, based upon TAG's experience in India, Brazil and elsewhere. These guidelines have been written especially for use in developing countries. Consequently, emphasis has been placed on achieving simplicity of design consistent with reliability of operation.

The note was originally prepared as an internal discussion document. Its wide distribution does not imply endorsement by the sector agencies, government or donor agencies concerned with programs, or by the World Bank or the United Nations Development Programme.

TAG will be interested in receiving comments and suggestions on the paper and, in particular, information on costs of technology, delivery and support systems and general information on program implementation. All communications should be addressed to the Project Manager, UNDP Project INT/81/047, Water Supply and Urban Development Department, The World Bank, 1818 H Street, N.W., Washington, D.C., 20433.

Project Manager

^{1/}TAG: Technology Advisory Group, established under the United Nations Development Program UNDP Interregional Project INT/81/047: **Development and Implementation of Low-Cost Sanitation Investment Projects** (formerly Global Project GLO/78/006), executed by the World Bank.

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I. INTRODUCTION

Basic needs in sanitation

1.1 One of the primary objectives of sanitation programs is the control of excreta-related infections. These infections are responsible for much morbidity and mortality in developing countries, especially in low-income communities, the majority of which have totally inadequate arrangements for the disposal of their excreta and sullage.^{1/} In low-income communities, in which domestic water consumption is generally below 30 litres per capita per day (lcd), basic needs in sanitation can in many cases be met by the provision of on-site systems for excreta and sullage disposal. At high housing densities or in adverse soil conditions more expensive off-site disposal systems may be required. In either case, the objective is to remove excreta and sullage from the immediate environment--the house, the yard or garden and the street--so that contact with excreted pathogens is substantially reduced (ideally eliminated) and thus excreta-related diseases controlled.

Complementary inputs

1.2 The provision of sanitation facilities, of whatever type, is necessary but in itself not sufficient for the control of excreta-related infections. Without such facilities, these infections can **never** be controlled. Even so, other inputs, such as improved water supplies and sustained educational programs on personal hygiene, are essential for success. It is essential, too, to determine user practices and preferences in sanitation so that socially acceptable sanitation systems can be evolved and adopted. This involves an approach to sanitation program planning in which the program beneficiaries play an active, rather than a passive, role in the planning process. Guidelines for this approach to sanitation program planning may be found elsewhere.^{2/}

Sanitation technologies

1.3 The traditional solution to providing sanitation facilities in urban areas has been conventional sewerage, but this technology is so expensive that it is not generally affordable by low-income communities. World Bank research has shown that full health benefits can be obtained through the use of a variety of lower-cost alternative sanitation technologies. Although the user convenience level of these technologies is not necessarily as high as that of

^{1/} Sullage is defined as all household wastewater other than that from toilets. ("Grey water" is a common synonym for sullage, in contrast to "black water," which is used to describe latrine wastewater.)

^{2/} J. M. Kalbermatten, D. S. Julius, C. G. Gunnerson and D. D. Mara, **Appropriate Sanitation Alternatives: A Planning and Design Manual**; Johns Hopkins University Press, 1982; H. Perrett, **Planning of Social Feasibility Analysis of Low-Cost Sanitation Projects**. TAG Technical Note No. 5, 1984.

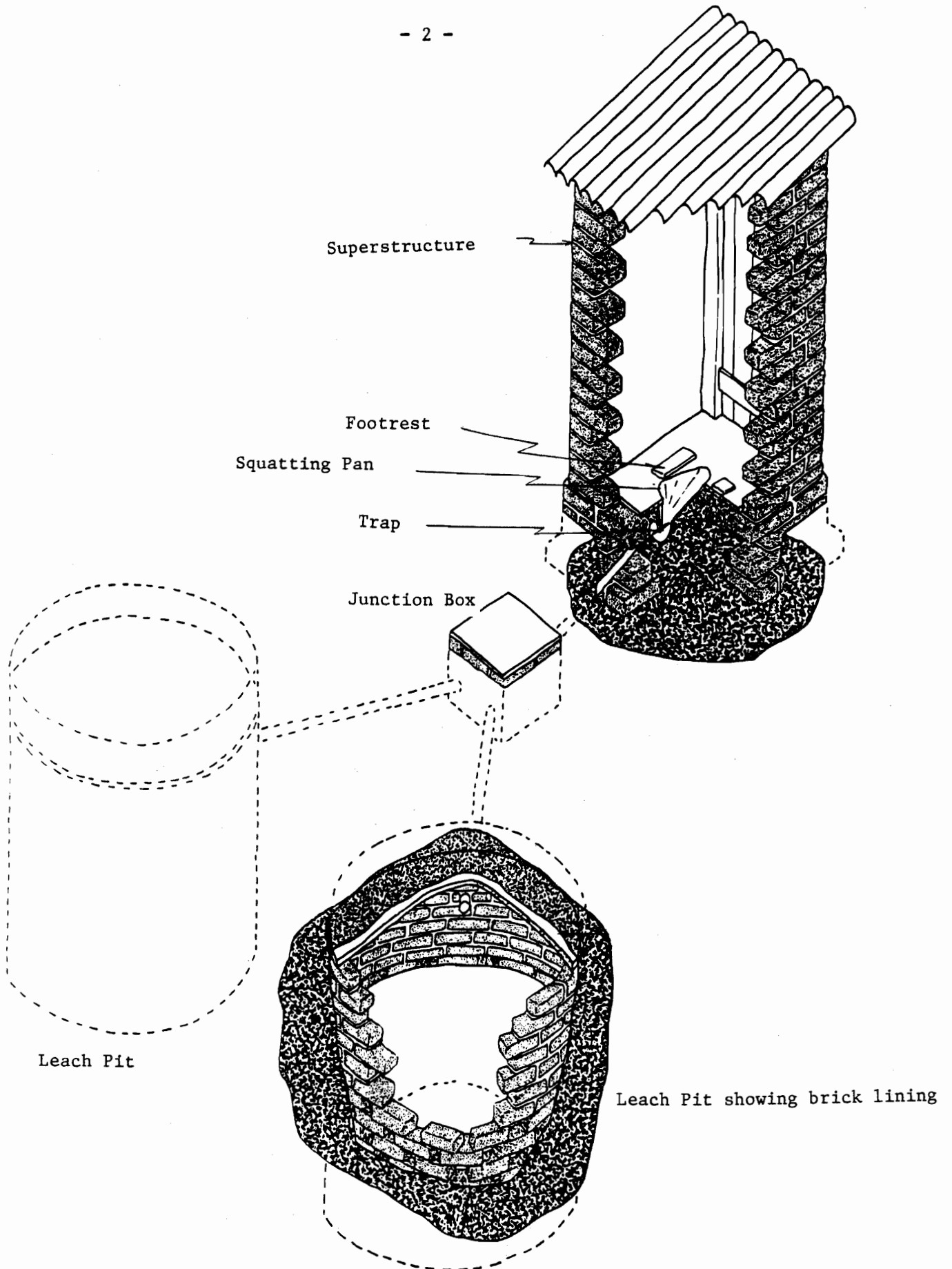


Figure 1. Schematic diagram of pour-flush latrine with alternating twin leaching pits.

conventional sewerage, this should not be considered a major disadvantage, since health improvements are initially more important than providing high levels of user convenience. This Technical Note describes in detail one of these technologies, the pour-flush latrine, which has been widely adopted during the International Drinking Water Supply and Sanitation Decade (1981-1990).

II. POUR-FLUSH LATRINES

Description

2.1 The pour-flush (PF) latrine (Figure 1) comprises two principal components: the latrine pan with its integral waterseal and either single or twin leach pits (Section 2.2). The pan can be located within the house, or it may be placed outside in a separate superstructure. It is located either immediately above the leach pits or connected to them by small diameter pipework; the latter option is generally preferred (Section 3.4). The trap maintains a waterseal, which helps in odor and fly control. The latrine functions as follows:

- (a) Excreta deposited on the pan are flushed by a low volume of hand-poured water through the waterseal and connecting pipework into a leach pit; about 2-3 litres of water are required (conventional cistern-flush toilets use between 10 and 20 litres per flush). The pan is thereby cleaned after each use, while the waterseal is maintained to provide a barrier against odors and insects.
- (b) The excreta flushed into the leach pit are biodegraded under both anaerobic and aerobic conditions. Between 4 and 10 litres/capita/day (lcd) of excreta and flushing water enter the pit; if water is used for anal cleansing, an additional 4-10 lcd may be flushed into the pit (Section 2.7). The water, together with the liquid and soluble products of biodegradation, pass through the leach pit wall into the surrounding soil and are thereby disposed of; this only occurs if the soil has sufficient long-term infiltrative capacity (Section 3.17). If it does not, the liquid effluent can be removed by shallow gradient small bore sewers (Section 5).
- (c) The solid products of biodegradation accumulate in the leach pit, which in time fills up. If single leach pits are used they must be desludged when full. If there are twin pits, then when one pit is full the excreta are diverted to the second leach pit and the first pit is rested; after a period of one to two years the enormous load of excreted pathogens will, by natural biodegradation and the action of time and temperature, be rendered harmless, and the pit will contain a friable humus that is both safe to use and inoffensive.

2.2 Single leach pits are appropriate in urban areas only if they can be desludged mechanically by a vacuum tanker, since their contents are not pathogen free. Twin leach pits are recommended if the pits are to be desludged manually, as the resting period ensures that material to be removed is substantially free of excreted pathogens. In rural areas mechanical desludging may not be affordable or reliable. Consequently, pits should be

designed for manual desludging. If twin pits cannot be afforded during the initial construction, the layout of pipework and the first pit should allow for the installation of a second pit when the first becomes full.

2.3 **Sullage** is produced in the household from a number of sources, including body and clothes washing, food preparation, dishwashing, personal hygiene and household cleaning. In conjunction with providing excreta disposal facilities, adequate provision should be made for the hygienic disposal of sullage. Sullage has a relatively low pathogen content and simple soakaways (preferably alternating types) are often sufficient for its disposal.

Merits and suitability

2.4 The PF latrine is a robust and well-tried technology that has been accepted in many developing countries. Its major merits, as compared with other on-site excreta disposal systems, are that:

- (a) the water required for satisfactory operation is usually about 2-3 litres per flush, or less than 10 lcd (see Section 2.6);
- (b) costs are low: for example, in India capital costs ranged between US\$120 and US\$150 in 1983;
- (c) social acceptability is high in many developing countries; the PF latrine is particularly appropriate where water is used for anal cleansing (as in most Hindu and Moslem societies), but it is popular elsewhere as well (for example, in South America);
- (d) with minimum householder care and maintenance, odor and insect nuisance are negligible; the PF latrine can therefore be constructed integrally within the house, and not necessarily only on the ground floor;
- (e) overall maintenance requirements are minimal;
- (f) both adults and children can use the toilet without fear;^{3/}
- (g) it is suitable for a variety of soil conditions in both urban and rural areas;
- (h) upgrading, which is dictated by increasing population densities or higher water use, is straightforward (see Section 6).

^{3/} Children have been known to fall into badly designed or badly constructed pit latrines.

- 2.5 PF technology would be inappropriate in situations where:
- (a) the trap could be regularly blocked by bulky anal cleansing materials (such as cement bags, cardboard, leaves, maize cob or grass) or other personal hygiene materials;^{4/}
 - (b) a supply of water for flushing cannot be relied on (a minimum of 5 lcd should suffice);
 - (c) incomes are extremely low (less than US\$200 per household per year) and no form of public assistance for provision of sanitation facilities is available.

Water requirements

2.6 The PF latrine requires water to flush deposited excreta through the waterseal into the leach pit and to wash down the pan. The system should therefore be designed to function with volumes of flushing water that users are prepared (and able) to carry regularly;^{5/} most PF pans have been designed to function satisfactorily using 3 litres or less of water per usage.

2.7 In cultures in which anal cleansing is by water (as opposed to a variety of dry materials), additional water is required for this purpose. Only limited data on cleansing water use are available; in one study it was found that women generally use more water than men, and that the water requirement was between one and two litres per usage. The total water requirement (for flushing and anal cleansing) may therefore be 4-5 litres per usage. However, this figure must be determined for each project as it is likely to be culture specific. For example, socioreligious ritual ablutions may require considerably greater volumes of water than those strictly required for hygienic purposes; alternatively, the traditional ablution vessel may be too small to enable sufficient flushing water to be carried into the toilet. Another factor of importance is the number of times the toilet is flushed per person per day; is the toilet flushed only when stools are passed, or is the toilet also flushed when only urine is passed? Since the total toilet wastewater flow is a major parameter in the design of the leach pits (see Section 3.13), it is clearly important to determine local practices and preferences so that its value may be accurately predicted at the design stage.

^{4/} Improved pipework design, user education or an increase in incomes might eliminate these problems. Alternatively, ventilated improved pit (VIP) latrines would probably be a more appropriate sanitation technology (see TAG Technical Note No. 13, **The Design of Ventilated Improved Pit Latrines**, by D. D. Mara).

^{5/} PF toilets are certainly feasible where water is supplied through yard taps. If the water supply is from public standpipes, the ability and willingness of the community to carry home sufficient water for pour-flushing should be established at the program-planning stage.

2.8 A tin, clay or plastic water vessel sized to local sociocultural preference (normally between three and five litre capacity) should thus be provided at each toilet for flushing and cleansing purposes; this will prevent excessive water use while ensuring reasonably regular flushing. Sufficient water for total household daily latrine requirements should ideally be stored in the latrine in a suitable storage jar, bucket or purpose-built storage tank. Since water is likely to be dipped from the storage jar using contaminated vessels and with contaminated hands, it is important that the storage jar be reserved for toilet/latrine use. If an on-site water supply is available, a self-closing tap with separate drainage could replace the storage vessel.

2.9 **Hand-washing facilities.** Where anal cleansing is by water, the users will achieve only very limited health benefits from using the latrines if they do not wash their hands thoroughly after anal cleansing. Soap, a bactericide, or at the least an abrasive material such as sand should be used for this.^{6/} Provision for hand washing should thus be an integral part of program design; this can be done in many socioculturally acceptable forms such as in a simple clay water pot, a drained yard standpipe or, if affordable, a washbasin with a self-closing tap. Facilities should also be designed to be accessible to children. Regular health education messages should encourage and motivate hand washing; this may need to be reinforced through religious communications channels.

III. DESIGN

Component parts

3.1 This section discusses the detailed design of the component parts of PF latrines: (a) the pan, (b) the waterseal, (c) the superstructure, (d) the interconnecting pipework and (e) the leach pits. Designs developed by TAG in India ^{7/} form the basis for this discussion. However, a more generalized approach is used so that design engineers may develop PF latrine systems appropriate to a wider range of physical and sociocultural conditions.

PF latrine pan

3.2 **Sociocultural considerations.** One of the first points to be established in discussion with the intended beneficiaries (or their leaders) of any sanitation improvement program is whether their preference is to sit or squat during defecation. The preferred position may be determined by

^{6/} See E. Nnochiri, **Parasitic Disease and Urbanization in a Developing Community**, p. 26. Oxford University Press, 1968.

^{7/} A. K. Roy and others, **Manual on the Design, Construction, and Maintenance of Low-Cost Pour-Flush Waterseal Latrines in India**. TAG Technical Note No. 10, The World Bank, 1984.

tradition, although squatting is the natural position for defecation. In some societies changing from squatting to sitting is regarded as a sign of progress and status. Other factors, such as the pan color and finish or being able to inspect deposited excreta (for example, by mothers concerned about diarrheal or parasitic infections in their children), may also be important design considerations. Prototypes and models should be prepared and discussed with the program beneficiaries before designs are finalized. Requirements for privacy when using the latrine or when collecting ablution and flushing water should also be established.

3.3 Squatting plate and pan. Figure 2 shows a typical squatting plate and pan of the type proposed for use in India, based on an analysis of many trials of alternative designs. This design, which is for PF latrines connected to adjacent leach pits by small diameter pipework, takes account of the prevention of urine splashing, the ease with which feces and sanitary towels can be flushed down the pan,^{8/} the comfort of the squatting position and use by children. Squatting plates and pans may be made in one piece or separately; the advantages and disadvantages of various construction materials are shown in Table 1. The final design and selection of materials should be based on sociocultural preference, program size (that is, scope for mass production), local capabilities, availability of materials and financial constraints. A smooth, high-quality finish is crucial for both appearance (for social acceptability) and hygiene (for ease of cleaning). Cracked or crazed surfaces harbor pathogens and nutrients for insects, cause odors and discourage hygienic and regular use.

3.4 "Gooseneck" pan. For PF toilet configurations in which the squat plate is located directly over the leach pit,^{9/} a gooseneck design of the type shown in Figure 3 has been found appropriate and is widely used, for example, in Thailand. The unit may be made in concrete, ferrocement, jute-reinforced cement mortar, jute- or glass-fiber-reinforced plastic, ceramics or high-density polyethylene. It is, however, susceptible to damage at the gooseneck if excessive force is used to clear any blockage.

3.5 Pedestal units. A typical pour-flush pedestal unit with integral waterseal for use in the sitting position is shown in Figure 4; this ceramic

^{8/} Effective flushing is most important. Since the hydraulics of flushing are complex, new shapes should be tested integrally with the waterseal and associated pipework before being mass produced (see J. A. Swaffield, "Building drainage system research: Past influences, current efforts and future objectives," **Construction Papers** 1, 45-61; 1981). If sanitary towels, tampons or other absorbent materials used by menstruating women are disposed of in the toilet pan, it is important that flushing tests are done with them as they, rather than feces, are commonly responsible for blockages.

^{9/} A performance specification for pour-flush pans and traps will be forthcoming as a TAG Discussion Paper.

Table 1. Materials for constructing pans, squatting slabs, and pedestal units.

Material	Sand-cement mortar <u>a/</u>	Sand-cement mosaic mortar <u>b/</u>	Glass fiber	High density polyethylene	Fired clay	Ceramic
Labor content	high	high	high	low	medium	medium
Capital cost	low	low	low	high	medium	high
Foreign exchange requirement	low	low	high	high	medium	medium
Consumer acceptability	low	medium	high	high	medium	high
Hygiene/quality of finish	adequate	adequate	good	good	very good	very good
Life	medium	medium	long	long	very long	very long
Strength	good	good	good	adequate	good	good

a/ 1:2 mix; plastered inside with white cement

b/ 1:2 mix; faced with mosaic (marble chips) in white cement

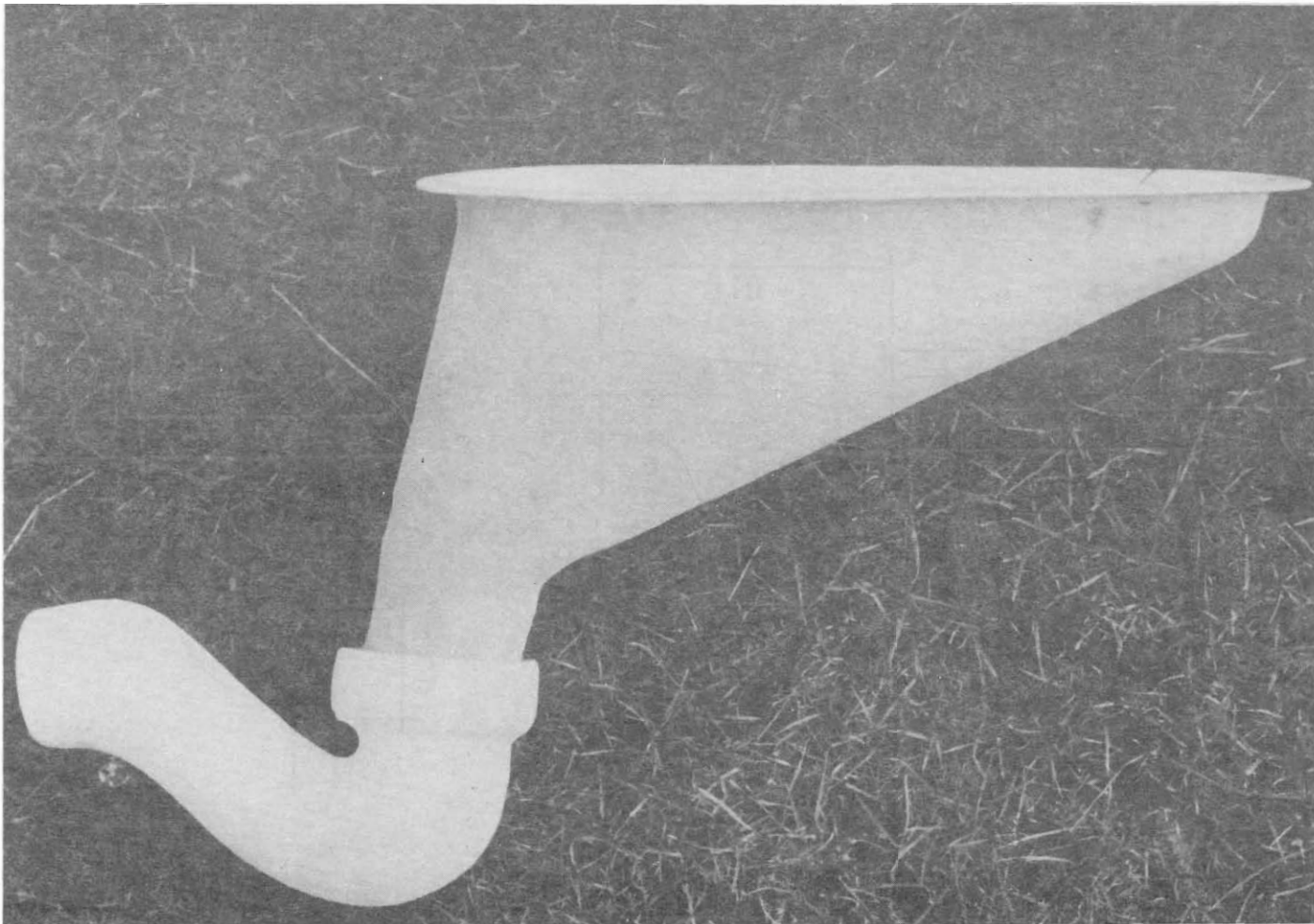
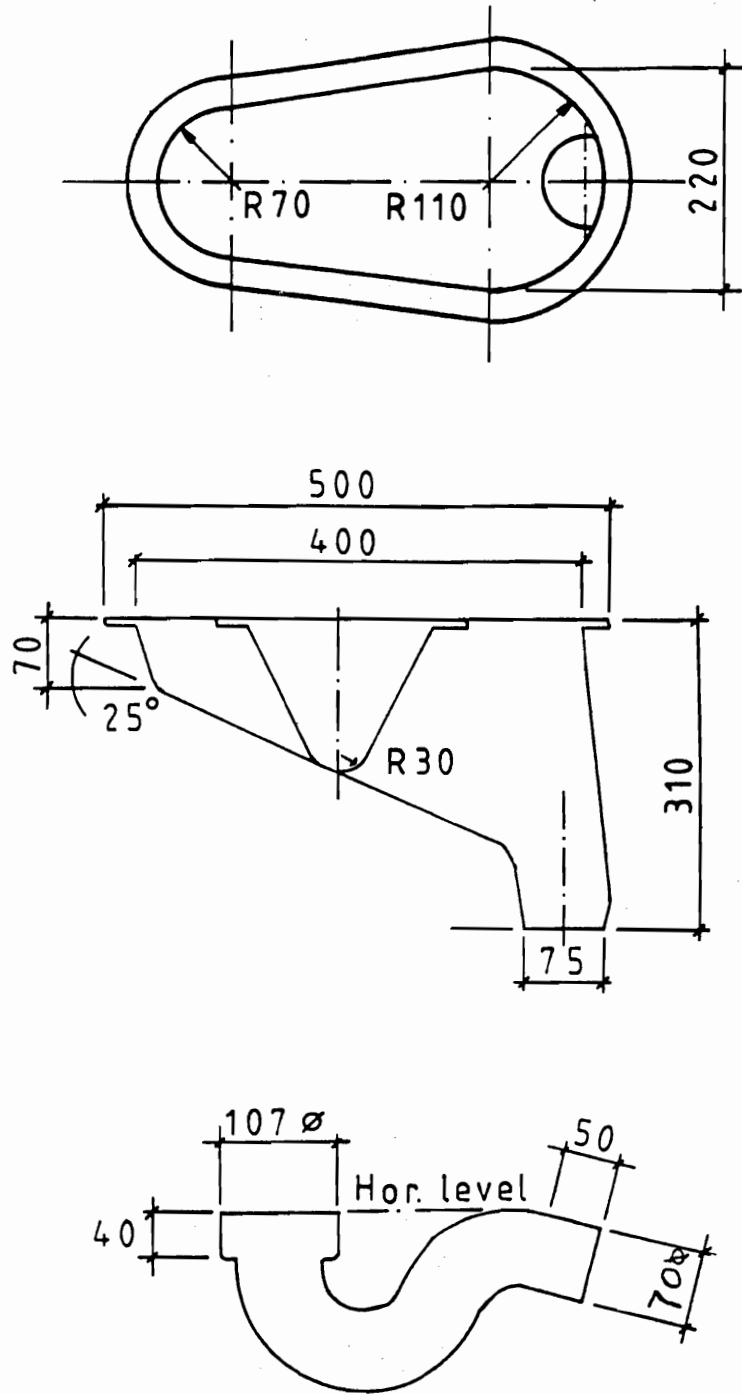


Figure 2a. Glass-fiber-reinforced plastic squat pan and trap (India).



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Figure 2b. Details of pan and trap shown in Figure 2.

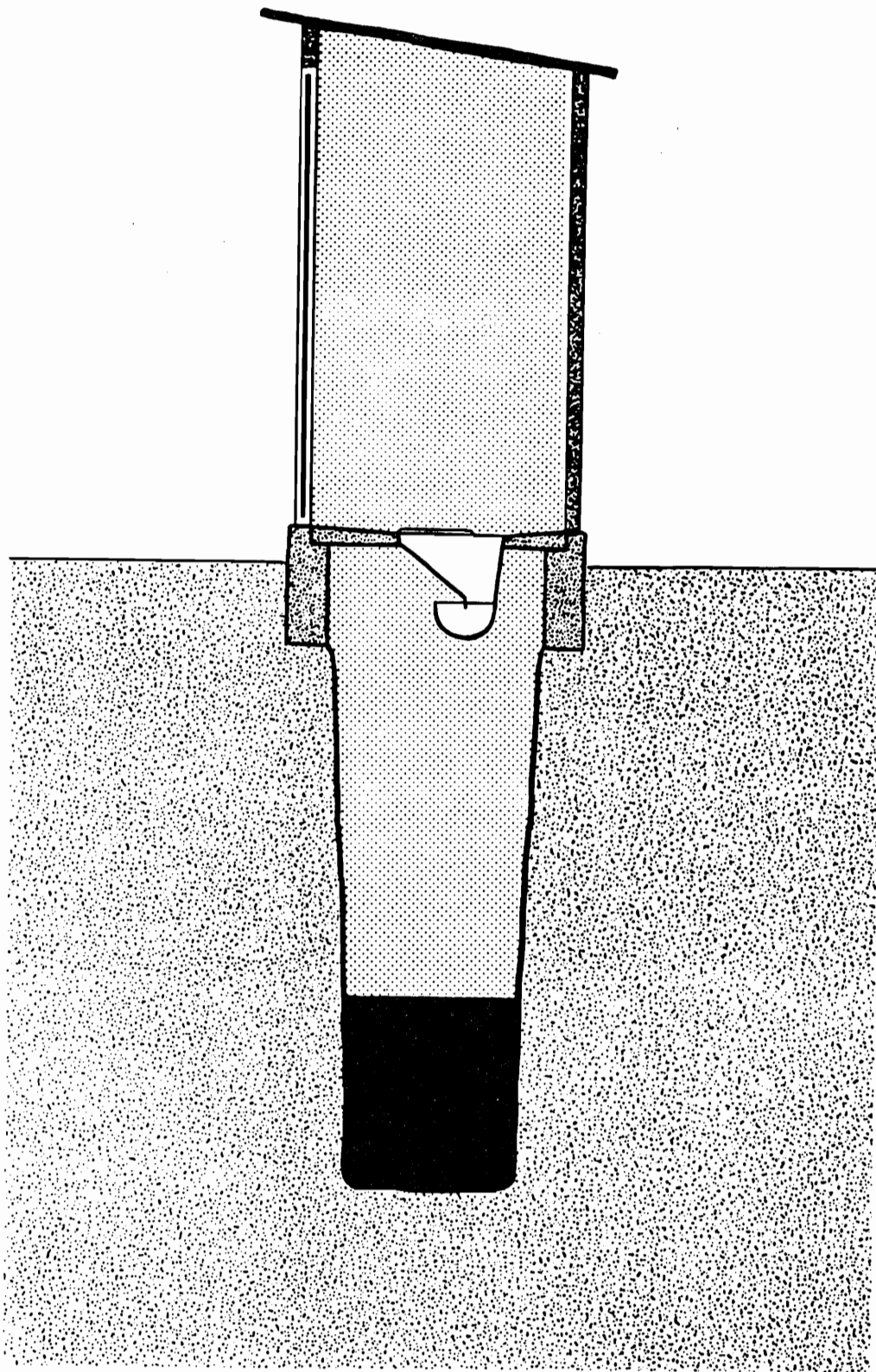
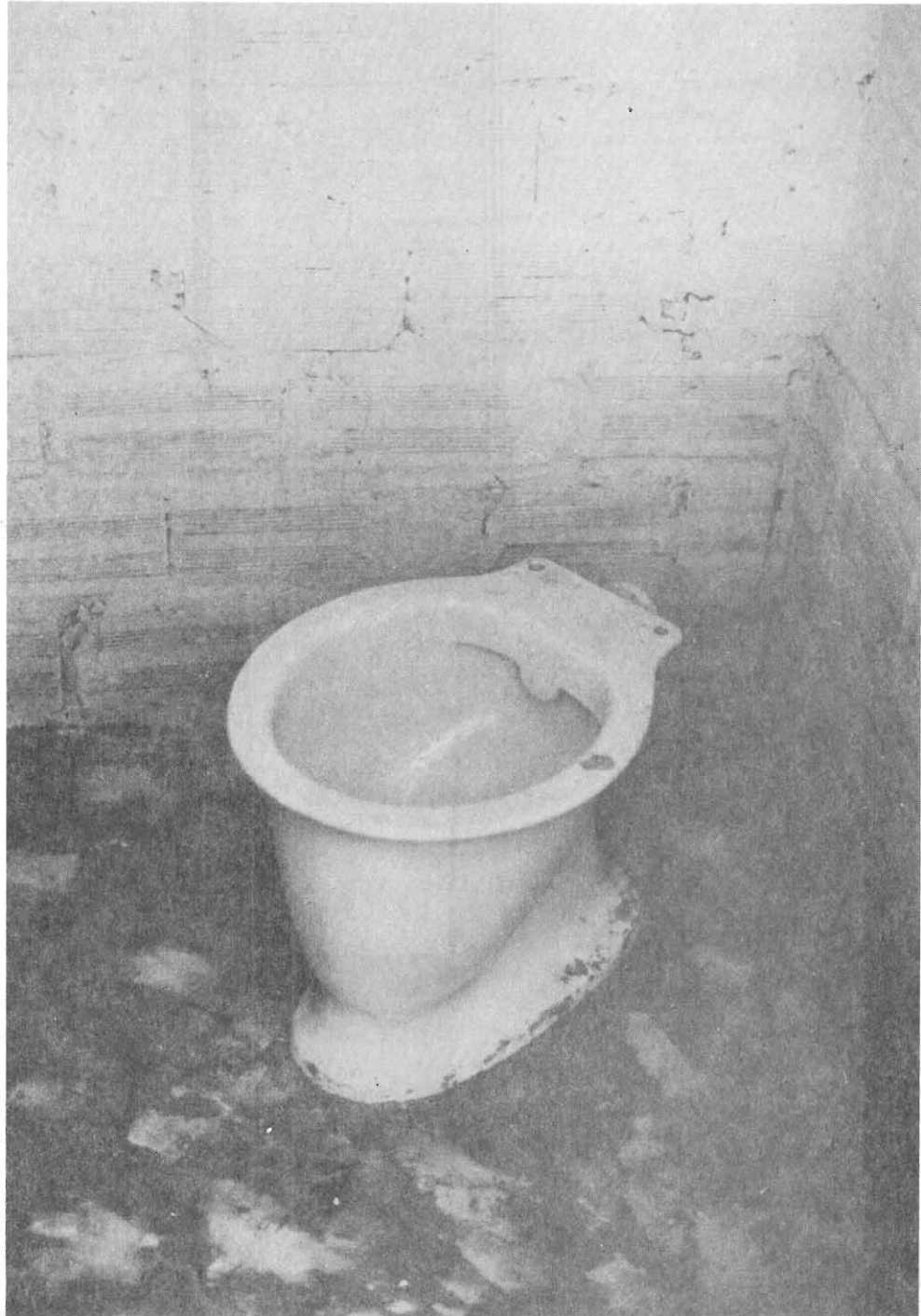


Figure 3. "Gooseneck" pan design located directly over leach pit.



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Figure 4. Ceramic pedestal latrine unit for use either in pour-flush mode (as above) or, when connected to a small cistern, in cistern-flush mode (Brazil).

unit is one of four models currently manufactured in Brazil ^{10/} and is designed to be operated either in the pour-flush mode (3 litres/flush) or in the cistern-flush mode (5 litres/flush).

Waterseal

3.6 The waterseal prevents odors and insects from escaping from the leach pits and therefore is a crucial component. Extensive research on waterseal design undertaken in India (see Footnote 11) has concluded that, to be able to ensure a positive seal while minimizing the volume of flushing water required, the depth of the waterseal for hand-flushed latrine systems should be at least 20 mm. Smaller depths of seal have been used, but construction inaccuracies can reduce the depth to an unacceptable and ineffective level. A depth greater than 20 mm (say 30 or 35 mm) might be required in multiple-latrine systems using a common leach pit or where latrines are located on floors above the ground floor. ^{11/} A smooth and unrestricted hydraulic flow passage is required for ensuring flushing and maintaining the seal. Optimal pipe diameters for hand-flushed latrines have been found to be in the region of 70 mm in India (the viable range is probably between 65 and 85 mm diameter; tests on low-volume, cistern-flush latrines in Europe have confirmed this). The waterseal, which may be manufactured in concrete, glazed clay, ceramics, glass-fiber-reinforced plastic or high-density polyethelene, should be robustly designed so as to withstand rodding and fairly rough treatment when blocked. It is most important that the pan and waterseal units are correctly aligned during construction so that the correct depth of waterseal is obtained (Figure 5). This may be achieved by designing the pan and the trap to fit together as an integral unit.

Superstructure

3.7 The PF latrine may be placed inside the house or in a separate superstructure; in the latter case the floor level should be at least 150 mm above ground level to prevent the entry of storm water and insects. The floor should have a smooth, free-draining surface, and it should be sloped at a minimum grade of 1 in 20 toward the pan to drain any spilt flushing water. The latrine can also be located on upper floors of houses. The location and latrine orientation should suit householder preferences (religious factors may be important; for instance, in Islamic countries the user should not face Mecca while using the toilet). The minimum internal dimensions of the

^{10/} L. C. M. Bonilha, A. S. P. Guimaraes, and D. D. Mara, **Low-Volume Latrines: Recent Developments in Brazil**. TAG Discussion Paper (in preparation).

^{11/} There is insufficient knowledge about the risks of back siphonage of shallow waterseals of this type. Venting the soil stack should, however, obviate any back-siphonage and loss of waterseal.



Figure 5. Proper installation of squat-pan to ensure correct depth of waterseal.

latrine room should be 800 mm from side to side and 1,000 mm from front to back. It should be designed to ensure privacy, convenience and comfort as well as easy maintenance of cleanliness.

Interconnecting pipework

3.8 The pipework between the pan and the leach pits must allow the smooth and unrestricted flow of flushed excreta to the leach pits. The diameter should be similar to the diameter of the waterseal (65-85 mm) and the pipe laid to a minimum gradient of 1 in 30; all joints should, if possible, be flexible. Any cost-effective material may be used (as with the waterseal). Standard pipe-laying bedding and protection procedures should be adopted.

3.9 To alternate the flow between twin leach pits, a flow diverter is required. This can be constructed either in the pit or, preferably, in the pipework as a Y-piece or as a chamber. A typical Y-shaped flow diverter, which has been found to work well in practice, is shown in Figure 6.

Leach pits

3.10 Leach pits serve the dual functions of: (a) storage and digestion of excreted solids; and (b) infiltration of the wastewater liquids. Leach pits are thus designed on the basis of the following external parameters:

- (a) the solids accumulation rate (expressed in litres per capita per annum: lca);
- (b) the long-term infiltration rate of the liquid fraction across the pit-soil interface (expressed in litres per square metre of infiltration surface area per day: litres/m² day);
- (c) the hydraulic loading on the pit (expressed in litres per day: l/d);
- (d) the minimum period (years) required for effective pathogen destruction; and
- (e) the optimal emptying frequency (year⁻¹).

These parameters are discussed below. The local soil and hydrogeology affect not only (a) and (b) above but also the structural design of the leach pit and the magnitude and extent of any groundwater pollution that may result. The position of the water table (that is, whether the pit is wet or dry) is also important. This is discussed in paragraph 3.17 below.

3.11 **Solids storage volume.** For a pit of any given size, the solids (sludge) accumulation rate controls the frequency at which pit emptying (desludging) is required. It is thus an important parameter and is a function of a wide range of variables, including water table level, pit age (in particular, the number of times it has been emptied), water and excreta-loading rates, microbial conditions in the pit and temperature; it is also

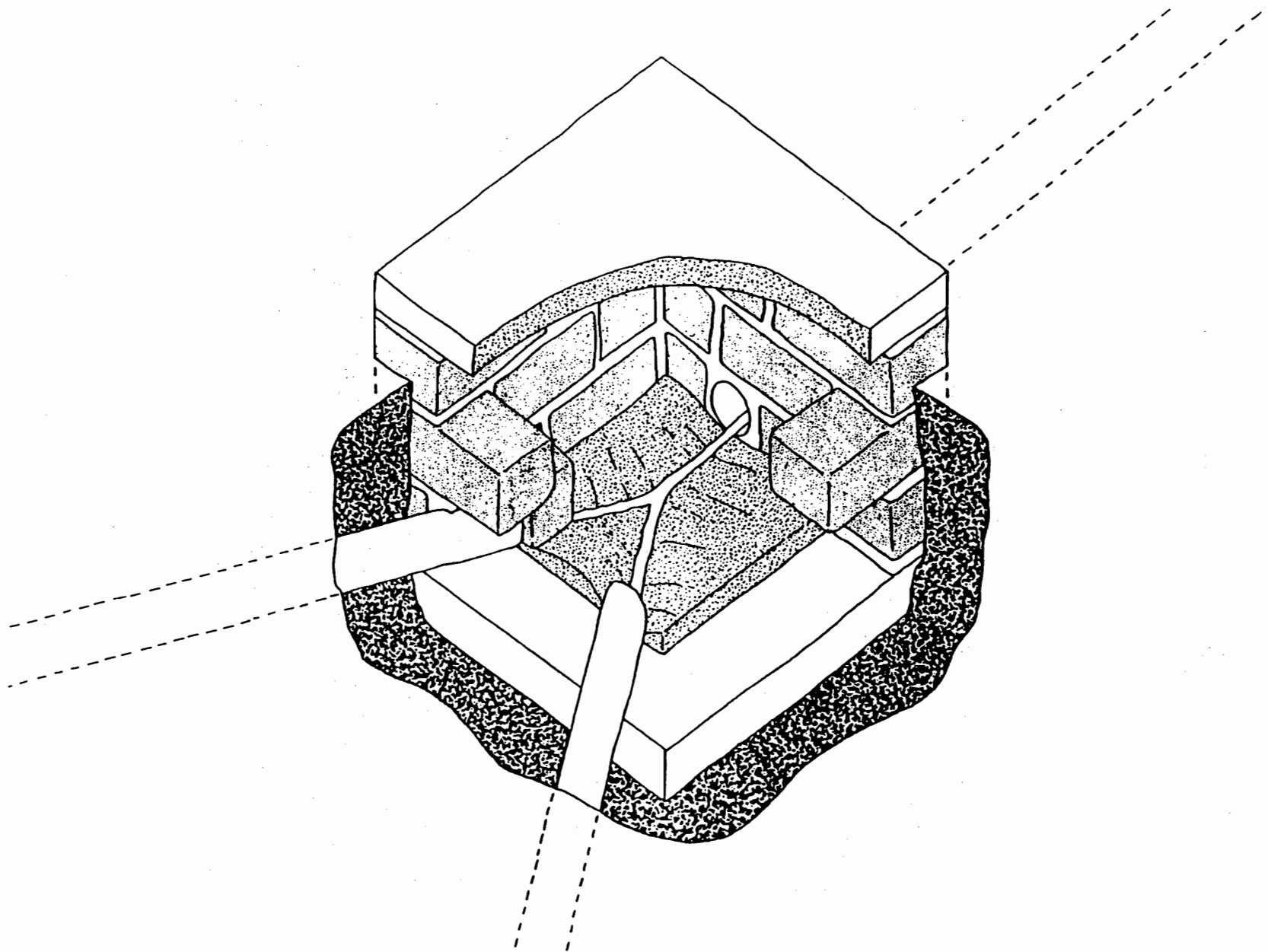


Figure 6. Y-shaped flow diversion chamber in brickwork (India).

a function of local soil conditions and the type of material used for anal cleansing. Data on long-term accumulation rates are limited, with reported rates ranging from 5 litres per capita per annum (lca) to 58 lca. Until further data are available, it is recommended that the rates given in Table 2 be used for design.

TABLE 2. Recommended Design Values for Solids Accumulation Rates		
Material Used for anal cleansing ^{a/}	Solids Accumulation rate (lca) in:	
	Dry Pits	Wet Pits
Water	30	25
Soft Paper	40	30

^{a/} Other cleansing materials (such as hard paper, leaves, mudballs and corncobs) are unsuitable for use with PF latrines as they cause blockage of the interconnecting pipework.

3.12 **Hydraulic loading.** The hydraulic loading rate is the total volume of liquids entering the leach pit and is expressed in litres per day, although it is often more convenient to consider per capita loadings (in litres per capita per day, lcd). As noted above in section 2.7, the volume of wastewater entering the leach pit depends on a variety of factors, both technical and sociocultural. The following formula can be used to estimate the volume (q) of wastewater generated in lcd:

$$q = N_f(V_w + V_c) + V_f + (aN_u V_f) + V_u$$

where N_f = number of times feces passed per day (usually two, sometimes three);

V_w = volume of flushing water, litres/flush;

V_c = volume of water used for anal cleansing, litres/cleansing;

V_f = volume of feces passed, lcd (approximately equivalent to the wet weight of feces in kg/day; typical values lie between 0.25 and 0.35;^{12/}

^{12/} Further information on the quantities of feces and urine produced per person per day may be found in the reference given in Footnote 2.

N_u = number of times urine passed per person per day;

a = 1 if the toilet is flushed after urine only is passed;
= 0 if it is not;

V_u = volume of urine produced, lcd (typically 1.2).

This equation accounts for variations in excreta quantities and excretion frequency, both largely dependent on diet, and for sociocultural factors such as flushing after urine only has been passed and whether water is used for anal cleansing. It assumes, however, that all of each person's excreta reaches the leach pit; this may not be the case (for example, excretion may also occur at the place of work; people, especially children, may not always urinate in the toilet). This leads to an overestimate of the hydraulic loading, but in practice this may not be too great in many societies. Hence overdesign of the leach pit will be minimal. It will be apparent from the equation that elicitation from the community, or from its leaders, of local practices and preferences in relation to defecation and urination is an essential part of leach-pit design.

3.13 **Long-term infiltration rate.** Leach-pit effluent enters the soil first by infiltrating the pit-soil interface and then by percolating away through the surrounding soil into the groundwater or soil water; part of the effluent may be removed from the soil by plant transpiration. The infiltrative capacity will be lower than the percolative capacity due to clogging of the soil pores at the pit-soil interface. Traditionally, percolative capacity has been established in the field by "falling head" percolation tests, and so it is a measure of the percolation rate of clean water through virgin (unclogged) soil. While serving as a useful guide to the hydraulic conductivity of the soil under saturated conditions, the method does not account adequately for flow being restricted by the clogging matter nor for flow under unsaturated conditions. These factors can be best accounted for by evaluating for any particular soil the change in permeability brought about by changes in moisture tension; this is established by the "crust" test.^{13/} From crust tests done on a wide range of different soils, recommended design values of the long-term infiltrative capacity can be derived for typical soil conditions; these values are shown in Table 3. Thus, if the soil characteristics of the proposed site are evaluated and the soil textures (loam, sand, silty clay etc.) established, an estimate can be made of the long-term infiltrative capacity of a well-designed and properly constructed and maintained leach pit. For a large-scale project where resources exist to undertake the more complex "crust" test in situ, it is recommended that this be done, developing a family of site-specific hydraulic conductivity/soil moisture tension curves from which the long-term infiltrative capacity can be estimated.

^{13/} J. Bouma and J. L. Denning, "Field Measurement of Unsaturated Hydraulic Conductivity by Infiltration Through Gypsum Crusts", **Soil Science Society of America Proceedings**, 36(5) 846, 1972.

TABLE 3. Recommended Maximum Effluent Loading Rates for Leach Pits	
Soil Type	Long-term Infiltrative Loading rate (litres/m ² day)
Sand	50
Sandy loam, loams	30
Porous silty loams, porous silty clay loams	20
Compact silty loams, compact silty clay loams clay ^{a/}	10
^{a/} Expansive clays should be absent; if present, the pour-flush latrine is generally infeasible.	

3.14 **Pathogen destruction.** Excreted pathogens--viruses, bacteria, protozoa and helminths--eventually die in the leach pit or in the surrounding soil.^{14/} Research undertaken by the World Bank (see Footnote 2 on Page 1) has shown that after one year all viruses, bacteria and protozoa will be dead, as will most helminths with the exception of *Ascaris lumbricoides* (the large round worm found in humans), although only a few *Ascaris* ova will be viable after this time. However, if the leach pit is wet *Ascaris* survival is enhanced. The **minimum** acceptable design interval between successive manual desludgings of each twin leach pit should therefore be one year.

3.15 **Design of twin leach pits.** Alternating twin leach pits should be designed initially on the volume required for the storage of the solids that accumulate within them during the period they are in use. Design rates of solids accumulation are given in Table 2. As noted above the minimum period of use (that is, desludging interval) is one year; if it can be guaranteed that desludging will occur exactly every 12 months, regular agricultural demand for the humus-like material (for example, every planting season) may ensure this. In such a case a one-year solids storage volume will suffice. If, however, this cannot be guaranteed, then to provide a reasonable degree of operational flexibility a two-year storage volume should be provided. The volume so calculated must be checked to determine whether it provides

^{14/} Under certain soil and hydrogeological conditions the travel distances of bacteria and viruses can be quite extensive (see paragraph 3.26).

sufficient infiltrative surface area (Table 3); if it does not, then additional volume must be provided. Finally, a free space of at least 0.5 m must be left at the top of the pit above the level of the invert of the inlet pipe. This design approach, which is illustrated in the first example given in Annex I, ensures that there is sufficient "resting" time while the pit is essentially empty for the regeneration of the infiltrative surface. Approximately one month is required for aerobic bacteria to oxidize the compounds responsible for clogging the pit-soil interface,^{15/} so the infiltrative capacity of the leach pit is quickly restored to close to its original value.

3.16 Design of single leach pits. Single pits, which are to be desludged mechanically, are designed in a slightly different way than are alternating twin pits. Sufficient volume has to be provided for solids storage, which depends on the rate of solids accumulation (Table 2) and the desired desludging interval.^{16/} Above this volume, additional space for infiltration must be provided (Table 3). This approach, which is illustrated in the second design example in Annex I, ensures that a sufficient resting period is provided, since the infiltrative surface area alternates between being aerobic and anaerobic on a daily basis. The result is that soil clogging is unlikely to occur for 10-15 years.

3.17 Watertable position. Whether a leach pit is wet or dry depends on whether it penetrates the groundwater table. In general, solids accumulation rates in wet pits are lower than those in dry pits due to the higher rate of microbial activity. However, recent work by TAG in India has shown that in low permeability soils wet pits designed for four years or less between successive desludgings surcharge to such an extent that their capacity has to be increased to prevent flooding (wet pits with large surface areas relative to depth require less capacity than similar dry pits, partly because of the improved digestion under wet conditions and partly because the surcharging effect appears to stabilize). Tentative design recommendations for the "wet pit volume correction factor" (that is, the ratio of wet pit volume to dry pit volume) are given in Table 4. The use of this factor is illustrated in the third design example in Annex I.

^{15/} J. T. Winneburger, P. B. Arnold and P. H. McGahey, **A Study of Methods of Preventing Failure of Septic Tank Percolating Fields**, Second Annual Report to the Federal Housing Authority, Sanitary Engineering Laboratory, University of California, Berkeley, 1962.

^{16/} The designer should seek to optimize the combination of pit volume and desludging frequency so as to arrive at the least-cost solution.

TABLE 4. Tentative Design Values for the Wet Pit Volume Correction Factor^{a/}

Desludging interval (years)	Wet pit volume correction factor
2	1.96 ^{b/}
3	1.47
4	1.12
5	0.91

a/ The values given were derived from data obtained on soils in the Gangetic delta, which had a permeability of 5×10^{-3} cm/sec. Lower factors would be expected to apply in higher permeability soils. However, many low-income areas are on poor soils (e.g., estuarine swamps) where the water table is high and permeabilities are low, so these values may be reasonable for PF program planning.

b/ The value given for a desludging interval of two years is based on an extrapolation from the remaining values; it is subject to verification in the field.

Communal PF latrines

3.18 PF latrines are very suitable for communal installations for either public use or in institutions such as schools, rural hospitals, prisons, barracks, etc.; but, as with any kind of communal sanitation facility, maintenance is vitally important. Without proper maintenance the facility will often become so unpleasant that people will not use it, and it may present a substantial health hazard. The availability of on-site water supply encourages regular flushing after use and helps to maintain cleanliness. The levying of a user charge and the provision of attendants have proven successful in many projects.

3.19 In communal units one compartment should be provided for every 20 persons. Of course separate facilities must be made available for men and women; in the men's area it is normal to provide a urinal facility. Suitable designs may be found in TAG Technical Note No. 10.

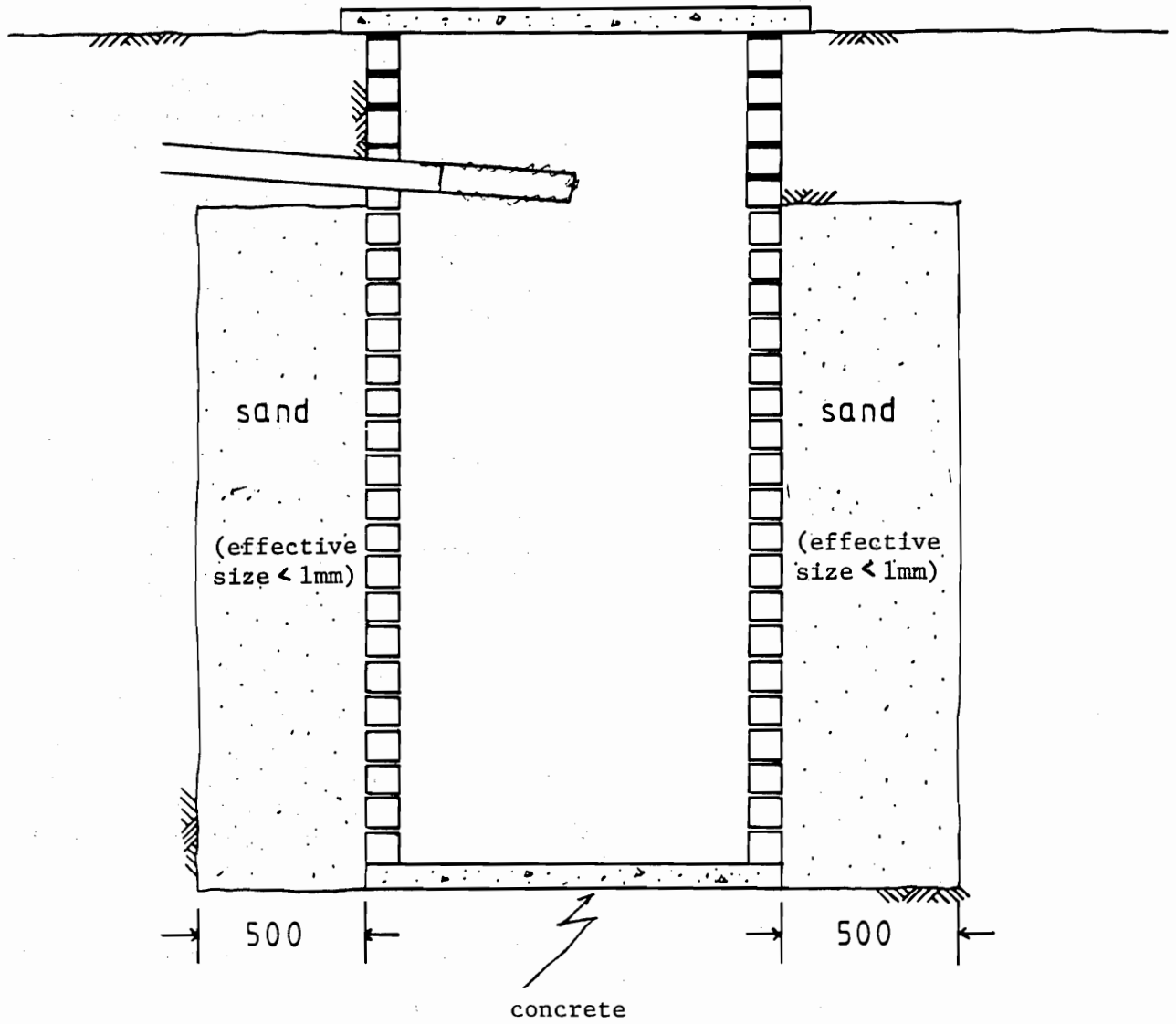


Figure 7. Sand envelope around leach pit side walls for pollution control.

Groundwater pollution prevention

3.20 The hydraulic loading on PF latrine leach pits is usually small, and thus in the areas where the groundwater table is at least 1 m below the pit bottom the risk of groundwater pollution is low.^{17/} If, however, there is serious risk that the local aquifer will be polluted, and if it is also being used as a source for public supply, there are two options:

- (a) permit the aquifer to be polluted and supply water from another source or even from the same aquifer but with abstraction at a point beyond the reach of the fecal pollution from the leach pits;
- (b) seal the pit bottom with lean concrete, cement-stabilized soil or puddled clay and place a 500 mm layer of clean sand (effective size less than 1 mm) around the outside of the pit lining (Figure 7).

IV. COST

4.1 Two types of costs are used in the evaluation of pour-flush latrines and other sanitation systems. They are economic costs and financial costs. Economic cost is that borne by a country or a community as a whole. It measures the value of all resources used up by a sanitation project, such as land, labor and capital, whether a cash outlay is involved or not. It is used for making a least-cost comparison among alternative technologies. The economically favored technology is deemed to be the one that yields full benefits at the lowest possible economic cost.

4.2 Economic costs have two components: investment cost and recurrent costs. Each component should be expressed in a way that reflects its real opportunity cost to the economy; this will normally involve shadow pricing of inputs such as labor and foreign exchange. The stream of investment and recurrent costs should then be converted, using a discount rate reflecting the opportunity cost of capital, into a total annual cost per household (TACH). The techniques for this form of analysis lie outside the scope of this Technical Note but are covered in any standard text on the economic analysis of projects.^{18/}

4.3 Financial costs are the sum of investment and recurrent costs without any adjustment to reflect economic considerations. They are relevant in selecting a technology that the consumer can afford. The financial burden on

^{17/} W. J. Lewis, S. D. D. Foster and V. S. Drasar, **The Risk of Groundwater Pollution by On-Site Sanitation in Developing Countries: A Literature Review**, IRCWD Report No. 01/82, International Reference Centre for Wastes Disposal, Duebendorf, Switzerland, 1982.

^{18/} See also John M. Kalbermatten et al., **Appropriate Technology for Water Supply and Sanitation: Technical and Economic Options**, World Bank, December 1980.

the individual consumer will be heavily influenced by the local conditions for each project: for example, the loan/grant mix used to make the initial investment more affordable (including hidden subsidies in below-market interest rates on loans), the extent of community participation and the use of local materials produced by the consumers themselves. The design of the project financing and cost recovery systems should be directed toward making the economically optimal solution affordable by consumers, both in terms of the proportion of their cash incomes they can reasonably be expected to spend on sanitation and of the self-help or other inputs assumed in the project design.

4.4 One major component of sanitation project costs that is often omitted in cost analysis is institutional and project delivery cost. This includes the cost of such activities as community mobilization and development, information dissemination and training and financial delivery. It also includes monitoring and evaluation and technology delivery activities such as logistic support and engineering supervision. The institutional and project delivery cost may constitute 15% to 50% of the total cost of a sanitation project. It is therefore an important cost component, and it must not be ignored. In the absence of adequate information, the institutional and delivery cost may be assumed to be 30% of the total cost of a project, or about 45% of the sum of material and labor costs.

4.5 Table 5 gives investment costs of five-user, twin-pit, pour-flush latrines from three countries. Excluding institutional costs, the range of cost is from US\$65 to US\$105. The cost range becomes US\$109 to US\$150 when institutional costs are estimated and included. A breakdown of material and labor costs is given in Table 6 for a five-user, twin-pit, pour-flush latrine in India. The cost of the pour-flush latrine relative to the cost of conventional sewerage varies from one country to another. In a recent World Bank study, the mean value of the TACH for sewerage was found to be twenty times higher than it was for the pour-flush latrine, as Table 7 shows. However, in another study in Indonesia the capital cost of conventional sewerage was found to be ten times the capital cost of the pour-flush latrine.

TABLE 5. Costs of Five-User, Twin-Pit, Pour-Flush Latrines

Costs: US\$ ^{a/}					
<u>Country</u>	<u>Materials</u> (M)	<u>Labor</u> (L)	<u>Institutional</u> ^{b/} (I)	<u>M+L</u>	<u>M+L+I</u>
India (1983)	77 (51)	28 (19)	45 (30)	105 (70)	150 (100)
Indonesia (1982)	45 (38)	40 (33)	35 (29)	85 (71)	120 (100)
Nepal (1982)	77 (70)		33 (30)	77 (70)	110 (100)
Philippines (1982)	65 (60)		44 (40)	65 (60)	109 (100)

^{a/} Relative costs are given in parenthesis.

^{b/} All institutional costs were assumed to be approximately 30% of total costs; the only exception was the Philippines where an estimated institutional cost was used.

V. CONSTRUCTION

Latrine unit

5.1 Construction of the latrine unit presents no difficulties provided good building practices are followed. Special care must be taken in the installation of squatting pans and trap units of the kind shown in Figure 3 so that there will be the correct waterseal depth of 20 mm (Figure 5). The trap unit must be carefully levelled to ensure that the design waterseal depth is provided, and the pan must be installed level with the floor draining freely to it. For user comfort there should be at least 100 mm (preferably 150 mm) space between the rear edge of the squatting plate and the back wall. Installation of ceramic PF pedestal units with their integral waterseal units is done in exactly the same way as conventional cistern-flush units.

TABLE 6. Material and Labor Costs for Five-User, Pour-Flush Latrines in India (1983) ^{a/}

Item No.	Description	Quantity	Unit	Rate	Costs	Subtotal
A. SUBSTRUCTURE						
Materials						
1.	Cement	108	Kg.	0.065	7.02	
2.	Sand	0.33	m ³	5.0	1.65	
3.	Aggregate	0.24	m ³	8.2	1.97	
4.	Steel Reinforcement	7.0	Kg.	0.48	3.36	
5.	Bricks (standard)	294	No.	0.08	23.52	
6.	Pan and Trap Unit	1	No.	10.0	10.00	
7.	Footrests	2	No.	0.28	0.56	
8.	Prefabricated pipe connecting drain to leach pit (asbestos cement, 75mm diameter)	4	length	0.77	3.08	51.16
Labor						
9.	Supervisor	0.05	Man-day	2.0	0.10	
10.	Bricklayer	0.94	Man-day	2.0	1.88	
11.	Carpenter	0.04	Man-day	1.7	0.07	
12.	Steel Bender	0.12	Man-day	1.7	0.20	
13.	Plumber	0.15	Man-day	1.7	0.26	
14.	Laborer	3.6	Man-day	1.6	5.76	8.27
15.	Contractor's overhead (15% of materials and labor)				8.91	
16.	Government engineering and/or supervision (15% of materials, labor, and contractor's overhead)					10.25
a/ Expressed in US\$ at an exchange rate US\$1 = Rp. 10 (1983).						

TABLE 6. (continued)

Item No.	Description	Quantity	Unit	Rate	Costs	Subtotal
B. SUPERSTRUCTURE						
Materials						
1.	Cement	27	Kg.	0.065	1.76	
2.	Sand	0.08	m ³	5.0	0.40	
3.	Aggregate	0.06	m ³	8.2	0.49	
4.	Bricks (standard)	176	No.	0.08	14.08	
5.	Door	1	No.	8.3	8.3	
6.	Paint	1	Litre	0.80	0.80	25.83
Labor						
7.	Supervisor	0.05	Man-day	2.0	0.10	
8.	Bricklayer	0.56	Man-day	2.0	1.12	
9.	Steel Bender	0.12	Man-day	1.7	0.20	
10.	Bhisti	0.16	Man-day	1.7	0.27	
11.	Laborer	2.2	Man-day	1.6	3.52	5.21
12.	Contractor's overhead (15% of materials and labor)					4.66
13.	Government engineering and supervision (at 15% of materials, labor, and contractor's overhead)					5.36
Sub Total:						US\$41.06
TOTAL COST:						US\$119.65
say,						US\$120.00

TABLE 7. Annual Average Investment and Recurrent Cost per Household for the Pour-flush and Conventional Sewerage^{a/}

1978 US\$				
Technology	Observations (number)	Mean TACH	Investment Cost	Recurrent Cost
Pour-flush Latrines	3	18.7	13.2	5.5
Sewerage	8	400.3	269.9	130.4

^{a/} John K. Kalbermatten et al., **Appropriate Technology for Water Supply and Sanitation: Technical and Economic Options**, World Bank, December 1980.

5.2 The floor space in the latrine unit should be at least 800 mm from side to side and 1,000 mm from front to back. Work in India has shown that these dimensions are satisfactory even for larger than average people. However, minimum space requirements should be discussed with the community. PF latrines require less space than close-coupled, cistern-flush latrines, since approximately 300 mm additional length is required for the cistern itself.

5.3 If the latrine is not located in a room inside the house, a separate superstructure must be provided. Its prime functions are to provide privacy and protection from the elements. Provided it fulfills these functions, its actual design is largely a matter of personal choice: local architectural styles and sociocultural preferences should be respected, and locally available building materials (traditional or modern) should be used.

Interconnecting pipework

5.4 The pipework that connects the toilet pan and trap to the leach pits should be 75 mm internal diameter drainage grade PVC or asbestos cement. Alternatively, for short runs (less than 5 m) a covered brick drainage channel can be used. This must be carefully laid to the correct grade, and the channel should be lined with cement mortar benching to give it a semicircular section. Considerable care has to be taken to provide a smooth finish, otherwise blockages can easily occur. The minimum gradient should be 1 in 30, and the maximum distance between the latrine pan outlet

and the entrance to the leach pit should be 15 m. Shorter distances and steeper gradients should be used wherever possible. Standard pipe bedding procedures should be followed, and, if suitable materials are locally available, all joints should be flexible.

5.5 The flow diversion chamber should be constructed in brickwork (or similar material) with smooth benching in cement mortar. Suitable internal dimensions are 250 mm square. Ideally, the chamber should be just below ground level and provided with a concrete or stone cover slab. The outlet to the pit not in use should be sealed with a plug of precast concrete or a brick set in lime mortar; in India a plug of clay or jute fabric is often used in place of mortar.

5.6 In view of the low flushing velocities associated with PF latrines, the risk of loss of waterseal is negligible. Consequently, vent pipes are unnecessary. If a vent pipe is required by local bylaws it need not be larger than 25 mm diameter, and it should be provided with a fly-screen at its top to prevent the entry and exit of insects. A vent pipe is, however, totally redundant and unnecessary in most situations, represents additional expense and, in many countries, requires the use of imported materials; design staff should attempt to persuade local authorities to waive the bylaw requirements when PF latrines are installed. Where PF latrines located on upper and lower floors are connected to the same stack, it may be necessary to extend the stack to serve as a vent to help maintain the waterseal in the lower floor.

Leach pits

5.7 **Lining.** It is always necessary to line the leach pit walls. Any suitable material can be used for this: for example, brick, blockwork, rough or shaped masonry or rot-resistant timber (for example, mangrove poles). The free space at the top of the pit should be fully mortared, but below this the vertical joints must be left open to permit the infiltration of liquids into the soil. In loose, sandy soils a layer of gravel or similar material (for example, small brickbats) should be provided outside the lining to prevent sand from entering the pit. In addition, vertical gaps should be reduced.^{19/}

^{19/} Further details on pit linings may be found in TAG Technical Note No. 13, **Design of Ventilated Improved Pit Latrines**, by D. Duncan Mara, The World Bank, 1985.

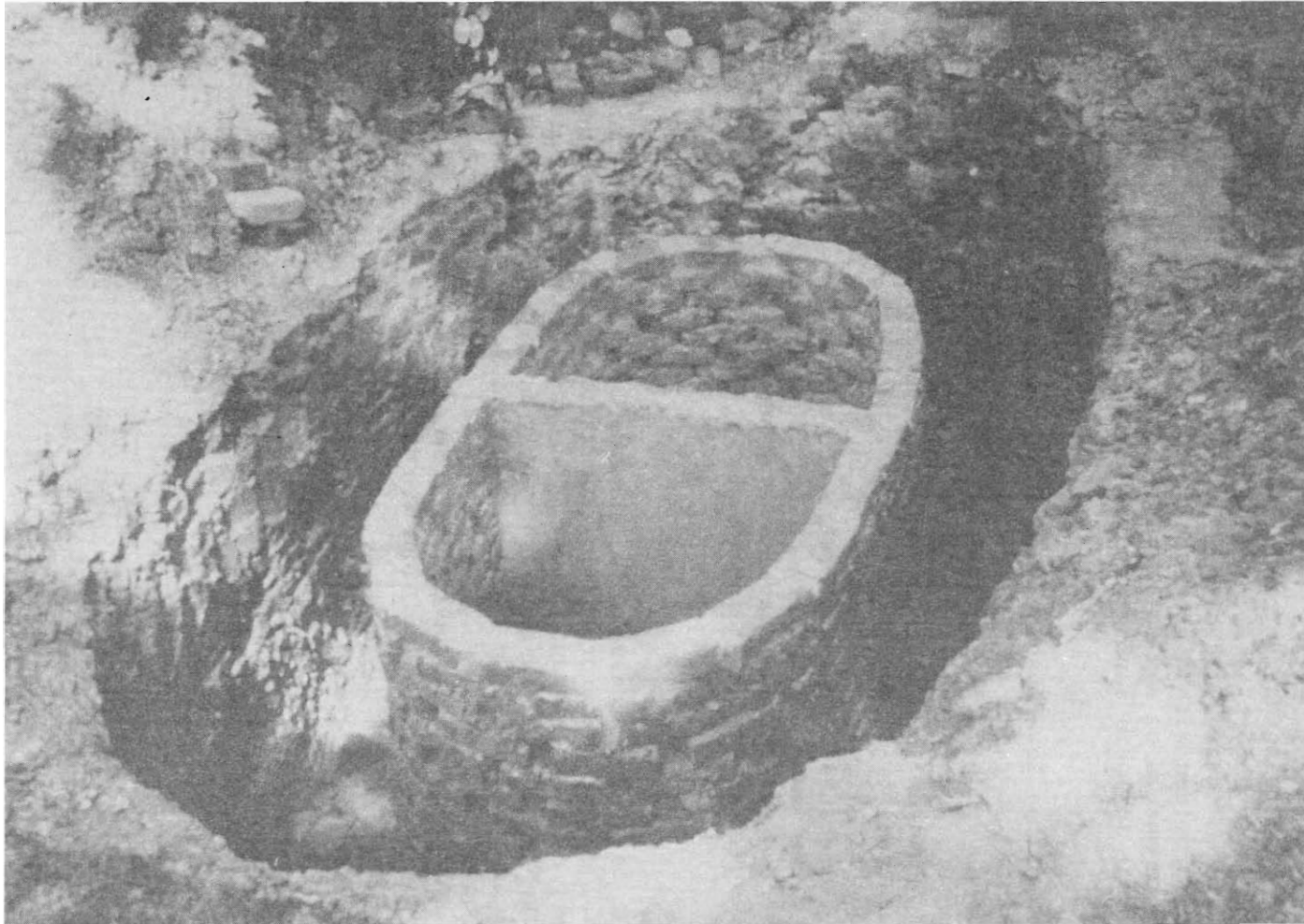


Figure 8. Divided leach pit serving as an alternating twin pit system (India). The design would be improved if the dividing wall was extended at least 0.5 m outwards on both sides in order to minimize cross-contamination due to water infiltrating from the pit in use entering the other pit.

5.8 **Covers.** Leach pit cover slabs are usually made in reinforced concrete and should be designed for the loading anticipated; a thickness of 50 mm is adequate for pits located within the premises they serve. Often for convenience the slab is cast in two or three pieces and set in lime or weak cement mortar so that it can be easily removed when the pit has to be desludged. Lifting handles should be set in the cover at the time of casting. If reinforcing steel is unavailable, unreinforced concrete domes and arched brick domes have been found to be feasible and economic solutions in areas where no significant loading is anticipated.

5.9 **Separation.** Where twin leach pits are installed (Figure 8), they should be separated by a distance equal to their diameter, or by 1 m, whichever is greater. This is to aid structural stability and to prevent the infiltrating liquids from the pit in use entering the other pit. If there is insufficient space for two separate pits, the design shown in Figure 8 may be adopted. Leach-pit location should be selected in full consultation with the householder.

5.10 **Location.** Wherever possible the leach pits should be sited within the premises they serve. Various geometrical configurations of latrine units and leach pits are possible (Figure 9). Even so, in very high density areas there may be insufficient space within the plot for their installation. In such cases they can be installed in public alleyways, under sidewalks and even under roads carrying vehicular traffic; structural design of the leach pit, especially the load-bearing capacity of its cover, becomes very important in these cases. In India, for example, leach pits located under footpaths are provided with lightly reinforced concrete dome covers. Those located under roads are similar, but they have a manhole-type access from the road surface. Further details are given in TAG Technical Note No. 10. Pits should not be sited too close to the building foundation. Normal sound building practice should always be adopted when siting pits near buildings.

VI. OPERATION AND MAINTENANCE

6.1 Maintenance of a household pour-flush latrine is very simple. Daily maintenance consists only of washing the latrine floor and cleaning the squatting pan. The squatting pan should be cleaned daily with a broom or a brush with a long handle after sprinkling a small quantity of detergent powder. This can be done by the householder or by someone else paid for the purpose. The minimum possible amount of water should be used when cleaning the floor, as otherwise it will reduce the life of the leach pits in some circumstances.

6.2 In the latrine a container of 1.5 to 2 litres capacity should be kept filled with water. The squatting position should be such that excreta fall as near as possible to the center of the trap opening. Before each use the surface of the squatting pan should be slightly moistened with water so that the excreta slide smoothly without sticking to the surface.

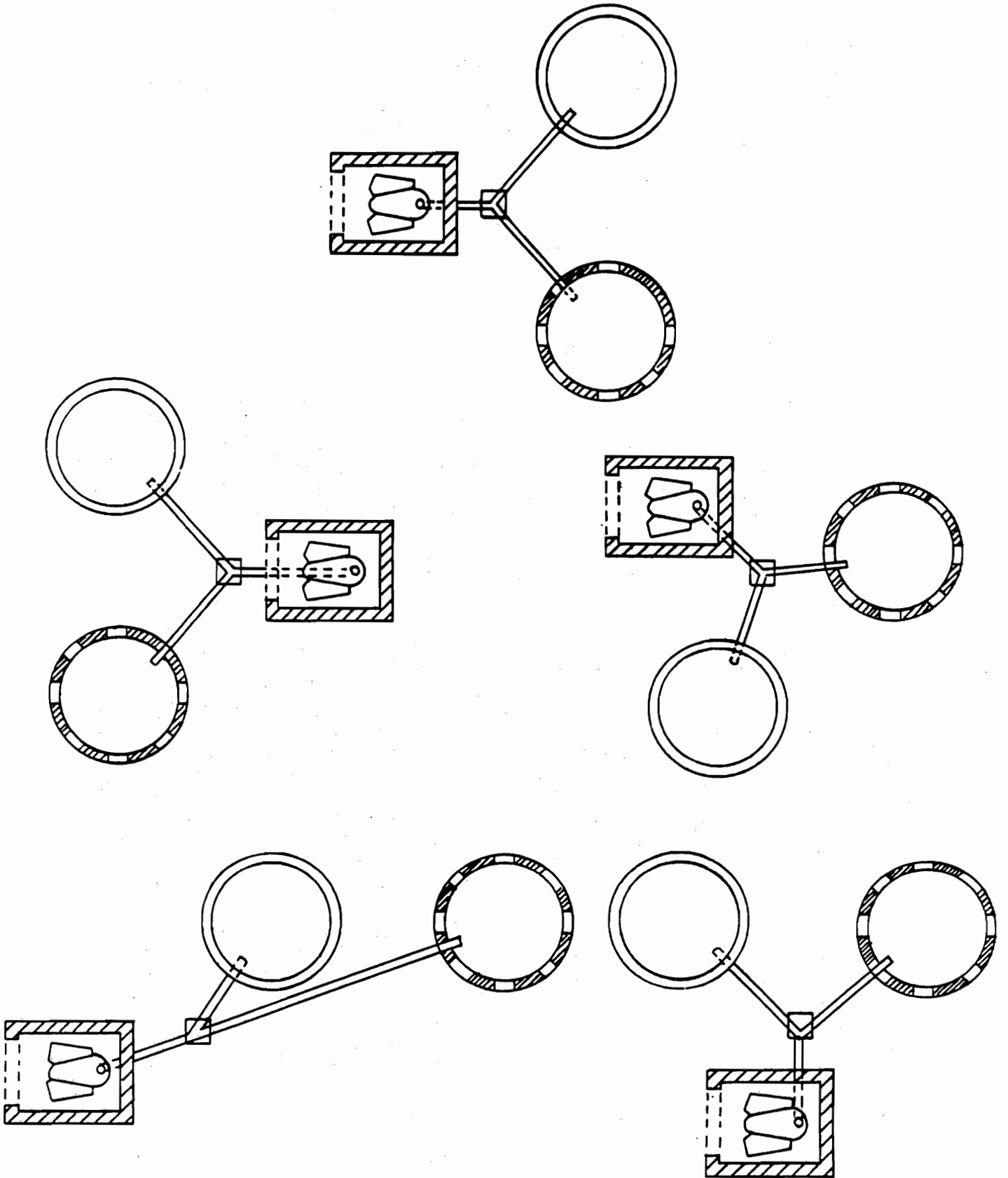


Figure 9. Possible geometric configurations of latrine unit and leach pits.

6.3 Wastewater from the bath or the kitchen, etc., or rain water should normally not be allowed to enter the leach pits or the squatting pan except where the leach pit is designed to accept such wastes. To avoid choking of the squatting pan or trap, no other waste, such as kitchen waste, sweepings, rags, cotton pieces, etc., should be thrown in the squatting pan. However, if somehow the squatting pan or the trap should get choked, it can be rodded from the pan side as well as from the trap side. A split bamboo rod can be used for this purpose. If the blockage cannot be removed, assistance should be sought from the local authority.

6.4 Only one of the pits is to be used at a time. After about three years, when the first leach pit is full (the indication being back flow when flushed), the discharge from the pan should be diverted to the second pit and the first pit should be allowed to rest. The diversion of discharge to the second pit can be undertaken by the householder, or, if he wishes, he can make private arrangements for this to be done. When the first pit becomes full and the latrine is connected to the second pit, the pit cover should be removed and soil to a depth of 150 mm should be used to fill this first pit, after which the cover should be put back into position again. Where adequate earth is not easily available, or where there is difficulty in removal of the pit cover, the earth can be added later when emptying the pit contents; this facilitates handling. When the resting pit has been withdrawn from service for about two years, it can be emptied by the householder himself or by the local authority. This can be done manually by shovel or auger. The contents will then be free of pathogens and safe for handling; they will also be dry and odorless. In special cases, such as flooded areas or high groundwater table areas, the sludge will be wet; after being taken out it may be spread out in a gravel bed during the dry season for sun drying and then utilized as manure. When the second pit is full, the first pit should be returned into service by diverting the discharge from the second to the first pit. Therefore, the two pits are to be used one at a time, alternately. The householder should keep a record of the time when each of the two pits is put into use, disconnected and emptied; a card may be supplied by the local authority for this purpose.

6.5 In India the local authority is urged to provide emptying services to the householder free of cost on request through local contractors or through its own employees. The humus becomes the property of the local authority, which can arrange to sell it.

LEACH PIT DESIGN EXAMPLES

Design example #1: Twin leach pits

1. Design leach pits to receive the effluent from a PF latrine serving a household of six people. Assume that: (a) the pan requires 2 litres/flush; (b) water is used for anal cleansing at the rate of 2 litres cleansing; (c) two stools are passed per person per day; (d) the pan is flushed on average once per person per day when urine only is passed; and (e) the excreta (feces + urine) production is 1.5 lcd. The local soil is a sandy loam and the watertable is 3 m below ground level. The pits are to be desludged every two years.

2. The **solution** is as follows:

(a) Calculate the wastewater flow in lcd (Section 3.13):

$$\begin{aligned} q &= N_f(V_w + V_c) + (V_f + V_u) + (aN_u V_f) \\ &= 2(2 + 2) + 1.5 + (1 \times 1 \times 2) \\ &= 11.5 \text{ lcd} \end{aligned}$$

(b) Calculate the total wastewater flow (Q) in litres/day:

$$Q = 6 \times 11.5 = 69 \text{ litres/day}$$

(c) Calculate the solids storage volume (V_s), assuming a solids accumulation rate of 30 lca for a dry pit with water being used for anal cleansing (Table 2), and for a desludging interval of 2 years and a household size of 6:

$$V_s = 30 \times 10^{-3} \times 2 \times 6 = 0.36 \text{ m}^3$$

Assuming an internal pit diameter (that is, to the inside of the lining) of 750 mm, this is equivalent to an effective depth (H) of 0.82 m.

(d) Check for infiltrative surface area (A_i); this is given by:

$$A_i = d H$$

where d is the external diameter of the pit (that is, to the outside of the lining).

If we assume that the pit is lined with standard bricks (laid flat), then $d = 750 + (2 \times 75) = 900 \text{ mm}$. Thus:

$$A_i = 0.9 \times 0.82 = 2.3 \text{ m}^2$$

For sandy loam soils, the long-term infiltrative loading rate is 30 litres per m² per day. But the wastewater flow rate is 69 litres per day. Therefore the infiltration area (calculated from Table 3) is (69/30), i.e., 2.3 m². So, in this case, the solids storage volume provides exactly the right amount of infiltrative area and no adjustment is necessary.

- (e) Allowing a free space of, say, 0.48 m, the dimensions for each pit are as follows:

Internal diameter 750 mm
Total depth 1300 mm

Thus the pit does not penetrate the groundwater table and so the assumption made in (c) above of the pit being dry is correct.

Design example #2: Single leach pit

- 3. For the same data as in Example #1, design a single leach pit.
- 4. The **solution** is as follows:
 - (a) The sludge storage volume is the same as in Example #1, that is 0.36 m³, equivalent to a depth of 0.82 m for an internal pit diameter of 750 mm.
 - (b) The infiltrative surface area required will also be the same as in Example # 1, that is 2.3 m². This is equivalent to a depth of 0.82 m for an external pit diameter of 900 mm.
 - (c) Thus, allowing for a free space of 0.46 m, the total depth is (0.82 + 0.82 + 0.46) = 2.1 m. The pit does not penetrate the groundwater table and so the assumption that it is dry is correct.

This design would also be checked for economics using local cost data.

Design example #3: Wet pits

- 5. If the groundwater table is 50 cm below the ground surface, but all other data are as given in Example #1, calculate the required size of:
 - (a) twin leach pits, and
 - (b) a single leach pit.

6. The solutions are obtained by multiplying the volumes obtained in the solutions given above by the "wet pit volume correction factor," which, for a desludging interval of two years is given in Table 4 as 1.96. This factor, since it relates to infiltration, must be applied to the external volume (V_e) of the pit.

(a) For the twin leach pits, the external volume is given by:

$$\begin{aligned} V_e &= (d_e)^2 H / 4 = (0.9)^2 (0.82) / 4 \\ &= 0.52 \text{ m}^3. \end{aligned}$$

Thus the corresponding volume for a wet pit is $(1.96 \times 0.52) = 1.02 \text{ m}^3$. For a free space of 0.50 m, the total depth of each pit is 2.1 m. If, as in the above example, the pit diameter obtained in Example #1 is to be used in the wet pit calculation, then the new pit depth is obtained simply by multiplying the pit depth obtained in Example #1 by the wet pit volume correction factor and adding a free space. Using this method the total depth of each pit is given by $(0.82 \text{ m}) \times 1.96 + 0.5 \text{ m} = 2.1 \text{ m}$.

(b) For the single leach pit the "wet pit volume correction factor" is applied only to the volume corresponding to the infiltrative area.

This external volume is 0.52 m^3 , the corrected volume 1.02 m^3 and the corresponding depth 1.60 m all as above. Allowing for a free space of 0.48 m, the total depth is $(0.48 + 1.60 + 0.82)$, = 2.9 m.

If these depths are considered too great, because of the high water table, then the internal diameter should be increased to, say, 1.5 m. Recalculation--M illustrated here only in the case of the single leach pit--yields:

(i) A sludge storage depth of:

$$4V / (d_i)^2 = 4 \times 0.36 / (1.5)^2 = 0.20 \text{ m}$$

(ii) An infiltration depth of:

$$A_i / d = 2.3 / (1.5 \times 1.8) = 0.40 \text{ m}$$

(iii) A total depth, allowing for a free space of 0.5m, of:

$$0.2 + 0.4 + 0.5 = 1.1 \text{ m}$$

This is likely to be more acceptable than a total depth of 2.9 m, allowing deep pits to be constructed then. However, a 1.5 m diameter pit requires a substantial cover slab, which may not be feasible unless the water table falls significantly during certain seasons.