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SIMPLIFIED SEWERS: A REVIEW OF BRAZILIAN EXPERIENCE[1]

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1. Introduction

Inadequate sanitation is one of the major environmental problems facing urban areas in developing countries today. This inadequacy stems from non-engineering as well as engineering failures. Non-engineering failures may include: failure of the market system to coordinate supply and demand for sanitation services, deficiencies in institutional structures for regulating supply and demand, and inadequacies in internal institutional capacity for managing the supply of services. These failures are exacerbated by the unprecedented rate of population growth, by declining economic performance, and by poverty. Engineering failures include the frequent use of high cost conventional sewerage and undue reliance on "supply side" factors in sanitation planning, without adequate consideration of what users want and are willing to pay for. One of the main reasons for such engineering failures is lack of adequate information about alternatives to conventional sewerage. This paper is about one such alternative.

2. Strategies for Sewerage Cost Reduction

Concern about the high cost of conventional sewerage has prompted attempts at developing lower-cost alternatives in various parts of the world. Such attempts usually focus on those elements in sewerage systems that influence cost the most. Among such key cost-determining factors are: the average diameter and depth of sewers; average slope; the number and depths of manholes; and such other factors as total sewer length, population density, set-up costs, and excavation in rock. Consequently, sewer cost reducing measures have invariably been directed at modifying one or more of these cost-determining factors. The wide range of technological options that can be produced through this process are collectively known as intermediate sewerage or intermediate sanitation systems.

The processes that have been used to reduce the cost of sewerage fall under two broad categories; one involves changes in technology and the other changes in design standards.

Changes that have been made in sewerage technology have usually involved the introduction of special ancillary appurtenances which make it technically feasible to use shallow, smaller diameters. An example is the introduction of a solids interceptor tank between house sewers and laterals. The tank captures

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[1] Acknowledgements: The information provided in this paper has been in part collected during discussions with the engineering staff of the state water companies of Sao Paulo (SABESP) and Parana (SANEPAR).

and stores the incoming solids, attenuates the flow, and allows the settled sewage to flow out by gravity. The absence of solids and the attenuation of flow makes it possible to use small diameter sewers laid at flat gradients, resulting in shallow sewers. Developed in Australia, this modification of conventional sewerage is known as a solids-free or small diameter gravity sewer system (Otis, 1986). Another example is the STEP (or septic tank effluent pump) sewerage system which is like the solids-free sewerage system except that the settled effluent is pumped, again making it possible to use shallower and smaller diameter sewers. Other examples are grinder pump sewerage and vacuum sewerage (Kreissl, 1987).

Changes in design standards to produce lower-cost sewerage have been based on hydraulic theory, advances in technology, satisfactory experience and acceptable risk. There is a wide range of possibilities; and differences between alternatives reflect differences in the number or types of design parameters that have been changed. One example is flat grade sewerage which was developed some 80 years ago in Nebraska (Gidley, 1987). Based on changes in design standards affecting only the minimum diameters and minimum slopes or self-cleansing velocities, its use in the flat terrain and high ground water table areas in Nebraska results in significant cost savings not only during construction phases (savings in the cost of: deeper sewers, deeper manholes, dewatering during sewer laying, and pumping stations), but also savings during the operational phases (savings in pumping costs). Another example is the condominial sewer system developed in Brazil; it is the product of changes in design parameters for minimum depth, minimum diameter, minimum slopes, and rules for connecting private property to public sewers. A third example is simplified sewerage, which is the subject of this paper.

3. Origin and Development of Simplified Sewerage

The simplified sewerage system was developed in Brazil. It is the outcome of changes in several design parameters, including the standards for minimum diameters, minimum slopes, minimum depths and the spacing and location of manholes. In addition, it makes use of design periods that are considerably shorter than those used in conventional sewerage.

The key impetus for its development was the realization that the application of the conventional design standards was making it difficult to expand coverage to middle and lower income communities. This led to a review of all design criteria used in Brazil for conventional sewerage. The review showed that the prevailing design criteria were very similar to (and in some cases even more stringent than) those used by Waring in his design of the first separate sewer system in the USA in 1880 which consisted primarily of 150mm diameter pipes laid at constant slopes (Otis, 1986).

The 1880 sewer system had been designed to carry peak flows at the minimum velocity of 0.60m/s. Waring argued that if that velocity was reached at least once a day the system would perform without any problems. But to ensure complete removal of deposits, flush tanks were installed at the head of each sewer line. Ventilation was provided through manholes with open grates spaced at a minimum of 300m (1000 ft) apart. Waring's system had worked very well, the only problems he reported being obstructions caused by objects such as ".. a splinter of wood, a carpenter's rule, a bottle, a bone... and they occurred primarily in areas near schools and shops". It is interesting to note that most of these criteria and appurtenances had survived intact (or became more conservative) in Brazil, with very few exceptions such as the flush tanks and the open grate manholes which have long disappeared. The idea of self cleaning sewers had become the central design criterion. Unfortunately the costs of sewer systems based on these century-old criteria had become too high for many cities, prompting engineers in Brazil to question their applicability in the context of their cities.

Consequently, a thorough critical review of the basis for conventional sewerage design standards was mounted. The review led to sweeping changes in conventional sewer design standards. The changes were based on a variety of factors such as findings of recent research in hydraulics, satisfactory experience, and redundancy. The outcome of these new standards is a lower-cost sewer system with smaller, flatter, and shallower sewers with fewer and simpler manholes.

4. Key Characteristics of Simplified Sewerage

The key characteristics of simplified sewerage are as described below.

Design period. In conventional design, it is common to design trunk sewers and interceptors for the projected peak flow expected during a 50-year period (or for the saturation population of the area). The use of such long design periods make it possible to capture economies of scale in sewerage systems. However, this has to be balanced against other factors, such as the opportunity cost of capital, uncertainties in predicting future directions of growth in developing country cities (a factor which may lead to a possible mismatch of future supply and demand of sewerage services), and the high cost of maintaining large sewers with low flows. The use of shorter design periods avoids such problems, and reduces the lumpiness of investment in sewerage systems, thereby facilitating financing or enhancing the prospects of achieving greater coverage with a given amount of investment. With shorter design periods, coupled with construction by phases, the effects of errors in forecasting population growth and their water consumption could be minimized and corrected. For such reasons, the Brazilian Code for simplified sewerage recommends the use of design periods of 20 years or less.

Wastewater flow. Where water use information is available, the wastewater contribution per capita is based on a return factor of 0.8. However, where water usage information is not available, the Code on simplified sewerage recommends that a minimum flow of 1.5 l/s be used. Infiltration is assumed to be 0.5 to 1.0 l/s per kilometer of pipe. The design flow is however based on this returned flow factor and a specified peak factor. A peak factor of 1.8[2] has been used in the simplified sewerage projects.

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[2] This factor is the product of two ratios: a) the ratio of the maximum day flow over the average day flow (equal to 1.2) and b) the maximum hour flow over the average hour flow (equal to 1.5); in other words the maximum sewage flow will be the hourly maximum, or the peak rate of the maximum day (plus the maximum infiltration)

Slope Computation: the tractive force approach. Many authors (Machado, 1985; Paintal, 1977; Yao, 1974, 1976) have proposed the use of the tractive force approach for determining the minimum slope of sewers. They advocate the use of the tractive force corresponding to the "threshold of movement" or that required to cause the resuspension of deposited particles. While the common practice uses the minimum velocity of 0.6 m/s as a surrogate for the force required to dislodge a given particle, it is argued that the tractive force approach is based on the use of the force itself. For design of sewers, the Brazilian code suggests the use of $I_{min} = 0.0055\ Q_i^{-0.47}$ where I_{min} is the minimum slope of the sewer and Q_i is the initial flow. This equation is derived for a tractive force of 1 Pa (0.1 kg/m^2 which is sufficient to transport a 1mm particle. A fuller discussion of this design approach is given by Bakalian et al. (1991).

Minimum diameter. A minimum diameter for sanitary sewers is usually specified in order to avoid clogging of systems by large objects that pass through house connections. In conventional systems, the house connections are usually 150mm in diameter; but smaller sizes have also been used. Therefore, for conventional sewerage, the minimum diameter commonly specified for street sewers in many countries has been 200mm. In the US some authorities permit 150mm diameter (which was used in late 19th century), but the commonly adopted minimum size is 200mm. In the simplified system, smaller sizes are recommended because in the upper reaches of a system where flow is low, the use of smaller diameter sewers results in greater depths of flow and higher velocities; experience in Latin America and elsewhere (e.g. Nebraska) shows that 150mm diameter street sewers do not present any additional maintenance problems, compared to conventional sewerage. In Brazil, 100mm diameter laterals or branch sewers are being used in residential areas for a maximum length of 400 meters. These 100mm diameter pipes are usually located under the unpaved streets of periurban communities.

Connections. In Brazil, as in many developing countries, the connection of basements to street sewers would necessitate increasing average sewer depths to serve relatively few houses. Consequently, in simplified sewerage, basement connections are avoided. Apart from the considerable increase in costs of laying sewers below basements, there is the serious potential of basement flooding as a consequence of clogging downstream.

Depth of sewers. At the starting point of laterals the minimum depth at which pipes are laid should suffice to: a) make house connections and b) have a layer of soil over the crown to protect the pipe against structural damage from external loads and frost. In conventional design, there is no one method to determine the minimum depth of sewer as long it satisfies the above criteria. However some rules of thumb suggest that 1) the top of the sanitary sewer should not be less than 1m below the basement and 2) in case there is no basement, the invert of the sanitary sewer should not be less than 1.8m below the top of the house foundation. In the simplified system, typical minimum sewer depths are 0.65m below sidewalks, 0.95m to 1.50m below residential streets, depending on the distance from the street centerline and amount of traffic, and 2.5m below heavily travelled streets. Building elevations are not considered in setting the invert elevation of the sewers. If buildings along the mains are too low to enter the sewer by gravity, it is the responsibility of the property owner to find other means of making a connection. In some cases, where topography permits, it may be possible to connect on the other side of the block if easements can be obtained from the neighboring owners.

Manholes. Manholes constitute an expensive component of a sewer system (about 25 percent of the total construction costs). Although manholes are now among the most familiar features of a sewer system, they were not used extensively on early sewers. Their use came with the combined systems where they were provided to facilitate the removal of grit. It appears that with time the criteria for manhole use have gradually become more conservative and have been contributing significantly to the high cost of sewerage.

In the early sewerage systems, some simple appurtenances such as lampholes were used. Presently some variations of these earlier systems are being reintroduced in Brazil: the inspection tube and the terminal cleanout. The first is similar to the old lamphole and the terminal cleanout is an appurtenance that replaces manholes at the upstream termini. The present requirement of placing manholes at 100m apart was introduced when sewers were cleaned using rods and canes. The availability of modern cleaning equipment calls for a review of manhole location guidelines.

In conventional systems, manholes are generally located at: i) the upper ends of all laterals ii) changes in direction and in slopes, iii) pipe junctions, with the exception of building connections, and iv) at intervals not greater than 100m for pipes of 600mm diameter or less, and at less than 120m for sewers between 700mm and 1200mm of diameter. In the UK the distance between manholes has been changed from 110m to 180m (Escritt and Haworth, 1984); however as little as 30m distance between manholes has been proposed for the Cairo sewerage project in the late 70s.

In light of the accumulated experience in Brazil, the simplified system is designed with the following guidelines:

i) where possible, conventional manholes are replaced with "simplified" manholes, cleanouts or buried boxes. Manholes are only used at major junctions; simplified manholes are similar to conventional manholes except they are reduced in size from 1.5m diameter to 0.6m-0.9m; they can be reduced in size because the need to enter the manholes by maintenance personnel is eliminated due to the shallower depths and to the availability of modern cleaning equipment; for small sewers, and where infiltration is not a major concern, manholes can be built with precast elements, such as concrete pipes or concrete rings with precast slabs and bottoms.

ii) manholes at changes of direction or slope are replaced by underground boxes or chambers;

iii) house connections are adjusted to serve as inspection devices; in this respect, a small box is built under the walkway and the connection to the sewer is made with a curve of 45 degrees and a "Y" (the cleaning rod is introduced through this box);

These guidelines on the design of manholes reduce considerably the costs of the system (as much as 25 percent) especially since up to 90 percent of manholes are never opened. In 1881, Waring wrote "it seems to me decidedly advantageous to use inspection pipes, or even lampholes on 6" and 8" sewers, rather build manholes and inspection chambers".

There are situations, however, where manholes should not eliminated; e.g. where there are: i) very deep sewers (more than 3.0m), ii) slopes smaller than required, iii) sewers with drops, iv) points of connections from certain commercial and industrial establishments and v) points of sampling and flow measurements. The guidelines for manhole replacement are summarized in Table I.

Table I. Use of manholes and other simplified appurtenances

situation	solution
starting point of a sewer	inspection & cleaning terminal
long straight sewer	intermediate inspection tube
horizontal curve of 90 degrees	two separate 45 degree curves
insertion of a sewer into another	Y branch and one 45 degree curve
change of diameter	underground concrete box
change of slope	underground concrete box

5. Costs

Simplified sewers have been predictably shown to cost significantly less than conventional systems. In many places, cost savings ranging from 20 to 50 percent have been reported. In the State of Sao Paulo, Brazil, the first projects have shown a reduction of construction costs of 30 percent but after about 8 years of experience, the reduction is estimated to be more around 40 percent. The cost reduction in sewage collecting systems in the city of Sao Paulo is reported to be 35 percent by SABESP, the water and sewerage utility of the State of Sao Paulo.

SABESP estimates the following average construction costs (1988 prices) for small towns (not including the per capita costs of treatment and house connection which are estimated to be about 40 and 50 US$ respectively):
Conventional systems...................150-300 US$/capita
Simplified systems......................80-150 US$/capita

Table II provides a summary of cost information on some of the systems reviewed for this paper. The cost per person is shown to range between US$ 51 and 151.

Furthermore, analyses carried out in the course of project preparation indicate that the savings are dependent on the number of design criteria that have been modified. For example, in a sensitivity analysis on costs of different design considerations carried out in Egypt, costs savings of up to 23% were seen to be achievable (see Table III). In another project, in Bogota, Colombia, it was estimated that the cost saving would be about 50 percent.

Table II. Costs of selected projects

	-----CITIES IN SAO PAULO STATE----- SAO PAULO	CARDOSA	CORAODOS	PARANA STATE TOLEDO
Total Cost of coll. system	$1,897,000	$48,125	$68,194	$3,762,066
Average cost per meter of sewer	$76	$13	$8	$21
Average cost/person	$151	$51	$87	$59

(Note: assume 6 persons per household)

Table III. Sensitivity analysis on costs of individual design variations (figures are percentages of the total cost of alternative a) (source: Gakenheimer and Brando, 1984)

		BENI SUEF		KAFR EL SHOKR	
		NO CONN. (1)	WITH CONN. (2)	NO CONN.	WITH CON
ALTERNATIVE					
A	Conv. stds.	100	100	100	100
B	Houses connected to sewer lines (instead of manholes)	100	92.41	99.56	90.27
C	Manhole spacing 50% larger than conv.	95.38	97.75	96.23	98.02
D	Lighter manhole covers (80 and 175 kg instead of 285)	95.37	96.08	95.25	96.1
E	No manhole at upstream end of branch	91.66	NA	94.45	NA
	B+C	93.47	86.89	90.69	82.99
	C+D	90.79	93.88	93.88	94.56
	B+C+D	89.12	83.21	83.21	80.13
	B+C+D+E	82.09	77.27	82.52	76.29

The total amount of savings that these modifications generate will therefore be a function of the number of modifications that are deemed feasible in a particular project given factors such as population density, topography, geology, soil/water conditions, etc.

6. Operational experience

Although simplified sewerage systems were first implemented in Brazil (Sao Paulo [3] and Parana), they have subsequently been applied in Bolivia (Cochabamba and Oruro), in Colombia (Bogota and Cartegena) and in Cuba (Matanzas). Although specific data on operational problems are not readily available, it is nevertheless known that no significant problems have been reported. In the city of Sao Paulo, it has been estimated that there are about 75 obstructions per 1000km of sewers each month. This infrequent occurrence of obstruction gives further support to the policy of minimizing the number of manholes. Engineers in SABESP reckon that it would be economical to install only a few manholes initially, with the intention of building additional ones as the need arises (i.e. at points of frequent obstructions).

Similarly no problems related to excess hydrogen sulfide generation have been reported from field surveys.

7. Discussion

As stated above, the present conventional engineering practice in sewer design was introduced more than a century ago and has since undergone relatively few significant changes. Engineers in Brazil who more than a decade ago took a serious look at the rationale for the various design criteria have found ample room for change and simplification without jeopardizing the operational integrity and safety of the system.

It is common knowledge that engineering design is not conceived exclusively on the basis of rigid and exact scientific facts; it is also heavily based on empirical data supplemented with probabilistic and risk criteria. The factors of safety which have been embedded in many design criteria (design flow, minimum diameter, depth of sewers, etc.) need not be the same at all times everywhere in all situations. For example, there is no valid basis to apply the same conservative standards in business districts (where breakdowns and repairs could create heavy economic losses and great inconveniences) as in the outskirts of a city (where the impact of similar breakdowns is less severe). In addition to economic aspects, the probability of breakdowns should be a prime consideration in design of a sewerage system. While Gakenheimer and Brando (1983) suggest additional research on uncertainty as it relates to infrastructure standards, they argue that there is enough evidence to move away from the stringent standards that have been adopted from industrialized countries; they contend that "when resource limited countries are using conservative standards, risk is lowered in one locality at the cost of fully exposing another".

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[3] As of 1988, in the State of Sao Paulo alone, this technology has been adopted in 26 cities and towns, and plans were made for at least 36 others.

8. Conclusions

The objective of this paper has been to present information on simplified sewerage which provides a new cost-saving approach to the design of sewer systems based on Brazilian experience. It is based mainly on rational changes in long-standing traditional sewer design standards. With this approach, depending on the prevailing "engineering culture" and codes, the project engineer still retains the option to apply all or some of the suggested modifications. The review shows that:

i) the simplified sewerage technology is being successfully applied, and it constitutes a viable lower-cost alternative to the conventional system;

ii) the design modifications that have been introduced in the simplified sewerage systems are based on sound engineering principles;

iii) the new design approach does not create a substandard level of service; it rationalizes some design standards without sacrificing level of service;

iv) the simplified sewerage system costs a fraction of the conventional system thus freeing up funds that could be used to extend the service coverage to larger segments of unserved populations.

Unfortunately information on the system has not been spread much beyond that country's immediate vicinity. It is hoped that in time, engineers in other parts of the world will become more familiar with it as increasing operational experience is accumulated and disseminated [4]. Already a growing number of cities are finding the simplified system attractive and are implementing projects using the modified criteria with considerable savings.

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[4] Relatively, very little information on these systems has been made available outside their immediate area of application; the reader is referred to a publication by UNCHS/HABITAT on the design aspects of "shallow sewers".

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