4.0 REHABILITATION TECHNIQUES

The previous section discussed the methods typically used in evaluating the existing condition of the sewer using various types of surveys. Upon evaluation of the condition of the sewer the extent of rehabilitation required can be determined. The next step then is to determine which method of rehabilitation is most suitable to the problem at hand.

This section will focus on the different remedial methods available in the market, their advantages and disadvantages. Installation methods for each of the techniques will also be discussed.

4.1 Excavation and Replacement

In Malaysia, excavation and replacement of sewers and other pipelines is the most common rehabilitation practice, however, as some local authorities prohibit excavation in areas of their jurisdiction, this method is no longer an option for rehabilitation works. Therefore, it is no surprise that excavation and replacement of deteriorated pipelines is now becoming more limited due to the availability of trenchless technologies.

Excavation and replacement of pipelines is normally undertaken under the following conditions:

1. When deterioration of the pipe in terms of structural integrity is too severe.
2. When misalignment of pipe has occurred.
3. When additional pipeline capacity is needed due to development and increase of population.
4. For short stretches that are too seriously damaged to be repaired by any other means.
5. When entire stretches of the pipeline are too severely damaged to be rehabilitated.
6. When removal and replacement is less costly than other rehabilitation methods.

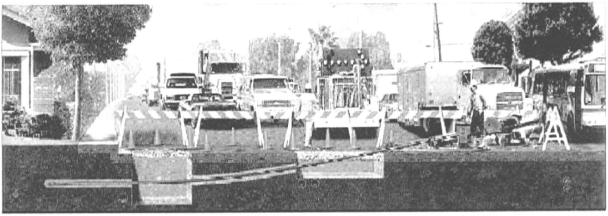
Excavation and replacement of deteriorated pipelines also has its shortcomings as a method of sewer line rehabilitation, some of which are (US EPA, 1977):

1. Removal and replacement is usually more expensive than other rehabilitation methods.
2. Removal and replacement construction causes considerably greater and longer-lasting traffic and urban disruption than does trenchless rehabilitation.
3. Removal and replacement construction involves a greater threat of damage to, or interruption of, other utilities than does trenchless rehabilitation.

Typically when rehabilitating the sewer via this method, the existing pipeline can be removed and replaced with a new pipeline of either same or higher capacity depending on whether only part of the sewer is being rehabilitated, or if the entire stretch of sewer is being rehabilitated. For larger sewers however, it will be most likely that the existing sewer will have to be abandoned in place and replaced by a new pipeline. The new pipeline could be laid either in physically parallel alignment adjacent to the existing line, or a functionally parallel alignment along a different route (US EPA, 1977).

Typical problems faced during removal and replacement of sewers via excavation include disruption of road traffic, blockage of access to residential, commercial and industrial areas and temporary loss of road parking. **Figure 4.1** shows how trenching can cause traffic congestion especially in town centres, while the trenchless method causes almost no disturbance to the traffic. Other operational problems are the possibility of trench shoring in unstable soil and trench dewatering in areas with high groundwater.

Figure 4.1 Traffic congestion: trenching versus trenchless.



TRENCHING

TRENCHLESS

Trenchless technology is another option to sewer line connections and was first proposed as a method of replacement of cast iron gas mains in Great Britain (Kramer and 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.

Some of the advantages of trenchless technology are listed below:

- Minimises traffic inconveniences
- Minimises public inconveniences
- Cost savings in paving excavation and replacement costs
- Useful in areas with high surface traffic
- Useful in areas where there is limited work surface
- Aids in good public relations
- Possible time savings

The primary disadvantage however, is the cost. It is an expensive option, therefore, it must be applied appropriately. Trenchless technology could also in some cases end up being too time consuming, as old services need to be traced to ensure that no damage is made to them during the trenching exercise.

4.2 Repair

When it has been decided that the existing sewer is to remain in service, and that when the sewer has only localised damage, and hence the defects within the sewer do not warrant complete replacement of the pipeline, repair techniques are used.

Repair techniques may involve the use of injected materials to stabilise the soil conditions outside of the pipeline and/or seal leakage points in the sewer (Chemical Grouting) and short lengths of lining (Part Lining) to give structural and sealing performance. Sewer repair techniques will renew the existing sewer to varying degrees and can provide structural remedies as well as leakage abatement. These two methods will be discussed in this section.

4.2.1 Part Lining

Part lining or patch repair system involves the lining of part of a sewer pipe length, and not lining of the full length. This type of lining is considered when localised rehabilitation works is necessary due to concentrated loadings or due to budget constraints which do not allow full length lining to be carried out. Proper judgement will be required to ensure that the part of the sewer to be part lined will not require further rehabilitation in the future, in which case it will be more practical to fully line the pipeline. Typically, part liners are made of epoxy resins, fiberglass matt and polyester felt (Insituform, 1996).

Advantages of Part Lining

1. No excavation is required.
2. The length of the lining can vary over a wide range.
3. This is a cheaper option than having to line the full length of the sewer.
4. Part lining is the quickest method of repairing short lengths of pipeline.
5. Liner thickness can be varied depending on the structural condition of the existing pipeline, for example, a thicker liner can be used at the point where part of a pipeline is damaged or missing.
6. Part lining work results in less sewer downtime in comparison to full lining works.
7. The hydraulic performance of the pipeline is improved due to the smoothness of the lining.
8. The job can be done much faster as several part linings can be achieved in a day.
9. Cracks however, will be prevented from enlarging due to the mechanical bond between the cracks and the resin (Melbourne Water, 1993).

Disadvantages of Part Lining

The only disadvantage of using resin part lining is that the adherence of the resin to the pipe wall is unknown as the epoxy would not chemically bind to the pipe (Melbourne Water, 1993).

Installation of Part Liners

Initially the length of the pipeline that is to be lined is cleaned of slimes, sediment, debris, roots and encrustations. Cleaning is typically done with high pressure water jets. Cleaning is necessary to allow for bonding of the epoxy resins to the surface of the pipeline.

Inspection of the pipeline is performed by experienced personnel trained in locating breaks, obstacles and service connections by closed circuit television. The interior of the pipeline is carefully inspected to determine the location of any conditions that may prevent the proper installation of the liner into the pipeline. Typical obstructions are crushed or collapsed lengths of pipe, offset joints and pipe lengths and severe reductions in the diameter of the pipeline. Such conditions are noted for rectification. A video tape and suitable log are kept for later reference.

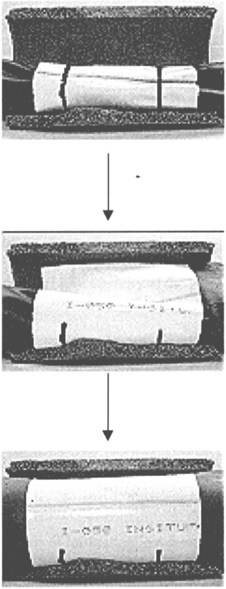
Sewage flows around the sections of the pipe upstream have to be by-passed by plugging the line at an existing upstream manhole and pumping or directing the flow into a downstream manhole or adjacent system. The pump and bypass lines shall be of adequate capacity and size to handle the flow. Raw sewage must be pumped back into the sanitary sewer system or disposed of in the most suitable manner, while ensuring that any regulations pertaining to the environment are adhered to.

The liner material (fiberglass, polyester felt, epoxy resin) is wrapped around an inflation device at the factory as shown in **Figure 4.2**. The overlapping seam of the fiberglass/polyester has to be lightly tacked.

Once on site, the fiberglass/polyester matt is immersed in a drum containing epoxy resin. The uncured epoxy has to be protected from any contact with water which can cause the resin to disintegrate. This can be done by placing a polyethylene sleeve around the liner. The liner is then winched down into position and inflated using pressure. The pressure level adopted varies according to the pipeline depth and the water table position. Hot air or steam is used to cure the resin. Upon curing of the resin (about 2-3 hours), the inflator is removed and sewage is allowed to flow through (Insituform, 1996).

The installation time for part lining is approximately one hour to prepare the sewer and divert flow, followed by 0.25 hours of installing the liner and 2-3 hours of curing. The total process takes approximately 4 hours (Insituform, 1996).

Figure 4.2 Installation of Part Liners/Patch Repair



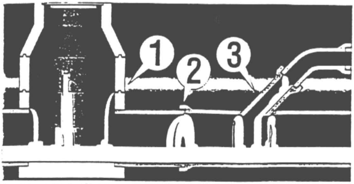
4.2.2 Chemical Grouting

Chemical grouting of sewer lines is used primarily to seal leaking joints, circumferential cracks, small holes and radial cracks (US EPA, 1991). When properly applied, it is considered to be one of the best cures for infiltration of groundwater into sewers and potable water pipes (Hayward, 1996).

Grouting techniques are used to repair discrete, identified defects within the existing sewer, hence enhancing the structural integrity of the pipeline and maintaining the hydraulic capacity of the pipeline.

Infiltration typically enters sewers through manholes, pipe joints, service connections and the first few feet of the sewer line, as depicted in **Figure 4.3**. If left unchecked, it can lead to multi-million dollar problems, including pipe collapse, overburdened sewage treatment plants and surcharged systems.

Figure 4.3 Sources of Infiltration into sewers.
(Source: No Dig International Vol.7, No.4, April 1996)

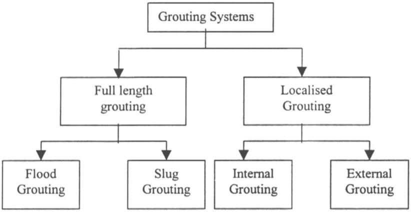


Grout Areas. Most infiltration enters sewer systems through manholes (1), pipe joints (2), service connections and the first few feet of the service line (3).

Grouts were first used in the late 1800s. Most of the grouts used were of sodium silicate base. In the early 1950s, the American Cyanamid Company marketed acrylamide grout, which permitted a single shot injection of a mixture of organic monomers. Acrylamide grout was an improvement to silicate based grout in terms of application, however, it became a health concern in the 1970s. Since then, American Cyanamid Company has stopped manufacturing acrylamide grout. Alternative grouts developed in the 1950s, 60s and 70s were urea formaldehydes, lignosulphates, silicates, polyphenolic polymers and urethanes (Melbourne Water, 1993).

According to the Webster's dictionary, grout is defined as 'a thin mortar used to fill cracks and crevices in masonry,'. This is however, not how chemical grouts work. Chemical grouts do not stop sewer leaks by filling joints. Instead, grouting chemicals are forced through joints into the soil surrcunding the pipeline. In the case of manholes, the chemicals are injected through holes bored in the manhole wall. Once the chemicals mix, they gel with the soil and the mass becomes impermeable to water. This water tight collar adheres to the outer surface of the pipe or manhole where it will stay indefinitely unless removed by excavation or exposed to ultraviolet rays from the sun for long periods of time. If groundwater pressure increases, the collar will be pressed even more tightly against the joint, increasing its ability to stop water. If the humidity in the soil declines for a long period of time, the grout may begin to dry also. However, when the soil humidity returns, the grout will absorb moisture and return to its original condition. The soil humidity around the leaking manholes and sewers is almost always high enough to prevent any significant shrinkage of the gel. All grouts gel as a result of catalytic action. For some grouts, the catalyst is water, for others it is another chemical. In either case, the catalyst and the reactant must be kept separated until they are injected into the soil (Hayward, 1996).

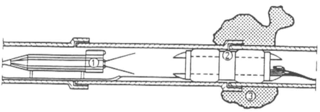
Grouting systems can be classified as below (Melbourne Water, 1993):



Full length grouting of a pipeline can be done via two methods: flood grouting and slug grouting. Flood grouting is where a pipeline length is filled with a grouting solution in order to seal all points of leakage in the pipeline. This can be done at cracks in the pipe, joints, laterals and at manholes. Slug grouting is a modified form of flood grouting, where a slug of grout is pushed along the pipeline, hence sealing the pipeline and laterals at one go.

Internal localised grouting can be used for both man entry pipelines and non-man entry pipelines. For a man entry pipeline, a grout injection gun is utilised, while for a non-man entry pipeline, a packer that isolates the area to be grouted is used as shown in **Figure 4.4** (Stein, 1994). The grout is then pumped to the packer and injected into the isolated area to seal cracks etc. This will be further explained in the following paragraphs.

Figure 4.4 Chemical grouting of pipe jointing.
(Source: European Water Pollution Control, Vol.4, No. 5, 1994)



1 – CCTV camera

2 – inflated grout packer

3 – injected area

External grouting involves pumping grout into the soil surrounding the pipeline. In the past, cement and bentonite grouts were used, presently however, chemical grouts such as acrylamides and silicates are more common (Melbourne Water, 1993)

There are many grouting products in the market, some of them are: Buchen: using polyurethane, Cues: using acrylates, silicates, urethanes and urea formaldehydes, Rocla: using urethanes, acrylate and acrylamide, Fulline: using and Sanipor: using silicone based grout. Most of the grouts are installed using different packers for different pipe sizes.

Advantages of Chemical Grouting

1. No excavation is required.
2. All equipment is contained in one truck, reducing site space requirements and public inconvenience.
3. Cheaper than lining, except when the number of infiltration points is large.
4. Grouting does not reduce the pipeline capacity, as there is no reduction in the pipeline diameter.
5. Sewage bypassing is not required, except for high flows.
6. A choice of chemical grouts is available in the market.

Disadvantages of Chemical Grouting

1. There is evidence that acrylamide grout is extremely hazardous to human health. Urethanes and acrylates are less hazardous, while silicates pose a negligible hazard.
2. Generally infiltration is not totally eliminated, unlike most lining methods.
3. When using certain types of grouts, protective clothing and breathing apparatus is required for handling purposes.

Installation Procedures and Equipment

The pipeline to be grouted has to be initially cleaned of all slimes, sediment, debris and encrustations. This is normally done via high pressure water jetting, following which the sewer is inspected using CCTV to ensure that it is clean and to check for any obstructions within the sewer. Should there be any intruding roots, they are removed and the root systems will be chemically treated.

An inflatable packer that is used for both pressure testing and grouting, is winched along the pipeline. Attached to the front of the packer is a television camera which is used to view the leakage, cracks and defects that require grouting, while the grout delivery line, water line and other controls are connected at the back end of the packer to the control van. All operations are controlled from the control room in the mobile unit above ground.

The sealing packer is positioned where grouting is or may be necessary. The ends of the packer are inflated, followed by the centre section and water is injected between the outer centre section and the pipe wall to test for leakage. The water pressure increases the pressure in the centre section and the pressure in this section is monitored. Should there be no pressure increase in the centre section or if the pressure cannot be sustained, sealing is required. The pressure in the centre is increased to press the centre section flat against the pipe wall and grout is injected under this high pressure condition.

Once the grout has cured, the test for leakage is repeated and the sealing is undertaken along the sewer line (Melbourne Water, 1993).

4.2.3 Applicability of Repair Techniques in Malaysia

Techniques such as lining and chemical grouting have great potential in Malaysia as these techniques are and 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 in accessible sewers, remote control robots or manipulators can be employed. These methods have been proven to be successful in Europe and in the United States.

In Malaysia, these techniques will be most applicable for smaller diameter sewers. Repair methods such as part lining and chemical grouting can be used to seal initial or hairline cracks in either relatively 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. Therefore a detailed cost analysis would have to be conducted prior to deciding on which method to use, the trench or trenchless method.

The repair method is most effective for repair of property connections as home owners would not want their expensive tiles under which lies the sewer line that connects to the toilet, to be damaged or cracked during rehabilitation works. For property connections, which generally use sewers of smaller diameter, remote control robots can be used to repair leaks, minor collapses, etc. This however would be more costly in comparison to the normal trenching method. It is likely that this method would be preferred by homeowners who are more concerned with the aesthetics of their homes. In this case, the costs of repair will be borne by the homeowner and not the local council.

Recently however, in Europe, there have been some concerns about the ecological effects of the injection liquids which may be applied during chemical grouting (Stein, 1994). These are typically based on soluble plastics and have the potential to contaminate the sol and groundwater. In Malaysia, groundwater is not used as a drinking water source, therefore, groundwater and soil contamination may not be a major concern at this stage. Even though ground water is not used now, research should be conducted to identify more environmentally friendly injection liquids by developing tests for judging the ecological consequences of the use of these substances. Hydraulically hardened mortar based on unshrinkable ultra fine ground special cement may be an environmentally friendly alternative to plastic fluids (Stein, 1994).

delay. Fewer traffic delays in themselves produce an environmental benefit since less fuel is wasted with consequent reduced atmospheric pollution.

The primary disadvantage of the replacement techniques however, is the cost. It is an expensive option, therefore, it must be applied only when it is the best possible rehabilitation option.

4.3.1 On-line Replacement

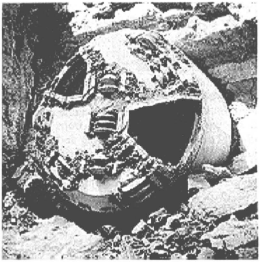
On-line replacement refers to replacement using an in-situ or on-line pipe replacement system such as microtunnelling, pipe jacking and pipe bursting. A pipeline with inadequate capacity or whose structural condition is too poor for relining can be replaced without excavation using an in-situ or on-line pipe replacement system.

There are many on-line replacement techniques and they will be discussed in the following sections.

4.3.1.1 Microtunnelling

Komatsu of Japan was the first company that developed microtunnelling machines in the 1970s, largely due to restrictions on open cut construction in high density urban areas. Japan's production of tunnel boring machines have gained significant recognition all over the world, with Germany becoming the other major producer in the 1980s. Iseki Incorporated of Japan, is one of the world's best known manufacturers and suppliers of microtunnelling equipment. Typical microtunnelling equipment is depicted in **Figure 4.5**.

Figure 4.5 Typical microtunnelling equipment.



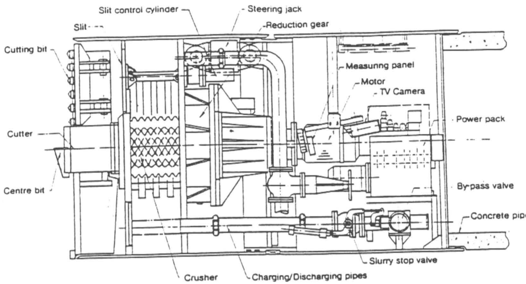
Microtunnelling machines eliminate the need for personnel to enter the tunneled excavation. This is accomplished by using remotely controlled and steerable tunnel boring machines (TBM). A laser guidance system is used to monitor and maintain the center line and grade during tunneling. Should the machine deviate from the centre line or grade, the operator can steer the machine back to the intended centre line. This method is capable of achieving accuracies of +/- 25 mm to +/- 75 mm in most situations. Therefore, microtunneling can be chosen for projects with especially critical line and grade requirements, such as gravity sewer design with relatively flat grades (Stahelli and Hermanson, 1995).

There are several types of microtunnelling machines (Balasubramaniam, (1989). They are classified according to the method of spoil removal. The methods are:

- *Slurry Balance Shield* - this method was designed especially for tunnelling below the water table and in unstable running soils, and is limited by the slurry pumping capabilities. Drives of around 150 m in length can present slurry transport problems. Therefore, booster pumps have to be installed in the slurry circuit to avoid this problem. However this is only possible in pipelines 900 mm or larger as the booster pumps will not physically fit in smaller pipelines, which tend to obstruct the laser guidance system.

Figure 4.6 shows a typical cross section of a Slurry Shield. The essential features in the shield are the balancing of tunnel face by the pressurised slurry and the removal system of the excavated soil. A high level of mechanisation and automation of the shield for the jacking operation and the computer processing of field data such as alignment rate of excavation and jacking speed enable an accurate directional control of the shield drive and jacking of pipes.

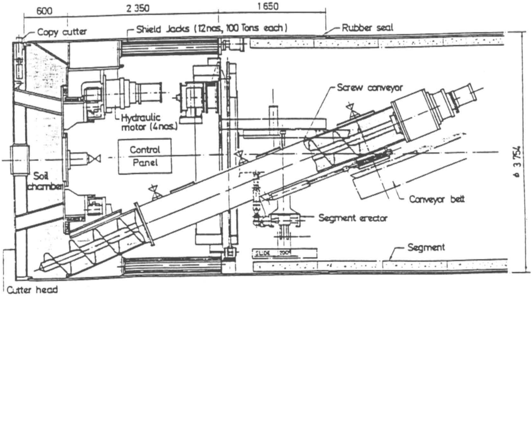
Figure 4.6 Slurry Pressure Balanced Shield
(Source: Balasubramaniam, 1989)



- *Earth Pressure Balance Shield* – According to Balasubramaniam (1989), this form of microtunneling was introduced in Japan in 1974 and since then several hundreds of these shields have been manufactured and used in Japan and more recently in other countries. It was used for the first time in Singapore in 1983 to construct the largest effluent outfall pipeline through very difficult soft soil, mostly marine clay, in the western part of Singapore. This form of microtunnelling is generally used for soft to hard clays and fine granular material. The available machine torque limits the length of the drive. Maximum lengths are 100 m (Thomson, 1993).

Figure 4.7 shows a typical cross section of an Earth Pressure Shield. In this shield, the soil excavated by the cutter head in front is temporarily confined in a chamber behind the cutter head. The soil in the chamber is kept under a desired pressure so that tunnel face is balanced by the pressurised soil in the chamber. A laser beam usually monitors the target and the shield is steered by controlling the thrust jack's speed and stroke.

Figure 4.7 Earth Pressure Balanced Shield
(Source: Balasubramaniam, 1989)



Microtunneling is often cost-effective when the depth of cover is greater than or equal to 4.5 m (Kramer, McDonald and Thomson, 1992). This is largely due to the high cost of shoring associated with deep open-cut excavations. However, according to Staheli and Hermanson (1995), microtunneling methods may be cost competitive to other methods, at depths less than 4.5 m in the presence of groundwater.

Advantages of Microtunnelling

1. There are various microtunnelling equipment available to suit varying types of soil conditions, from hard rock to cobble gravel, etc.
2. Minor surface disruption as equipment is contained in a truck mounted container.
3. More recent microtunnelling machines can operate in a circular shaft of small diameter (2 to 4 m).
4. Highly accurate grades are achievable via the microtunnelling method.
5. Immediate jacking of the replacement pipe following the microtunnelling further prevents ground subsidence and eliminates form work required.
6. Microtunnelling is suitable in areas with contaminated groundwater and soils (Rasa Industries Ltd. Brochure).

Disadvantages of Microtunnelling

1. Connections of laterals or property connections require construction of a shaft and hence breaking through the pipe wall.
2. When tunnelling through softer soils using tunnelling equipment for softer soils, problems may arise if harder type of soils for example, rock is encountered.
3. Earth pressure microtunnellers cannot be used below the water table unless they are fitted with a pressurizing system.
4. Slurry microtunnellers require settling tanks for the slurry spoil (Rasa Industries Ltd. Brochure).
5. The disposal of slurry could pose problems, as it is not possible to dispose of it on land without pre-treatment. For example, filter plate presses could be used to dewater the slurry prior to its disposal on land (Balasubramaniam, 1989).

Installation Procedures and Equipment.

The launch and reception shafts of the right size are constructed. This is followed by the lowering of the tunnel boring machine (TBM) into the shaft. The jacking station is then lowered into the shaft, it then is positioned against the back of the shaft for thrust restraint. For the earth pressure microtunnelling, an auger drive motor is incorporated in the jacking station. For the slurry method however, a settling tank is positioned on site and slurry lines are connected to the TBM and settling tank. The slurry control lines are connected between the control room and the TBM (Melbourne Water, 1993). Similarly, the control lines for steering hydraulics are connected between the control room and the TBM.

The microtunnelling shield is then set to the required line and level and is pushed forward by the jack. When the end of the microtunnelling shield is about to enter the shaft, excavation is temporarily halted and the first replacement pipe is lowered in and placed behind the shield. Excavation is then started again and the pipe is jacked, pushing in both the pipe and the shield. This process is then repeated till the entire pipe has been replaced (Rasa Industries Ltd. Brochure).

From Melbourne Water's experience, jacking rates for the slurry method is about 10 to 20 m per 8 hours, and 8 to 20 m per 8 hours for the earth pressure balance method.

4.3.1.2 Pipe Jacking

Pipe jacking is a technique for installing underground pipelines, ducts and culverts, similar to microtunelling. The major applications for pipe jacking include new sewerage and drainage construction, sewer replacement and relining, gas and water mains, oil pipelines, electricity and telecommunications cable installation, and culverts.

Pipe jacking can be used to negotiate obstacles such as motorways, railways, rivers, canals, buildings and airfields in the path of pipe laying projects, as minimal surface disruption is experienced.

According to Thomson (1993), the difference between pipe jacking and microtunnelling is simply the size of the pipe. Pipe jacking refers to pipes of roughly 36 inch or greater in diameter while microtunnelling refers to installation of pipes smaller than 36 inches. Pipe jacking allows for personnel at the face of the cutting head or shield whereas in microtunnelling, the diameter of the pipe prohibits this and operations and observations must be made from the jacking pit.

Pipe jacking is primarily used for multiple lengths as an alternative to open cut excavations or other tunnelling methods. Lengths in excess of 300 m are regularly attainable using mechanised driving of man entry size pipe jacks. Pipes below 900 mm in diameter are installed using remote control microtunneling systems while lengths in excess of 80 m are attainable using non-man-entry microtunneling machines (Pipe Jacking Association U.K.).

Pipe jacking provides a flexible, structural, watertight, finished pipeline. Powerful hydraulic jacks are used to push specially designed pipes through the ground behind a shield simultaneously as excavation is taking place within the shield. There is no theoretical limit to the length of individual pipejacks although practical engineering considerations and economics may impose restrictions.

Similar to microtunnelling, there are two methods of pipe jacking: the slurry and auger methods. From the author's conversation with various contractors, the slurry method seems to be the most popular pipe jacking methodology to be used both in Singapore and Malaysia.

Advantages of Pipe Jacking

1. Inherent strength of lining.
2. Minimal surface disruption.
3. Less risk of settlement.
4. Minimal reinstatement.
5. Reduced requirement for utilities diversions in urban areas.
6. Smooth internal finish giving good flow characteristics.
7. No requirement for secondary lining.
8. Considerably less joints than a segmental tunnel.

9. Prevention of ground water ingress by use of pipes with sealed flexible joints.
10. Provision of invert channels in larger pipes to contain the dry weather flow of a sewer in a combined system.
11. A virtually maintenance free construction.
12. Significant reduction in social costs when compared to open cut trenching in urban areas.
13. Reduced environmental disturbance (Pipe Jacking Association U.K.).

Disadvantages of Pipe Jacking

1. Similar to microtunnelling, connections of laterals or property connections require construction of a shaft and hence breaking through the pipe wall.
2. When pipe jacking through softer soils using jacking cutters for softer soils, problems may arise if harder type of soils for example, rock is encountered.
3. Similar to microtunnelling, the auger method cannot be used below the water table unless they are fitted with a pressurising system.
4. Similar to microtunnelling, slurry jacking requires settling tanks for the slurry spoil (Melbourne Water, 1993).

Installation Procedure and Equipment

In order to install a pipeline using this technique, thrust and reception pits are constructed, usually at manhole positions. The dimension and construction of a thrust pit may vary according to the specific requirements of any drive with economics being a key factor. Mechanised excavation may require larger pits than hand excavated drives, although pipe jacking can be carried out from small shafts to meet special site circumstances, which are similar to the microtunnelling shafts.

A thrust wall is constructed to provide a reaction against which to jack. In poor ground conditions, piling or other special arrangements may have to be employed to increase the reaction capability of the thrust wall. Where there is insufficient depth to construct a normal thrust wall, for example through embankments, the jacking reaction has to be resisted by means of a structural framework constructed above ground level having adequate restraint provided by means of piles, ground anchors or other such methods for transferring horizontal loads.

High pressure jacks driven by hydraulic power packs provide the substantial forces required for jacking pipes. The ram diameter and stroke of the jack may vary according to an individual contractor's technique. Short stroke jacks with multiple spacer blocks, medium stroke jacks with shorter length pipes or long stroke jacks, which can push a full length pipe at one setting may be used.

To ensure that the jacking forces are distributed around the circumference of a pipe being jacked, a thrust ring is provided of a design dependent on the number of jacks being used. The jacks are interconnected hydraulically to ensure that the thrust from each is the same. The number of jacks used may vary because of the pipe size, the strength of the jacking pipes, the length to be installed and the anticipated frictional resistance.

A reception pit of sufficient size for removal of the jacking shield is normally required at the completed end of each drive. The initial alignment of the pipe jack is obtained by accurately positioning guide rails within the thrust pit on which the pipes are laid. To maintain accuracy of alignment during pipe jacking, it is necessary to use a steerable shield, which must be frequently checked for one and level from a fixed reference. For short or simple pipe jacks, these checks can be carried out using traditional surveying equipment. Rapid excavation and remote control techniques require sophisticated electronic guidance systems using a combination of lasers and screen based computer technologies, similar to microtunelling.

4.3.1.3 Pipe Bursting

Pipe bursting is yet another trenchless technology technique. It is a method for inserting a new pipe by forcing the material into the surrounding soil using a burster. The burster is a soil displacement hammer, and its head varies from one supplier to another. Some bursters may have ribs, fins that expand or otherwise or may have an expanding cone. The burster comprises a piston that under force is driven to strike an anvil several times a second. A typical burster head is shown in **Figure 4.8**.

Pipe bursting has the capability to restore the original hydraulic capacity of a pipeline, unlike many lining techniques, which may not, depending on the condition of the pipeline and whether the lining is close fitting or not (Melbourne Water, 1993). Yet another advantage of pipe bursting is that it can increase the hydraulic capacity of the existing pipeline by bursting a hole of a diameter much larger than the existing pipeline outside diameter. This method is also referred to as the Pipeline Insertion Method (PIM), which was developed by British Gas in the mid-1980s, originally for the replacement of old cast iron gas mains. This was followed by widespread use in the U.K. water industry due to its cost-effective replacement of small diameter cast iron potable water systems, and now, pipe bursting has an increasing market in north America and worldwide (McArthur, 1995).

Pipe bursting technology involves installing larger pipes into the place of existing older lines. This is done by fragmenting the pipe in place and forcing it into the surrounding soil with an impact mole, which is why, pipe bursting is often referred to as impact moling. A new pipe is then pushed into the existing sewage collection route, manhole to manhole. This process requires excavation for insertion pits for removal of the mole. Smaller excavation pits are required for every functioning lateral connection (Purdue University Construction Industry Institute).

There are four pipe bursting techniques, being pneumatic, hydraulic, mechanical and cone cracking. The differences between these bursting techniques are (Melbourne Water, 1993):

- *Pneumatic* – The pneumatic method involves the hammering forward of a burster using pneumatic force. Pipelines can be upsized in diameter using this method.
- *Hydraulic* – The hydraulic burster uses hydraulic force to burst the pipe. Pipelines can be upsized in diameter using this method.
- *Mechanical* – The mechanical burster has a vibratory head to burst the existing pipeline and it is pulled through the pipeline via a winch cable. Pipelines cannot be upsized using this method.
- *Cracking Cone* – The cracking cone is a tapered nose cone with raised ridges. Force for bursting is provided by a winching cable. Only certain diameters (150 mm and 200 mm) can be upsized using this method.

Both the pneumatic and hydraulic method however, seem to be the most common methods quoted in literature.

Typically, pipe bursting allows replacement of pipelines within the range of 6 to 15 inches in diameter, however, recently larger pipes of 32 to 36 inches have been replaced (Scholze, *et al.*, 1990). It is anticipated that pipe bursting for sewer rehabilitation will go from strength to strength, and proof of this is evident with the now available 48 inch diameter burster in the market (Hayward, 1996).

There are many corporations that offer the various pipe bursting variations, for example, CSR Pipelines use a method called IMPIPE (IMPIPE Systems Brochure) and Tracto-Technik offers the Grundocrack technique (Grundocrack Pipe and Sewer Cracking Systems Brochure).

Figure 4.8 A typical pipe bursting head
(Source: Tracto-Technik Brochure)

Advantages of Pipe Bursting

1. It has been shown to be cost effective when compared to open cut methods.
2. It can be less disruptive to traffic.
3. It can be accomplished in congested areas.
4. It can be used to increase the capacity of the system by upsizing the line.
5. A contractor can use polyethylene pipe which has no joints, has a high soil load factor and has a long life expectancy.
6. Pipe bursting can be accomplished in unstable ground conditions.
7. When compared to excavation or trenching, it can have a lower risk of coming in contact with existing utilities. There may also be less soil compaction than other boring methods.
8. It uses the existing pipeline. This method helps locate the existing laterals at the main and it keeps the lateral in the same place and on the same grade.
9. Minimum excavation is required.
10. In comparison to other types of pipe, the life expectancy of polyethylene pipe can range from 50 to 100 years.
11. Pipe bursting requires less manpower and equipment, which improves efficiency (Grundocrack Pipe and Sewer Cracking Systems Brochure).

Disadvantages of Pipe Bursting

1. The pneumatic pipe bursters are rather noisy and cannot be used from manholes in sewers.
2. Bursters in general are unsuitable for rocky and stiff clay soil conditions.

3. This method may not be suitable in Malaysia for sewerage purposes, as reinforced concrete pipes generally cannot be burst. Furthermore most pipe bursting operations worldwide replace the existing pipeline with high density polyethylene pipes which is contrary to the Malaysian sewerage industry which typically uses only reinforced concrete or vitrified clay pipes.
4. Some amount of damage to adjacent ground service lines may occur by deviation of the burster from the existing pipeline due to the expansion or hammering vibrations.
5. When the winch cable is not taut, deviation from the line of existing pipeline may occur.
6. The broken fragments of the old pipeline may damage the new pipeline on insertion.

Installation Procedures and Equipment

Initially the length of damaged pipe is isolated and flows through it are diverted (see **Figure 4.9** for the pipe bursting operation). All property connections have to be excavated and disconnected following which launch and reception shafts are constructed. The length of the launch shaft depends entirely on the length of the pipe burster and the length pipeline to be inserted (whether it is made up of continuous or discrete pipe segments). Therefore if short discrete pipe segments are used and if the burster is relatively short in length, manholes may be used for both launch and reception sites.

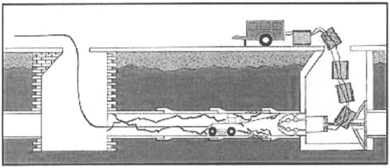
All obstructions in the pipeline to be burst are cleared to ensure that during the brusting exercise, the replacement pipeline is not damaged. A winch is positioned at the reception shaft and the winch cable is pulled through the existing pipeline back to the launch shaft.

The burster is then lowered into the launch shaft and connected to the winch cable. All required hoses for air or hydraulic pressure are threaded through the "new" discrete or continuous pipes and connected to the burster. Typically the replacement pipeline is pushed in by jacking or pulled/pushed using a pulling chain through the pipeline connected to a backing plate behind the last pipe.

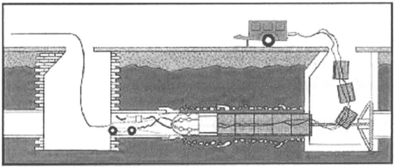
When the alignment of the burster with respect to the pipeline is correct, tension is applied to the bruster via the winch. Air, hydraulic, vibratory or pulling pressure is supplied to the burster. For discrete pipes, when the rear of the first pipe is about to enter the pipeline, the bursting operation is stopped and the next pipe length is positioned behind the first and the two are joined together. This process is repeated until the entire pipeline has been replaced.

All hoses and pulling chains are disconnected from the rear of the burster and pulled back through the replacement pipeline. The bruster is also removed from the reception shaft, following which all laterals are reconnected (Melbourne Water, 1993; Grundocrack Pipe and Sewer Cracking Systems Brochure; Insituform Permaline Brochure, and Duratec Brochure).

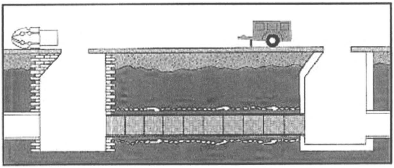
Figure 4.9 The Pipe Bursting Technique.
(Source: Insituform Permaline Brochure)



START OF RENEWAL



RENEWAL



RENEWAL COMPLETE

4.3.2 Off-line Replacement

Off-line replacement is typically used when the new sewer's alignment varies from the alignment of the original sewer. The off-line techniques discussed in this section include directional drilling and guided drilling.

4.3.2.1 Directional drilling

Directional drilling technology has long been used for the exploration of oil and natural gas. Literature indicates that this trenchless technology has also been applied successfully to projects for both the cable television industry and municipal water or sewer force mains worldwide (Husselbee, 1995). Generally, directional drilling is a trenchless system which is predominantly used for the installation of long, vertically curved pipelines usually under bodies of water such as rivers, estuaries, and canals (McArthur, 1995). This method uses substantial surface equipment, which are capable of up to more than 1,000 m lengths. According to Husselbee (1995), this technique is best suited to major schemes that need expensive and heavy equipment.

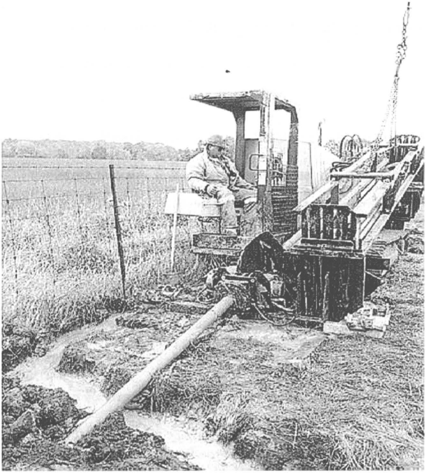
This technique is an offshoot of the slant drilling technology that is used in the oil fields, and is usually conducted in two steps. The first step involves drilling in a small diameter pilot hole into the soil. This is done by drilling the hole using a steerable drilling head whose position and direction are constantly monitored and adjusted to stay on line and grade. A washover pipe, slightly larger than the pilot tube follows the drill string. The washover pipe serves as a temporary support and a method of reducing friction on the drill string before enlargement. Following which, the completed pilot bore is enlarged using back reaming techniques until sufficiently large to receive the final pipe, which is normally steel, however, in many cases, polyethylene and bundles of pipes have also been used (Husselbee, 1995). **Figure 4.10** shows a typical directional drilling rig in operation.

This form of trenchless drilling has already been introduced into Malaysia. Directional drilling is currently playing an important role in Malaysia as many of the larger cities have banned open cutting. Cities that have been employing this method of drilling are Kuala Lumpur, Ipoh, Johor Bahru, Melaka, Butterworth and Penang, however directional drilling is fast gaining popularity across the whole country. From the author's conversation with several contractors, it was noted that one of the main projects using this system is a major development to improve the telecommunications infrastructure in Bandar Baru Bangi by Celcom, where ducting for fibre optic cables are required.

Directional drilling was also used in the preparation for the 16th Commonwealth Games, for the installation of telecommunications and power (Clarke, 1997).

This method is generally ideal when there is limited working space available for installation of pipes, especially in already built-up areas. Using this method will ensure that there is little or no disruption to traffic flow and the quick completion of projects as unnecessary cutting and filling after the job is not required.

Figure 4.10 A Typical Directional Drilling Rig in Operation.



Advantages of Directional Drilling

1. Excavation equipment can be easily set up on the surface as depicted in the figure above.
2. Directional drilling allows for a wide range of diameters and long lengths of pipeline for rehabilitation.

3. The pilot string can be easily steered around obstructions such as pipelines, hard rocks, etc., hence making this method the most effective and least disruptive method for long river crossings (Melbourne Water, 1993).

Disadvantages of Directional Drilling

1. The main disadvantage is that as only continuous pipe can be used, directional drilling is limited to steel or plastic pipes (Melbourne Water, 1993), this limits its usage to long crossings under highways and water courses for pressure mains or siphons. This method is highly unlikely to be used in the Malaysian sewerage industry that strictly uses only reinforced concrete and vitrified clay pipes.
2. Steering control and monitoring requires highly trained personnel due to sophistication of the equipment and computer graphics involved.
3. This method requires room to lay out the continuous pipeline prior to installation.
4. A large volume of water is required for the directional drilling operation.

Installation Procedure and Equipment

Initially the drill rig is positioned on the ground to achieve the required trajectory. A pilot hole is then commenced using a small diameter drill string equipped with a high-pressure steerable jetting head. A washover pipe with a drill bit attached to its open end is then used to enlarge the pilot hole. The washover pipe follows closely behind the drill string head. Upon completion of the bore, the pilot drill string is removed.

Following this, a barrel back reamer is attached to the end of the washover pipeline at the reception site to upsize the bore. For large upsizing, backreaming may be necessary more than once. The backreamed bore which is now larger than the washover pipe is supported by bentonite slurry. This procedure is repeated for further upsizing.

For the final backreamer upsizing the pulling head of the continuous product pipeline is attached behind the backreamer using a swivel and universal joint. The washover pipe is then pulled back to the drill rig as the rotating backreamer expands the hole for the pipeline (Werner, 1997; Rabol, 1997; Clarke, 1996 and Melbourne Water, 1993).

4.3.2.2 Guided Drilling

Guided drilling, also commonly known as steered horizontal boring, refers to directional drilling using small to medium sized drilling rigs. This system was developed in the early 80's, and employs a similar method to directional drilling. However, the head tracking system is not as sophisticated as that with the larger directional drilling systems.

The drilling system is mounted on a tractor or wheel mounted rig, which is capable of having its elevation altered, hence allowing the drill string to enter the ground at the required angle. The drill string has a head that creates a bore either by displacement or excavation (Melbourne Water, 1993). An impact mole or a slant head is used to displace the earth while a mechanical cutting tool or fluid jet cutting head is used for excavation.

The head tracking system for the guided drilling systems is monitored directly above it, using a manually directed locater. An electronic transmitter which is mounted on the drilling head sends a signal to the manual directed locater. This signal will enable the location, depth and orientation to be determined. More expensive systems have a second transmitter that sends the head orientation details to a receiver on the drill rig (Melbourne Water, 1993).

Guided drilling however, is not suitable for drilling rock, cobbles and gravel. As guided drilling rigs are light and compact, they can be easily used in confined spaces, unlike directional drilling.

Advantages of Guided Drilling

1. The drilling rig is compact, lightweight and wheel mounted. This allows for easy transport, manoeuvring and set up.
2. Operation of the guided drill does not need a highly trained operator as the directional drilling equipment, as guided drilling equipment is relatively simple in comparison.

3. It is possible to steer the pilot bore both vertically and horizontally.
4. It is possible to steer small radius bends of 9 to 12 mm turning radius.
5. The drill line can be pulled back and the line resteered in another direction when an obstruction is met.
6. The drilling head can be remotely located to ensure obstructions or other utilities can be avoided.

Disadvantages of Guided Drilling

1. The route has to be properly monitored by the operator to ensure that other buried utilities are not an obstruction.
2. When passing under certain materials, the drilling head cannot be located.
3. The uniformity and shallowness of grading required for gravity sewers cannot be achieved via this method.
4. Similar to directional drilling, only continuous pipe can be installed.
5. Guided drilling has difficulty when drilling through rock and certain types of gravel, hence making steering difficult when these materials are detected.

Installation Procedures and Equipment

Initially the drill rig is positioned on the ground to achieve the required trajectory. The flexible drill rods are pushed through the ground and the drill head is steered both vertically and horizontally as required to avoid obstructions such as other utilities (Clarke, 1997).

When the drill head reaches the reception pit, a backreamer is attached to the end of the drill string similar to the directional drilling method. And the pulling head of the continuous product pipeline is attached behind the backreamer using a swivel and joint. The drill string is withdrawn by the drill rig which in turn pulls the backreamer and the product pipeline through the pilot bore. Finally where the drilled line commences its horizontal path in the ground, connection is made to the existing pipeline (Clarke, 1997).

4.3.3 Applicability of Replacement Techniques in Malaysia

Sewers that cannot be repaired or renovated due to hydraulic, structural, chemical or economic reasons must be renewed. Most of the existing sewer lines in Malaysia fall into this category, primarily because Malaysian sewers were laid decades ago, hence are incapable of serving the increasing population. A large percentage of the existing sewers connect urban areas (cities, townships and residential areas), causing renewal of sewers to be particularly difficult due to the existing interconnected supply network. This often presents a considerable obstacle during laying of new sewer networks, which is reflected in the costs.

In states such as Melaka and Penang, which have especially narrow roads and densely located buildings, replacement via the open cut method, may result in damage of other supply lines (water pipes, telephone cables, traffic light cables, etc.). This will indefinitely cause chaos, public frustration, business interruption, traffic upsets, etc.

According to Balasubramaniam (1989), trenchless replacement systems have been successfully used in Singapore. He further elaborates that the replacement method causes only minimum ground disturbances with negligible effects on the structures and services in the vicinity of the work area. Furthermore, the measured surface and subsurface ground movements are appreciably smaller than those that would be expected using the conventional trenching method. The trenchless replacement method therefore, will prove to be highly effective if used to both renew and upgrade Malaysian sewers.

In conclusion, replacement methods can be successfully used in Malaysia, in high density urban areas, where there is a high risk of damaging other underground services and causing severe traffic disruptions due to the narrow roads, etc.

4.4 Renovation

Renovation of sewer lines involves using techniques that improve or maintain the structural condition of the entire pipeline. Pipeline renovation tends to be a more common rehabilitation method. The renovation method typically involves the usage of liners, which are applied using variable methods to suit the rehabilitation needs of a particular sewer. Some of the available liner technologies are:

- Soft lining or cured-in place pipe
- Folded lining or deformed lining
- Spiral lining
- Spray on lining
- Slip lining

Each of the above will be briefly described in this section, in terms of its applicability, procedures and equipment required, advantages and disadvantages. Information provided in this section has largely been obtained from brochures produced by specialists in the particular renovation method.

The Water Research Centre (WRc) of the U.K. has classified the structural condition of linings into two categories as defined as in the following paragraphs (WRc Rehabilitation Manual , 1994).

Type I linings

Definition: The renovated sewer is considered to be acting as a composite section, consisting of the existing sewer, grout and lining. Type I lining assumes that these three components are bonded together and that the grout is stiff and strong enough to transfer stress to the lining (WRc Rehabilitation Manual, 1994).

As the design philosophy of this type of lining is to create a rigid structure that carries all ground and traffic loads, this type of lining is restricted to man entry sewers where high confidence annulus grouting can be achieved.

Type II linings

Definition: The lining systems acts as a flexible pipe with the old sewer, annulus grout (where appropriate) and soil providing the necessary support to maintain stability. No bond is required between the lining and the grout (where present) or the existing sewer (WRc Rehabilitation Manual, 1994).

Techniques used for non-man entry pipelines fall into this category (Melbourne Water, 1993). **Figure 4.11** depicts the typical type I and type II linings, however note that for type II, the bond is beneficial but not required. Typical lining materials include glass reinforced plastics, polyethylene, polypropylene.

Figure 4.11 Typical type I and type II lining.

4.4.1 Soft Lining/Cured in Place Pipe

The first company to introduce soft lining was Insituform in 1971. Insituform still remains to be one of the world's most successful lining techniques, with 25 years experience and more than 20,000 contracts throughout the world (Insitutube Cured in Place Pipe Lining Brochure). Since Insituform's original patent ran out in 1991, the number of soft lining alternatives has significantly increased. Typical diameter for soft linings could range from 100 mm to 1500 mm.

Soft linings can be categorised into two groups. They are (Melbourne Water, 1993):

- ***Full inversion*** – the lining has the inside pipe wall on the outside prior to installation, and water or air pressure is used to evert the lining and push it along the pipeline, and retains the lining inflated prior to resin curing. Once the pipe has hardened and cooled, the water pressure is released and the ends are trimmed. Service connections are reinstated internally with a remote control cutting device, or by man entry techniques.

- ***Tow in/inversion inflation*** – the lining is towed into place along the pipeline using a winch and cable. Once in place, the lining is inflated using water or air pressure.

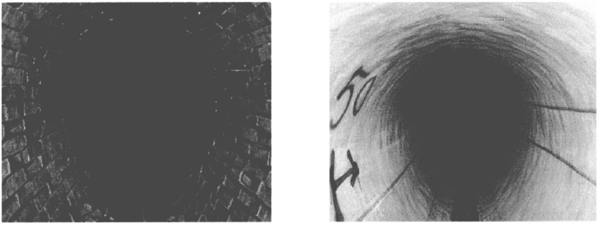
Typically, two (WRc Rehabilitation Manual, 1984) used are polyester and epoxy resins, which are liquid thermosetting resins. The resin used is pliable prior to curing and hence allows installation around curves, filing of cracks, bridging of gaps, and manoeuvring through pipe defects. After installation, the fabric cures to form a new pipe of slightly smaller diameter but of the same shape as the original pipe. The new pipe has no joints or seams and has a very smooth interior surface which in many cases improves flow capacity despite the slight decrease in diameter (USEPA, 1991).

This process has been prove to work successfully in virtually any type of pipe reconstruction application, especially in areas of high traffic, concentrated utility lines, or high density neighbourhoods and buildings. **Figure 4.12** indicates renovation of an old cracked pipe with Insituform's liner, Insitutube (Insitutube Cured in Place Pipe Lining Brochure).

Some of the soft lining available in the market are Permaline (Permaline Brochure), Insitutube (Insitutube Brochure), Renoline (Renoline Brochure), Superliner (Superliner Brochure), Inliner (Inliner Brochure) and Paltem (Paltem Brochure).

Figure 4.12 Renovation of an old cracked pipe with Insituform liner.

Before Renovation **After Renovation**



Advantages of Soft Lining

1. No excavation is required and access to the pipeline is via manholes or shafts.
2. Improved hydraulic roughness as the lining surface is smoother, there are no joints and the liner creates a continuous surface over irregularities.
3. Annulus grouting is not required.
4. Laterals can be installed via an internal remote cutter.
5. There are no joints for infiltration or root intrusion.
6. The lining operation is rather quick as several manhole lengths can be lined in a single operation.
7. The liner can cater for minor bends, wide radius bends, multiple bends and slight deformation.
8. Most resins used have excellent resistance to hydrogen sulphide and sulphuric acid produced by septic sewage.

9. The lining thickness can be custom designed to aid in structural strength especially in localised areas, such as when a section of the pipe wall is missing.
10. The lining adds some structural integrity to the existing pipeline.
11. The lining exercise does not interfere with or damage other utilities.
12. No pavement repairs will be required after the lining exercise.
13. This method is considered to be safer than some other rehabilitation methods.
14. This method only costs 50 – 70% of replacement costs (USEPA, 1991; Melbourne Water, 1993; 5, Permaline Brochure; Insitutube Brochure; Renoline Brochure; Superliner brochure; Inliner Brochure and Palterm Brochure).

Disadvantages of Soft Lining

1. By-pass pumping will be required for the duration of the liner installation.
2. Should there be insufficient head from the manhole depth, an inversion standpipe will be required.
3. The liner may wrinkle at bends.
4. Post-installation CCTV is required to reopen lateral connections.

Installation Procedures and Equipment

Initially, flows through the pipeline have to be diverted, using pumping equipment and by-pass piping, and/or sewage eduction equipment. This is followed by cleaning of the existing pipeline is cleaned to ensure that all slime, debris, sediments, roots and encrustations that could interfere with the installation of the liner are removed. This may be done via water jetting, suction, pigging and root cutters. For larger pipelines, manual entry may be used.

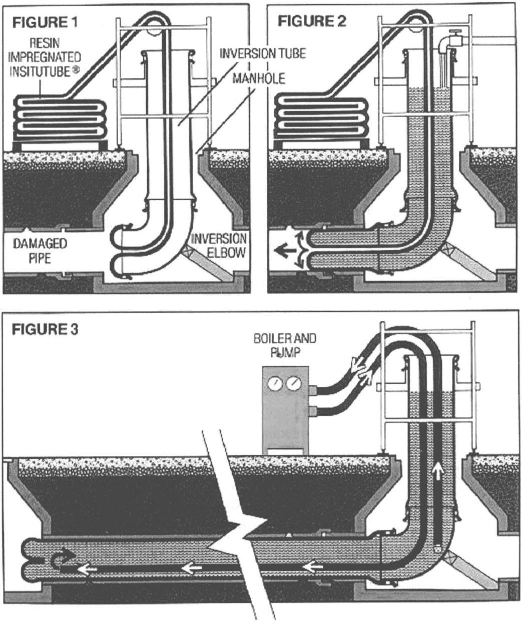
The pipeline is then to be inspected using CCTV, to check for cleanliness, to determine the location of further obstructions and to record the length of live laterals requiring reconnection. Obstructions such as protruding laterals, collapses, severe pipeline displacements and cross section reductions of more than a predetermined percentage will have to be remedied. The truck containing the liner is backed up to the launch manhole or shaft. The resin saturated material is installed in the existing pipe through the manhole or shaft via an inversion standpipe and inversion elbow. An inversion tower will be necessary where the depth of the manhole is insufficient to achieve the head required for the liner inversion. The special needled felt re-construction tube, coated and manufactured to fit the damaged pipe exactly is impregnated with a liquid thermosetting resin and lowered into the manhole through the inversion tube. One end of the resin impregnated tube is firmly attached to the lower end of the inversion tube elbow (as depicted in **Figure 4.13 - 1**).

The inversion tube is then filled with water. The weight of the water pushes the tube into the damaged pipe and turns it inside out, while pressing the resin impregnated side firmly against the inside walls of the old pipe. The smooth coated side of the tube becomes the new interior surface of the pipe (see **Figure 4.13 - 2**).

After the tube is inverted through the old pipe to the desired length, the water is circulated through a boiler. The hot water causes the thermosetting resin to cure within a few hours, changing the pliable tube into a hard, structurally sound, pipe within a pipe, as shown in **Figure 4.13 - 3**. It has no joints or seams and is usually stronger than the pipe it replaced. The ends are then cut off and the inversion tube and scaffolding are removed.

The laterals are then reinstated internally with a remote control cutting device, or by man-entry techniques. The laterals are identified using log records in combination with dimpling of the lining. Normally there are no messy excavation repairs to be made since most of the work is done without digging or disruption to traffic.

Figure 4.13 (1 to 3) The soft lining process



4.4.2 Fold and Formed Lining

Folded or deformed linings are typically used for lining of smaller diameter sewers due to its ability to provide a tight fit and furthermore, it is simpler and quicker to install in comparison to soft lining. Folded lining became popular in the late 80's (Melbourne Water, 1993).

Folded linings are continuous lengths of pipe that have had their cross sectional shape altered from its original circular shape to either a C or a flat cross section. This method helps to temporarily reduce the cross sectional area of the liner for installation, hence ensuring that a tight fit is provided when inserted into an existing pipeline.

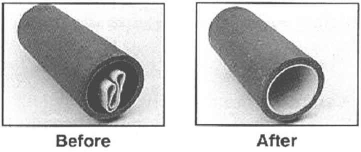
Typically, fold and formed method of pipeline rehabilitation is suitable for pipe diameters of 10 to 40 cm (4 – 16 in) with typical lengths of installation of 90 to 180 m (300 – 600 feet) (USEPA, 1991).

Two of the most common and easily available fold and formed liners are the U-Liner which was developed by Pipe Liners Inc. (U-Liner Brochure) and NuPipe (NuPipe Brochure). These liners have been successfully used in both the United States and Australia. Other less common fold and form liners in the market are EX (developed by the EX Pipeline Association, Osaka Bousui Construction Company and Tsutsunaka Plastic Industry Company) (EX Brochure), and

Compact Pipe (developed by Wavin, the largest plastic pipe systems manufacturer in Europe, in conjunction with research organisations) (Compact Pipe Brochure).

The U-Liner for example is extruded as round pipe (typically polyethylene material), and then through a combination of heat and pressure, is deformed into the "U" shape (U-Liner Brochure). It is then wound into spools ready for installation. NuPipe however is extruded in a folded shape, and while it is still pliable, the folded PVC is wound onto spools (NuPipe Brochure). **Figure 4.14** shows the folded liner within an existing pipeline before and after installation.

Figure 4.14 Fold and formed lining



Advantages of Fold and Formed Liners

1. No excavation is required and access to the pipeline is via manholes or shafts.
2. Hydraulic roughness is improved as the lining surface is smoother, there are no joints and the liner creates a continuous surface over irregularities.
3. Annulus grouting is not required, as there is no annulus gap, this maximises the pipe diameter.

4. Laterals can be installed via an internal remote cutter.
5. There are no joints for infiltration or root intrusion.
6. The lining operation is rather quick as several manhole lengths can be lined in one operation.
7. The liner can cater for minor bends, wide radius bends, multiple bends and slight deformation.
8. Most resins used have excellent resistance to hydrogen sulphide and sulphuric acid produced by septic sewage.
9. Generally cheaper than soft lining methods and quicker to install in comparison to soft linings.
10. As folded lining is made of thermoplastics, it does not set like soft lining that uses thermoset resins. Therefore, there is no time restraint on installation posed by the setting of resins (Melbourne Water, 1993; U-Liner Brochure and NuPipe Brochure).

Disadvantages of Fold and Formed Liners

1. By-pass pumping will be required for the duration of the liner installation.
2. Should there be insufficient head from the manhole depth, an inversion standpipe will be required.
3. Folded liner conforms to all surfaces hence creating points of hydraulic disturbance at cavities, missing pipe or misaligned joints, therefore, the pipeline needs to be circular as far as possible.

4. Lateral connections need to be in good order to ensure leak free connections after cutting in the pipe (Melbourne Water, 1993; U-Liner Brochure and NuPipe Brochure).

Installation Procedures and Equipment

Initially, flows through the pipeline have to be diverted, using pumping equipment and by-pass piping, and/or sewage eduction equipment. This is followed by cleaning of the existing pipeline is cleaned to ensure that all slime, debris, sediments, roots and encrustations that could interfere with the installation of the liner are removed. This may be done via water jetting, suction, pigging and root cutters. For larger pipelines, manual entry may be used.

The pipeline is then to be inspected using CCTV, to check for cleanliness, to determine the location of further obstructions and to record the length of live laterals requiring reconnection. Obstructions such as protruding laterals, collapses, severe pipeline displacements and cross section reductions of more than a predetermined percentage will have to be remedied.

A short pipe of slightly smaller diameter to the existing pipe is pulled through the existing pipeline to ensure that the lining will have no obstructions during inflation to the required diameter. Following which, the truck onto which the liner is reeled is backed up to the launch manhole or shaft. Most trucks will have an operator control room, complete with CCTV inspection equipment and equipment to control the steam generator which is used to inflate the liners.

The folded liner is then preheated to make the liner flexible for insertion into the existing pipe. The folded pipe is then inserted into the existing pipe using a winch and cable connected to the end of the folded pipe. The winch is equipped with a dynamometer to record the pulling forces required during installation.

After the liner has been inserted into the existing pipe, it shall be heated until the thermocouple reaches the necessary temperature. The liner is then expanded using a pressure driven rounding device that mechanically expands and progressively forms the pipe from the insertion point to the termination point. After the liner has been rounded, the liner is cooled under pressure and the lateral connections are reopened using a remote control, robotic cutting device.

Figure 4.15 depicts the installation process of a typical fold and formed liner.

Figure 4.15 Installation of fold and formed liners.
(Source: NuPipe Product Brochure)

Figure 4.15-1 Delivery of preheated liner.

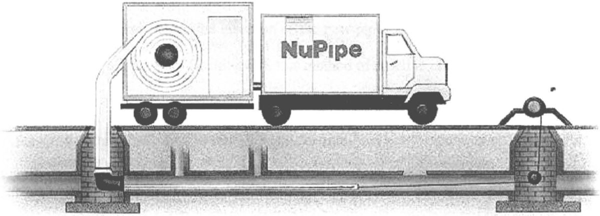


Figure 4.15-2 Rounding device is propelled through to unfold and expand the liner.

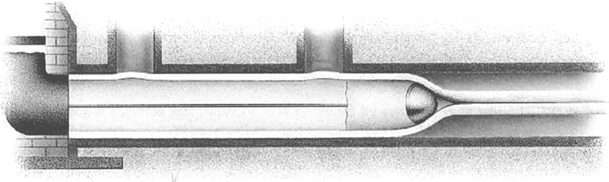
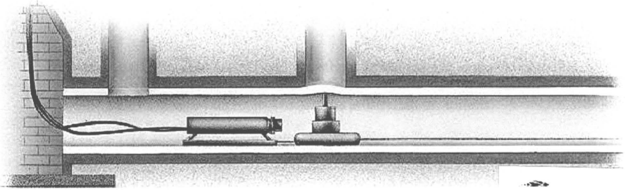


Figure 4.15-3 Liner is cooled under pressure and laterals are reinstated.



4.4.3 Spiral Lining

The spiral pipe lining system was developed in Australia and has been licensed worldwide (WRc, 1984). This form of lining eliminates the need to construct a lead in shaft to permit the insertion of the new pipe. The local Malaysian vendors however are not very familiar with this method of pipeline rehabilitation.

The spiral pipe lining system is ideal for non-man entry pipelines as it creates a pipe within the manhole using a sophisticated and compact winding machine. However, some spiral lining systems involve manual operations inside man entry pipe sizes.

From the various product brochures studied, it was observed that this method used PVC, UPVC and HDPE to line the sewers. PVC and HDPE are resistant to hydrogen sulphide and sulphuric acid produced by septic sewage while UPVC is resistant to any chemical conditions that would be expected in domestic sewage. It also has excellent resistance to sulphuric acid resultant from hydrogen sulphide in septic sewage. UPVC however can be damaged by some chemicals depending on the contact time, concentration and temperature.

Following are some of the spiral-lining methods in the market, and also note that all of the following spiral lining techniques are Australian inventions:

- Rib Loc Fixed Diameter (Rib Loc Fixed Diameter Brochure) – using UPVC with the ability to line from 150 to 900 mm diameter.
- Twin Lok (Twin Lok Brochure) – using UPVC with the ability to line one or two manhole lengths.
- Rib Lok Expanda Pipe (Rib Lok Expanda Pipe Brochure) –using UPVC with the ability to line 225 to 600 mm diameter.
- Panel Lok (Panel Lok Brochure) – using UPVC with the ability to line various shapes of sewers, and man entry size sewers.
- Flap Loc (Flap Lok Brochure) – using HDPE with the ability to line various shapes of sewers, and man entry size sewers.

Advantages of Spiral Lining

1. No excavation is required as installation is through manholes.
2. Hydraulic roughness is improved due to the smoother surface of the lining.
3. As a spiral liner does not follow the existing surface irregularities closely like soft linings, the points of ponding and silting are reduced.
4. Installation is quicker than soft lining and may be quicker than folded lining and it is not labour intensive.
5. The lining material is normally lightweight.
6. A system for reconnecting laterals without excavation is also available.

Disadvantages of Spiral Lining

1. Sections of the launch manhole benching may be required to be removed in order to correctly position the pipe winding machine.
2. It may be difficult for the liner to negotiate certain bends.
3. For some of the techniques, annulus grouting may be required.
4. There may be some loss in pipeline diameter.

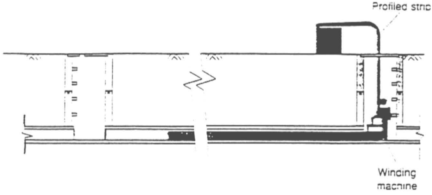
Installation Equipment and Procedures

Initially, flows through the pipeline have to be diverted, using pumping equipment and by-pass piping, and/or sewage eduction equipment. This is followed by cleaning of the existing pipeline to ensure that all slime, debris, sediments, roots and encrustations that could interfere with the installation of the liner are removed. This may be done via water jetting, suction, pigging and root cutters. For larger pipelines, manual entry may be used.

The pipeline is then to be inspected using CCTV, to check for cleanliness, to determine the location of further obstructions and tc record the length of live laterals requiring reconnection. Obstructions such as protruding laterals, collapses, severe pipeline displacements and cross section reductions of more than a predetermined percentage will have to be remedied.

The winding machine is lowered down into the manhole and positioned as shown in **Figure 4.16**. It is then connected to a hydraulic power pack that is placed at a distance from the launch manhole. The continuous lining coil is positioned over the manhole on a cassette that aids the unwinding of the coil. The lining strip is then lowered down the manhole and connected to the winding machine. When the machine is turned on, the drive roller rotation winds the strip within the rollers. The drive roller provides the pressure to produce the mechanical locking between strips (typically the strip has a male key on one edge and a female lock on the other edge, and when the strip is spirally wound, the female lock overlaps the male key). As the pipe rotates within the rollers, the drive roller forces the pipes forward into the pipeline until it exits the pipeline at the exit manhole. The pipes will then be trimmed ready for grouting if required. The pipeline is plugged and filled with water under a pressure sufficient to counteract flotation and grout pressures (Melbourne Water, 1993; Rib Loc Fixed Diameter Brochure; Twin Lok Brochure; Rib Lok Expanda Pipe Brochure; Panel Lok Brochure and Flap Loc Brochure).

Figure 4.16 Lining with spirally wound pipes
(Source WCR Rehabilitation Manual, 1984)



4.4.4 Spray-On Lining

This is a well tried and tested technique for applying either an anti-corrosion or structural lining to pipelines. For more than fifty years (USEPA, 1975) cement mortar has been used for lining water mains from 75 mm diameter upwards, to prevent encrustation, discoloured water and loss of capacity. More recently, spray on lining uses mainly epoxy resins, polyurethanes, and aluminates.

Spray on linings act to prevent corrosion by numerous aggressive agents, in particular acidic and bacterial corrosion, and to prevent abrasion and point impact (USEPA, 1975). When using speciality concretes containing sulfate resistant additives such as potassium silicate and calcium aluminate, the weakened concrete pipes and structures can be reinforced by applying an acid resistant coating over the original surface of the pipeline. Speciality concretes are unique in that their matrix is not formed by a hydration reaction, rather they are the result of the reaction of an acid reagent with an alkaline solution of a ceramic polymer of potassium silicate (USEPA, 1991). Speciality cements can resist attacks by many substances including mineral salts, mild solutions of organic and mineral acids, sugar solutions, fats and oils (USEPA, 1991).

Figure 4.17, Figure 4.18 and **Figure 4.19** show how spray lining is conducted both manually and via a spray lining machine for manual entry pipelines, and for non man entry pipelines respectively.

Advantages of Spray Lining

1. Minimal excavation required as access is through manholes.
2. Prevents further corrosion of the existing line.
3. Improves hydraulic properties of the pipeline.
4. Improved structural integrity to the sewer or pipeline that would otherwise require replacement.
5. Applicable for a wide range of pipe sizes, from non-man entry pipes to man entry pipelines.
6. Cement lining is generally cheaper than other lining methods.
7. Epoxy lining however, is more abrasion resistant in comparison to cement lining (USEPA, 1975).

Disadvantages of Spray on Lining

1. Extensive cleaning of the existing pipeline is required to ensure a bond with the existing pipeline.
2. The corrosion and abrasion resistance of speciality concrete lining is not as good as plastic lining methods, as the lining will be eroded/corroded away in time unlike plastic linings.
3. There is a possibility of infiltration and root intrusion at joints unlike continuous plastic lining methods.
4. If speciality concrete is used, the concrete shelf life is to be tracked for project duration.

5. Transportation cost is higher for speciality concrete.
6. This process cannot be used if the pipeline has missing segments of if it no longer has any structural strength.

Installation Procedures and Equipment (using speciality concrete)

Initially, flows through the pipeline have to be diverted, using pumping equipment and by-pass piping, and/or sewage eduction equipment. This is followed by cleaning of the existing pipeline is cleaned to ensure that all slime, debris, sediments, roots and encrustations that could interfere with the installation of the liner are removed. This may be done via high pressure water jetting, suction, pigging and root cutters. For larger pipelines, manual entry may be used.

The pipeline is then to be inspected using CCTV, to check for cleanliness, to determine the location of further obstructions and to record the length of live laterals requiring reconnection. Obstructions such as protruding laterals, collapses, severe pipeline displacements and cross section reductions of more than a predetermined percentage will have to be remedied.

Speciality concrete lining is applied using a centrifugal lining machine. The machine has a revolving, concrete dispensing head with trowels on the back to smooth the concrete immediately after application. In smaller diameter pipelines, a variable speed winch pulls the lining machine through a supply hose. Reinforcement can also be added to the concrete with a reinforcing spiral wound rod. The reinforcing rod is inserted into the fresh concrete and a second coat is applied over it. For man entry structures, the concrete can be applied manually using a trowel or by a self-propelling lining machine that is controlled by a person riding it. In this case the concrete is supplied to an electrically driven supply cart that conveys the concrete from the access hole to the feeder which is attached to the lining machine. The dry speciality cement and aggregate is mixed with water in a specially designed spray nozzle. Hydration occurs, and the resulting mixture is shot into place under pressure. Curing occurs under moist conditions for the first approximately 5-24 hours, depending on the sewer size, before returning flows to the sewer. The lining is inspected with CCTV and video recorded (USEPA, 1975).

Figure 4.17 Manual lining of a man-entry sewer.

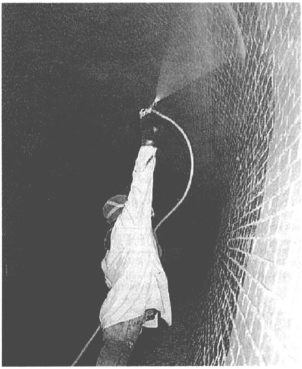


Figure 4.18 Machine lining of a man-entry sewer.

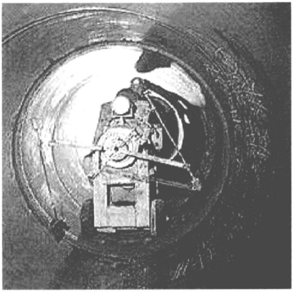
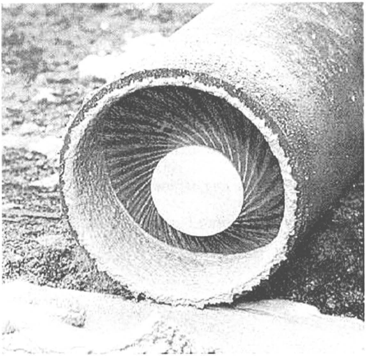


Figure 4.19 Spiral lining of a small diameter sewer



4.4.5 Slip Lining

Slip lining or pipe insertion method is the earliest type of pipeline lining and is the least sophisticated of the lining techniques available as it involves pushing and/or pulling discrete or continuous lengths of pipe into an existing pipeline from a manhole or shaft. The slip lining technique can be used to rehabilitate sewers, water and other pipelines that may have severe structural problems such as extensive cracks, lines in unstable soil conditions, deteriorated pipes in corrosive environments, pipes with massive and destructive root intrusion problems (USEPA, 1991). To reconnect laterals to the slip lined pipeline, excavation is required.

The most popular materials to be used in this technique are polyolefins such as polyethylene (PE) and high density PE (HDPE), fibreglass reinforced polyesters (FRP), polyvinyl chloride (PVC), ductile iron (cement line and polyvinyl lined), and reinforced thermosetting resins (RTR). It has been found that PE is the most common material used due to its availability in low, medium and high density. HDPE compounds are the best suited for rehabilitation purposes due to its good stiffness, hard, strong and corrosion resistant properties (Hayward, 1996).

Advantages of Slip Lining

1. Minimal disruption to traffic and urban activities as compared to replacement.
2. Significantly less costly than replacement.
3. Quick installation time.
4. Can be used to rehabilitate pipelines with severe corrosion and hence provides good protection against acid corrosion.
5. Does not require thorough cleaning as debris can be pushed out ahead or accumulated in the slipped line to be later flushed.
6. Requires less quality control in comparison to other high technology methods as less can go wrong.
7. The hydraulic roughness of a slip-lined pipeline is generally better than soft and folded lining systems.
8. Future ground settlement can be alleviated as annulus grouting will fill up the voids about the pipeline.
9. Can be used for a wide range of pipe sizes.
10. May not require bypass pumping.

Disadvantages of Slip Lining

1. As a gap has to be left between the new and existing pipeline to prevent snagging and drag upon insertion of the new pipes, hydraulic capacity is lost to an extent.
2. The annulus has to be grouted.
3. Need to excavate at laterals in order to reconnect them to the new pipeline.

4. Slip lining using longer pipe lengths may require the excavation of a launch shaft.
5. As some slip lining systems have joints they could be susceptible to future infiltration and root intrusion if the jointing materials is not of good quality.
6. For sharp bends on the pipeline, excavation will have to be done at the bend and the pipeline launched from the newly excavated pit.
7. Slip lining is more labour intensive in comparison to soft and folded lining.

Installation Procedure and Equipment

Prior to slip lining, the sewer must be first thoroughly cleaned and inspected using CCTV to identify all obstructions such as displaced joints, crushed pipes and protruding service laterals. Cleaning may be done via high pressure water jetting, suction, pigging and root cutters. For the slip lining technique, it is not necessary to bypass the entire sewage flow within the existing pipeline structure as it has been found that low flow can assist positioning of the liner by acting as a lubricant along the liner length as it moves through the deteriorated pipe structure.

Slip lining is performed by either a push or a pull. In the pull method, a pulling head is attached to the end of the pipe. A cable is run from the exit manhole to the launch manhole and is connected to the pulling head. The slip lining pipe is then pulled through the existing pipe with the cable by a track mounted winch assembly. The push method however is performed by either a backhoe or a jacking machine. Once the slip lining pipe has been positioned, it has to be grouted in place. Grouting however, is only required at the manholes and not at the entire lengths of the pipeline, provided the liner is sufficiently strong to support loads in the even of collapse of the original pipeline. Grouting is recommended as it provides the following advantages (USEPA, 1991):

- Provides structural integrity
- Increases hydrostatic and structural loading capabilities
- Prevents liner from moving
- Locks in service connections
- Prolongs the life of the pipeline.

4.4.6 Application of Renovation Techniques in Malaysia

As explained in this section, 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, however has some internal defects such as corrosion and leaks, that have to be rectified immediately. It must be borne in mind that even though some lining systems (spiral lining) may provide some structural support, this should not be the aim of the renovation method, if chosen as a possible rehabilitation method.

This method will be especially useful in rehabilitation of existing property connections that are damaged, as most house owners would like to find an alternative method to having to dig through the flooring of their homes (which may be tiled, etc.).

The renovation method may not be suitable if the existing trunk sewer is heavily damaged and needs to be resized to serve an increasing population. Therefore, this method should only be utilised when the existing pipeline is in relatively good condition and has the capability to serve the required population, but does not warrant totally replacing the sewer.