WATER RESEARCH CENTRE

TECHNICAL REPORT TR 87

SEWER RENOVATION

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September 1978

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SUMMARY

This report presents the first results of a continuing assessment of sewer renovation methods.

The stimulus for the work came from the Standing Committee on Sewers and Water Mains who, in 'Sewers and Water Mains, A National Assessment', gave a clear indication of the neglected state of many of our sewers. They recommended that urgent attention should be given to the assessment of existing methods and the development of new methods for the repair and renovation of sewers and water mains.

In this report types of fault commonly found in sewers are defined and the renovation methods are classified into nine types. A brief description of each method is given together with some guidance on cost where case history information was available. Suggested renovation methods for each fault type are presented in matrix form.

The better known manufacturers and contractors capable of supplying either the renovation materials or a service are listed, together with addresses. Some sewer renovation techniques which are under development but not yet commercially available are described together with some future requirements which will improve existing methods.

The report concludes that none of the major renovation techniques are ideal in all aspects, that little information is available on performance and consequently cost effectiveness of renovation cannot be assessed at this time.

1. INTRODUCTION

The main purpose of this report is to present the results of a survey of sewer renovation methods. Evaluation of the techniques covered has not been attempted but is the subject of further project work at both the Water Research Centre (WRC) and Transport and Road Research Laboratory (TRRL). The stimulus for this work has come from the NWC/DOE* Standing Committee on Sewers and Water Mains whose recently published report 'Sewers and Water Mains, a National Assessment' gives a clear indication of the neglected state of our sewers.

Data from the Standing Committee Report have been used in this review to emphasis the scale of the problem and to stress the need for further development of renovation systems and for innovation with an objective of simpler, cheaper methods of repair with a minimum of excavation and disruption.

The problems that may be encountered in a sewerage network are considered together with the faults that cause them. The fault classification used is one that is being developed jointly by WRC and TRRL. Photographs illustrating the conditions which are common in a number of Britain's sewers are shown in Fig. 1.

A list of specialist contractors and manufacturers has been compiled but it must be emphasised that this is by no means exhaustive. It contains mainly those companies which advertise nationally and does not include the numerous small local firms, many of whom may well be capable of specialised sewer maintenance and renovation. It is indeed a sobering thought that in view of the magnitude of the backlog of work that is known to exist there are so few specialists in this field. Even the ones that are listed can only be described as small by normal industrial standards.

The decision whether to renew† or renovate† will depend on a number of factors, one of which will be comparative cost. Therefore in order to make this report meaningful some indication of the economics of the various systems was essential. Unfortunately contractors are loath to quote against hyphetical situations and this is understandable if one considers the number of variables which make each project unique. To try to overcome this problem some costs of actual operations have been included which, it is hoped, will at least act as a guide.

An important factor which must not be overlooked is the cost of disruption caused by renewal which, although very difficult to value, should be considered in any cost comparison.

Renovation methods covered in this report have been grouped into types which are listed in Section 5. A selection matrix suggests suitable types to use for each particular fault. The individual renovation techniques are then described in Section 6.

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* National Water Council/Department of the Environment

† The meanings of these terms adopted in the context of this work are given in Section 3.

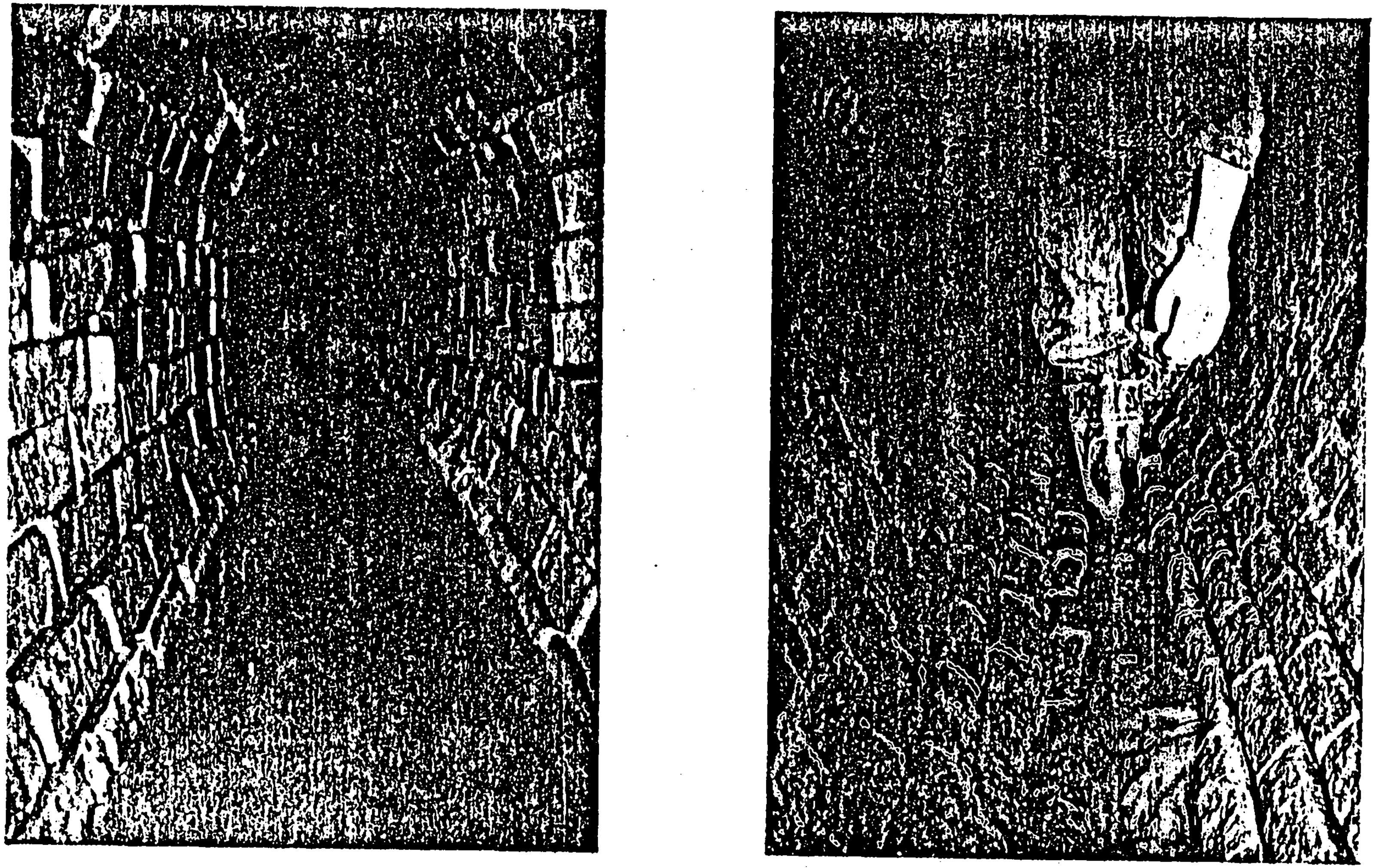
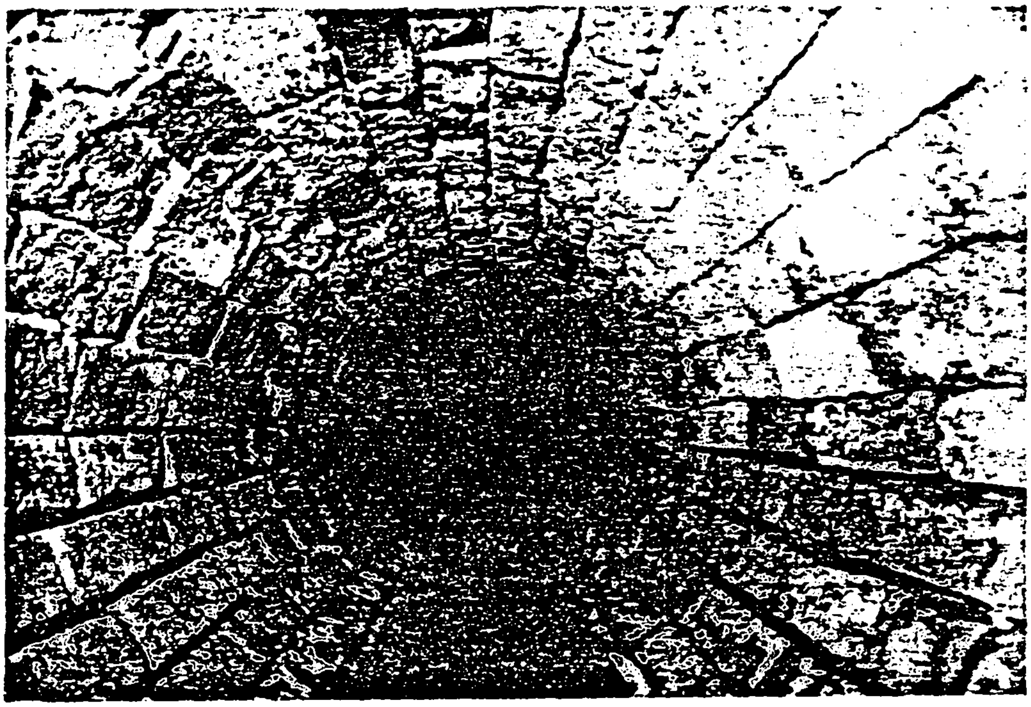


Fig. 1. Condition of sewers (Courtesy Transport and Road Research Laboratory)



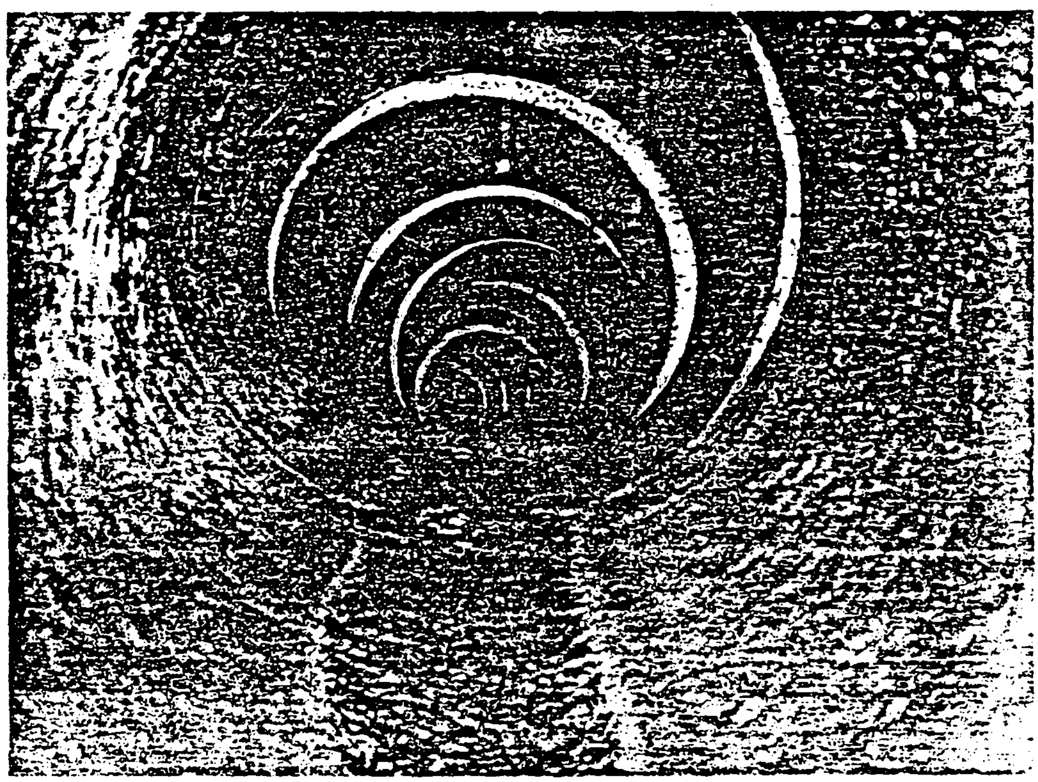


Fig. 1. (continued) Condition of sewers (Courtesy Transport and Road Research Laboratory)

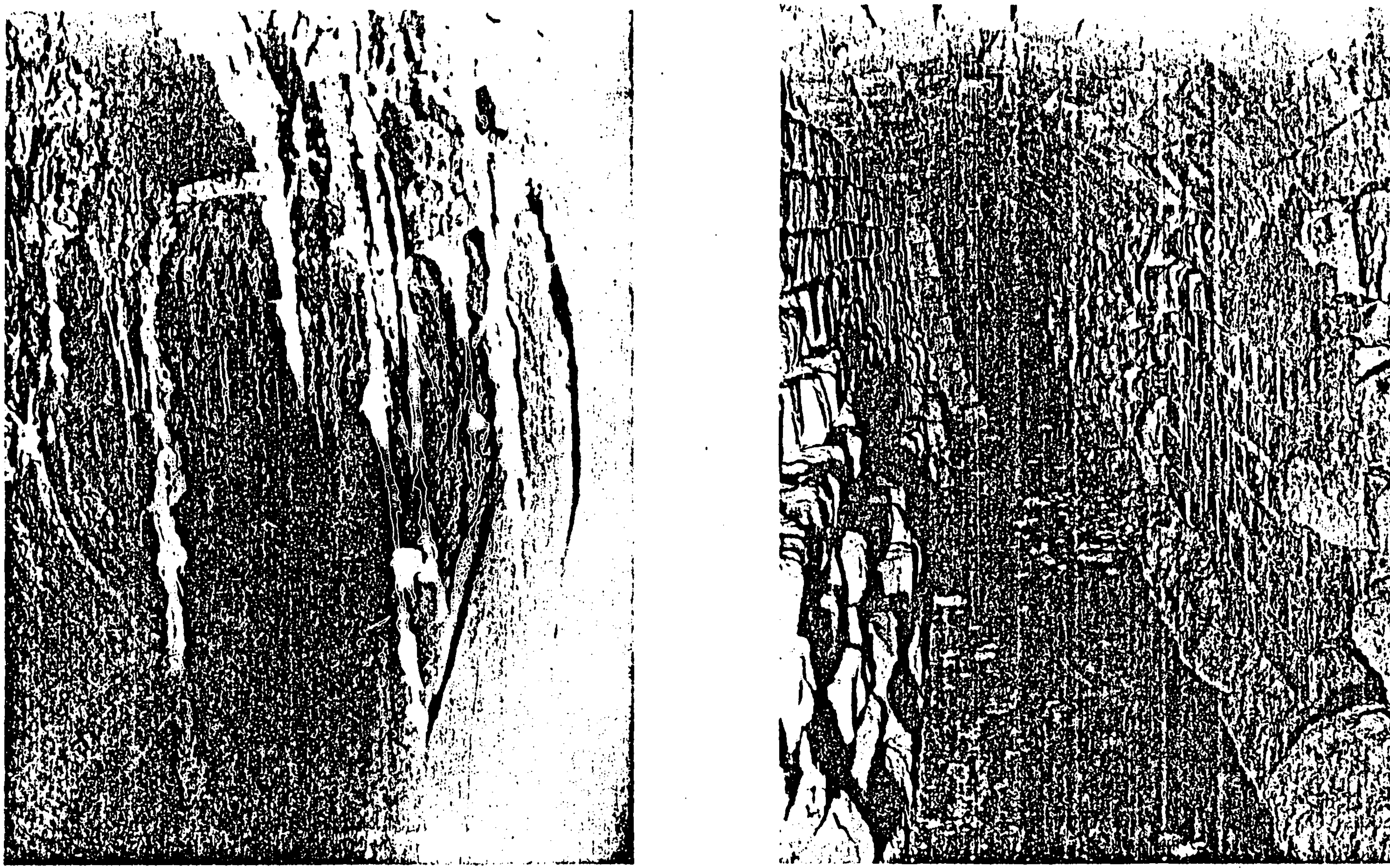


Fig. 1. (continued) Condition of sewers (Courtesy Transport and Road Research Laboratory)

2. SCALE OF THE PROBLEM: A NATIONAL ASSESSMENT

Many of the main arteries of our sewerage networks, in both towns and cities, date back to the middle of the nineteenth century.

The total length of sewer in the United Kingdom is estimated at 234 000 km.

If sewers are considered to fall into three principal size categories the breakdown is as follows:

1.	Sewers greater than 1000 mm diameter	5%	11 700 km
2.	Sewers 300 mm to 1000 mm inclusive	25%	58 500 km
3.	Sewers less than 300 mm diameter	70%	163 800 km

For the purpose of maintenance and renovation those with diameters of 1000 mm and above are considered as man-entry sewers with reasonable working space.

Sewers with diameters of 600 mm to 1000 mm are also considered to be man-entry but the restricted space allows only simple operations and inspection to be carried out.

It is extremely difficult to put an accurate figure on the value of the buried assets but the cost of renewing all of the public sewers has been estimated at £19 000 000 000 (January 1975)*.

A simplified estimate of the required annual expenditure to renovate and renew our existing system of sewers is £139 000 000, an amount which is well in excess of what is actually spent.

A number of visits were made to see man-entry sewers in various parts of the country by WRC and TRRL staff. As a sample this number is unfortunately very small, but the impression gained is one of neglect. If this sample is representative of the whole then the backlog of work is enormous. Unless something is done to increase the effort to renovate them, and the money found to enable the work to be done, the outlook will be extremely bleak.

A survey carried out by WRC, again only a small sample, indicated an almost total lack of planned inspection. Shortage of both personnel and money was blamed for the fact that only a breakdown maintenance policy was performed.

The same survey also indicated that generally renewal is chosen in preference to renovation. Often the only time that renovation is considered is when it is impossible or highly undesirable to excavate to lay a new pipe.

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*NWC/DOE Standing Technical Committee Report No.4.

3. DEFINITIONS

The definitions of maintenance, renovation and renewal are taken from the NWC/DOE report 'Sewers and Water Mains, a National Assessment'. Throughout this review a distinction will not be drawn between maintenance and renovation; any method which improves or utilises the existing sewer will be referred to as renovation.

3.1. MAINTENANCE - The systematic inspection and cleaning of a sewer including minor repairs but not involving reconstruction of the main structural fabric or alteration of the original dimensions. Maintenance includes joint repair, renewal of inspection covers, step irons, etc. and sealing of cracks when the structural fabric is not impaired.

3.2. RENOVATION - The operation of effectively improving the condition of an existing sewer by *in situ* techniques such as will provide for a substantially increased life. Renovation may or may not improve the structural strength of the pipeline.

3.3. RENEWAL - The reconstruction of the whole structure of a sewer as an entity to the same dimensions as the original pipeline but not necessarily in the same position.

3.4. REPLACEMENT - The construction of a new sewer either in the same location as the original or in a new location so that the fundamental purpose of the original sewer will be incorporated in the functions of the new conduit. Replacement can include a proportion of improvement or development work.

3.5. MAN-ENTRY SEWERS - A sewer of 1000 mm diameter or greater is considered to be sufficiently large for internal maintenance and renovation to be carried out. Sewers from 600 mm to 1000 mm diameter may be entered but the restricted space allows only simple tasks or inspection to be carried out.

3.6. NON-MAN-ENTRY SEWERS - A sewer of less than 600 mm diameter is considered as non-man-entry.

3.7. STRUCTURAL RENOVATION - A method of sewer renovation which does not require the existing sewer to assist it in supporting the ground loading. In general this applies to pipes which could be laid as sewers in their own right.

3.8. NON-STRUCTURAL RENOVATION - Methods which do not stand by themselves but augment the structural strength of the existing sewer are considered as non-structural. Generally the combination of the original sewer plus a non-structural renovation method plus pressure grouting forms a whole which is structurally strong.

4. SEWER CONDITION: FAULT CLASSIFICATION

4.1. FAULTS AND CAUSES

A service failure in a sewer is very quickly brought to notice by the resultant surcharging or flooding. This is not necessarily the case with structural failure as crushed, partly-collapsed pipes may still operate for years in this condition. The latter situation is often only discovered by visual inspection in man-entry sewers, or television inspection or flow monitoring in the smaller diameter pipes.

It is possible to divide the faults referred to in this section into structural or service conditions, but for the purpose of this report this division is not made as maintenance or renovation is required in all cases to extend the life of the sewer by a reasonable factor.

The following list includes the major contributory factors to sewer failure. Where it is applicable the classification and definition of faults is that recently compiled by TRRL and WRC.

Service failure		Sewer fault
Complete failure	caused by	Total collapse
Local flooding Flooding at treatment works and pumping stations Voidage/subsidence/cave-in	caused by	Infiltration
Pollution of groundwater	caused by	Exfiltration
Repeated blockage	caused by	Cracks Leaking joints Fractures Breaks Deformation Collapses Displaced joints Open joints Root penetration Badly made connections Badly designed bends or intersections
Smell and corrosion problems Flooding	caused by	Slack or zero gradients
Corrosion attack	caused by	Aggressive effluents
Surcharging Flooding	caused by	Undersized pipes

4.2. DEFINITIONS OF TERMS USED IN FAULT CLASSIFICATION

Cracked pipe	-	crack lines visible along the longitude and/or circumference of a pipe, with the pieces still in place
Fractured pipe	-	cracks opening visibly along the longitude and/or circumference of a pipe with the pieces still in place
Broken pipe	-	pieces of a pipe along its longitude and/or its circumference visibly displaced or missing
Deformed pipe	-	a pipe which is extensively broken and out of round
Displaced joint	-	the spigot of a pipe is not concentric with the socket of the adjacent pipe
Collapsed pipe	-	a pipe which has lost all of its structural integrity and flattened out
Open joint	-	the longitudinal displacement of adjacent pipe sections.

5. RENOVATION METHODS

5.1. TYPES

A - Pointing, pressure pointing
B - Cement grouting
C - Chemical grouting
D - Sealing and waterproofing compounds
E - Lining with pipes
F - Lining with segments or panels
G - Slip lining with thermoplastic tubing
H - Flexible linings
I - Coatings

5.2. SELECTION

Type of Fault	Man-Entry Sewers (Over 1000 mm)	Man-Entry Sewers Limited Working Space (600 mm - 1000 mm)	Non-Man-Entry Sewers (Under 600 mm)
1. Cracked pipe/ leaking joints	B,C,D	B,C,D	B,C
2. Fractured pipe	B,C,D,E,F,G,H	B,C,D,E,G,H	B,C,G,H
3. Broken pipe	E,F,G,H	E,G,H	G,H
4. Deformed pipe	E,F,G,H	E,G,H	G,H
5. Displaced joint	B,C,E,F,G,H	B,C,E,G,H	B,C,G,H
6. Open joint	B,E,F,G,H	B,E,G,H	B,G,H
7. Corroded pipe	I	I	I
8. Abraded pipe	I,F	I,F	I
9. Open joints in brick sewers	A,B,D	A,B,D	B
10. Structurally unsound brick sewers	E,F,G,H	E,F,G,H	G,H

5.2.1. Notes on selection of renovation method

Before the selection can be made the severity of the fault requires assessment. This may be extremely difficult if it is based solely on one survey. Ideally, the answers to the following questions should be available before a decision is made.

Is the pipe in an equilibrium state? (For example, it has been cracked for some time but it is not worsening.)

Is the pipe in a transition stage? (For example, it has cracks that may soon become fractures or fractures that may become breaks.)

What has caused the transition? (If this cannot be assessed the renovation may not prevent eventual failure.)

The following comments on each fault type provide additional guidance on method selection.

5.3. CRACKED PIPE AND/OR LEAKING JOINTS

Cracks may vary from 'hairline' to approaching a fracture. Cementitious materials will not penetrate hairline cracks so chemical grouts must be used if it is thought necessary to seal them. However, if there are many hairline cracks a complete cement mortar lining may be the answer.

5.4. FRACTURED PIPE

Assuming that a fracture is a large crack but the pipe is not necessarily structurally unsound, sealing or grouting may be adequate. If the fracture is assessed as severe and therefore approaching the 'broken' category, a lining method will be necessary.

5.5. BROKEN PIPE

A structural lining method is essential.

5.6. DEFORMED PIPE

A lining method may be used but the deformation will mean a loss of capacity. A method such as 'Insituform' has the advantage that it will tailor itself to the deformed shape.

5.7. DISPLACED JOINT

The degree of displacement will guide the decision. Slight displacement may be overcome by grouting techniques whilst more severe displacement may require a lining. A loss of capacity will again be the penalty of using a rigid pipe.

5.8. OPEN JOINT

Severity is again the deciding factor. Grouting methods will suffice for less severe cases but lining systems may be required. A large loss of capacity will be unavoidable if there is a large degree of misalignment.

5.9. CORRODED PIPE

The cause of any corrosion must be established so that the correct measures may be taken. A slack gradient may result in hydrogen sulphide attack which occurs above the flow line. If the attack is not severe a coating system may be used. Severe damage to the pipe may require a lining method but, whichever solution is adopted, all the corroded material must be removed and the pipe flushed out or the corrosion may continue under the new surface.

Corrosion attack by aggressive industrial effluents will be in the invert. A coating system may solve this problem although severe damage may require a new invert section or a complete lining using a material capable of resisting further attack.

5.10. ABRADED PIPE

Badly worn inverts may be coated, lined or replaced, depending on the cause and the severity.

5.11. OPEN JOINTS IN BRICK SEWERS

This assumes structural integrity, in which case replacement of the lost joint material is all that is necessary.

5.12. STRUCTURALLY UNSOUND BRICK SEWERS

Any lining material may be used that will provide adequate ground support after installation.

6.1. TYPE A. POINTING AND PRESSURE POINTING

The loss of joint integrity due to ground movement, aggressive effluents, root penetration or abrasion, can result in infiltration or exfiltration. Infiltration accelerates the process by washing in fines from outside the sewer and causing the additional problem of voidage. Small cracks, although not necessarily detrimental to the structural integrity of the sewer, may also manifest themselves in the same way.

Assuming that there are no other problems which may affect the service condition, namely that the sewer is sufficiently large and of good design, with well made connections and a good line and gradient, all that is necessary to increase its useful life is to restore the jointing material and fill any cracks and voids.

6.1.1. Pointing

Many of the old man-entry sewers were constructed in brick, with lime mortar jointing material. In many cases the original pointing has deteriorated and continuous neglect has, in some cases, resulted in the complete loss of the joint material allowing the brickwork to squat, making renewal of the jointing material impossible. Where this is not the case it is necessary to rake out the old pointing mortar, to a depth of at least 25 mm, and to repoint by hand. This is a time-consuming job which is possibly acceptable for short lengths carried out as routine maintenance. Where large sections of brick man-entry sewers require attention pressure pointing is faster and more efficient.

6.1.2. Pressure pointing

Pressure pointing is a mechanical method of applying pointing mortar. The equipment, which is operated inside the sewer, consists of a mortar hopper, constant delivery pump, hose and a pelletising gun. The apparatus, which is driven by compressed air from the surface, achieves good penetration and high adhesion in the joints (see Fig. 2). The repointing may be hand finished or 'bagged' off to give reasonable flow characteristics.

Pressure pointing is preceded by raking out the joints to a minimum depth of 25 mm and washing out to remove dirt and all loose debris from the joints. High-pressure water jetting is a very efficient method of doing this, but care must be taken as too powerful jets may cause a collapse.

Often the infiltration through the joints of brick sewers causes voids outside the barrel and these require grout filling to prevent further cavitation, subsidence or road collapse. In man-entry sewers this may be achieved by pressure grouting through holes drilled in the barrel of the sewer, an operation which may be safely accomplished after completion of repointing.

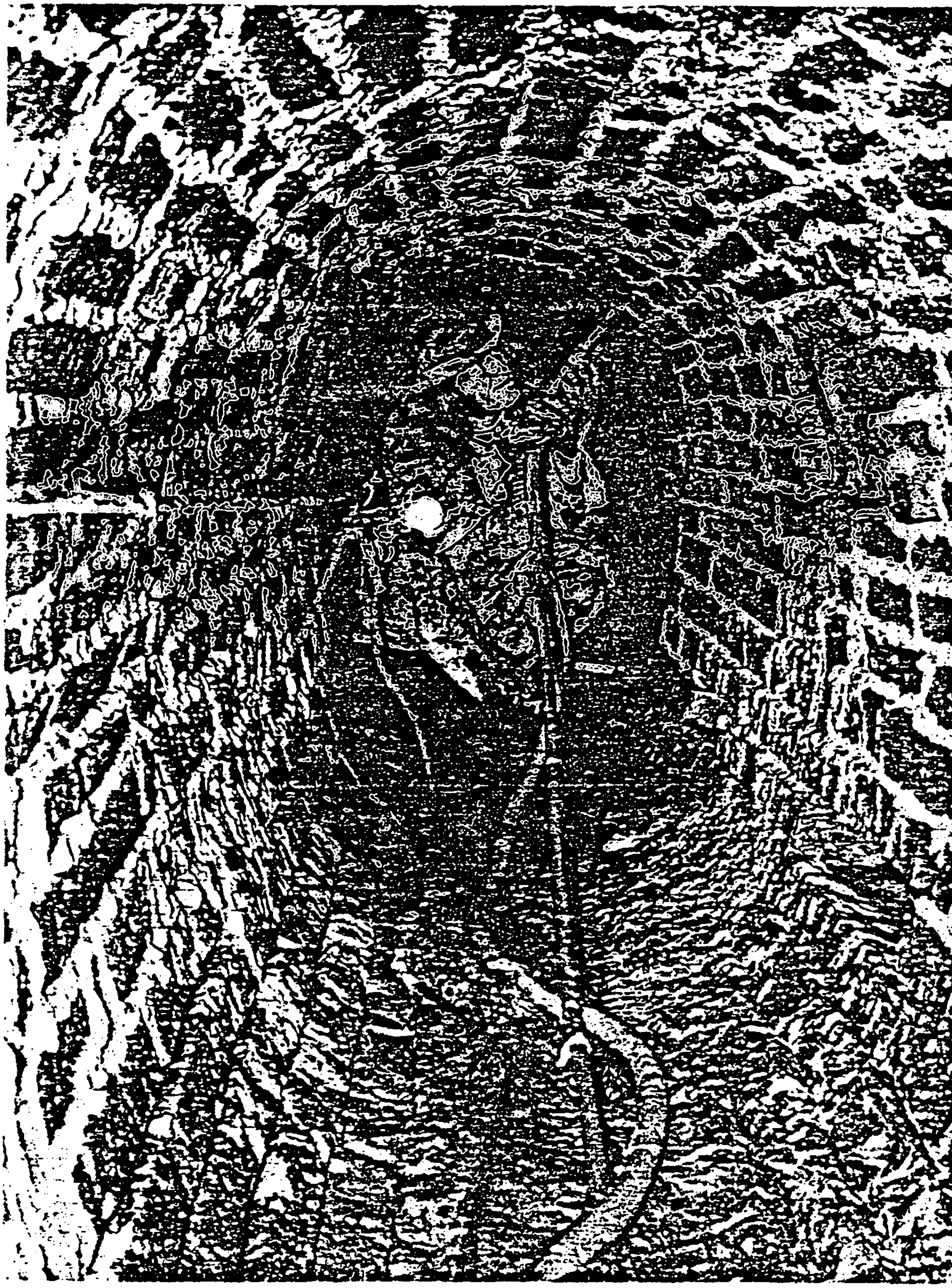


Fig. 2. Pressure pointing (Courtesy Transport and Road Research Laboratory)

In non-man-entry sewers, void filling may be accomplished by injecting grout from the ground surface.

6.2. TYPE B. CEMENT GROUTING

Ordinary Portland cement is still used widely as a renovation material. It may be used to fill cracks and voids or to provide a complete lining which can be cast or applied in particle form at high velocity. A range of admixtures are available to enhance its properties or control the curing time. Composite materials are also possible using fibres and the use of these materials is a project in hand at WRC.

The following methods are those which are readily available for sewer renovation.

6.2.1. Cement grout applicator

A unique method of applying a cement grout, which is possibly one of the oldest systems in use today, is shown in Fig. 3. A device similar to the one illustrated, used by Economic Drain Repairs Ltd. was invented 80 years ago.

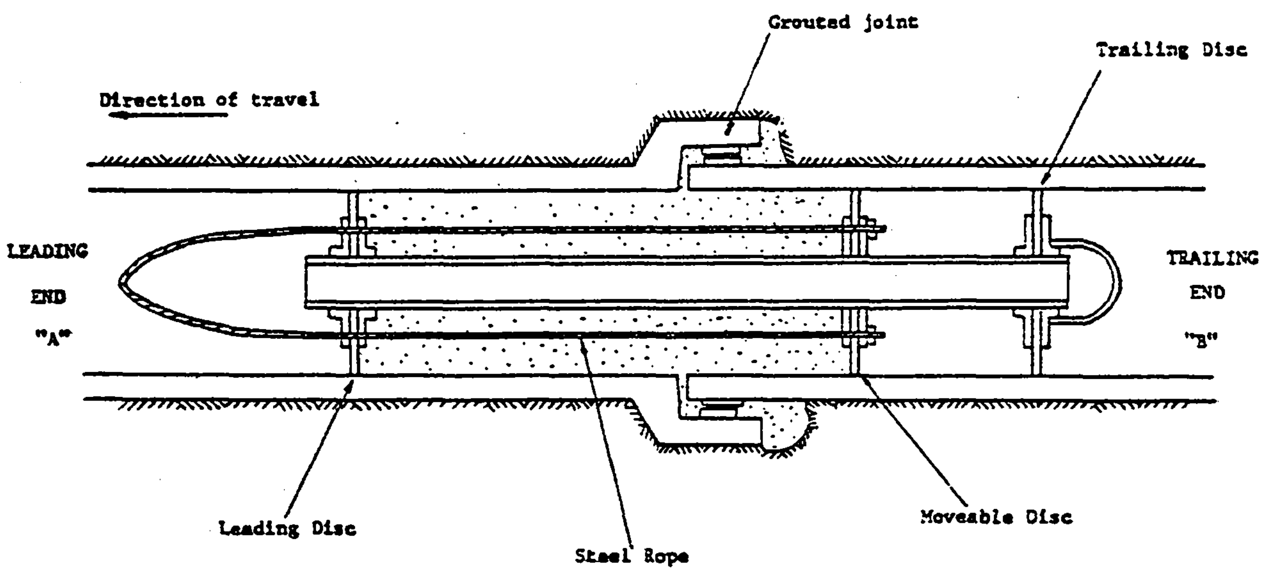


Fig. 3. The 'Squeeze Box' – Australian grouting device

The device shown in Fig. 3 is in use in Australia although there is no known connection between it and Economic Drain Repairs Ltd.

The equipment is very simple and consists of solid flexible rubber seals which are an oversize fit in the sewer. Cables are attached to the seal rings in such a way that pulling on them draws the rings together. Cement grout is placed between the rings so that as the assembly is pulled back and forth through a section of a sewer, the action pumps the cement grout into any cracks or leaking joints. Obviously a degree of expertise and team work is required before the two men operating the device achieve maximum efficiency. The operation is repeated until refusal. The oversize rubber seals are self cleaning and ensure no surplus cement remains in the sewer.

Advantages	-	Cheap, readily available sealing material
	-	Cheap, simple equipment
	-	No reduction in capacity
Disadvantages	-	Only suitable for small bore drains and sewers (100 mm, 150 mm and 225 mm)
	-	Not suitable where infiltration is actually flowing
	-	Flows must be diverted.

6.2.2. Reinforced cement mortar lining

If an expanding mandrel such as a Contiduct, manufactured by Cufflin Ductube Ltd, is supported with suitable spacers, and a cylinder of reinforcing mesh is spaced centrally in the annulus, filling this annulus with cement mortar produces a reinforced concrete lining in the sewer. After an initial curing period the Contiduct is collapsed and drawn through to the next section.

Advantages	-	Uses cheap material
	-	Equipment relatively simple
	-	Can be used in non-man-entry and man-entry sewers
Disadvantages	-	Inflow or infiltration is unacceptable
	-	Flow must be diverted
	-	Sealing section ends is a problem
	-	Successful application of pumped mortar requires a great deal of expertise.

6.2.3. Hand spraying - Gunite/Shotcrete

This method is only suitable for large man-entry sewers as it is a very dusty operation. The dry mix is pumped down from the ground surface and is only combined with water at the point of exit from a special gun. This allows cement mortar particles to be applied at high velocity, impinging on the pipe surface to form a dense, well-compacted lining. Structural strength is achieved by placing a steel reinforcing mesh with suitable spacers. See Fig. 4.

Advantages	-	Cheap material
	-	Produces a jointless lining
	-	Simple to produce with suitably trained labour
Disadvantages	-	Only suitable for large man-entry sewers
	-	Degraded material continuously collects in the invert and has to be removed. A pre-cast concrete invert section overcomes the possibility of failure due to degraded materials.
	-	Infiltration is unacceptable
	-	Flows must be diverted
	-	It is difficult to produce a smooth finish as too much trowelling tends to pull the Gunite coat away from the surface.

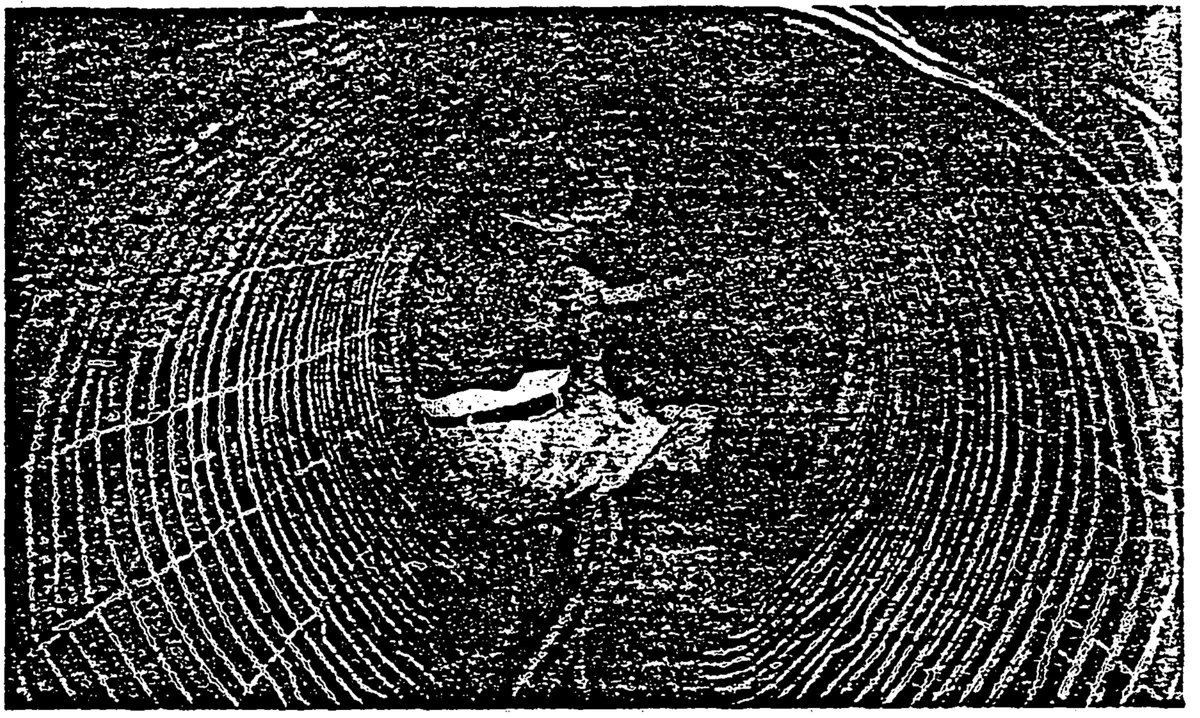


Fig. 4. Gunite spraying (Courtesy William F. Rees Ltd)

6.2.4. Centrifugal spraying

Cement mortar lining has been used in the water industry in newly manufactured pipes for over half a century and renovation in situ has been successfully carried out for forty years. It differs from Guniting in that the mix is prepared on the surface and pumped wet to the lining machine. The lining machine may be powered by high-velocity air or electrically driven. A number of radial blades are attached to the head so that cement mortar exuding from the delivery pipe is sheared off and thrown by centrifugal force against the walls of the pipe (Fig. 5). Lining machines exist for pipe sizes from 75 mm diameter up to large man-entry sewers.

Lining small diameter pipes has to be remotely controlled, the machine being winched through. The machine used for large diameter sewers has a driver who controls the operation.

Rotary or drag trowels are available which produce a reasonably smooth finish. In the untrowelled state, the surface finish resembles an orange peel which is how it is described.

Advantages
- Possibility of working from existing manholes
- Suitable for all sewer sizes
- Cheap material
- Sewers with lateral connections could probably be lined without excavation. Some remote device may be necessary to improve the side connections but this should be relatively straightforward

Disadvantages
- Infiltration cannot be tolerated
- Flow must be diverted
- Non-structural - only suitable for sealing. (This may be overcome, see Section 9.)

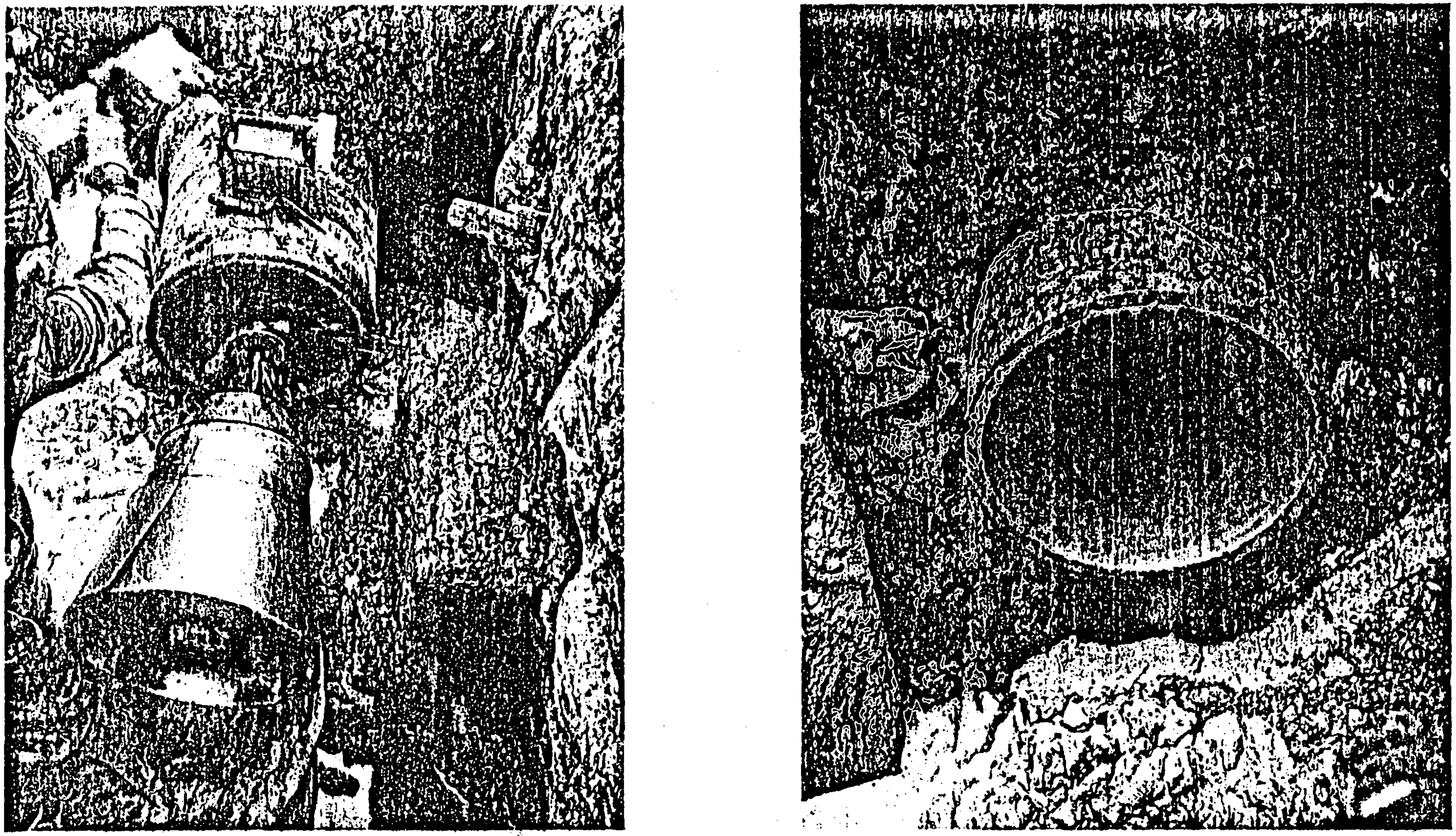


Fig. 5. Cement mortar lining

6.3. TYPE C. CHEMICAL GROUTING

It has been estimated that 70% of the public sewers in England and Wales are under 300 mm diameter. Leaking joints and small cracks in these non-man-entry sewers are likely to be the main sources of infiltration and there have been major advances in equipment and materials in recent years for sealing them by remote control.

Chemical grouts were first developed as soil stabilisers, having the characteristics of low viscosity, good adhesion, quick and controllable setting. The following are the better known sewer grouts.

6.3.1. AM9 Chemical Grout (American Cyanamid Company)

AM9 chemical grout is a mixture of two organic monomers - acrylamide and N,N' - methylenebisacrylamide in proportions which produce very stiff gels from dilute aqueous solutions when properly catalysed. The process by which gelation occurs is a polymerisation-crosslinking reaction. A number of catalysts and mixtures of catalysts may be used to gel AM9. For normal use the catalyst system is composed of catalyst DMAPN (β - dimethylaminopropionitrile), ammonium persulphate, and potassium ferricyanide.

The aqueous solution has a very low viscosity so that when it is applied under pressure it permeates through cracks and joints and into the material surrounding the pipe. Gel time is controllable and may be as short as four seconds. The grout forms a white jelly-like substance which, when combined with the material surrounding the pipe, forms a stabilised impervious collar.

Under conditions which allow water to evaporate, AM9 gels will gradually dehydrate and shrink. Re-swelling to the original volume will occur if the gel is rewetted. Under moist conditions the gel appears unchanged after several years in the ground. The longest known period of use is one which was excavated in the USA after 15 years.

Development of this chemical grout has been in parallel with the development of the remote application equipment.

The system has now reached a fairly high degree of sophistication. The application equipment plus closed circuit television is housed in a special purpose van to form a very compact unit (Fig. 6).

The procedure is to work from manhole to manhole using a winch to tow the packing device and CCTV camera. The packing device (Fig. 7) is a steel body with inflatable collars at either end. The packer is placed to straddle a joint using the CCTV to locate it. Once in place the collars are expanded and the joint is isolated from the rest of the pipe.

Fig. 6. Chemical grouting unit (Courtesy William F. Rees Ltd)

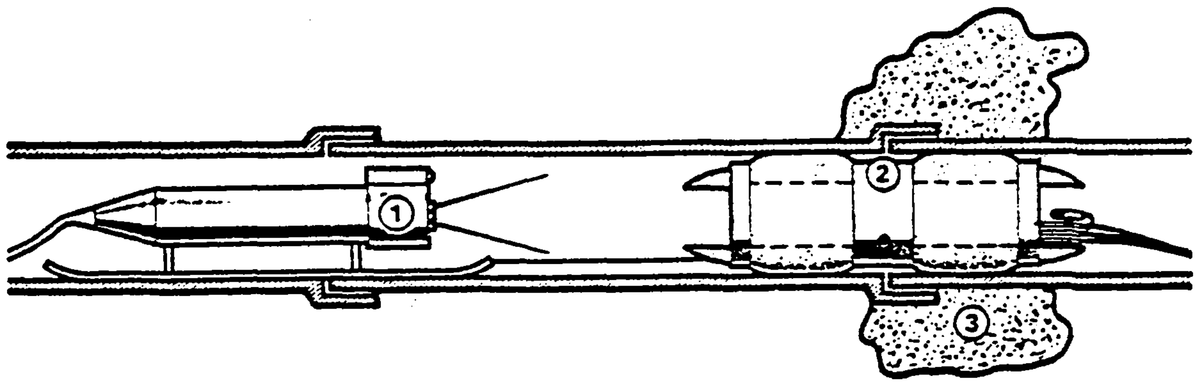


Fig. 7. AM9 Chemical grout packer (Courtesy William F. Rees Ltd)

The annulus between the collars is pressurised to air test the joint; if it fails, the chemical grout is pumped into the same annulus so that it is forced under pressure through the joint and out into the pipe bedding. The chemical is continupusly pumped until an acceptable back pressure is achieved. The fast gel time prevents groundwater from re-entering the joint after the pressure is repeated and the sealed joint is again air tested.

Advantages	-	Operation is carried out from existing manholes
	-	The chemical grout may be used to seal leaking manholes or leaks in large man-entry pipes
Disadvantages	-	It is expensive, especially if large voids exist
	-	Work can only be carried out by specialist contractors
	-	Flows must be diverted.

6.3.2. Elastomeric Chemical Grout (New Business Ventures Division, 3M Company)

The chemical is a hydrophilic polymer with the appearance of a medium grade motor oil. When it is combined with water containing a special accelerator it expands 10 to 12 times its original volume and cures to a flexible, cellular, rubber-like material.

Cure times range from 15 minutes at 4°C to 4.6 minutes at 37°C although the addition of a second accelerator will reduce these times to 5.5 and 2.6 minutes respectively.

The material is also available with added herbicide root inhibitor and two years' protection is claimed.

Resistance to most organic solvents, mild acids and alkalis is claimed.

Its advantage is its flexibility, an elongation of 700 to 800% is claimed and it returns to its original shape after repeated deformations.

The equipment used to place the grout in the joints of non-man-entry sewers is very similar to that which is used for AM9 (see Fig. 8) and therefore the procedure is also similar. The main difference is that a measured quantity of grout is applied to each joint and the foaming action takes place in the annulus between the two expansion collars. The centre of the packer is then expanded, forcing the foamed grout into the joint recess. An advantage over AM9 is that a more accurate estimation of cost may be made at the outset.

The cure time is longer than with AM9 but the application time is slightly reduced.

Equipment is also available for joint sealing in man-entry sewers (Fig. 9).

Hand injector tools are available to repair longitudinal cracks in man-entry sewers or in manholes.

An extension to the use of this chemical grout is known as Activated Oakum. Jute oakum is soaked in the 3M compound and used as a packing material for joints and cracks. The addition of water containing an accelerator causes the foaming reaction which quickly expands the compound to form an effective gasket.

Both AM9 and 3M Elastomeric chemical grouts require expensive application equipment. This equipment, which comprises holding tanks for the chemicals, special metering and pumping units and closed circuit television is usually housed in a special purpose vehicle. This, combined with experience, is an essential requirement if successful results are to be achieved.

Advantages	-	Similar to those for AM9
	-	Additional advantage is that is is not dependent on soil type
Disadvantages	-	The work can only be carried out by specialist contractors
	-	Flows must be diverted

6.3.3. Resin grouts

Resin grouts require less special purpose equipment than the other chemical grouts. The Geoseal range produced by Borden (UK) Limited has been developed for soil stabilisation as was AM9. It is in a powder form and requires only to have water added in the specified ratio.

Gel time is dependent on the concentration and temperature and is relatively slow, even with an accelerator added, compared with the other chemical grouts.

For this reason, the technique in small diameter sewers is to fill the sewer with grout using a header pipe to supply sufficient pressure for satisfactory penetration. Just prior to the grout gelling the surplus must be pumped out.

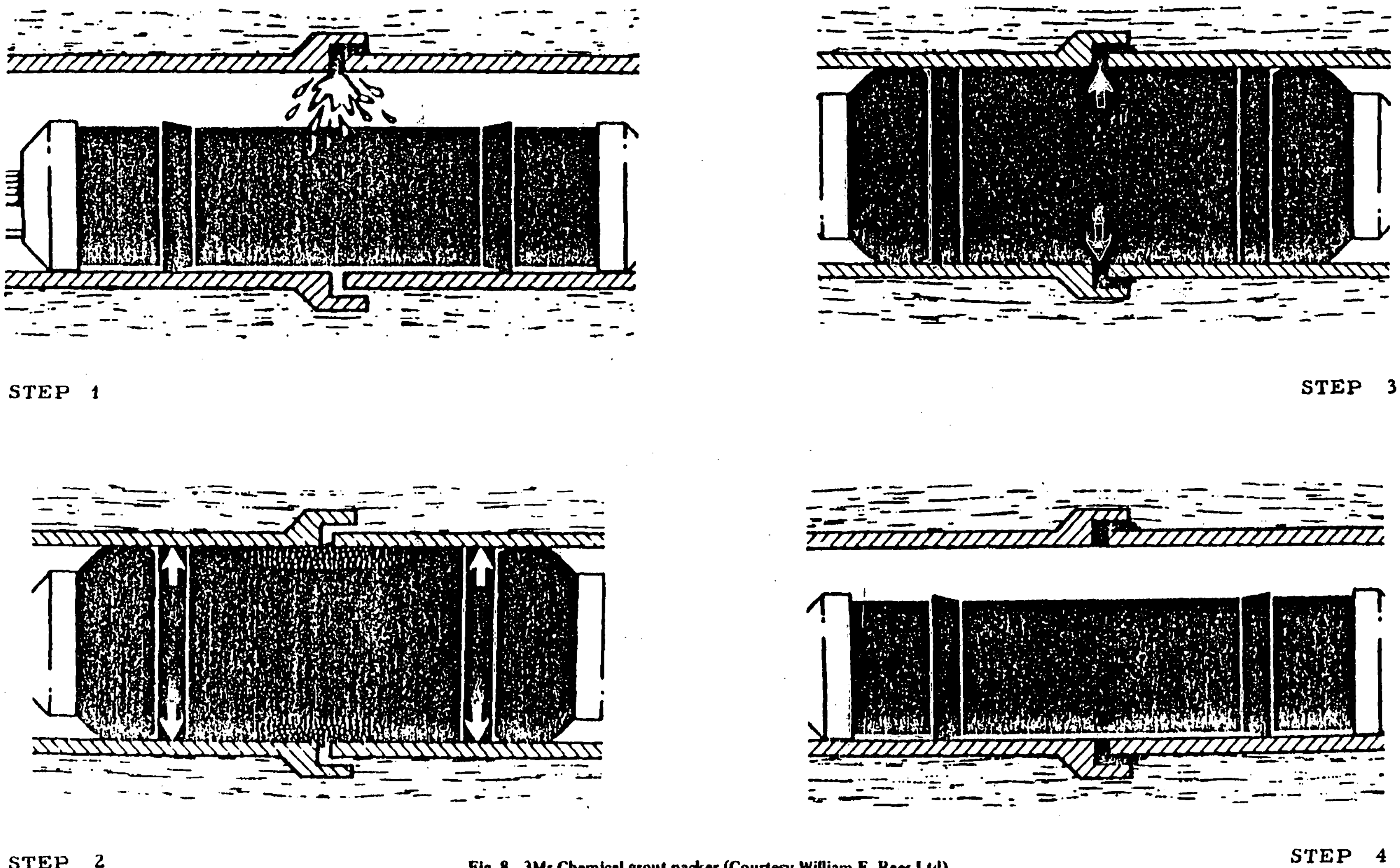
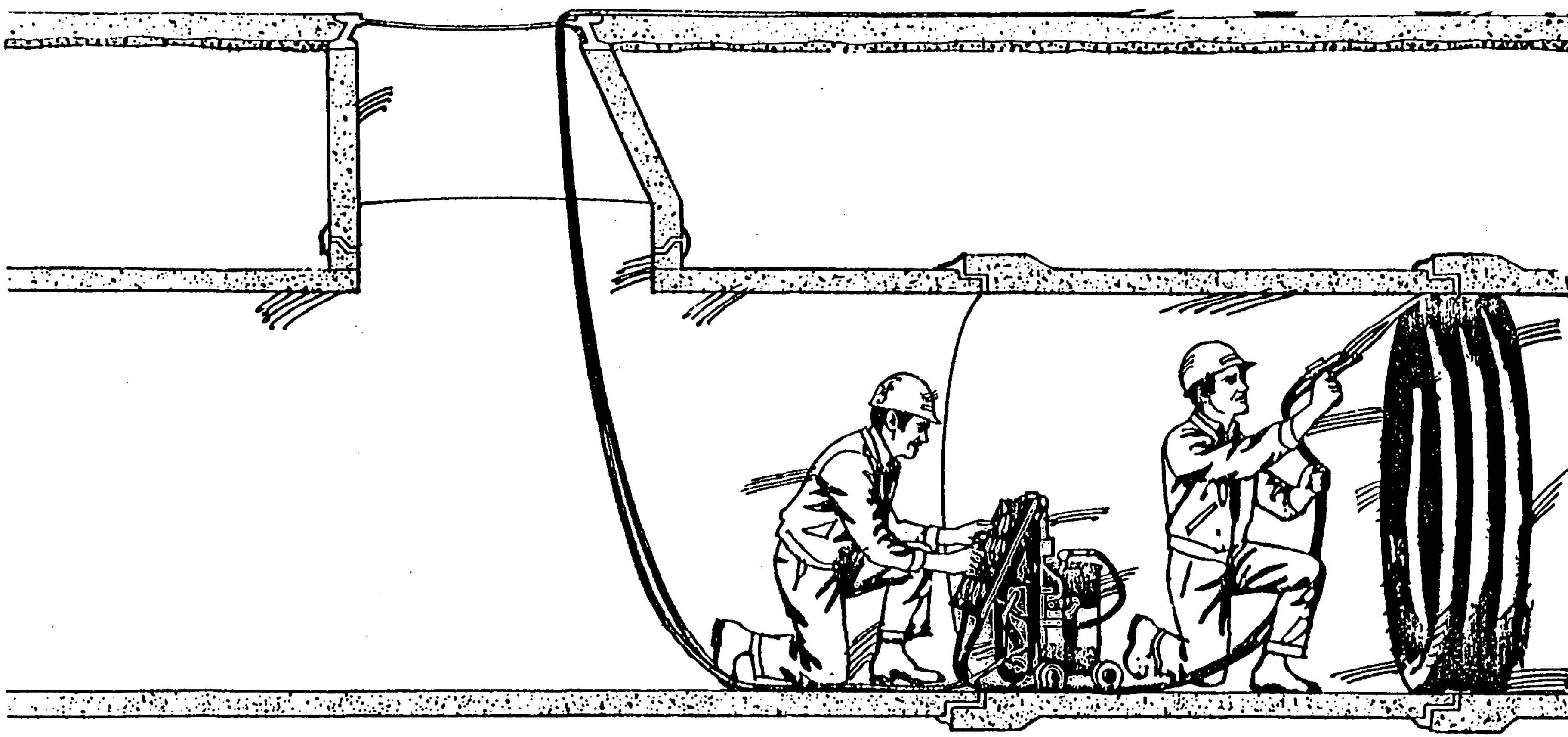
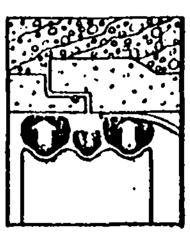
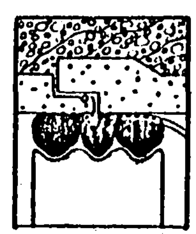


Fig. 8. 3Ms Chemical grout packer (Courtesy William F. Rees Ltd)

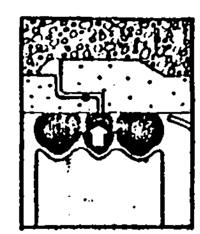




STEP 1
The 3-element packer is positioned at the faulty joint. The injection probe is held as shown while the end elements are inflated to isolate the joint.



STEP 2
Next, the 3M sealant is injected with the probe into the void space between the end elements. The sealant foams and begins to expand.



STEP 3
Finally, the center element is inflated, forcing the sealant deep into the joint. Pressure is maintained until the sealant cures to form a rubberlike gasket.

Fig. 9. Chemical grout sealing in man-entry sewer

All lateral connections must be blocked off but this can be done to each manhole, which allows at least part of the lateral pipe to be sealed at the same time as the sewer.

Advantages	-	House drains can be sealed at the same time as the sewer if the flow is interrupted in the house manhole.
Disadvantages	-	Large quantities of grout are used, so the technique is restricted to the smaller diameters
	-	Flows must be diverted.

6.4. TYPE D. SEALING AND WATERPROOFING COMPOUNDS

A number of quick-setting materials exist which permit leaking joints and cracks to be satisfactorily sealed. Some examples of these materials are as follows.

6.4.1. WATERPLUG is a quick-set hydraulic cement which, it is claimed, will stop fast flowing infiltration in three minutes. This material is manufactured in the USA and marketed in the UK by J. & F. Hewett Ltd.

6.4.2. EXPANDITE-HEYDI SPECIAL is another cementitious quick-set waterproofing material which may be applied in a running water situation. It is claimed to withstand a reasonable head of water but is inflexible and therefore unsuitable where further movement is expected. The material is marketed by Expandite Ltd. The same company also markets, amidst a whole range of concrete repair materials, Epoxocrete which is a two-part, sand-filled, epoxy resin compound developed for the repair of broken and spalled reinforced concrete and may be applied under water.

6.4.3. SILVERLOCK is the BTR Development Services Ltd trade name for a range of underwater curing, epoxy resin compounds. The advantage over cementitious materials is their ability to bond to most materials.

6.4.4. COLEBRAND LTD also produce a range of resin compounds suitable for crack and joint sealing. It is not practicable to list the numerous resin formulations so it is recommended that crack sealing problems in man-entry sewers are discussed with the manufacturers.

6.5. TYPE E. LINING WITH PIPES

A sewer with space capacity, and which is probably of large diameter, may be treated simply as a tunnel through which a new pipe may be laid. However, it is essential that the annulus is grout filled to provide adequate ground support.

Where it is necessary to use as much of the original sewer capacity as possible the requirement for thinner wall pipes becomes greater. The following plastics and composite materials may be used to meet this requirement.

uPVC	-	Unplasticised polyvinyl chloride
RPM	-	Reinforced plastic mortar
GRP	-	Glass reinforced plastic
GRC	-	Glass reinforced concrete

6.5.1. uPVC

uPVC pipe may be laid with flexible joints if there is sufficient space. If this is not the case, simple solvent-cemented sleeve joints may be used.

An example of this method was a relining of a 750 mm diameter brick barrel with a standard 558 mm inside diameter uPVC pipe. The section was 240 m long and had more than 50 side connections which were made good as the work progressed.

6.5.2. Reinforced plastic mortar (RPM) pipe

RPM pipe is a composite structure of polyester resin mortar - reinforced with continuous glass fibre filaments. It is resin enriched at the inner surface (and outer if required) to provide good chemical and abrasion resistance. The pipe is now manufactured in the UK by Stanton and Staveley. It was first introduced as Techite by Amoco Reinforced Plastics in the USA. RPM standard pipe is manufactured in 20-foot lengths (6.13 m) in a size range 8 inches (200 mm) to 54 inches (1370 mm) inside diameter. A conventional type socket and spigot joint with a Neoprene 'O' ring is used.

If this standard pipe is used as a sewer lining the minimum loss of diameter would range from 2½ inches (63.5 mm) for an 8-inch pipe (200 mm), to 6 inches (150 mm) for the 54-inch pipe (1370 mm).

A special liner pipe is also produced with inverted socket and spigot ends (Fig. 10) which allow the outside diameter to be constant throughout, thus maximising the utilisation of the existing pipe.

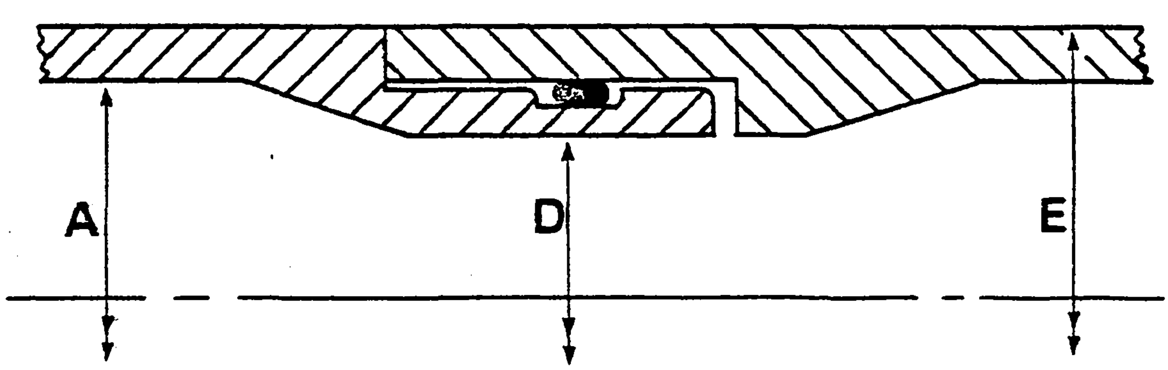


Fig. 10. RPM inverted bell and spigot pipe joint

The following sizes of liner pipe are manufactured (dimensions are in inches):

NOMINAL INSIDE DIAMETER A	18	21	24	27	30	33	36	39	42	45	48	51	54
INSIDE DIAMETER OF JOINT D	16.36	19.36	22.44	25.44	28.44	31.01	34.01	37.01	40.01	43.01	46.01	47.95	51.8
OUTSIDE DIAMETER OF PIPE E	19.0	22.0	25.1	28.2	31.2	34.3	37.4	40.4	43.5	46.6	49.7	52.8	56.0

From Fig. 10 it can be seen that the Neoprene ring does not support the thrust on the pipe for lining purposes. It is also obvious from the diagram that the inverted bell and spigot does reduce the inside diameter at the joint. The pipe is produced on a polished steel mandrel which imparts a very high finish to the bore of the pipe. This gives a smooth finish but is a slippery surface in a walk-through sewer.

As an example of improved flow characteristics, the manufacturer quotes that a 27-inch liner pipe inserted into a 30-inch concrete pipe gave 95% of the original design flow.

Prior to any pipe lining careful inspection after cleaning is essential. A change in section due to distortion or any other obstruction may cause a major problem if it is discovered after lining has commenced.

Three techniques are possible for inserting the liner pipe.

(1) Pushing the suitably protected pipe end into position with a modified backhoe

(2) Towing the liner through the pipe with a winch

(3) Jacking the liner into position with a special purpose machine.

The procedure for any of these techniques is to open up a working shaft; this is usually 30 feet long (9.25 m) × 4 feet (1.23 m) wider than the pipe diameter. The top half of the sewer is removed to the springline; this leaves the lower half to act as a cradle for the liner pipe and as a channel for the flow if the sewer is live.

It is usual to line through intermediate manholes and to cut out the crown of the pipe and make good when the insertion is completed.

If the original sewer is structurally sound it may only be necessary to grout around the pipe in the vicinity of the manholes. If there is any doubt about the integrity of the original structure, complete grouting of the annulus is essential. It may be necessary to give support to the liner during the back-grouting operation. A patented USA technique for supporting the pipe during grouting uses internal air pressure which serves the dual purpose of joint testing.

The USA manufacturer claims that the installation of 5000 feet (over 1.5 km) of liner pipe per day is not uncommon.

Economics of RPM

The USA manufacturers claim that the cost of lining a pipeline with RPM is only 40% to 70% of the cost of replacement. The only evidence to support this claim is in the form of the following case histories, all but one of which are from the USA.

Case history 1 (UK)

The only UK example is the supply, laying and jointing of a 1600 mm internal diameter × 3 m long RPM pipe sections within an existing 1980 mm diameter brick sewer. The total cost of this was £228 per linear metre in January 1977.

Pressure grouting the annulus with 3:1 sand/cement grout cost £79/linear metre.

As it was necessary to lay some sections to curve a number of specials were supplied 1.5 m long with bevelled spigots, at an additional cost of £72.00 each. Some 2.0 m long pipes with straight spigots cost an additional £49.00 each.

Case history 2 (USA)

A 36-inch (900 mm) liner pipe installed in a 42-inch (1050 mm) concrete pipe was inserted by winch, pulling at a rate of 1600 feet/day (500 m). The labour and equipment cost for 2400 feet (740 m) was approximately $2.50/foot ($6.25/m) in 1967. This cost does not include preparation and backfill of the working pit or grouting the annulus.

Case history 3 (USA)

A badly corroded 30-inch (762 mm) concrete sewer was lined with a 27-inch (686 mm) RPM liner pipe. The sewer ran under a busy industrial area of a city. The working shaft was sited midway in the 400 feet (123 m) to be lined. 200 feet (60 m) was jacked in each direction and the closure was made by drawing back one length approximately 2 feet (610 mm). The sewer was live during the installation period and flowing one-third to half full.

The contract price was $12 420 or $33.75/foot ($110/m) compared with the original cost of $62.50/foot ($203.00/m) for the fourteen-year-old pipe (installed in 1954). The estimated 1968 replacement cost was $100.00/foot ($325.00/m).

Case history 4 (USA)

In 1969 5510 feet (1700 m) of 18-inch (450 mm) RPM pipe was installed in a 24-inch (600 mm) concrete sewer 18 feet deep (5.5 m). There were eleven manholes on the lined length.

The entire 5510 feet (1700 m) was inserted from one shaft located at the lower end of the line. A special jacking machine was used and installation was completed in 44 hours. During the installation period the sewer flowed quarter to half full.

The engineers' estimate for open cut replacement was $130 000. Contract price for the liner pipe and installation was $59 838 or $10.86/foot ($35.30/m).

Case history 5 (USA)

In 1969 a 12-inch (300 m) clay pipe 15 feet deep (4.6 m) was lined with 8-inch (200 m) standard bell and spigot RPM pipe. The length lined was 950 feet (292 m). The first 300 feet (92 m) was inserted by two men pushing by hand. The remainder was installed using a hand-operated winch. The cost of the pipe and the installation was $5.00/foot ($16.25/m).

Case history 6 (USA)

An RPM liner pipe 33 inches diameter (838 mm) × 1330 feet long (409 m) was installed in a 36-inch (900 mm) concrete pipe in 1969. The contractor was able to use a jacking machine from a previous job. Three shafts were required as the line was not straight. Special, fabricated pipe L fittings were installed at the angle manholes. The sewer was live during the two working days required to insert 1330 feet (409 m) of liner pipe. The contract price which included the replacement of two manholes was $41 400 or $31.00/foot ($100/m).

The foregoing USA case histories are as supplied by the manufacturer and no attempt has been made to verify them.

6.5.3. Glass reinforced plastic (GRP) pipe liners.

A GRP pipe liner is produced by Redland Pipes Ltd and has the trade name Fibaflow.

Fibaflow liners are manufactured from filament-wound glass fibre reinforced polyester and one of three types of resin: orthophthalic for low duty, isophthalic for medium duty, or vinylester for high duty.

The tube is made by a winding process where raw materials are impregnated with resin and wound in layers. The tube is then heat treated and cut to length.

The size range is 700 mm to 2500 mm inside diameter in 50 mm increments. Lengths are normally 2 to 3 m.

Jointing is by a spigot and socket joint bonded (see Fig. 11) with a two part epoxy jointing compound with filler. The sockets are laminated by hand over a former inserted into one end of the liner barrel.

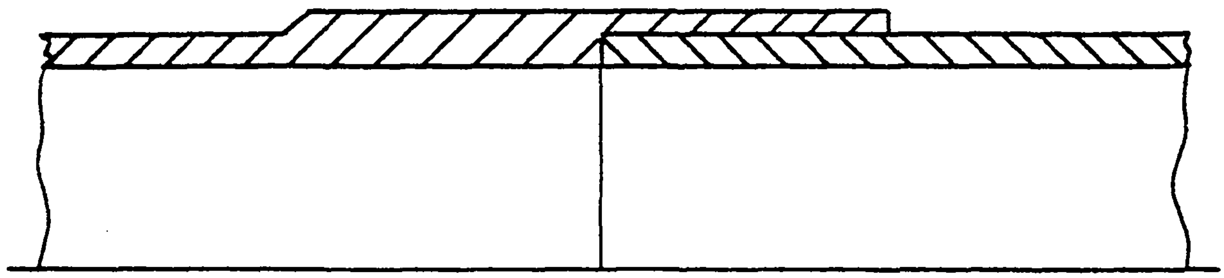


Fig. 11. Fibaflow spigot and socket joint

The manufacturer recommends that prior to installation the existing pipe must be sealed, pumped dry, cleared of silt and debris and made good by filling any cavities. The recommended maximum size for a liner is 100 mm smaller in diameter than the original and not more than 3 m in length. The pipe sections are pushed together using a suitable jack and jointed with the manufacturer's recommended material. During the jointing operation it is necessary to support the liner in its circular shape with timber formers. The formers are left in whilst the annulus is grouted which is preferably done progressively as each section is laid.

The abrasion resistance of Fibaflow linings is claimed to be comparable with other commonly used pipe materials such as uPVC or concrete.

The low duty resin material is adequate for effluents of a standard permitted by the Public Health Act 1936. For effluents of a more aggressive nature or for higher temperatures the higher-duty resin materials should be used. These are resistant to most chemicals and aggressive agents commonly present in effluents and industrial processes but it is recommended that advice is sought from the manufacturer.

A minimum life of 30 years is claimed.

6.5.4. Glass reinforced concrete (GRC) pipes

Glass reinforced concrete is a composite material which combines ordinary concrete with Pilkington's alkali-resistant Cem-Fil glass fibre.

ARC Concrete Ltd have produced a pipe using this material, referred to as Slimline 750. A distinct advantage with this pipe is the flexible joint which is contained within the wall thickness.

6.6. TYPE F. LINING WITH SEGMENTS OR PANELS

Many of the old trunk sewers are man-entry size, constructed of brick and egg-shaped. Pointing or the placement of cement mortars, described in another section of this report, may be adequate for their renovation. If not, for reasons of flow characteristic or strength, there are two alternative courses of action; to line the egg-shaped structure with a round pipe, which involves an enormous loss of area, or to build an egg-shaped pipe within the old, using panels or segments.

Most construction materials can be used such as GRC (glass reinforced concrete), GRP (glass reinforced plastic), 'pre-shot' reinforced Gunite, galvanised steel and stainless steel.

It is essential that the void between the segments and the original structure is properly grout filled to give adequate ground support. Any voids outside the original sewer must be similarly treated, either through the walls or lanced down from the ground above. If there is a risk that the existing structure in in danger of collapse, any external void grouting should be carried out after the lining and internal grouting, because the existing sewer may not withstand the pressure of the grout. The thin wall panels are not structurally strong by themselves and act only as a permanent shutter. It is the combination of panel, grout and original pipe that provides the required structural strength.

6.6.1. Glass reinforced concrete (GRC) linings

Glass reinforced concrete is a composite material of ordinary Portland cement (OPC), or sulphate-resistant cement, either neat or with a fine aggregate filler, and Cem-Fil, an alkali-resistant glass fibre specially develcped for use with OPC.

The material can be produced semi-automatically or hand sprayed on a flat-bed machine. A 5% addition of 50 mm-long glass fibre is added until a thickness of approximately 10 mm is reached. This flat strip is then wrapped around a wooden former which has been made to suit the section of the sewer to be lined.

Egg shapes are usually produced in two sections as shown in Fig. 12. Joints are formed by overlapping strips which are produced by hand whilst the material is still on the wooden mould.

Circular sections are usually made in three parts although this number would be increased for very large pipes. The lining sections are normally 1.2 m long but shorter lengths are possible.

After a seven-day cure the liners are ready for installation. The invert panel is installed first and this is either bedded on cement or supported on wooden blocks. The crown section may then be placed in position and secured at the overlap joints by pop rivetting, self-tapping screws, special expander bolts, or spiked though into the existing barrel. Wooden wedges or props may be necessary to centralise and stabilise the units whilst the joints are secured.

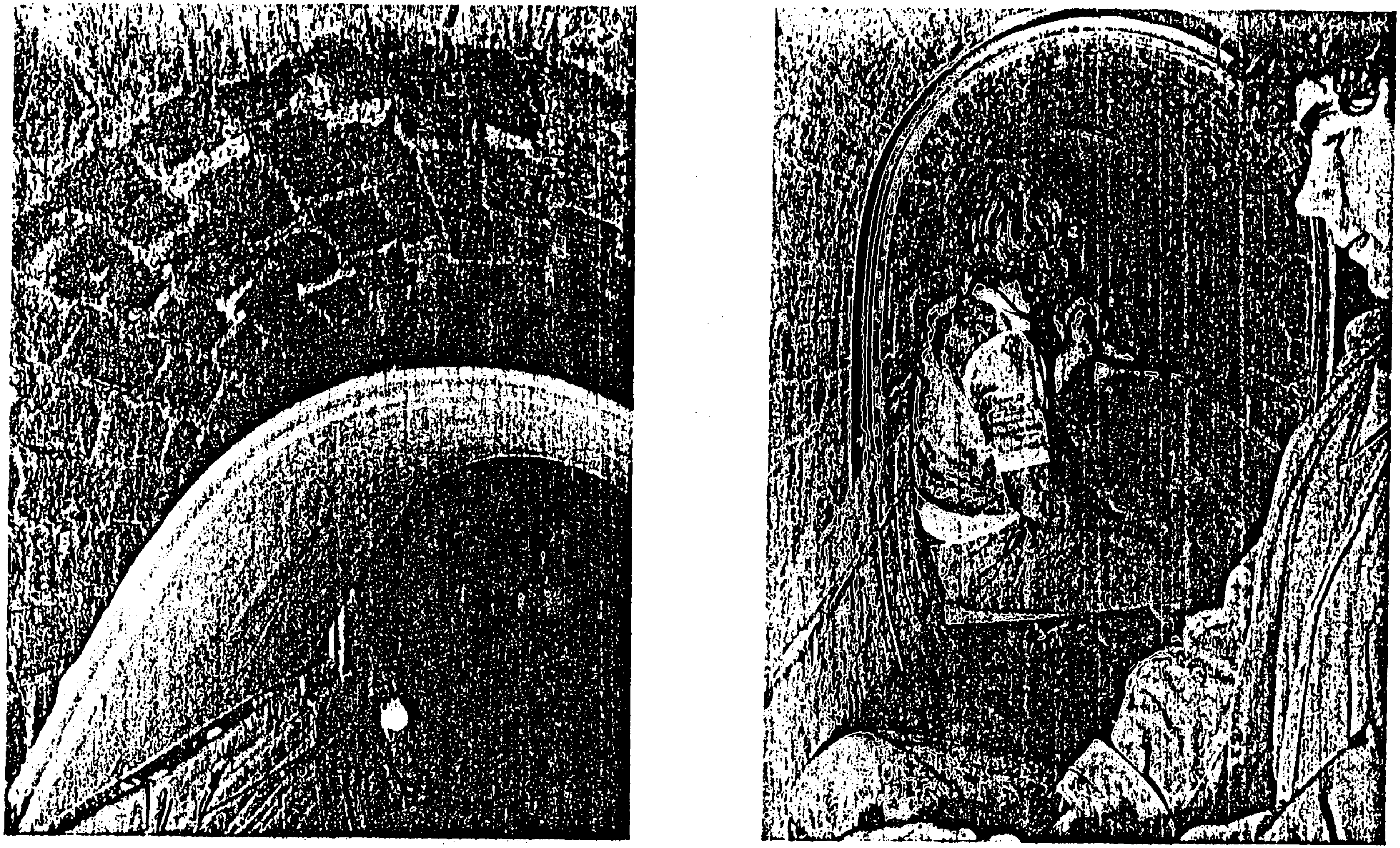


Fig. 12. Sewer lining with Charcon Composites GRC panels (Courtesy Transport and Road Research Laboratory)

Back grouting may be carried out as the work proceeds and whilst the wedges are in position.

An access shaft is necessary to take materials into the sewer. The siting of this is not important to the operation but is preferably close to the material store. The panels are relatively light in weight and sufficiently strong to withstand some rough handling. Several panels together may be lowered down the access shaft and a simple trolley used to transport them to the working face.

Lateral connections may be cut out and hand finished from inside as the work progresses (see Fig. 13).

A high finish is obtained on the inner surface which gives a good flow characteristic but can be slippery underfoot. A chequered finish is available in the invert but this does increase the cost.

The material is claimed to have a good resistance to varying conditions of acidity and alkalinity, negligible absorption and permeability, and a high resistance to abrasion. These properties may be further increased by the use of sulphate-resisting cements. Even greater performance is claimed for a GRC composite laminated to 1½ to 2 mm-thick polyester sheet. Material costs for the UK are £33 to £39 per linear metre for a nominal 1 metre internal diameter using standard 10 mm-thick GRC.

The GRC/polyester laminate 12 mm overall thickness is approximately double this cost for UK applications.

6.6.2. Glass reinforced plastic (GRP) panels

The use of GRP panels is very similar to GRC except that the material requires more support during the construction and grouting stages.

The advantages and disadvantages are the same as those for GRP pipes, the main ones being the excellent flow characteristics but these may become a slippery hazard in a walk-through sewer. This problem was overcome by one contractor who laid a pre-cast concrete invert section and a GRP crown which tied into special slots in the cast section.

6.6.3. Stainless steel

Stainless steel has been used to renovate an invert where abrasion was a particular problem due to very fast, corrosive flows. Again rivet, screw or spike methods may be used for jointing and anchoring prior to grouting.

6.6.4. 'Pre-shot' Gunite segments

The placement of cement mortar in the form of high velocity particles has been described in a previous section of this report. Similar equipment is used to produce the 'pre-shot' factory-made segments.

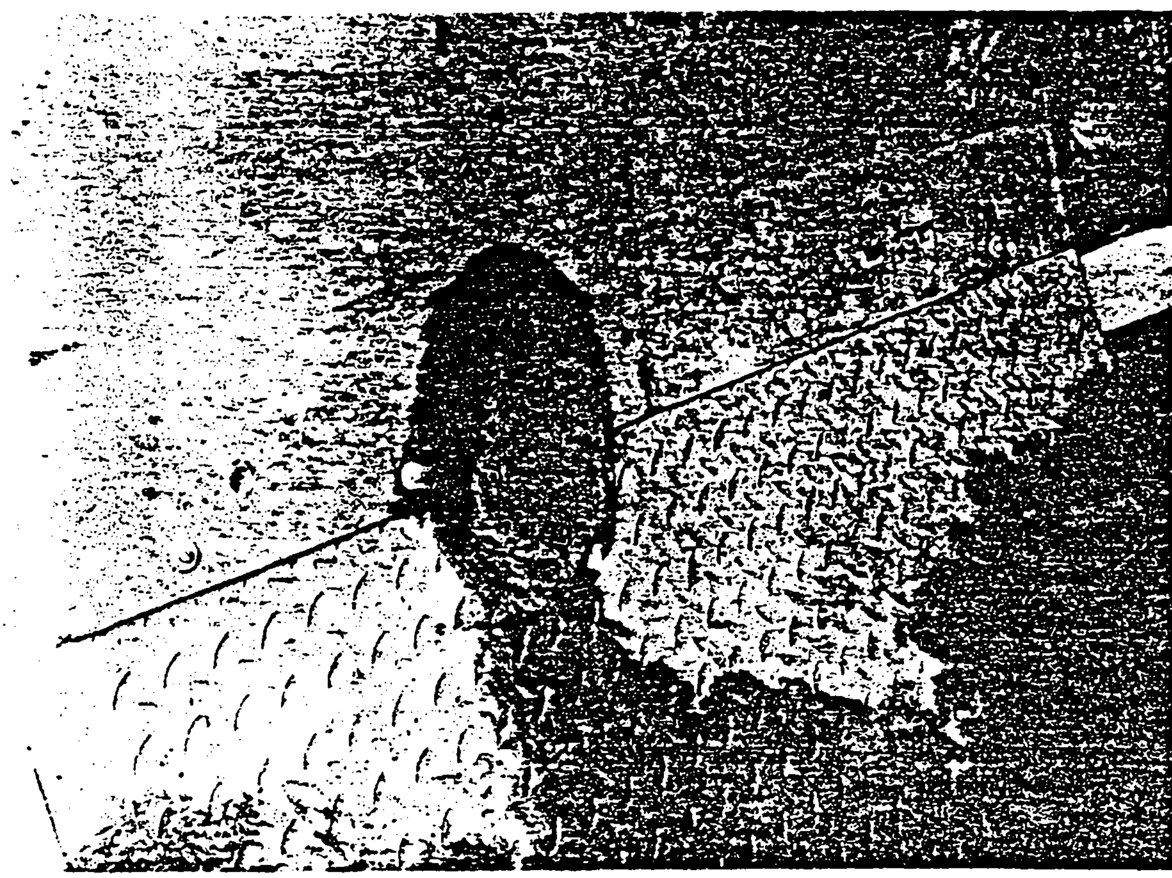


Fig. 13. Side connection before and after GRC lining (Courtesy Charcon Composites Ltd)

Gunite is shot on to a simple steel mould which imparts a smooth finish to the inner surface and leaves the outer one rough, providing a good grout key. Steel reinforcement is placed during the manufacture and this is allowed to project on all edges by 100 mm. When the units are assembled in the sewer the reinforcement is tied together to provide a continuous mesh. The 100 mm reinforcement projection allows for some size tolerance and for slight bends to be negotiated.

Egg shapes are normally made in two sections, invert and crown. The thickness is generally 40 mm and the segments 1.2 m long. Additional panels may be incorporated where the sewer has a high height to width ratio.

The normal method of construction is to bed the invert segments on cement mortar through the section being worked, using wooden wedges to hold the line. The full length of the invert section is then back grouted. A small flow in the sewer can be tolerated during this work. The crown segments are then jacked into position and the reinforcement tied. *In situ* Guniting is used to make the joints, Fig. 14. Grout holes are provided in the crown segments so that pressure grouting is used to fill the annulus completely. Good penetration of the existing brickwork is usually achieved during the pressure grouting operation.

Infiltration does not normally interfere with this work, as any incoming groundwater can flow in the space between the lining and the existing sewer and this will be stopped by the grout when it is applied under pressure.

Pre-shot Gunite segments provide an extremely strong structural member although the ability to support the ground completely without subsidence is still dependent on effectively grouting the annulus and any voids outside the existing sewer barrel.

The fairly thick segment wall does reduce the area by an appreciable amount, although some of this loss is regained by a smooth finish. The reduced invert radius combined with the smoother surface also tends to reduce silting.

Costs

Case history

An egg-shaped brick sewer approximately 1000 mm × 650 mm × 74 m long section lined with Gunite segments cost £127.50/m. This cost included silt removal and pressure jetting and was part of a large renovation job completed in 1976.

Another section, 74 m long, of the same contract was 700 mm × 530 mm but so badly distorted that to maximise the area a 'U' section with a flat concrete slab was used, costing £127/m.

The total contract price was £40 000 which included three new manholes.

Fig. 14. (a) Making Gunite segments (Courtesy Transport and Road Research Laboratory)

Fig. 14. (b) Sewer lining with pre-shot Gunite segments (Courtesy Transport and Road Research Laboratory)

Fig. 14. (c) Gunite spraying joints (Courtesy William F. Rees Ltd)

6.6.5. Armco corrugated steel pipe

Corrugated steel pipe was first manufactured in the USA in 1896. The first installation in the UK was a culvert lining in 1913 and this is still in operation.

Armco manufacture riveted pipes and pipe sections from hot dip galvanised steel. Pipes are available in the size range 150 mm to 2000 mm diameter. Multi-plate pipe sections are available in the size range 1.50 m to 7.31 m. Special pavings and coatings are available to improve the corrosion resistance further.

Advantages of using steel sections are:

High structural strength
No breakages during installation
Specials are easily made in the workshop.

Disadvantages of using steel sections are:

Handling damage during installation may allow corrosion to start.

Multi plate segments are expensive compared with other panel systems such as G.R.C.

6.7. TYPE G. SLIP LINING WITH THERMOPLASTIC TUBING

6.7.1. Polyethylene/polypropylene

Both polyethylene (PE) and polypropylene (PP) belong to the family of thermoplastics and are used as pipes or pipe lining materials.

Polyethylene is available in two types, high density and medium density. The more expensive high density material is hard, strong and tough, whilst the medium density type is softer, more flexible and melts at a lower temperature. Both have the same pressure and external load rating.

Polypropylene tends to be more expensive than high density PE. It is rigid, tough, has a high melting point and equivalent resistance to soivents.

Both materials may be joined by fusion butt welding (Fig. 15), which, if carried out with care, can produce a joint having a strength equal to that of the parent material. Fig. 16 shows the weld form.

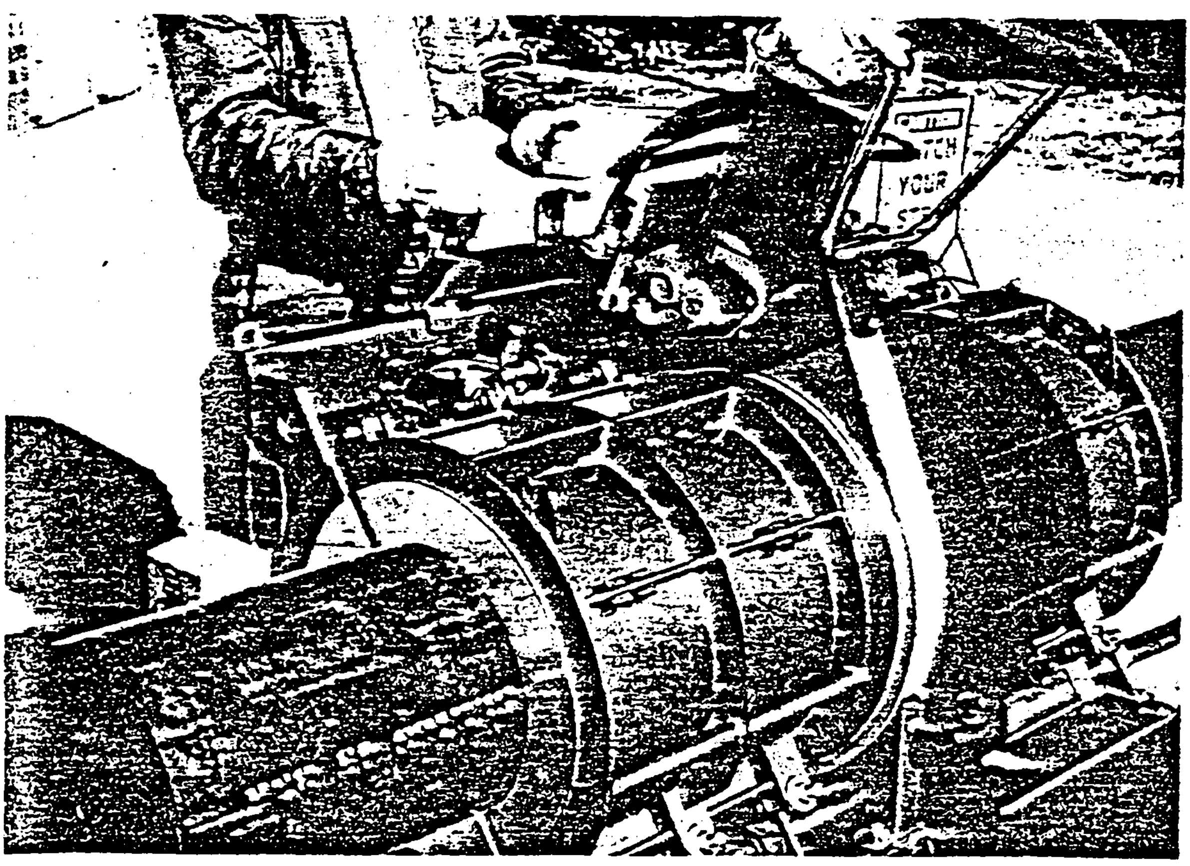


Fig. 15. Fusion butt welding machine (Courtesy Du Pont (UK) Ltd)

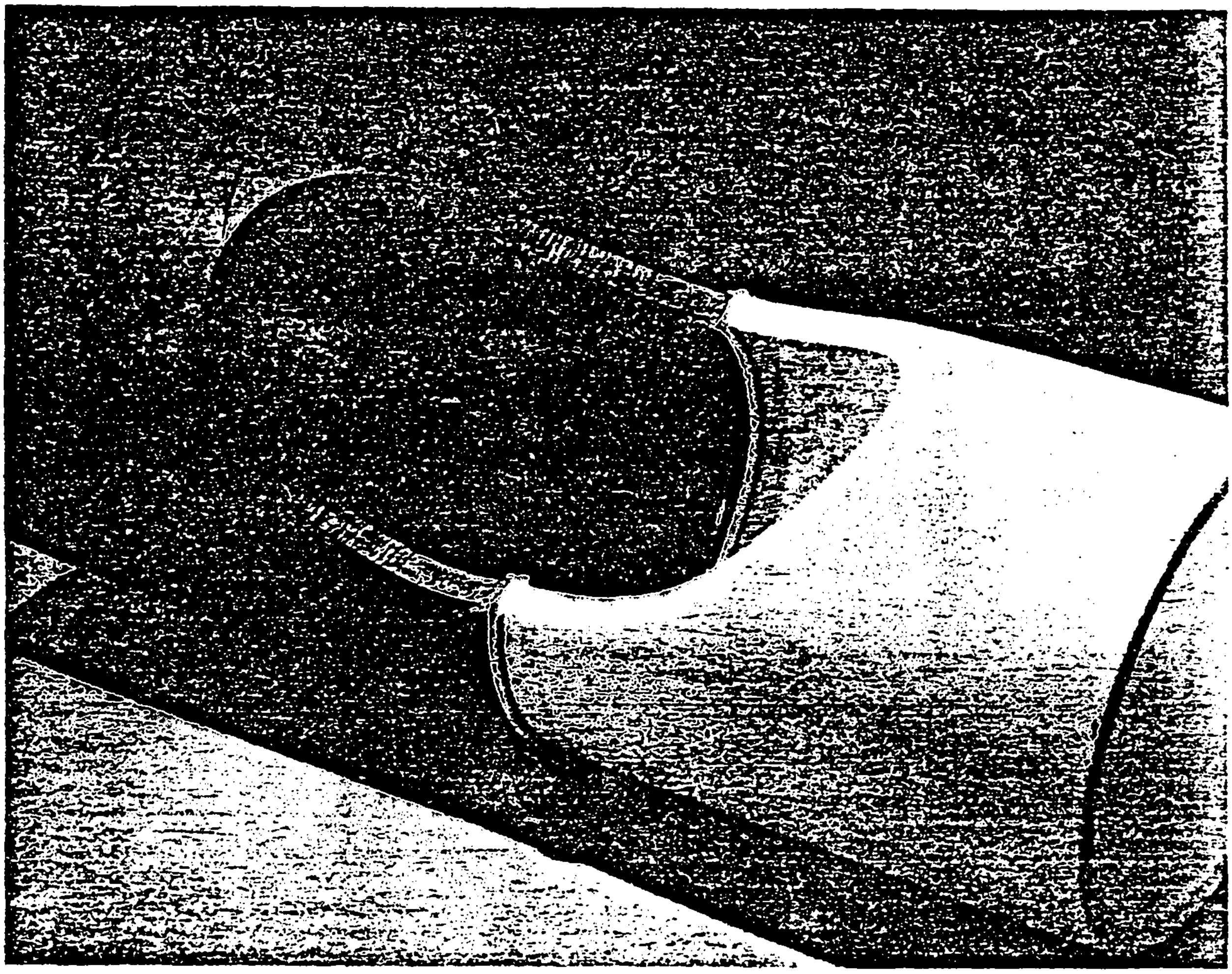


Fig. 16. Section through fusion butt weld showing weld bead (Courtesy Stewarts and Lloyds Plastics)

Slip lining is achieved by pushing or pulling a plastic pipe into the existing sewer. A slit trench is necessary and its dimensions are dependent on pipe size and depth. One pipe manufacturer recommends that the length of the trench should be theee times the sewer depth plus ten times the liner pipe diameter.

Before work commences the sewer must be cleared of silt and debris and clearance should be checked by pulling a section of the liner pipe through the sewer.

After 'proving' the sewer, the liner pipe is pulled by a special nose cone attachment butt-fused to the pipe and attached to a cable. Often several manhole lengths may be lined in one operation. The crown of the pipe can then be removed later at the manholes.

Slip lining is now a recognised method of renovation in the gas industry. In the USA it has also been used extensively for sewers, and linings up to 36 inches (900 mm) diameter have been inserted.

One manufacturer includes several different wall thicknesses in his range with appropriate strength ratings. For example a thin wall pipe (D/t ratio = 32) having an internal pressure rating of 45 p.s.i. (3 bar) and an external hydrostatic pressure rating of 0.76 m of water. Heavier pipe is also available (D/t ratio = 18) with internal pressure rating = 84 p.s.i. (5.6. bar) and an external pressure rating of 4.7 m head of water. Special diameters have been developed to maximise the capacity of the lined sewer, for example 7.13-inch (181 mm) o.d. pipe for lining an 8-inch (203 mm) i.d. sewer.

To prevent the lined sewer from becoming a secondary drain it is necessary to seal the entry and exit at each manhole. Non-shrink cement grouts, mechanical closures and urethane foams have all been used for this, with the urethane foams being the more popular for smaller diameter pipes at present in the USA. If complete structural integrity is sought then the annulus must be fully grouted.

Lateral connections on non-man-entry size sewers are a major problem with any pipe lining system. If there are few side connections on any one length then it is probably acceptable to excavate to make them. The excavation work necessary if a large number of side connections are required may well render an *in situ* renovation uneconomical.

6.8. TYPE H. FLEXIBLE LININGS

Lining an existing sewer with a rigid pipe must reduce the size. If the sewer is deformed the reduction is even greater as a rigid pipe must pass through the smallest dimension.

Insituform lining developed by a specialist company in 1971, overcomes this problem. A UK licence was granted to Edmund Nuttall in 1973 who formed the Insituform Division. The company name has since been changed to the Nuttall Permaline Division.

The material is needled polyester-felt impregnated with polyester resin. The tube of felt is made up to match the periphery of the sewer barrel which may be of any shape. The felt thickness is approximately 3 mm and several layers may be combined to give the required lining thickness which may vary between 3 mm and 19 mm depending on the sewer size.

The impregnation process is carried out with the felt inside a polyethylene or polyurethane tube which is also used to enclose it during transportation to the site.

When the system was first introduced a refrigerated van was an essential part of the process but the resin formulations currently used only require refrigeration on hot, sunny, summer days.

Installation may be by one of two methods. The one preferred, which requires the flow to be bypassed, is the inversion method. Excavation is unecessary as the existing manholes may be used (Fig. 17).

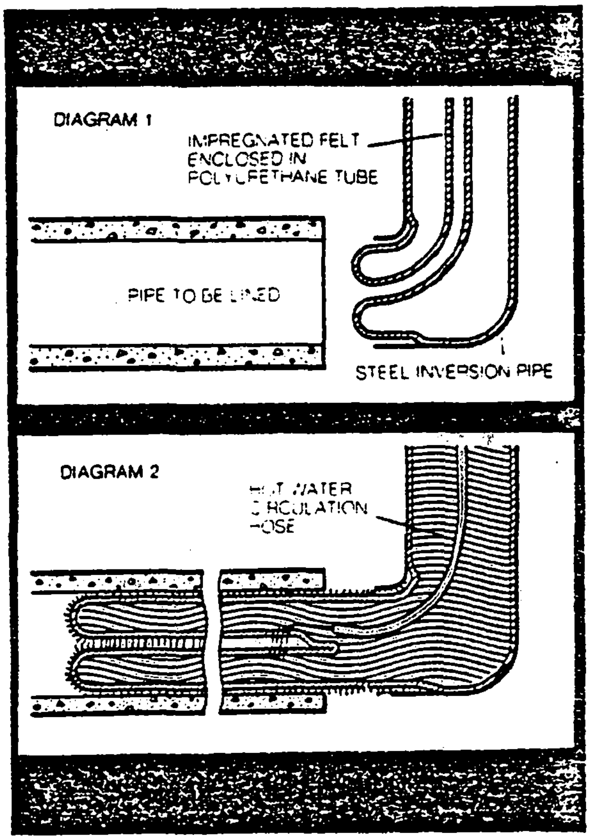


Fig. 17. Insituform lining (Courtesy Nuttall Permaline Division)

A vertical tube (which may be flexible) with a 90° bend at the bottom is set up in the manhole. The lining is fed down this tube, via a conveyor, directly from the lorry. When the felt emerges from the bottom of the tube it is turned back and anchored to it (Fig. 17).

The polyethylene outer casing has already been turned back and anchored to the top of the vertical tube forming a well into which water is poured. The head of water inside the loop of polyethylene in the vertical pipe causes it to invert, together with the felt liner. The liner travels down the inside of the sewer rather like a stocking being rolled on. Water is continually added until the lining is through the section being worked. Before the end of the liner disappears into the vertical tube an open-ended lay-flat hose is attached to it. This lay-flat hose is dragged into the sewer with the liner and is used to circulate the water through a boiler on the surface. This raises the water temperature to 65°C which is necessary to start the resin reaction. The curing time is approximately two hours.

If it is not practicable to divert the sewer flow the second method, the flow through system, is used. The polyester felt is encased both inside and outside in polyethylene. Inside the felt tube are two concentric tubes of nylon-reinforced PVC fabric. The outer one is open at both ends and has a flexible inflation ring at one end. The inner tube is closed at both ends with an air inlet and outlet.

On reaching the site the liner is fed, via the conveyor, from the lorry down into the manhole and is winched through the sewer using the sewage flow as a lubricant. When the liner is in position it is inflated to about 800 mm water gauge. The inflation collar is also inflated so that it presses the outer later of nylon reinforced fabric against the sewer barrel.

The sewer is now blocked and the flow will back up until a head develops in excess of the 800 mm water gauge inflation pressure. When this happens the flow will be forced through the open-ended nylon-reinforced fabric inner tube. Steam is now introduced into the inflation air and the resin reaction started as before.

The flow through the inner plastic tube may continue during the time that the resin cures.

Lateral connections must be made by hand from inside man-entry sewers and excavations are necessary if connections are in non-man-entry sizes.

Sewers and other pipelines ranging in size from 100 mm to 1200 mm have been lined by this method.

The material is claimed to have considerable structural strength although back grouting is necessary to establish full strength of the lined sewer (especially if there is evidence of voids) and to prevent the annulus from becoming a secondary drain. The material is being further developed by the Nuttall Permaline Division to increase its strength by adding glass fibres to the polyester felt.

The advantages over other lining systems are the small reduction in size, the high finish and therefore good flow characteristics and its resistance to a wide range of chemicals; also,the work can usually be carried out through a normal manhole opening.

Costs

The new factory that Edmund Nuttall have recently acquired at Wakefield has facilities to manufacture linings up to 7 tons in weight, thus virtually doubling the original insertion length for a specific diameter and reducing the unit lining cost.

Case history 1

A contract involving the relining of 550 m of 900 mm × 600 mm brick ovoid sewer which ran under a factory was carried out between November 1976 and February 1977. The contract value was £150 000 consisting of £200/m for lining and £70/m for overpumping.

Casing history 2

A sewer pumping main 600 mm diameter, 128 m long was lined in two sections working from a central 3 m × 2 m shaft approximately 2 m deep. In June 1976 the cost was approximately £102/m. This did not include the excavation or the cleaning.

Case history 3

An egg-shaped sewer 1000 mm × 60 m long and 5½ m deep lined with 10 mm thick polyester felt was quoted at £142/m. This includes pumping costs but not cleaning. There were no lateral connections on the section lined.

Case history 4

A 305 mm diameter sewer 155 m long was lined in December 1977 at a cost of £10 600 for lining and £4 675 for ancillary work. This represents £68.40/m for lining and £30.20/m for ancillary work.

This particular sewer had such a large infiltration that a polyurethane liner was inserted first to safeguard the resin in the polyester liner from washing out.

6.9. TYPE I. COATINGS

Hand applied, hand sprayed, or remotely sprayed coatings may be used to extend the life of an existing sewer by protecting the material from corrosion attack and abrasion, or to prevent infiltration.

Many of the coating materials that are available are resin compounds, numerous formulations are possible to cope with a wide range of problems.

The examples given are just a small sample, and it is recommended that the manufacturers are contacted for further information or help with specific problems.

6.9.1. Sika Contracts Limited

Sika Contracts Limited supply Colmasyn lining which is applied by skilled operators. It is a glass-fibre reinforced polyester resin. The glass-fibre reinforcement may be a chopped strand mat or a woven glass-fibre cloth.

It has excellent adhesion to most surfaces, is completely impervious, and has excellent chemical resistance, with good resistance to impact.

6.9.2. Index Finishes (UK) Limited

(i) water-thinned epoxy coating; this will adhere to damp surfaces. When it has cured if forms a tough flexible film with excellent resistance.

(ii) epoxy mortar; this may be trowelled to produce a chemical and abrasion-resistant surface.

6.9.3. Colebrand Group

The Colebrand Group of companies produce a range of materials and equipment for coatings.

(i) A cold-cured epoxide resin/calcinated bauxite system was developed as an anti-abrasion coating and is applied to the pipe invert. A special application and tamping machine has also been developed.

(ii) The CXL range of epoxy resin compounds provide corrosion and abrasion-resistant coatings.

(iii) A polyurethane putty which is flexible enough to allow further pipe movement was developed to seal leaking joints in concrete pipes.

7. RENOVATION METHODS 'IN THE PIPELINE'

This report has dealt with renovation methods which are available at present in the United Kingdom. There are some systems which are not as yet fully developed but may be available in the not-too-distant future. These are listed as follows, together with the name of the company responsible for the development.

7.1. BALFOUR BEATTY VACUUM GROUTING PROCESS

The Balvac system has been used for some time for sealing above-ground structures.

The procedure is to cover the face to be grouted with a plastic sheet, remove the air from beneath the sheet with a vacuum pump and then inject a resin grout beneath the sheet. The grout penetrates deeply into all cracks. A system has been patented for lining underground pipes but has not been tried as yet (Fig. 18).

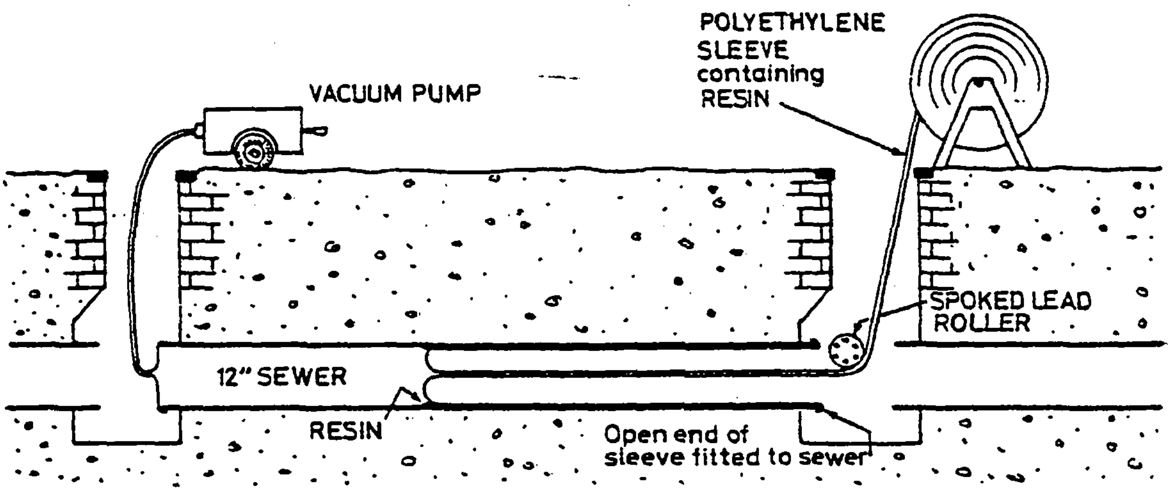


Fig. 18. Balfour Beatty vacuum grouting process

For further information, contact:

Balfour Beatty Power Construction Co. Ltd
P.O. Box 12,
Acornfield Road,
Kirkby,
Liverpool, L33 7VG.

7.2. MEMBRANE LINING PROCESS

The membrane lining process is under development for the gas industry and has been reported as a potential repair method for water mains in WRC Technical Report, TR 38. The lining consists of a nylon membrane which is drawn into the pipe and bonded to the surface by a modified epoxy resin. The total lining thickness is only

1 mm and if a satisfactory bonding material could be developed, the system would be useful for structurally strong but badly leaking pipes. The suppliers are as follows:

Howson Ross Pipeline Services Ltd.,
Old Bracknell Lane,
Downshire Way,
Bracknell, Berkshire.

7.3. EXPANDING POLYETHYLENE TUBE

A Norwegian company has developed a polyethylene tube which may be expanded by several hundred per cent when heated. The wall thickness is dependent on the percentage expansion and may vary from a membrane lining to a fairly stiff tube. A bonding agent is necessary if it is used as a membrane lining as in the Howson Ross process and this would make a useful renovation method for cracked infiltrating pipes. The manufacturer is:

Myco Industry A/S,
3470 Slemmestad,
Norway.

7.4. CROSS-LINKED POLYETHYLENE TUBE

Pesalex is the trade name for patented cross-linked polyethylene tube that has been developed by Stewarts and Lloyds Plastics, a division of British Steel Corporation. One of the possible uses of this material is a sewer lining. The pipe would be suppled reduced in diameter so that the insertion process is simplified. A special process causes the lining to expand to be a snug fit inside the existing sewer pipe.

The advantage over normal slip lining would be the elimination of the annulus around the liner pipe and thus the need for grouting.

8. RENOVATION METHODS – SPECIALIST CONTRACTORS/MANUFACTURERS

The following list of specialist manufacturers/contractors is grouped in the type categories used throughout this report. Some names appear more than once as they are involved in more than one type of renovation. For this reason the addresses are listed separately to avoid repetition.

The companies included in this list are those that advertise nationally. In addition there are many small firms specialising in sewer repairs and cleaning that are often capable of carrying out the less sophisticated renovation methods.

8.1. CONTRACTORS/MANUFACTURERS

Type A

Colcrete Limited
Rees (Seergun) Limited

Type B

Cementation Ground Engineering Limited
Civation Limited
Colcrete Limited
D.S.M. Limited
Economic Drain Repairs Limited
G.K.N. Keller Foundations
E. Gunite Limited
Intrusion Prepakt (UK) Limited
Rees (Seergun) Limited
Rock Bolting and Grouting Services
Soil Mechanics Limited
Tate Pipelining Processes Limited
Tenders International Limited

Type C

Borden UK Limited
Colcrete Limited
Rock Bolting and Grouting Services
Seer TV Surveys Limited

Type D

B.T.R. Development Services Limited
Camel Contract Services Limited
Colebrand Limited
Expandite Limited
J. & F. Hewett Limited

Type E

A.R.C. Concrete
Armco
Redland Pipes Limited
Stanton & Stavely Limited
Wavin Plastics Limited

Type F

Charcon Composites Limited
Civation Limited
D.S.M. Limited
E. Gunite Limited
Ficem (Fibre Reinforced Cement) Limited
Foraky Limited
Hippo Glass Fibre Products Limited
Intrusion Prepakt (UK) Limited
Rees (Seergun) Limited

Type G

Du Pont (UK) Limited
Hoechst (UK) Limited
Stewarts & Lloyds Plastics Limited.

Type H

Nuttall Permaline Division

Type I

Borden (UK) Limited
Camel Contract Services
Colebrand Limited
Glass Shield Coatings Limited
Index Finishes (UK) Limited
Sika Contracts Limited

8.2. ADDRESSES

A.R.C. Concrete
Central Sales Office (Dept 5)
Wickwar Road
Chipping Sodbury
Nr. Bristol
Avon. BS17 GBJ
Tel: Chipping Sodbury 312 488

Armco Limited
P.O. Box 11
Jubilee Road
Letchworth
Herts. SGG 1NQ
Tel: 046266588

Borden (UK) Limited
North Baddesley
Southampton. SO5 92B
Tel: 0703 732131

B.T.R. Development Services Limited
Burton-on-Trent. DE13 0SN
Tel: 0283 61611

Camel Contract Services Limited
130 Range Road
Stockport
Cheshire.
Tel: 061 794 4954

Cementation Ground Engineering Limited
Denham Way
Maple Cross
Rickmansworth
Herts.
Tel: Rickmansworth 76666

Charcon Composites Limited
Porter Lane
Middleton by Wirksworth
Derby. DE4 4LS
Tel: 062 982 3476

Civation Limited
Home Close
High Street
Kidlington
Oxford.
Tel: Kidlington 2820

Colcrete Limited
Bryant House
Gun Lane
Strood
Rochester
Kent.
Tel: Medway 722571

Colebrand Limited
Colebrand House
20 Warwick Street
Regent Street
London. W1R 6BE
Tel: 01 439 9191

D.S.M. Limited
81 Highgate Road
Kentish Town
London. NW5

Du Pont (UK) Limited
Hilcote Plant
P.O. Box 1
Blackwell
Derby. DE5 5JD
Tel: Ripley 811112

Economic Drain Repairs Limited
17 Linhope Street
Dorset Square
London. NW1
Tel: 01 723 2273-5

Expandite Limited
Chase Road
London. NW10 6PS
Tel: 01 965 8877

Ficem (Fibre Reinforced Cement) Limited
3 Willow Avenue
London. SW13 0LT
Tel: 01878 5877

Foraky Limited
Colwick
Nottingham. NG4 2BB

G.K.N. Keller Foundations Limited
8 Gate Street
Lincolns Inn Fields
London. WC2A 3HX
Tel: 01 242 0521

Glass Shield Coatings Limited
Valley Works
Monton Road
Eccles
Manchester. M30 5NJ
Tel: 061 789 5191

E. Gunite Limited
Colwick
Nottingham. NG4 2BB
Tel: 0602 247877

J. & F. Hewett (Southampton) Limited
Spurling Yard
Wallington
Fareham
Hants. PO17 6AB
Tel: Fareham 89022

Hoechst (UK) Limited
Plastics Department
Hoechst House
Kew Bridge
Brentford
Middlesex.

Hippo Glass Fibre Products Limited
Horbury Bridge
Wakefield
Yorks. WF4 5PW
Tel: 0924 272 106

Index Finishes (UK) Limited
Index House
Dawkins Industrial Estate
Poole
Dorset. BH15 4JY

Intrusion Prepakt (UK) Limited
8 Fieldings Road
Chadmore Lane
Cheshunt,
Herts.
Tel: Waltham Cross 35515

Nuttall Permaline Division
Unit 6
Roundwood Industrial Estate
Ossett
West Yorks. WF5 9SQ
Tel: 0924 277076

Redland Pipes Limited
Reinforced Plastics Division
Ashley Road
Poole
Dorset. BH14 9BJ
Tel: Bournemouth 761226

Rees (Seergun) Limited
Unit 5
Yeoman Street
London. SE8 5DU
Tel: 01 237 5402
01 237 5403

Rock Bolting and Grouting Services
Unsworth Station Road
Washington
Co. Durham.

Seer T.V. Surveys Limited
Westminster House
Old Woking
Surrey.
Tel: Woking 62221

Sika Contracts Limited
Howley Lane
Warrington
Cheshire. WA1 2DP
Tel: 0925 34136

Soil Mechanics Limited
Foundation House
Eastern Road
Bracknell
Berkshire.
Tel: 0344 24567

Stanton & Stavely Limited
P.O. Box 72
Nr. Nottingham. NG10 5AA
Tel: Ilkeston 322121

9. RENOVATION METHODS – FUTURE REQUIREMENTS

A fairly extensive range of renovation systems exists but there is still room for innovation and further development.

During the course of the survey work for this report some areas were highlighted where there was either an unsatisfied need or an existing method which may benefit by further development.

The following list contains the more important areas of work that have been started or will feature in future research programmes.

9.1. LATERAL CONNECTIONS

A weakness with *in situ* lining systems is the excavation work that must be carried out to reconnect laterals. Some remotely controlled techniques have been used in North America but these are untried in the UK. WRC will evaluate these techniques and develop others if the existing ones prove to be unsuccessful.

9.2. VOID DETECTION

In certain soil conditions, infiltration through cracks and leaking joints washes in fines and causes voidage around the sewer. For subsequent renovation work to be completely successful the voids must be located and filled. Instrumentation to locate voids does not exist; two feasibility studies have been placed by WRC as extramural contracts.

9.3. REPLACEMENT OF SMALL BORE PIPES WITH SAME SIZE OR LARGER

Often smaller sewers are relaid because reduction in area by relining cannot be tolerated. WRC are considering a feasibility study to overcome this problem. It is anticipated that the solution may be a machine to remove the existing sewer and at the same time draw in a thermoplastic pipe which is as large or larger than the existing sewer.

9.4. GLASS-FIBRE REINFORCED CEMENT

As stated in Section 6.2.4. of this report cement mortar lining is a proven method for pipe relining but is only suitable for crack or joint sealing in a stable, structurally strong sewer. The addition of glass fibres may enhance the properties of the material to extend its use to more unstable conditions. Evaluation work on sprayed GRC was started early in 1978 at WRC.

9.5. CEMENT GROUT SEALING

The simple cement grouting device employed by the Economic Drain Repair Company is limited to small diameters. Further development of such a machine may be suitable for crack sealing in larger non-man-entry sewers.

9.6. COSTS/CASE HISTORIES

Cost data is still being collected and this will continue.

9.7. EVALUATION OF RENOVATION SYSTEMS

The available methods of renovation require evaluation to determine structural strength and estimated life. Laboratory testing and site observation will be carried out by WRC and TRRL.

9.8. INTEGRITY OF EXISTING BRICK SEWERS

Techniques for assessing the integrity of existing brick sewers are required and this project may be placed as an extramural contract.

9.9. RENOVATION OF DROPPED JOINTS

It is sometimes impossible to grout seal pipes with misaligned joints by remote control. Lining systems greatly reduce the capacity in this situation so a method to reduce the misalignment would be desirable. This project may be placed as an extramural contract.

10. CONCLUSIONS

Renovation can be used to overcome the majority of faults found in sewers using the methods and materials available today. However, with the exception of leak repair and crack sealing systems, none of the more major renovation techniques achieves all of the following objectives:

1. No excavation, that is, all the work can be performed through the existing manholes
2. Ability to cope with existing side connections without excavation
3. Quick installation, which reduces both cost and disruption
4. Competitiveness with cost of renewal.

The majority of the available renovation methods require special equipment, operator training and experience, but this is not considered to be a disadvantage.

There is very little information available on performance and it is unlikely that simulated life and loads tests will provide more than a very rough guide.

Cost effectiveness is also very difficult to establish as performance data are not available and each contract is unique. Only experience will provide answers to these questions and to gain the experience will mean making well-considered gambles on innovations.