UrbanWater

Urban Water 1 (1999) 257–259

www.elsevier.com/locate/urbwat

Technical note

Simplified sewerage: potential applicability in industrialized countries

D.D. Mara [a,*], A.S.P. Guimarães [b]

[a] *Department of Civil Engineering, School of Civil Engineering, University of Leeds, Leeds LS2 9JT, UK*

[b] *GAIA Engenharia Ambiental Ltda, Av. Nilo Peçanha 50/1115, Centro, Rio de Janeiro 20044-900, Brazil*

Received 19 February 1999; received in revised form 5 August 1999; accepted 30 September 1999

Abstract

Simplified sewerage was developed in Brazil in the early 1980s and is the sanitation technology of first choice in high-density peri-urban areas with a reasonably reliable water supply. Modern design, based on a minimum tractive tension of 1 Pa being achieved at peak flow, shows that up to 234 households having a peak wastewater flow of 765 l d^{-1} can be served by a 100 mm diameter sewer. In industrialized countries simplified sewerage can be easily adapted to higher design requirements. For example, a 100 mm diameter sewer can serve up to 56 households having a peak wastewater flow of 4,000 l d^{-1} and attain a minimum tractive tension of 2.5 Pa at peak flow.

Keywords: Low-cost sewerage; Tractive tension

1. Introduction

During the 1980s, the years of the international drinking water supply and sanitation decade, much emphasis was placed by the international agencies (such as the World Bank and the UNDP-World Bank Sanitation Technology Advisory Group, TAG) on the promotion of on-site sanitation systems, though some development work was done on settled sewerage (Otis & Mara, 1985), simplified sewerage (Guimarães, 1986; Sinnatamby, 1986) and "alternative" sewer systems (WPCF, 1986). Few simplified sewerage schemes were implemented, except in Brazil (see, for example, Rodrigues de Melo, 1985; de Andrade Neto, 1985; Azevedo Netto, 1992) and Pakistan (Sinnatamby, Mara & McGarry, 1986); yet it is now abundantly clear that simplified sewerage is generally the sanitation technology of first choice in high-density low-income peri-urban areas (Mara, 1996b).

2. Hydraulic design of simplified sewerage

The hydraulics of simplified sewerage are now well understood, with the generally preferred design based on the concept of minimum tractive tension (Machado Neto & Tsutiya, 1985; Bakalian, Wright, Otis & Azevedo Netto, 1994; Mara, 1996a), rather than minimum self-cleansing velocity (Guimarães, 1986; Sinnatamby, 1986). A simplified design procedure has been developed (Mara, 1996c), and Table 1, based on Manning's equation with $n = 0.013$, gives the numbers of households able to be served by simplified sewers of 100–300 mm diameter for typical conditions in Brazil (Table 1, footnote). The procedure is as follows:

1. determine the number of households to be served by the length of sewer under design;
2. select from Table 1 the sewer diameter (valid only for the assumptions given in the footnote of Table 1);
3. determine the peak flow (q, l s^{-1}) from:

$$q = k_1 k_2 p w N / 86\,400, \tag{1}$$

where k_1 is the peak factor (= 1.8 for simplified sewerage), k_2 the return factor (= wastewater flow/water consumption), p the average household size, w the water consumption, l person^{-1} d^{-1} and N is the number of households (if the peak flow calculated from Eq. (1) is <2.2 l s^{-1}, then use in Eq. (2) a value of 2.2 l s^{-1}, which is the peak flow resulting from a single WC flush; see Sinnatamby, 1983, 1986);

4. calculate the minimum sewer gradient ($I_{\min}$, m m^{-1}) from:

$$I_{\min} = 0.00518 q^{-6/13} \tag{2}$$

* Corresponding author. Tel.: +44-113-233-2276; fax: +44-113-233-2243.

E-mail address: d.d.mara@leeds.ac.uk (D.D. Mara).

1462-0758/00/$ - see front matter
PII: S1462-0758(99)00015-1

Table 1
Number of households served by simplified sewers of 100–300 mm diameter[a]

Sewer diameter (mm)	Maximum number of households served[b]
100	234
150	565
225	1360
300	2536

[a] Source: Mara (1996c).
[b] Assumptions: initial proportional depth, 0.6; peak flow factor, 1.8; return factor, 0.85; water consumption, 100 l person^{-1} d^{-1}; household size, 5; minimum tractive tension, 1 Pa; Manning's n, 0.013; wastewater density, 1000 kg m^{-3}; g, 9.81 m s^{-2}.

(Eq. (2) is valid for a minimum tractive tension of 1 Pa and the initial flow in the sewer being at a proportional depth of flow (d/D) of 0.6, where d is the depth of flow in the sewer and D is the sewer diameter) and ensure that the actual sewer gradient is not less than this.

The above procedure was developed for a fully saturated housing area, i.e., one where any future increase in wastewater flow is due not to population increase, but to an increase in water consumption. Setting the initial proportional depth to 0.6 allows for an increase in water consumption of 46%, with the final proportional depth being 0.8. Thus, if w is now 100 l person^{-1} d^{-1}, the sewer can cope with an increase in the future to 146 l person^{-1} d^{-1}, which is more than adequate for both good flow conditions in the sewer and the control of water-washed and excreta-related diseases (see Mara & Feachem, 1999).

3. Applicability in industrialized countries

Table 1 was developed for typical conditions in peri-urban Brazil. In industrialized countries water consumption is >100 l person^{-1} d^{-1} and a minimum tractive tension of 1 Pa may not be considered sufficient for secure self-cleansing in foul sewers – for example, Marriott (1994) recommends that sewers be laid at a minimum gradient of 1 in D, where D is the sewer diameter in millimeter; he shows that this is equivalent to a minimum tractive tension of 2.5 Pa at full-bore flow (but also at half-bore flow since the hydraulic radius is $D/4$ under both conditions). Thus, Eq. (2) can be recalculated for a minimum tractive tension of 2.5 Pa and for $d/D = 0.5$, as follows:

$$I_{\text{min}} = 0.0159q^{-6/13}. \quad (3)$$

Similarly, the flow is related to the sewer diameter for these conditions, as follows:

$$q = 1.21 \times 10^{-4} D^{13/6}. \quad (4)$$

Table 2
Number of industrialized-country households served by simplified sewers of 100–300 mm diameter

Sewer diameter (mm)	Maximum number of households served[a]
100	56
150	136
225	328
300	612

[a] Assumptions: initial proportional depth, 0.5; peak flow per household, 4000 l d^{-1}; minimum tractive tension, 2.5 Pa; Manning's n, 0.013; wastewater density, 1000 kg m^{-3}; g, 9.81 m s^{-2}.

Since q = the peak flow per household multiplied by the number of households (N), and taking the peak flow per household as 4000 l d^{-1} as recommended in British practice (Water Services Association, 1995), i.e., 0.046 l s^{-1}, N is given by

$$N = 2.63 \times 10^{-3} D^{13/6}. \quad (5)$$

Thus, an "industrialized country" version of Table 1 can now be developed (Table 2), which shows how simplified sewerage could be safely applied in these countries. There is an inherent allowance for the peak wastewater flow per household to nearly double to 7800 l d^{-1}, assuming that the final d/D is permitted to be 0.8.

4. Concluding remarks

1. Simplified sewerage is a low-cost sewerage technology applicable not only in the high-density peri-urban tropics, but also in medium and high-density housing developments in industrialized countries.
2. Sewer diameters smaller than those recommended in national codes (for example, British practice recommends a minimum sewer diameter of 150 mm; Water Services Association, 1995) can be safely adopted provided they are correctly designed. Here it is shown that a 100 mm diameter sewer laid at a gradient of 1 in 100 can safely drain the wastewater from 56 households which have a peak wastewater flow of 4000 l d^{-1}. "Safely" in this context refers to the achievement at peak flow of a minimum tractive tension of 2.5 Pa.

References

Azevedo Netto, J. M. (1992). *Innovative and low cost technologies utilized in sewerage*. Environmental Health Program, Technical Series No. 29. Washington DC: Pan American Health Organization.

Bakalian, A., Wright, A., Otis, R., & Azevedo Netto, J. (1994). *Simplified sewerage: design guidelines*. Water and Sanitation Report No. 7. Washington DC: The World Bank.

de Andrade Neto, C. O. (1985). Uma solu¸cão eficaz e de baixo custo para o esgotamento sanitário urbano. *Engenharia Sanitária* (*Rio de Janeiro*) *24* (2), 239–241.

Guimarães, A. S. P. (1986). *Redes de esgotos simplificadas*. Brasilia: Ministério do Desenvolvimento Urbano e Meio Ambiente/PNUD.

Machado Neto, J. C. O., & Tsutiya, M. T. (1985). Tensão trativa: um critério econômico para dimensionamento das tubula¸cões de esgoto. *Revista DAE* (*São Paulo*) *45* (140), 73–87.

Mara, D. D. (1996a). *Low-cost urban sanitation*. Chichester: Wiley (Chapter 9).

Mara, D. D. (1996b). Unconventional sewerage systems: their role in low-cost urban sanitation. In D. D. Mara, *Low-cost sewerage* (pp. 13–18). Chichester: Wiley.

Mara, D. D. (1996c). Simplified sewerage: simplified design. In D. D. Mara, *Low-cost sewerage* (pp. 169–174). Chichester: Wiley.

Mara, D. D., & Feachem, R. G. A. (1999). Water- and excreta-related diseases: unitary environmental classification. *Journal of Environmental Engineering American Society of Civil Engineers 125* (4), 334–339.

Marriott, M. J. (1994). Self-cleansing sewer gradient. *Journal of the Institution of Water and Environmental Management 8* (4), 360–361.

Otis, R. J., & Mara, D. D. (1985). *The design of small bore sewer systems*. TAG Technical Note No. 14. Washington DC: The World Bank.

Rodrigues de Melo, J. C. (1985). Sistemas condominiais de esgotos. *Engenharia Sanitária* (*Rio de Janeiro*) *24* (2), 237–238.

Sinnatamby, G. S. (1983). *Low-cost sanitation systems for urban peripheral areas in northeast Brazil*. Ph.D. thesis, University of Leeds.

Sinnatamby, G. S. (1986). *The design of shallow sewer systems*. Nairobi: United Nations Centre for Human Settlements.

Sinnatamby, G., Mara, D., & McGarry, M. (1986). Sewerage: shallow systems offer hope to slums. *World Water 9* (1), 39-41.

Water Services Association 1995. *Sewers for adoption*: *a design and construction guide for developers* (4th ed). Marlow: Water Research Centre.

WPCF, 1986. *Alternative sewer systems*. Manual of Practice No. FD-12. Alexandria, VA: Water Pollution Control Federation.