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Case study

A survey of sewer rehabilitation in Malaysia: application of trenchless technologies

B. Sen Gupta *, S. Chandrasekaran, S. Ibrahim

Institute of Post Graduate Studies and Research, University of Malaya, 50603 Kuala Lumpur, Malaysia

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Abstract

This work presents a review of applicable sewer rehabilitation options using trenchless technology in Malaysia. The typical problems faced in wastewater collection systems are analysed and factors that determine the selection method are outlined. This study also highlights the necessary steps to be taken prior to the rehabilitation work. The trenchless technology reviewed here comprises repair, renovation and replacement options. The cost-effectiveness of different rehabilitation methods was identified to assess the economic viability of various options in the Malaysian context. This study reveals that not all the trenchless technologies available in the market are suitable for use in Malaysia, mainly due to incompatibility of the rehabilitation materials used. Furthermore, as trenchless rehabilitation generally involves higher capital outlay than open-cut methods, the choice of rehabilitation method has to be made on a case-to-case basis. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

The traditional technique for rehabilitating defective sanitary sewers and associated appurtenances is excavation and replacement. Since sewer pipes in urbanised areas are, for the most part, located in the middle of streets, excavation and replacement creates traffic disruptions. In addition to the cost associated with traffic disruptions, additional expenses are incurred during the repair of excavated roads and other structures. In an attempt to reduce the cost and disruptions associated with excavation and replacement, the sanitary sewer collection system rehabilitation industry has developed "no-dig" (trenchless) technologies for sanitary sewer collection system rehabilitation (USInfrastructure, 1999).

Sewerage system is one of the most capital-intensive underground infrastructures in developed and developing countries. Maintaining sewer lines is essential to ensure proper transfer of wastewater to the treatment facility. When sewer systems deteriorate, water enters the system by infiltration and inflow and decreases capacity of the sewer system. Owing to their low visibility, sewer systems are often neglected until there is a major failure, resulting in difficult and costly rehabilitation. This also increases the operation and maintenance costs significantly. Pipeline rehabilitation, which reduces the infiltration/inflow into the system, increases the efficiency of treatment facilities (Wirahadikusumah, Abraham, Iseley, & Prasanth, 1998). Considering the high capital requirement in sewer rehabilitation, extensive planning (deMonsabert, Ong, & Thornton, 2000; Hansen & Pedersen, 1994) and appropriate selection of construction technologies is necessary (Gokhale & Hastak, 2000). Two main problems affect sewer rehabilitation programmes in most cases. First, the rehabilitation work has to carried out in heavily built-up areas, and secondly the maintenance work is carried out when any failure occurs (Wirahadikusumah et al., 1998).

Since 1980, rapid developments in infrastructure have taken place in almost all the major cities in the South-East Asia. This also includes expansion of underground infrastructure and rehabilitation of sewers in appropriate cases. This study, however, only deals with the Malaysian scenario and was commissioned by Indah Water Konsortium (IWK), a public limited company incorporated in Malaysia.

* Corresponding author. Present address: School of Chemical Engineering, David Keir Building, The Queen's University of Belfast, Belfast BT9 5AG, UK. Tel.: +44-2890-274-554; fax: +44-2890-381-753.
E-mail address: b.sengupta@qub.ac.uk (B. Sen Gupta).

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The privatisation of the national sewerage system is a milestone in Malaysia's public health service. IWK Sdn. Bhd. has been awarded a 28-year contract by the Government of Malaysia, which will allow IWK the right to the takeover of sewerage services of 144 local authorities in the country. Under this agreement, IWK will be responsible for the takeover, upgrading, operation and maintenance of the existing sewerage system. The purpose of this study was to review the available sewer rehabilitation techniques in the market, with the intention of utilising reliable and cost-effective methods. The scopes of the agreement are as follows:

1. Connect existing toilets and individual septic tanks to modern sewage treatment plants.
2. Provide desludging services to owners of individual septic tanks.
3. Refurbish existing public sewerage systems.
4. Operate and maintain these sewerage systems.
5. Collect revenues to fund these sewerage systems.

A project of this nature is quite new in Malaysia. However, Singapore has been using modern technologies in construction and rehabilitation of sewers for more than a decade. For example, an earth pressure balance (EPM) machine was used in 1987 to construct a 3.7 m diameter tunnel approximately 3 km long to accommodate a 3 m diameter sewage pipeline (Hulme & Burchell, 1999). Major tunnelling work in Singapore was undertaken in connection with the mass rapid transit (MRT) project, which involved constructing 11 km of twin tunnels having 5.2 m internal diameter between March 1984 and June 1987. Since this period, a number of projects on sewer rehabilitation were undertaken in Singapore using trenchless methods.

This survey, however, specifically focuses on the refurbishment of sewer systems in terms of the available technologies in the market and to identify suitable methods available to undertake sewer rehabilitation in Malaysia. This study would also evaluate the various technologies used in the rehabilitation of sewers, their advantages, disadvantages and the cost-effectiveness. During the British rule in Malaysia, septic tanks were widely used around the country and sewer lines were laid in the bigger towns. The septic tank itself produced over one million cubic meters of sludge per year (IWK, 1998). These tanks are normally designed to be emptied between 6 months and 3 years on a regular basis, however, it has been found that only 1% of existing septic tanks was desludged annually prior to 1994. Moreover, most septic tanks in the country are not designed with filter systems. As such, the built-up sludge is usually carried over with the effluent into the roadside drains, causing the drains of old residential areas to be septic (blackish and bubbling) with a distinct stench. This is one of the main reasons why IWK intends to connect existing septic tanks to trunk sewers, which will eventually lead to a proper sewage treatment facility.

The major problems faced by many countries are collapse of sewers and hydraulic overload due to infiltration and inflows and from new developments. In Malaysia according to IWK's records, up to May 1998, there have been 823 reported incidents of sewer collapses while 51,457 blockages have been resolved. In most cases however, until and unless there is a backflow of sewage, the collapse is often left unidentifiable.

2. Rehabilitation of wastewater collection systems

2.1. The current situation

Currently, there is a total of 7462 km of sewers, which connect all major towns in Malaysia to sewage treatment plants. The proposed survey would cover the entire length of sewers. Table 1 shows the length of sewers in different states of Malaysia, with Selangor having the largest length of sewer, followed by Penang Island. In most of the major towns in Malaysia, ageing sewers are in urgent need of repair, renovation or replacement. Furthermore, most of the existing sewer lines were laid between 30 and 50 years ago. Although a sewer may work for a long time, if designed, built and used properly, periodic inspection and proper maintenance are essential to protect such a capital-intensive infrastructure (Rome, Hertzber, Kirchner, Licht, & Christaller, 1999).

In the past, when damage to the sewer was extensive, the local authority used the open-cut (trench) method to lay a duplicate sewer line adjacent to the defective sewer and the old line was bypassed. This involves digging up pipelines under high streets, business areas and historic buildings, which is an appalling task that causes severe disruption to traffic and people's everyday lives and the cost enormous. Extensive field trials showed that no-dig or trenchless techniques for rehabilitating sewers did not

Table 1
Length of pipelines by local authorities

State	Pipelines (km)
Johor	380.46
Kedah	208.80
Melaka	252.41
Negeri Sembilan	494.25
Pahang	107.56
Perak	884.17
Perlis	2.54
Penang	1407.69
Selangor	2415.12
Terengganu	41.83
Kuala Lumpur	1244.10
Labuan	23.25
Total	7462.18

cause such chaos. Moreover, trenchless methods of rehabilitating sewers extended the life of the pipeline. By making use of the existing pipeline, costs of excavation and pavement restoration could be saved. Moreover, trenchless technology also reduced the indirect costs of open-cut pipe replacement, the costs of traffic delays, diversions and lost business revenue. They also cause less dirt, noise and risk to health. Similar benefits in the use of trenchless technology have been reported in the literature (Kolonko & Madryas, 1996; Tregoing, 1996).

2.2. Outline of IWK's network refurbishment plan

IWK would perform the following tasks before undertaking the complete refurbishment plan:

1. Physical survey.
2. Cleaning of the sewer.
3. Internal Inspection.

2.2.1. Physical survey

A physical survey will be performed to isolate the problem areas and to determine the general physical conditions of the sewer sections, which are identified for rehabilitation work. The following tasks will be included in the survey.

1. *Aboveground inspection* – Investigation of general conditions of the study area such as topography, streets, access to manholes will be conducted. Potential problem areas such as waterways, river crossings and natural ponding areas will be identified. Key manholes will be identified for additional flow measurements and groundwater monitoring. During the aboveground inspection, the accuracy and completeness of the sewer maps will be verified.

2. *Flow monitoring* – Flow monitoring will be conducted to identify the flow fluxes in the sewer. This will enable the identification of areas where inflow/infiltration (I/I) exists. Flow monitoring will be conducted particularly during the second monsoon, which brings in heavy showers between October and January.

3. *Flow measurement* – The primary aim of flow measurement is quantification of base flow, infiltration and inflow. Flow measurement of the sewers will provide a clear understanding of the variations of the three flow components with time.

4. *Manhole and sewer inspection* – This will determine the actual condition of the sewer system. An inventory of the length, size, type, depth and the general conditions of the sewer pipes would provide a basis for the estimation of work required for the preparatory cleaning and internal inspection. The depth of flow in the sewers would provide a rough indication of the capacity of the sewer and whether or not I/I is present in the particular section of sewer.

5. *Rainfall simulation* – Malaysia experiences rainfall throughout the year with unpredictable heavy showers during the second monsoon. Hence, a rainfall simulation would be useful to identify the I/I conditions during rainfall events. In order to determine whether rainfall simulation is required, a careful study of the sewer maps, current or previous I/I analysis, smoke test results and the physical survey will be carried out.

2.2.2. Cleaning of the sewer

Preparatory cleaning of the sewer is essential for a proper internal examination of the sewer. The main reason for cleaning the sewer is to ensure that the pipe walls are sufficiently clean to provide clear images when a camera is used for the internal inspection. A clean sewer will clearly identify structural defects, misalignments and I/I sources. The procedure should ensure the cleaning of sludge, mud, sand, gravel, rocks, bricks, grease and roots from the sewer line.

Moreover, access and condition of manholes, depth and size of the sewer, type of solid materials to be removed, degree of root intrusion, amount of flow, structural integrity of pipe and availability of hydrant water will be assessed before undertaking the cleaning operations.

2.3. Internal inspection

The structural grading of the existing sewer and its hydraulic capacity are the important factors, which will determine the rehabilitation option. Where physical entry into the pipe is possible, manual inspection will be undertaken with due regard to confined space training and safety requirements. Defects will be identified and logged by certified operators who are able to classify the structural integrity of the sewer. For non-man-entry sewers, closed circuit television camera (CCTV) and electronic tracing equipment will be used to assess the condition. Before any CCTV survey can commence, it will be necessary to examine the routes of the critical sewers. This procedure will be managed by experienced engineers to reduce operational faults. For this purpose self-propelled crawler TV camera will be used from a single manhole entry by skilled operators. Typically the length of survey per day is 100 m per unit. During the CCTV survey, apart from general inspection of the sewer, manholes will also be inspected. Manholes play an important role in trenchless rehabilitation methods. For example, buried manholes and jammed covers cause severe access problems. During the survey, the information will be recorded by a computer and a video cassette recorder, and will contain information on size of sewer, direction of flow, manhole reference and date.

It is expected that refurbishment of a single sewer network will take approximately 3 years from conception to completion. The structural criticality of sewers has to be taken into consideration when choosing the most suitable rehabilitation method. IWK's sewer re-

Table 2
Definition of condition grades (Melbourne Water, 1994)

Internal condition grade	Typical defect description	Possible collapse
5	Already collapsed; or deformation >10% and cracked or fractured or broken; or extensive areas of missing fabric.	Imminent
4	Deformation 5–10% and cracked or fractured or broken; or broken or fractured; or serious loss of level.	Within 12 months
3	Deformation 0–5% and cracked; or fractured; or longitudinal/multiple cracking; or occasional fractures; or severe joint defects; or minor loss of level; or badly made connections.	Within 3 years
2	Circumferential cracking; or moderate joint defects.	Within 10 years
1	No structural defects.	Unlikely

furbishment programme focuses primarily on critical sewers, which may cost huge losses if rehabilitation programme fails. Initial estimate shows that critical sewers may take up to 5% of the total length of the networks. IWK uses the following criteria to define a sewer as critical.

- Any sewer in good ground 6 m or deeper.
- Any sewer in bad ground 5 m or deeper.
- Any sewer of 600 mm diameter or greater.
- Any sewer under highly important traffic routes with a traffic flow of more than 7500 vehicles per day.
- Any sewer under railways, rivers, express ways, major buildings, major commercial streets, primary access to major industrial areas.
- Any sewer adjacent to major hospitals, sports stadiums, exhibition centres, and conference centres.
- Any sewer within a local site of high tourist attraction.
- Any sewer adjacent to high-risk installations (electricity, oil pipelines, etc.).

It is important to have a target performance standard or standard of service, as this will enable IWK to measure its level of performance. This step is also essential to narrow down the focus of the refurbishment effort in order to save time and cost, and to ensure that unnecessary work is not undertaken on non-strategic sewers. The target performance standard for all critical sewers on completion of the programme is condition grade 3 in a scale of 1–5 as shown in Table 2.

3. Rehabilitation techniques

In Malaysia, excavation and replacement of sewers and other pipelines is the most common rehabilitation practice. However, some local authorities prohibit excavation in areas of their jurisdiction. Therefore, excavation and replacement of deteriorated pipelines is now quite restricted due to the availability of trenchless technologies. In Malaysia excavation and replacement of pipelines is normally practised under the following conditions.

1. Deterioration of the pipe in terms of structural integrity is too severe.
2. Pipes are misaligned.
3. Additional pipeline capacity is needed due to development and increase in population.
4. Short stretches that are too seriously damaged to be repaired by any other means.
5. Removal and replacement is less costly than other rehabilitation methods.

Excavation and replacement of deteriorated pipelines has its shortcomings as a method of sewer rehabilitation (Chandrasekaran, 1999), some of which are:

1. not cost-effective,
2. causes traffic disruption,
3. may damage other utility lines.

Hence trenchless technology is an excellent rehabilitation option in urban areas. It was first proposed as a method of replacement of cast iron mains in Great Britain (Kramer & Gauthier, 1995). Trenchless technologies now permit total sewer system rebuilding of collectors, interceptors, manholes, service laterals and force mains without excavation. Through the use of trenchless technologies, infiltration and exfiltration can be controlled more effectively, while restoring structural integrity to sewer systems.

3.1. Applicability of repair techniques in Malaysia

Techniques such as lining and chemical grouting have great potential in Malaysia, as these techniques are easy and relatively low-budget option of rehabilitation. The repair method can be carried out either manually or mechanically, depending on the accessibility of the sewers. For inaccessible sewers, remote control robots or manipulators will be employed. Repair methods such as part lining and chemical grouting can be used to seal initial or hairline cracks in either newly laid sewers or property connections. Should rectification of local damage be required for newly laid sewers of smaller diameters, this method would prove to be highly effective. However, if the sewer is relatively shallow, trenching may prove to be a cheaper solution. Property connections, which generally use sewers of small diameter, remote control robots can be used to repair leaks and minor collapses. This, however, would be capital-intensive in comparison with the normal trenching method. It is likely that homeowners who are more concerned with the aesthetics of their homes would prefer this method. In this case, the costs of repair will be borne by the homeowner and not by the local council.

3.2. Applicability of renovation techniques in Malaysia

The renovation method is aimed at improving the functioning of drains and sewers incorporating all or part of its original elements. This is achieved by lining and coating methods. The renovation technique is highly applicable in Malaysia, for both the trunk sewers of smaller diameter and lateral connections or property connections. As almost all the renovation techniques, to some degree, depend upon the condition of the existing host sewer, the type of liner or coating to be used has to be carefully studied prior to final selection. In Malaysia, it is likely that the renovation method will be used when the existing sewer can still serve the existing population.

4. Cost analysis of rehabilitation technologies

For the purpose of this study, the cost figures were obtained primarily from the local contractors in the sewer rehabilitation business and other tender documents. The authors of this report would like to emphasise that obtaining quotations was the most difficult task of this study, as contractors and suppliers were not willing to provide cost estimates due to following reasons.

1. It is generally difficult to provide a cost estimate as rehabilitation of sewers depends on many factors, such as the condition of the sewer, depth and accessibility to conduct rehabilitation works.
2. Due to stiff competition in the market, many suppliers were reluctant to provide a quotation in black and white, as IWK could not specify the tentative start date. Moreover, rehabilitation of sewers in Malaysia can be considered to be a relatively new market and local contractors have limited expertise in it.
3. The local contractors/suppliers could not provide quotations for the rehabilitation techniques that use materials such as high density polyethylene (HDPE) and polyvinyl chloride (PVC), as the standard materials used in Malaysian sewers are vitrified clay and reinforced concrete.

Therefore, some indication of costs has been provided for the available techniques and is listed in Tables 3–5. Table 3 shows the estimated cost of excavation and replacement as well as grouting and preparation. The excavation and replacement cost covers site preparation, excavation, backfill, pavement work, pipe materials, removal of existing pipes, pipe installation and restoration of one house property connection for every 6 m in moderately wet soil conditions up to a depth of 3 m. The grouting cost is based on a minimum of 300 m of pipe work and covers root kill and application of herbicide. Table 4 provides the rehabilitation and mobilisation costs of pipe jacking and Table 5 shows the approximate cost of sewer rehabilitation by cured-in-place inversion lining (CIPP).

Table 3
Rehabilitation cost in Malaysia in Ringgit Malaysia (RM)

Pipe diameter (mm)	Excavation and replacement (RM/m)	Grouting and preparation (RM/m)
150	543	234
200	583	279
250	660	326
300	738	372
450	930	465
525	1125	791
750	1590	1116
1000	1860	1535

Note: 1 US$ = 3.8 RM.

Table 4
Rehabilitation and mobilisation costs of pipe jacking in Malaysia (RM)

Pipe diameter (mm)	Rehabilitation cost, RM/m (typical range)	Mobilisation cost, RM/m (typical range)
375	2400	15000
600	3000	20000
1000	3800	30000

Note: 1 US$ = 3.8 RM.

Table 5
Cost of renovation by soft lining (CIPP) in RM

Pipe diameter (mm)	Rehabilitation cost RM/m
150	233
200	350
250	465
300	583
450	970
525	1240
750	1705
1000	2093

Note: 1 US$ = 3.8 RM.

5. Conclusions and recommendations

The past decade marked the beginning of a revolution in construction and rehabilitation of the underground infrastructure in Malaysia. The entire construction industry has experienced tremendous growth, borne out of necessity for a method of construction that allows continued development of the underground infrastructure with minimum adverse effect on public life. This has generated interest in trenchless technology which can be defined as a family of methods, materials, and equipment that can be used to repair, renovate, or replace underground infrastructure systems with minimal surface disruption and disturbance by minimising the need for excavation. However, depending on the technique utilised, trenchless technology may require some excavation or trenching.

In Malaysia, there is a growing preference for trenchless construction methods as the local authorities are becoming increasingly aware of their advantages such as very little traffic disruption, air and noise pollution. As the Malaysian public become more aware of various trenchless construction methods, their willingness to tolerate open-cut construction will invariably decrease.

From this study, it has been found that the sewerage industry has much to gain from the various trenchless technology options available for sewer rehabilitation. However, prior to deciding on which technique to use, IWK needs to perform a nationwide evaluation of the condition of the existing critical sewers. Unless the condition of the sewer has been determined, it is not possible to identify the appropriate rehabilitation method. Once the conditions of the most critical sewers have been determined (via CCTV and manual surveys), it will be possible to narrow down the rehabilitation options and choose the most appropriate trenchless technology for the rehabilitation work.

This study has highlighted the various sewer rehabilitation techniques available and their advantages and disadvantages in the Malaysian context. It has also been indicated that not all trenchless technologies used in other parts of the world are viable for use in Malaysia. This is primarily because Malaysian sewers are made of either vitrified clay or reinforced concrete as a standard practice, whereas many other countries use more flexible materials such as different grades of polyethylene, polyvinyl chloride, and various composites. Furthermore, as trenchless technology is relatively new to the Malaysian construction industry, it needs to go through a period of evaluation. During this period, it is imperative that local designers and municipal engineers gain experience on the correct rehabilitation methods.

It was difficult to get quotations from both contractors and suppliers for the various trenchless technology techniques described throughout this study. From protracted discussions, with vendors and various consulting engineers, it appears that trenchless technology will be more expensive due to some of the following reasons.

1. Some of the trenchless techniques are proprietary, and only a selected few contractors can install the materials (for example pipe lining materials) or have expert knowledge on how to use the equipments.
2. Equipments used in trenchless technology are generally very expensive, especially for replacement techniques such as microtunnelling, pipe jacking and pipe bursting which require hydraulic or pneumatic systems.
3. It is expected that contractors have to repair, renovate or replace long stretches of sewers in a relatively short time in comparison to the open-cut method.

Although there has been significant advancement in the trenchless technology abroad, Malaysian engineers seem to be rather apprehensive in adopting it. This can perhaps be altered once Malaysian design professionals become conversant with trenchless methods.

In conclusion, it may be suggested that it may be worthwhile to conduct an independent testing program that can provide a basis for comparison and evaluation of various trenchless construction and rehabilitation products available in Malaysia. In order to promote awareness towards trenchless technologies, Malaysia needs to set up its own agency like the North American Society for Trenchless Technology (NASTT) and Trenchless Technology Centre (TTC) at Louisiana Tech University (Ruston, Louisiana). Until such an agency is established in Malaysia, design engineers and local authorities or municipal councils will always be at a risk in terms of knowledge gap.

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References

deMonsabert, S., Ong, C., & Thornton, P. (2000). Integer program for optimizing sanitary sewer rehabilitation over a planning horizon. *Water Environment Research*, *71*(7), 1292–1297.

Gokhale, S., & Hastak, M. (2000). Decision aids for the selection of installation technology for underground municipal infrastructure systems. *Trenchless Technology Research*, *15*(1), 1–11.

Hansen, O. B., & Pedersen, J. (1994). Integrated planning of improvements of sewer system and treatment plant for suburbs of Copenhagen. *Water Science and Technology*, *30*(1), 157–166.

Hulme, T. W., & Burchell, A. J. (1999). Tunnelling projects in Singapore: an overview. *Tunnelling and Underground Space Technology*, *14*(4), 409–418.

Kolonko, A., & Madryas, C. (1996). Modernization of underground pipes in towns in Poland. *Tunnelling and Underground Space Technology*, *11*(2), 215–220.

Kramer, S. R., & Gauthier S. W. (1995). Testing and evaluation of trenchless renewal systems for gas distribution pipes, *North*

American NO-DIG conference 1995, Chicago, IL, USA, North American Society for Trenchless Technology.

Melbourne Water Structural Assessment guide (1994). (1st ed.), p. 19. Melbourne, Australia.

Chandrasekaran, S. (1999). *Property connections for sewerage systems*, M.Tech Thesis, University of Malaya, Kuala Lumpur, Malaysia.

Rome, E., Hertzber, J., Kirchner, F., Licht, U., & Christaller, T. (1999). Towards autonomous sewer robots: the Makro project. *Urban Water*, *1*(1), 57–70.

Tregoing, E. C. (1996). Trenchless technology research in the UK water industry. *Trenchless Technology Research*, *11*(2), 61–66.

USInfracstructure (1999). Published Report, September 1999, USInfrastructure Inc. Birmingham, Alabama, USA.

Wirahadikusumah, R., Abraham, D. M., Iseley, T., & Prasanth, R. K. (1998). Assessment technologies for sewer system rehabilitation. *Automation in Construction*, *7*, 259–270.