



# WATER RESEARCH CENTRE

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## TECHNICAL REPORT

## TR 38

# A SURVEY OF RENOVATION TECHNIQUES FOR WATER MAINS

R. W. Parkinson, BSc, PhD

and

R. G. Giles, BSc

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for Community Water Supply

February 1977

MEDMENHAM LABORATORY  
P. O. Box 16, Medmenham,  
Marlow, Bucks. SL7 2HD  
Tel: 049 166 531

STEVENAGE LABORATORY  
Elder Way, Stevenage,  
Herts. SG1 1TH  
Tel: 0438

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TECHNICAL REPORT TR38  
A SURVEY OF RENOVATION TECHNIQUES FOR WATER MAINS

Correction

Page 27, Table 5.

The cost/metre figures in the second column for the item 'Move contractor's equipment to site' should read:

0.50

Water Research Centre  
Medmenham Laboratory  
PO Box 16, Medmenham,  
Marlow, Bucks. SL7 2HD

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Technical Report TR 38

February 1977

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by

R. W. Parkinson, BSc, PhD

and

R. G. Giles, BSc

Distribution Division

Water Research Centre

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for Community Water Supply

Stevenage Laboratory,  
Elder Way,  
Stevenage, Herts. SG1 1TH  
0438 2444

Medmenham Laboratory,  
Henley Road, Medmenham,  
P.O. Box 16, Marlow, Bucks. SL7 2HD  
049 166 531

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## SUMMARY

A survey of techniques applicable to the renovation of water mains has been carried out. Eight processes have been considered, and the salient features of each process are given in Table 1. Bitumen and cement mortar lining have been used extensively in the water industry. Thermoplastic pipe insertion, Insituform, and in situ resin coating (train method), have been used in analogous industries. Membrane lining, in situ resin coating (spray method) and fibre-reinforced cement lining have not been practised commercially.

With our present knowledge, cement mortar lining is the most satisfactory alternative to renewal as a solution to problems of water discoloration and reduction in hydraulic capacity resulting from tubercle growth.

A cost sensitivity analysis of renewal and renovation using existing techniques has been included. It is concluded that the cost of non-structurally renovating a water main can be as little as one quarter of renewal.

Table 1. Summary of salient features of renovation techniques

Process	Strength rating	Diameter range (mm)	Single run length (m)	% reduction in cross-sectional area of 150-mm pipe	Hazen Williams C-value	Effect on water quality	Life expectancy (years)
Bitumen lining	Non-structural	75 - 250	140	0.3	140	NWC approved materials available	≤ 10 observed
Cement mortar lining	Non-structural	75 - 3600	150 approx.	6.5	120-140	No detrimental effect	> 40 observed
Thermoplastic pipe insertion	Structural	10 - 1200	150	20 (series 1)* 40 (series 4)†	150	NWC approved material	50 estimated
Insituform	Semi-structural	100 - 1200	140	8	Not known	Not known	50 minimum estimate
In situ resin coating - Train Method	Non-structural	75 - 1100	2000-5000	0.4	150	Certain resin systems have NWC approval	> 10 observed
Membrane lining	Non-structural	75 - 600	100-150	1.3	Not known	Not known	Not known
In situ resin coating - Spray Method	Non-structural	75 - 600	20	0.6 - 1.3	150 (expected)	Certain resin systems have NWC approval	Not known
Fibre reinforced cement lining	Structural	75 - 3600	150 approx.	Not known	Not known	Not known	Not known

\* Series 1. Working pressure 0.24 MPa (35 psi)

† Series 4. Working pressure 1 MPa (145 psi)



## 1. INTRODUCTION

The introduction outlines firstly the philosophy behind the need for research into the renovation, renewal and replacement<sup>\*</sup> of water mains and secondly the approach to the different aspects and progress made to date. The report itself concentrates on renovation of water mains, but it is envisaged that further reports will be produced to complement the present one as data become available.

With the reorganization of the water industry into larger units, a more systematic policy on renovation, renewal and replacement of both sewers and water mains is required. The publication by the National Water Council of its document entitled 'Paying for Water' (1) indicates that, assuming a 1% per annum replacement policy, £330 million per annum needs to be spent to prevent existing services from deteriorating. It is clear that even a small percentage saving on renewal costs would result in large capital savings. Existing renovation techniques, although non-structural in nature, show an approximate four-fold saving with respect to renewal.

The above analysis has been based on an average life expectancy of 100 years. The life of water mains can be significantly reduced to less than their expected life by such problems as those listed below.

- Dirty water.
- Loss in hydraulic capacity.
- Joint leakage.
- External corrosion.
- Beam failure.

The first three are basically non-structural in nature and require for their solution a barrier to be introduced between the aggressive water and the pipe.

The latter two require structural solutions. The need in this case is for a lining capable of withstanding both the hydrostatic pressures exerted on the water main and the external soil loadings.

As a starting point, a survey of renovation techniques has been carried out. The survey includes existing techniques and potentially applicable techniques: in total eight techniques are discussed. For each process a description of the operation is given with advantages and disadvantages. Where possible, data are given relating to operational cases, lining life and effect on water quality. Renewal costs are included for comparison.

---

\* See Section 2 for definitions of these terms.

## 2. DEFINITIONS

Throughout this report the terms renovation, renewal and replacement have the definitions used by the NWC/DOE\* Standing Committee on Sewers and Water Mains:

### Renovation

The operation of effectively improving the condition of an existing sewer or water main such as will provide for substantially increased life. Renovation may or may not improve the structural strength of a pipeline.

### Renewal

The reconstruction of the whole structure of a sewer or water main as an entity to the same dimensions as the original pipeline.

### Replacement

The construction of a new sewer or water main either in the same location as the original pipeline or in a new location, so that the function of the original sewer or water main will be incorporated into the functions of the new conduit.

---

\* National Water Council/Department of the Environment

### 3. RENOVATION TECHNIQUES

#### 3.1. BITUMEN LINING PROCESS

##### 3.1.1. Introduction.

The technique has been used for a considerable number of years for the renovation of small diameter water mains in the diameter range 75 mm to 250 mm. A dry film of asphaltic bitumen is developed on the pipe wall. Since the material source is asphalt, possible problems associated with polyaromatic hydrocarbons are obviated.

##### 3.1.2. The process.

A schematic diagram of the process is shown in Figure 1. Excavations are made at a maximum separation of 140 m. Encrustation is removed by power boring using a diesel driven boring machine. The resultant debris is water-flushed. The lining machine, consisting of a system of centralizing arms and a rotatable brush head, is introduced into the pipe. Connection is made to a diesel-driven winch. The bitumen paint is pumped to the brush head by a positive displacement pump driven by compressed air. The head is caused to rotate by compressed air supplied by a separate air line from the compressor. The lining machine is winched backwards through the pipe at approximately 3 metres per minute. By control of the pumping rate and withdrawal speed a coating of average thickness of 1.0 mm (0.040 in) is imparted to the pipe wall.

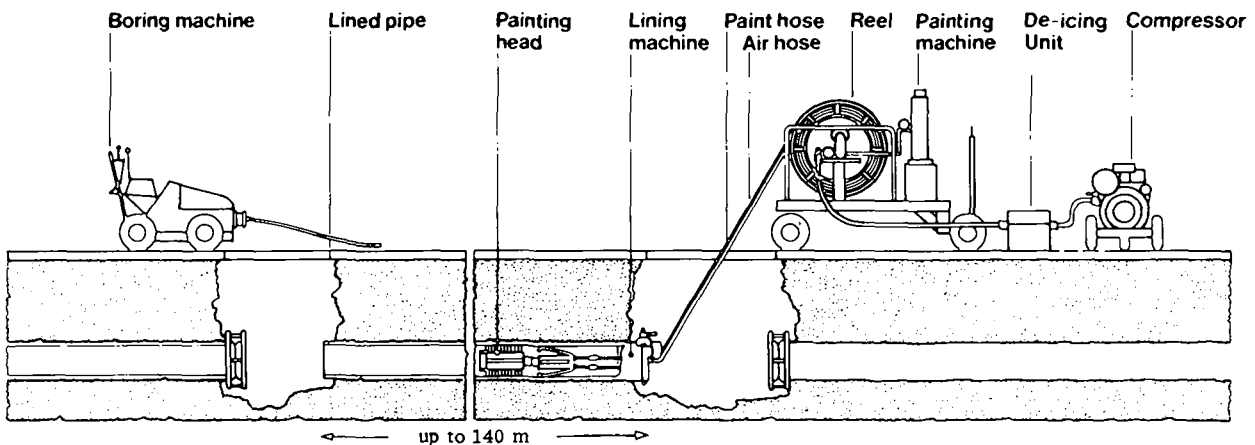


Figure 1. Bitumen lining process

##### 3.1.3. Advantages.

- (a) The cost/metre of this process is significantly lower than cement mortar lining or renewal.
- (b) The water supply can be reconnected the same day.
- (c) The thin lining of approximately 1 mm causes minimal reduction to pipe bore.
- (d) A significant improvement is observed in Hazen Williams C-value with respect to the pipe prior to lining. C-values of 140 to 150 are typical.

#### 3.1.4. Disadvantages.

- (a) Uncoated areas can occur.
- (b) Very sensitive to surface preparation.
- (c) Short life (10 years approx.). The process can, however, be repeated.

#### 3.1.5. Conclusions.

There is a large variation in observed coating life. It cannot therefore be recommended as a long-term renovation technique, but, because of its low cost and the ability to reconnect the supply the same day as starting the work, it has been used as a short-term expedient.

#### 3.1.6. Contractors.

General Descaling Co. Ltd.,  
Worksop, Notts. S80 3PY.

Mercol Descaling Co. Ltd.,  
Pipelining Contractors,  
Carr Vale, Bolsover, Chesterfield,  
Derbyshire.

### 3.2. CEMENT MORTAR LINING PROCESS

#### 3.2.1. Introduction.

In situ cement mortar lining techniques for the renovation of water mains have been available in this country since 1934. The original technique utilized a plug of cement mortar in advance of a drag machine. By drawing the machine through the pipe a lining was pressed onto the pipe wall. One major disadvantage of this technique was the production of a flat invert causing excessive reduction in pipe bore. The technique was superseded by the centrifugal method of application. It is this technique which is widely used today.

The process can be used to renovate water mains in the diameter range 75 mm to 3600 mm. The length that can be processed in one operation varies according to diameter. For diameters of 75 to 150 mm lengths of 85 to 120 metres can be achieved, the longer length being used for the larger 150 mm diameter pipe. Up to 165 metres can be processed between access points in pipelines of 200 to 450 mm diameter, whilst up to 180 metres can be lined in one length in pipe diameters of 450 to 600 mm. In really large diameter pipelines, such as those used as aqueducts, lengths of 550 metres can be dealt with.

The thickness of lining varies according to diameter. For the diameter range 75 to 150 mm, a 5 mm  $\pm$  2 mm lining is applied. For 200 to 475 mm diameter pipe, a lining thickness of 5 to 6 mm with a tolerance of from -2 to +3 mm is desirable. In pipelines of 475 to 600 mm diameter, the thickness of the lining should be 9 to 10 mm, again with a tolerance of from -2 to +3 mm. Above 600 mm diameter, 9 to 10 mm is also the objective with tolerances of from -5 mm to +3 mm.

Two types of finish can be produced. A lining centrifugally 'shot' onto the pipe surface, left untrowelled and giving an 'orange peel' appearance is standard practice for the diameter range of 75 to 150 mm. This avoids the need for location and removal of consumer connections which would otherwise tend to block during trowelling. A Hazen Williams C-value of 100 to 120 is typical of the 'orange peel' finish. For diameters greater than 150 mm, mechanical trowelling of the lining is employed, producing C-values in the range 130 to 145.

### 3.2.2. The process.

#### (a) Cleaning methods.

Several methods are available and to some extent selection of the method depends on the size of the pipe. The various types of cleaning equipment are as follows:

##### (i) Boring machine and flail (75 to 150 mm)

This method involves a diesel-engine boring machine driving a 4900 mm long, flexible steel rod on the end of which is mounted a flail; further rods are added as the flail is pushed through the pipe: different flail heads and rotary scrapers are used for differing pipe conditions. A flow of water is necessary to remove the broken-down encrustation.

##### (ii) Drag scraping (150 to 375 mm)

The drag scraper is essentially a mass of spring-steel knives set into a main body, which is pulled through the pipe by winches positioned at the access points. As the drag scraper brings out only a proportion of the loosened encrustation, the remainder is removed by plungers which are winched backwards and forwards until the pipe is clean.

##### (iii) Hydraulic pressure scraper (375 to 750 mm)

For this method, which is most usefully employed on long, fairly straight runs of mains, a special scraper is inserted into the pipe and driven through by water pressure. Sufficient volume of water must be provided to carry freed encrustation products to a drain-off point, and the pressure must be adequate to carry the scraper through the pipe. In general, the larger the pipe, the lower the pressure required.

##### (iv) Mechanical cleaning (above 600 mm)

Here, an electrically-driven machine manned by an operative is driven through the pipe by its own power. Large, slowly rotating scrapers on the front of the machine ensure that no encrustation growth is left on the pipe walls. This method is especially useful for lines with awkward bends or access points, or where insufficient water pressure makes hydraulic scraping difficult.

(b) Lining techniques.

When the length of pipeline has been satisfactorily cleaned, lining operations can be commenced and, again dependent to a large degree on the diameter of the pipeline and any special features, various machines are available for this work. A schematic representation of the process is shown in Figure 2.

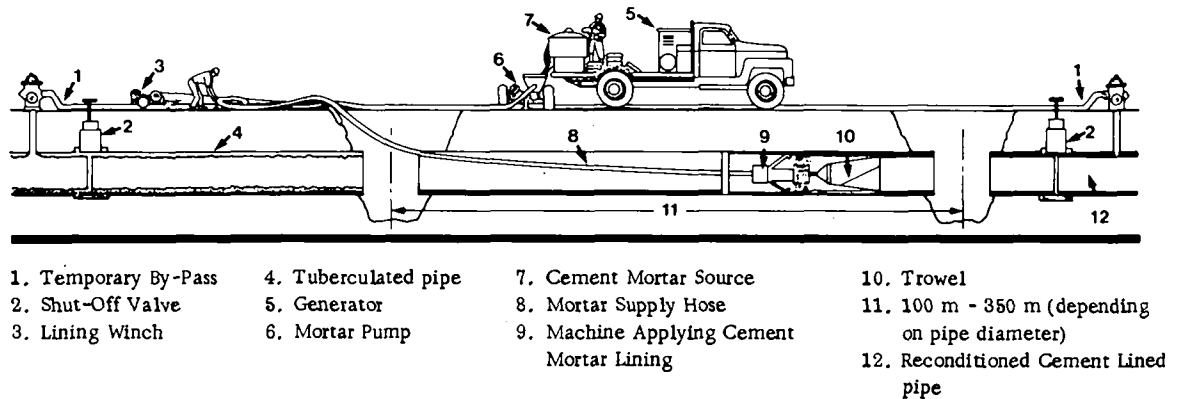


Figure 2. Cement mortar lining process

The placing of linings by the centrifugal method involves the use of an electrically-driven lining machine linked to a cement mortar storage hopper which also carries the operative controlling the machine. A cement mortar mixer, situated adjacent to the access opening in the pipe, feeds the cement mortar in batches to a conveyor trolley, also carrying an operative. This trolley travels along the pipe and, by means of a screw-feed, maintains the contents of the storage hopper that is attached to the lining machine. From the storage hopper, the mix is again screw-fed under the control of the machine operative, into the lining machine itself. From here, still by screw-feed, the mix of 1:1 is passed into the lining-head outlet.

The head, spinning at high velocity, discharges the cement mortar through a series of openings and thus on to the walls of the pipe where, by means of slowly rotating trowels, carefully spring-adjusted, the lining is trowelled to a smooth, dense finish as the machine slowly travels backwards to the pipe access. The desired thickness of lining is obtained by adjusting the rate of travel of the machine. The operative-controlled machine can, of course, only be used on pipelines above 600 mm diameter.

Electric power for the equipment is provided by diesel-driven mobile generators of large output.

For the cement mortar lining of 180 to 600 mm diameter pipelines, the centrifugal machine is employed. The principal differences from the larger machine are the omission of the rotating trowels and the method of supply of cement mortar mix to the machine. The mix is pumped from ground surface level by means of a screw-

feed pump, along a supply hose to the machine, and, as with the larger machine, is sprayed centrifugally at high speed on to the pipe. Smoothing of the surface is achieved by a cone-shaped drag-trowel, designed for the pipe size, drawn behind the spinning head: the speed of travel again determines the thickness of the lining.

In the small diameter pipelines (75 to 150 mm) a lining machine, basically centrifugal in operation but again without trowels, is also used. This machine may be operated either by compressed air or electricity depending on conditions and the specification. A drag-trowel completes the smoothing as in the larger sizes, and the machine and trowel are winched through the pipeline at a pre-determined speed to achieve the specified thickness of lining. The whole of the equipment for use on these smaller-diameter pipelines can be mounted on a very compact trailer, making this type of process very suitable for use in built-up areas, where this class of work usually occurs.

### 3.2.3. Advantages.

- (a) In general the cost/metre of this process is significantly lower than that of renewal.
- (b) Available evidence indicates that any cracks which may develop in the lining tend to seal by a process termed autogenous healing.
- (c) A significant improvement in C-value is observed. Values of 130 to 140 are typical.
- (d) Linings have been observed to last for over 40 years.
- (e) There are no known health problems associated with the use of cement mortar in conjunction with drinking water.

### 3.2.4. Disadvantages.

- (a) On small diameter mains there is a short term problem of leaching of free lime with resultant increase in pH to values in excess of 10. In certain waters this can also induce alum precipitation. A programme of early morning flushing is required.
- (b) The lining causes a significant reduction in pipe bore on small diameter mains.
- (c) Between 24 and 48 hours are required to elapse before reconnection and tanker supply is normally provided for this period.

### 3.2.5. Conclusions.

Experience has indicated that water mains suffering from water discoloration and tubercle growth can be successfully renovated and given a further life in excess of 40 years, by cement mortar lining.

### 3.2.6. Contractors.

Centriline Limited,  
Clifton House,  
83-89 Uxbridge Road,  
Ealing, London, W5 5TA.

Maccudor Limited,  
3 Elystan Street,  
London, SW3 3NT.

Tate Pipe Lining Processes Limited,  
Redgate Lane,  
West Gorton,  
Manchester, M12 4PA.

## 3.3. THERMOPLASTIC PIPE INSERTION (SLIP LINING)

### 3.3.1. Introduction.

The renovation of deteriorating ferrous gas mains by the insertion of polyethylene (PE) pipe within the existing pipeline structure is now considered by most gas distribution engineers as an acceptable installation practice. For small diameters, the PE pipe from a continuous coil is winched through the existing main; final installation being effected by socket fusion or butt fusion welding of the pipe ends in the trench. For large diameters, a continuous coil cannot be used and sections have to be fusion welded above ground prior to insertion.

In addition, the process has been used in Europe and the United States to renovate sewer outfalls, storm drains, and industrial plant pipework. In recent years DuPont have designed a complete urban sewer renovation system.

Interest is developing within the UK into the applicability of this technique to the structural renovation of water mains. The first trial operation took place in 1975 for the Thames Water Authority, Metropolitan Division.

A 600 mm diameter cast iron main was structurally renovated by inserting a 560 mm outside diameter, 31.7 mm wall thickness, high density polyethylene pipe (HDPE).

Pipe diameters up to 1200 mm are available for water supply use.

The maximum length capable of being lined in a single run is quoted as approximately 550 metres; however, in practice this is normally restricted to 150 metres.

### 3.3.2. The process.

The process can be seen schematically in Figure 3.



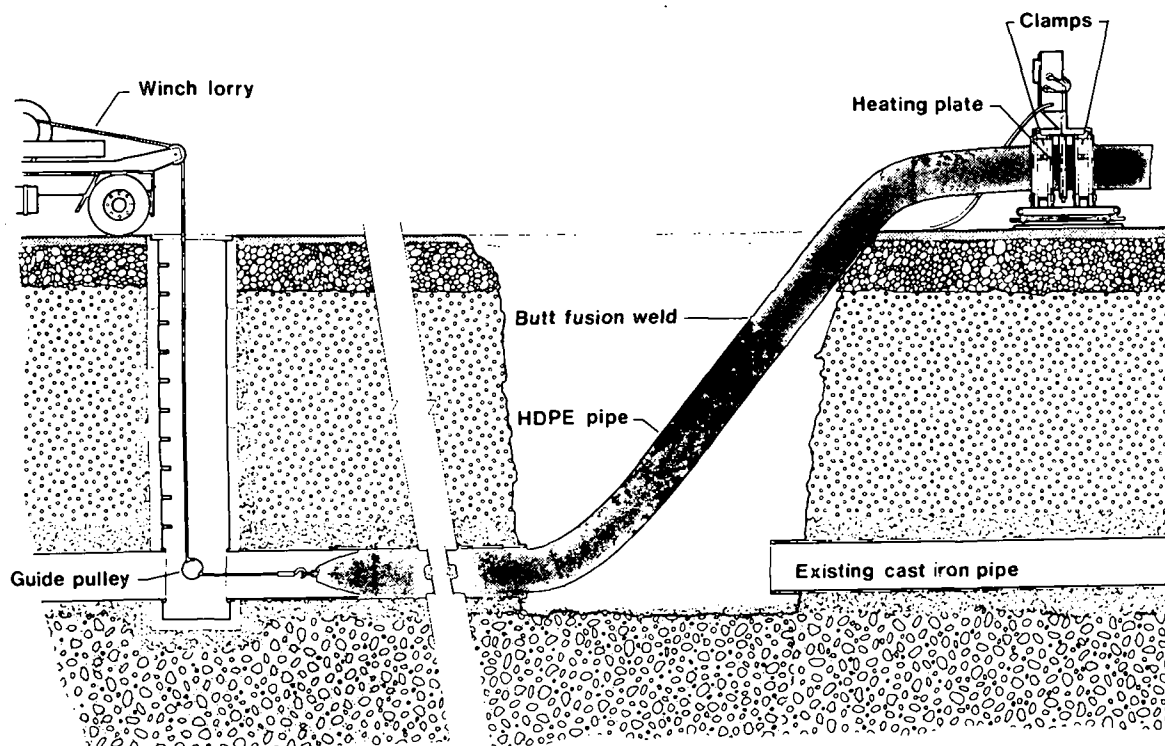


Figure 3. Thermoplastic pipe insertion process

Excavations are made at approximately every 150 metres. Each excavation has a radiused lead-in (Figure 4), the curvature of which is determined by the diameter of pipe to be inserted. A small section of HDPE pipe of identical diameter to that to be inserted is winched through the main to ascertain whether obstructions are present; if they are the main is scrapped.

Sufficient HDPE pipe sections for a 150-metre insertion are welded together above ground. A tapered nose piece with a winch hook is fusion welded to the leading pipe section. The HDPE pipe is winched through the existing main and fusion welded in the trench to the previously inserted length.

The integrity of each weld is assessed using X-ray radiographical techniques.

### 3.3.3. Advantages.

- (a) The process is the only available structural renovation technique.
- (b) The first application showed an 18 per cent cost saving with respect to renewal.
- (c) In densely populated areas disruption can be reduced.
- (d) HDPE has been approved by NWC Approval Board for contact with potable water.



← Radiused lead-in

← Butt fusion weld  
performed in trench

Figure 4. Thermoplastic pipe insertion technique. General view of excavation showing lead-in trench

#### 3.3.4. Disadvantages.

- (a) A significant reduction in pipe bore is produced. This effect is compensated somewhat by the high Hazen Williams C-value of HDPE of 150.
- (b) A long excavated lead-in is required for installation.
- (c) No satisfactory technique is available for making remote connections.
- (d) The effects of surge are unknown.
- (e) It has been shown that large diameter pipe under the relatively high water distribution pressures is susceptible to catastrophic brittle fracture if air is entrapped. Available information indicates that relatively small volumes of air can produce this effect.

#### 3.3.5. Conclusions.

This process is the only commercially-available alternative to renewal where structural damage is a problem. The technique appears ideally suited to densely populated urban areas where the partial excavation can significantly reduce disruption compared with open trench replacement.

### 3.3.6. Principals.\*

DuPont (UK) Limited,  
Plastics Department,  
Hilcote Plant,  
PO Box 4,  
Blackwell,  
Derby, DE5 5JD.

Hoechst UK Limited,  
Hoechst House,  
Salisbury Road,  
Hounslow,  
Middlesex, TW6 6JH.

Paragon Plastics Limited,  
Broomhouse Lane,  
Edlington,  
Doncaster,  
South Yorkshire, DN12 4ES.

Stewarts and Lloyds Plastics,  
St Peters Road,  
Huntingdon, PE18 7DJ.

## 3.4. THE INSITUFORM PROCESS

### 3.4.1. Introduction.

The early development of the process from 1971 to 1973 was carried out by Insituform (Pipes and Structures) Limited. In 1973 Edmund Nuttall Limited acquired a UK licence and set up the Insituform division. The development activities have been generally directed towards the domestic and industrial sewerage systems and the medium pressure gas mains.

Pipes in the diameter range 100 mm to 1200 mm may be renovated using this process. Lengths of up to 140 metres can be lined in one run. The process is diameter dependent as the maximum handleable weight of the liner is at present 5 tonnes.

### 3.4.2. The process.

A needled Terylene felt, encapsulated in a polyurethane bag, is vacuum impregnated with polyester resin at the factory. The polyester resin is so formulated as to produce a gel time of ten days at ambient temperature. The lining is transported to site in a refrigerated van.

Excavations are made and the pipe cleaned by flushing or scraping. A header pipe (Figure 5) is located in the trench. A driven conveyor feeds the lining into the header pipe, the leading edge being clamped over the outside of the pipe. Water is pumped into the pocket formed by the folded-back polyurethane bag. This action forces the lining to travel through the pipe, inverting itself onto the pipe wall. A

---

\* It was felt that since the application of this process to water mains is in its infancy, the names of principals rather than contractors would be more appropriate.

lay-flat hose is attached to the end of the polyurethane bag during insertion. On completion of insertion, water at 65°C is passed through the hose to accelerate the cure of the resin.

It should be noted that during the cure the lining may contract slightly, producing a small annular gap.

### 3.4.3. Advantages.

(a) The lining is claimed to be structural in nature, having the following properties.

Tensile strength	24 MPa	(3500 psi)
Compressive strength	140 MPa	(20 000 psi)
Modulus of elasticity	3.7 GPa	(0.54 × 10 <sup>6</sup> psi)

It is reported that a 200 mm pipe renovated with a 3 mm lining can be operated at a working pressure of 0.2 MPa (30 psi).

(b) The lining will conform to variations in cross-sectional shape.

### 3.4.4. Disadvantages.

(a) Excavation of branches and ferrules is required.

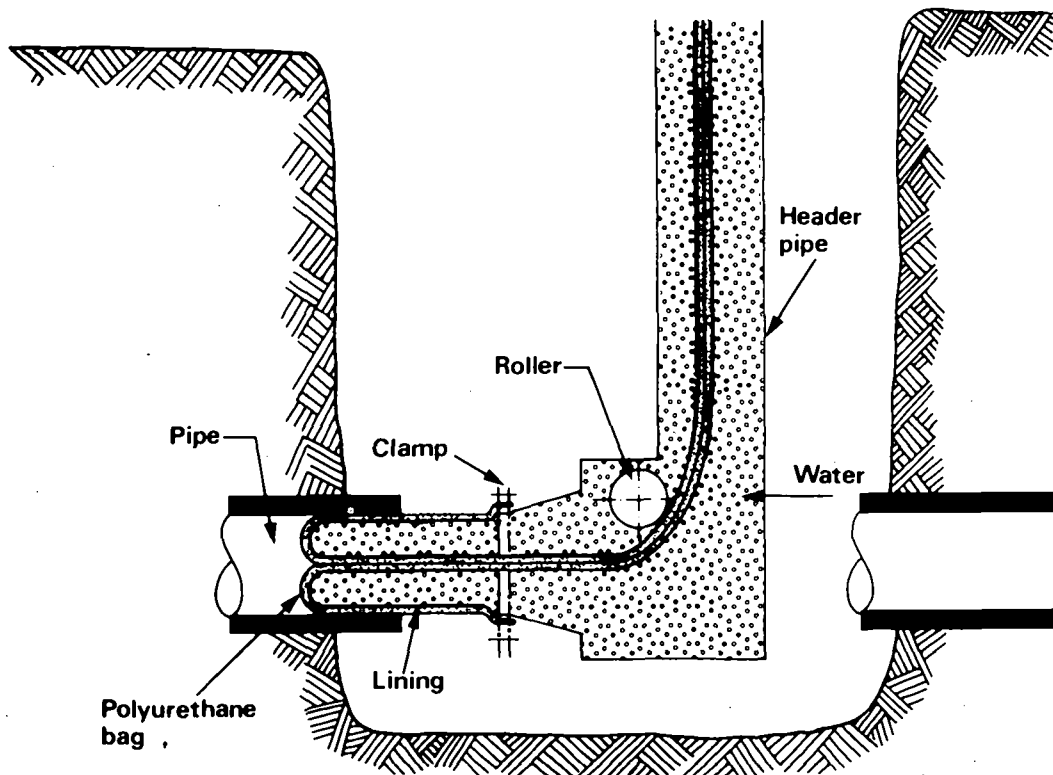


Figure 5. Insituform process

- (b) Although some structural strength is inherent in the lining, it is insufficient to withstand the pressures normally experienced in a water main without the production of thick linings. The process must therefore be classified as non-structural with respect to water main renovation and as such is expensive.
- (c) No assessment has yet been carried out to analyse the effect on water quality.
- (d) The lining appears at present to be susceptible to faults in manufacture and installation, but these are gradually being eliminated as experience is gained with the process.

#### 3.4.5. Conclusions.

As a non-structural renovation technique with respect to water distribution pressures, the process is expensive.

#### 3.4.6. Contractor.

Edmund Nuttall Limited,  
Insituform Division,  
Caldervale Industrial Estate, Forge Lane,  
Horbury Junction,  
Nr Wakefield, Yorks.

### 3.5. IN SITU RESIN COATING (TRAIN OR PIG METHOD)

#### 3.5.1. Introduction.

Historically the first in situ coating of pipe using an epoxy resin system was carried out in the United States in 1947 to 1948 on oil and gas lines. In 1953 the process was extended to salt water lines and has been used subsequently in the petrochemical industry. In recent years the process has received some publicity in the UK for use in the water industry. To date no water main has been renovated in the UK using this technique.

The process has been designated the 'train' or 'pig' method since the technique utilizes rubber pigs to transport the resin along the pipe. Pipes in the diameter range 75 to 1100 mm have been coated using this technique. It is claimed that 40 miles can be coated in a single run, but normally runs of 2 to 5 km are employed. Lining thicknesses of 0.3 mm to 2 mm can be applied.

#### 3.5.2. The process.\*

The basic equipment set up is shown in Figure 6. The air dryer is introduced into the compressed air line to remove moisture. Loading and receiving chambers are attached to the ends of the run as shown in Figure 7.

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\* The process details are taken from a site visit. Variations in procedure between contractors will exist.

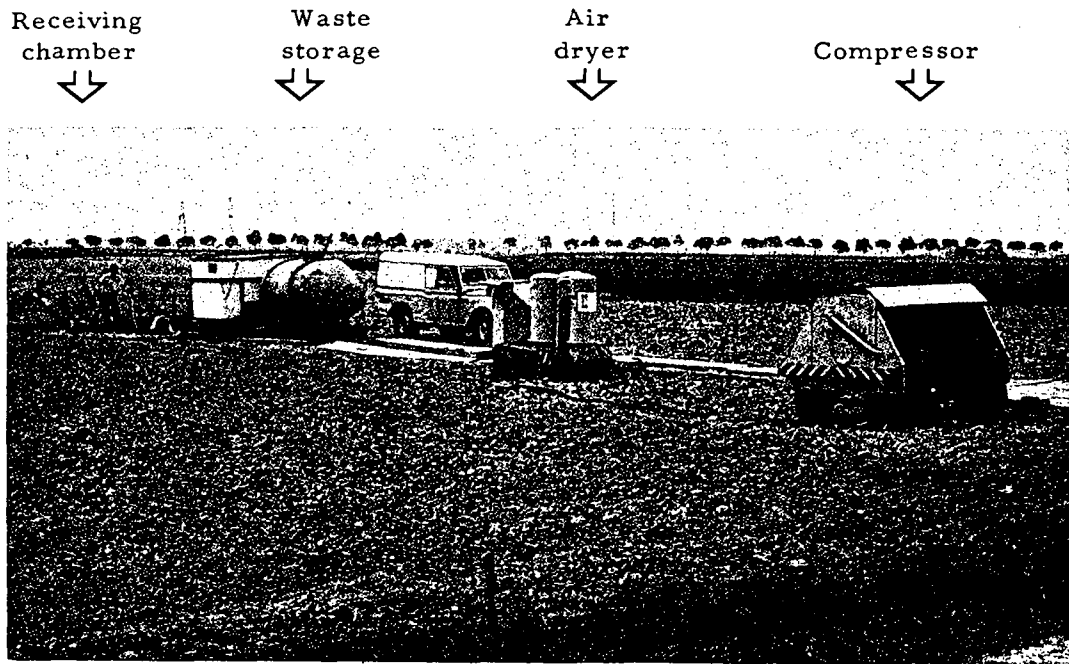


Figure 6. In situ resin coating—train or pig method. Equipment set up at each pipe end

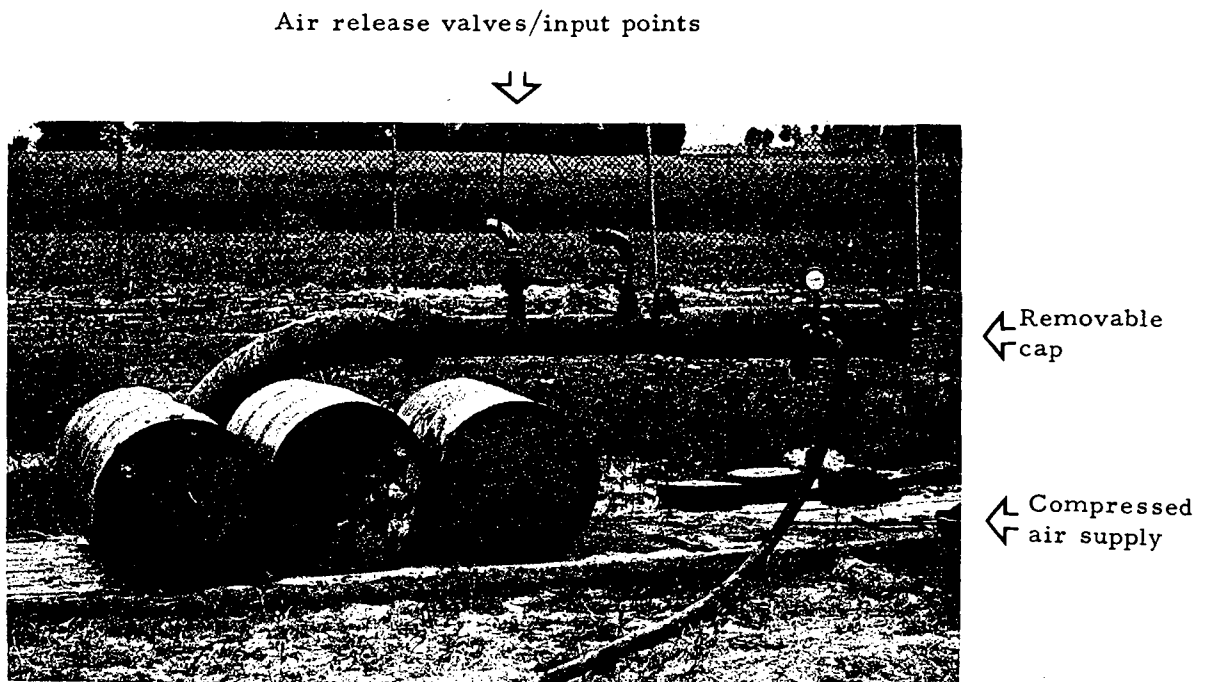


Figure 7. In situ resin coating—train or pig method. Loading/receiving chamber

(a) Surface Preparation

(i) Scale and weld debris removal

A scraper pig is passed through the lining using compressed air. Resultant scale and debris is removed by flushing with soapy water.

(ii) Rust removal

Dilute inhibited hydrochloric acid (HCl) is introduced into the space between two oversize rubber spheres. This train is passed repeatedly along the line until all surface rust has been removed, indicated by the characteristic green colour. The used HCl is passed to waste storage and the residue removed by foam pigs.

(iii) Phosphate treatment

A phosphate solution is passed along the line in a similar train to the HCl treatment, firstly to remove residual HCl, and secondly to prime the surface.

(iv) Acetone treatment

The pipe surface is first dried by a train containing acetone.

(v) Methyl ethyl ketone (MEK) treatment

Final drying of the line is facilitated by a train containing MEK. The surface preparation of 2 km of 150 mm pipe took 48 hours.

(b) Resin Coating

Three separate coatings are applied to the pipe surface to minimize the probability of pinholing. One to three days are required to elapse between the application of each coat to allow the solvent from the resin to evaporate. If this is not carried out, inter-coat blistering develops. A calculated volume of activated resin (gel time 8 hours) is introduced into the pipe in advance of a single rubber sphere. Compressed air is applied behind the sphere causing the train to move along the pipe. A squeeze film of resin is applied to the pipe wall. At the end of the run the excess resin is collected and if this volume exceeds a certain value the coating thickness is classified as inadequate and the train is returned. This process is repeated until sufficient resin has been applied to the pipe bore.

3.5.3. Advantages.

- (a) Minimal reduction in pipe bore.
- (b) Long lengths can be coated in a single run.

#### 3.5.4. Disadvantages.

- (a) All branches need to be blocked off.
- (b) Ferrule intrusion would disturb the seal.
- (c) Pipe eccentricity would present problems in maintaining an adequate seal.
- (d) The coating tends to slip if ground vibration occurs before gelation. This problem could be serious in urban areas.
- (e) As a result of the long duration of the process, by-passing would be essential.
- (f) Not all the resin systems used in this process have NWC approval for contact with potable water.
- (g) One hundred per cent coverage cannot be guaranteed.

#### 3.5.5. Conclusions.

The process appears attractive for the renovation of pipe in rural areas where long runs may be encountered.

#### 3.5.6. Contractors.

E. Wood Limited (Resin Supplier),  
Talbot Works,  
Stanstead Abbots,  
Ware, Hertfordshire, SG12 8DP.

ECTA Construction Materials Ltd.,  
PO Box 65,  
Comet Way,  
Southend-on-Sea, Essex, SS2 6XY.

### 3.6. MEMBRANE LINING PROCESS

#### 3.6.1. Introduction.

The membrane lining process has been under development primarily for the sealing of leakage in cast iron gas mains resulting from the drying out of joints caused by the changeover from town gas to natural gas. A nylon membrane externally coated with a modified epoxy resin is winched into the cleaned main and expanded onto the pipe wall using differential air pressure.

To date no gas mains in service have been lined using this technique although demonstrations have taken place on a number of abandoned gas lines.

The process has obviously been developed for application in pipe diameters up to 450 mm. Above this value man access is possible to effect joint sealing.

It is claimed that lengths of up to 250 metres can be lined in a single run, but demonstrations have been limited to 200 metres.

#### 3.6.2. The process.

The process can be divided into three distinct phases.



(a) Preparation of the main

A scraper train consisting of a four-cutter revolving scraper driven by compressed air is propelled along the main by a back pressure of compressed air or by winching. The air stream created is utilized to remove debris. The rate of travel is 2 to 3 metres per minute. A foam swab is blown through the main to remove residual debris. Moisture is absorbed by the application of a ketone scavenger using a spray unit.

(b) Insertion of lining

The basic set-up for insertion is shown in Figure 8. The nylon membrane lining with the sacrificial underlay is drawn into the pipe; the underlay prevents damage during insertion. Before entry, the upper surface of the membrane is coated with modified epoxy resin as shown in Figure 9. On insertion the lining ends are cut and bonded to the pipe by a strip of nitrile rubber.

(c) Lining placement

The pipe ends are capped and the main evacuated to a pressure of two-thirds atmospheric. The membrane is now inflated, the differential air pressure causing the resin to flow round the pipe bore and effecting the adhesion of the lining to the pipe wall.

3.6.3. Advantages.

- (a) Little reduction in pipe bore, the total lining thickness being 1 mm.

3.6.4. Disadvantages.

- (a) The installed membrane lining is wrinkled in appearance. This is expected to reduce the C-value. In addition fatigue of the wrinkles during service may develop. The manufacturer believes that this problem can be obviated.
- (b) Methods for reinstatement of branches and ferrules have not been investigated.
- (c) Effects on water quality and health are unknown.
- (d) The durability of the lining is unknown.

3.6.5. Conclusions.

The simplicity and anticipated cost of the process are sufficiently attractive to warrant continued development.

3.6.6. Contractor.

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

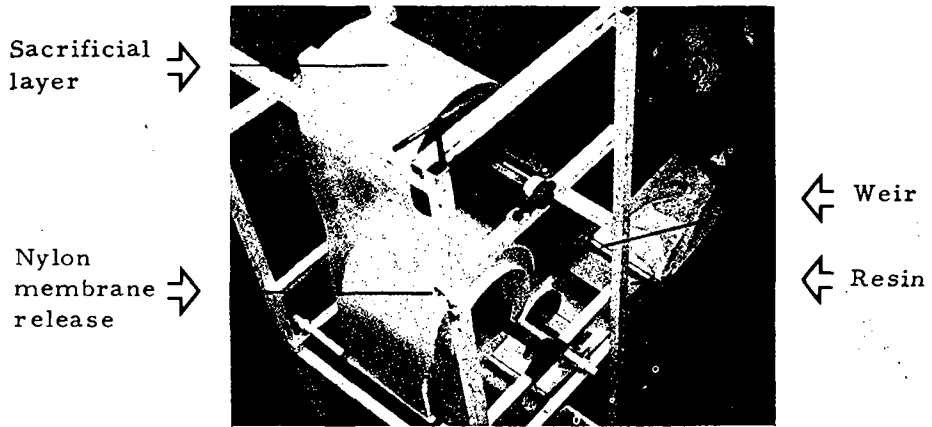


Figure 8. Membrane lining technique. General set-up

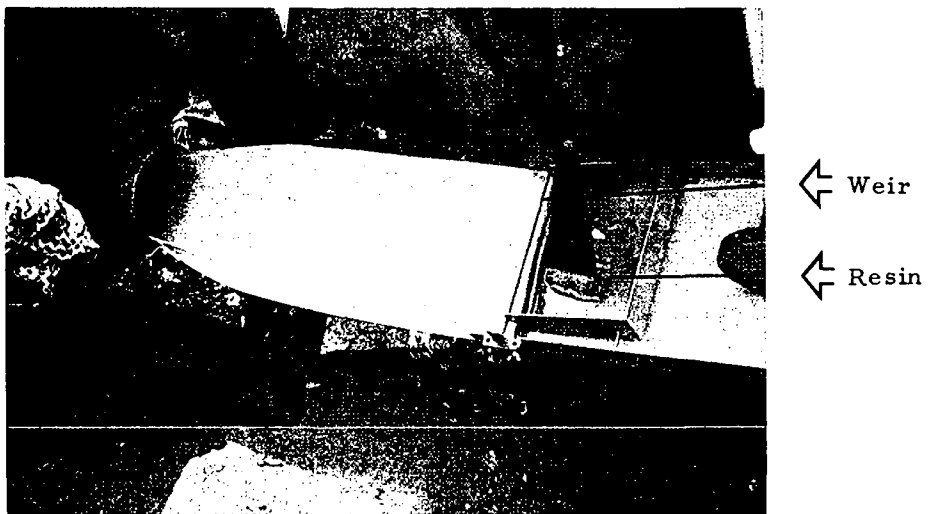


Figure 9. Membrane lining technique. Close-up of insertion

### 3.7. IN SITU RESIN COATING (SPRAY METHOD)

#### 3.7.1. Introduction.

During the last twelve months resin spray equipment for the lining of pipes in the diameter range 100 mm to 1800 mm has become available. Two types of machine are at present produced. The first machine consists of an airless spray head mounted at the front of a pneumatically-driven four-wheeled carriage. For pipes of diameter less than 1000 mm a stationary spray head is utilized and for diameters greater than 1000 mm the spray head is rotatable. The second machine consists of a cylindrical air motor driving a centrifugal spinner head. Both machines are fed from airless-spray pumps positioned outside the pipe.

The four-wheeled drive machine appears to have overcome the erratic coating application problems associated with manual withdrawal of the spray unit by incorporating a pneumatically-powered drive mechanism. Controlled withdrawal of the second machine is under development.

Although there is no theoretical limit to the length of pipe which may be sprayed in a single run, the present range of airless-spray pumps and fittings set a practical limit of approximately 20 metres.

Coating thicknesses of 0.2 to 4.0 mm can be applied. Coatings have been applied under factory conditions on short lengths of pipe, but no in situ work is known to have taken place to date.

A demonstration utilizing the centrifugal spinner-head machine was held recently at WRC Medmenham Laboratory. The process description given below is taken from this demonstration. It is hoped that a demonstration of the alternative machinery will be held in the future.

#### 3.7.2. The process.

For satisfactory adhesion of the coating, thorough cleaning of the pipe is essential. This is achieved by grit blasting the surface with expendable shot. The energized shot is passed to the applicator lance which is designed to produce a cone-shaped blast of particles. The debris is blown out of the pipe by compressed air. The lance is withdrawn manually at a rate of 1 metre per minute. Multiple runs may be required to produce a satisfactory surface. If tuberculation is present, scraping of the pipe prior to grit blasting is required.

A phosphate primer coat is applied to the grit-blasted surface using the spinner-head spray unit. The unit is withdrawn manually at a rate of approximately 4 metres per minute. Sixteen hours are allowed to elapse for the primer to dry.

Two separate resin coatings are applied to the primed surface using the spinner-head spray unit. The process is shown in Figure 10. Withdrawal is manual at a rate of approximately 4 metres per minute. Two hours are allowed to elapse between each coat application.

The resin system used for this technique is a solvent containing vinyl ester resin. Preliminary results of leaching experiments under stagnant water immersion conditions, carried out on samples from the demonstration, indicate that a minimum of 100 hours will need to elapse before the lined pipe can be reintroduced into service.

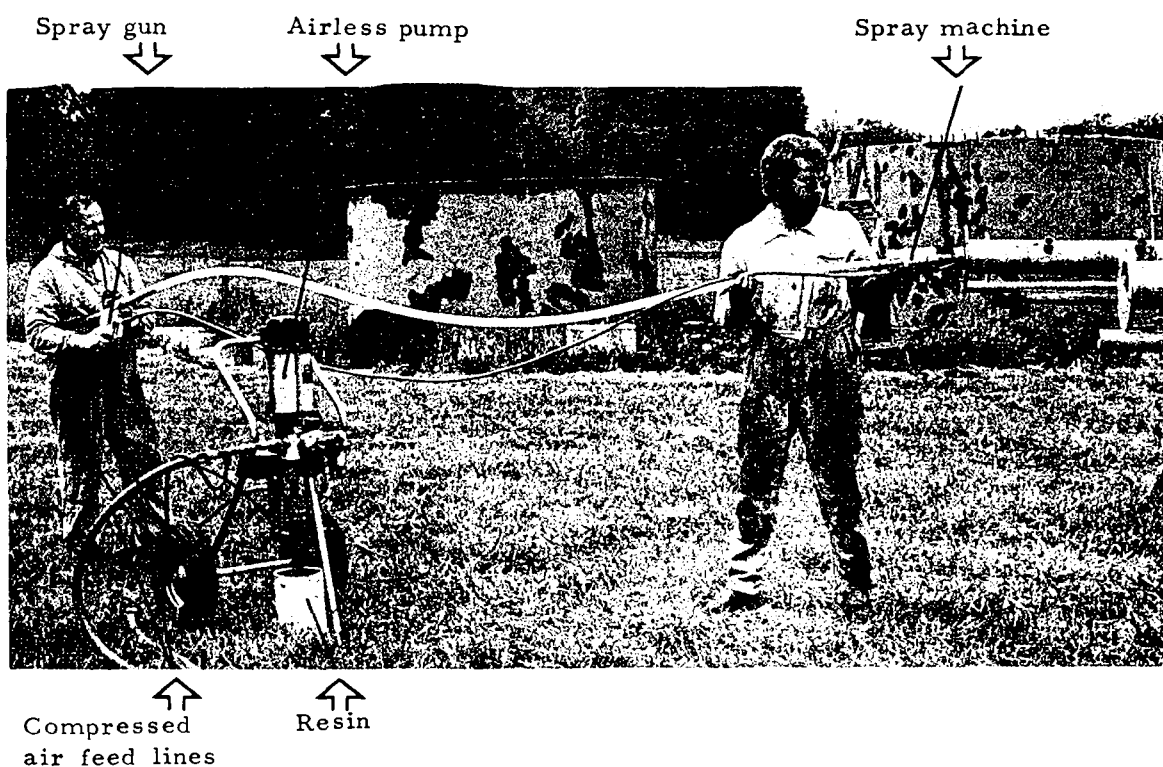


Figure 10. In situ resin coating—spray method

#### 3.7.3. Advantages.

- (a) The spray process can be used on pipelines containing branches, ferrules, and so on.
- (b) Minimal reduction in pipe bore.

#### 3.7.4. Disadvantages.

- (a) At present, only short lengths can be coated in a single run.
- (b) To avoid taste and odour problems, the pipeline would need to be out of service for a considerable time.
- (c) Effect on water quality is not known.
- (d) Life expectancy is unknown.
- (e) 100% coating coverage cannot be guaranteed.

### 3.7.5. Conclusions.

The process can be used for factory application of coatings on short pipe lengths. However, further development is required before its use for the in situ renovation of water mains can be contemplated.

### 3.7.6. Contractors.

#### Pneumatically driven carriage

Colebrand Engineering Limited,  
Colebrand House,  
20 Warwick Street, Regent Street,  
London, W1R 6BE.

#### Centrifugal spray head machine

Hodge Clemco Limited,  
Orgreave Drive,  
Handsworth,  
Sheffield, S13 9NR.

## 3.8. FIBRE REINFORCED CEMENT (FRC) LINING

### 3.8.1. Introduction.

Joint collaboration between Pilkington Brothers and the Building Research Establishment has seen the emergence of a new glass fibre resistant to attack by ordinary Portland cement. The fibre is termed Cem FIL 'AR' glass fibre.

By the introduction of small-volume fractions of glass fibre (1 to 5 %) into cement, significant improvements in mechanical properties can be achieved. Of particular relevance to renovation techniques are the improvements in tensile strength, impact resistance and significantly reduced shrinkage.

Joint development is being initiated between WRC Medmenham Laboratory and Pilkington Brothers to assess the applicability of the material to the renovation of water mains and sewers.

Other fibre types will also be evaluated.

### 3.8.2. Advantages.

- (a) The material can be applied using existing cement mortar lining equipment.
- (b) The reduction in shrinkage, particularly in above-ground application.
- (c) Increased flexibility and impact resistance can reduce the possibility of cracking at joints caused by ground movement.
- (d) Structural strength can be imparted to the lining.

### 3.8.3. Disadvantages.

- (a) The mechanical properties of glass fibre reinforced cement (GRC) show a reduction with time (2). It is felt that sufficient data are available to allow life expectancies, under different operational conditions, to be assessed (3).
- (b) The effect of the presence of glass fibre on water quality is unknown.

3.8.4. Conclusions.

The material is of sufficient potential as both a non-structural and structural lining for the renovation of water mains and sewers to warrant further development.

3.8.5. Manufacturer.

Pilkington Brothers Limited,  
Cem FIL Marketing,  
Fibreglass Head Office,  
Prescot Road,  
St Helens, Merseyside, WA10 3TR.

## 4. COSTS OF RENEWAL AND RENOVATION

### 4.1. DIFFICULTIES IN MAKING COMPARISONS

As with any cost comparison, it is important to compare like with like, otherwise the comparison could be misleading. The costs of renovation and renewals are particularly difficult to compare for a number of reasons, some of which are listed below.

- (a) The cost of a contract is dependent upon techniques used, diameter, length, depth, location (such as the carriageway, footpath or verge), number of services, state of the market at time of tender, and so on.
- (b) The amount of work undertaken by water authority staff is often not specified nor included in quoted costs.
- (c) The durability of the lining is often not known.
- (d) The cost of a temporary supply, if required.
- (e) Actual permanent reinstatement costs incurred are difficult to obtain.

Whilst a concerted effort is being made to collect this information, it may prove to be impossible without a detailed study of a number of specific jobs and even then the results may not be applicable elsewhere. Consequently, it is felt that the immediate task of WRC should be the identification of the major cost items involved in each technique, leaving the water undertakings to provide the detailed costs for particular areas.

### 4.2. COSTS OF RENEWAL

N.B. Generalized costs are given in this report, but it is important that they are not used by engineers for decision-making since they may be totally inappropriate for a particular problem.

Since the ultimate solution to all problems associated with mains failures is renewal, the cost of renewal is a convenient 'yardstick' to measure all methods of renovation. In practice the cost of renewing a water main will depend upon the items mentioned in (a) above, and consequently the actual cost could vary from job to job, place to place and month to month. However, an attempt has been made to determine the average costs of renewal with factory-applied concrete-lined ductile iron mains in an essentially non-corrosive soil area.

The costs\* shown in Table 2 are based on average costs taken from two annual contracts using the following assumptions.

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\* At August 1976.

- (i) Renewal of 300 m of main with concrete-lined ductile iron.
- (ii) Transfer of 50 services.
- (iii) Install 2 hydrants including tees.
- (iv) Install 2 on-line valves.
- (v) Connect three tee junctions.
- (vi) Permanent reinstatement of road using asphalt on lean mix concrete.
- (vii) 1 m ground cover.
- (viii) New main laid in road adjacent to existing main.
- (ix) Old main to be sealed and grouted.

The costs of renewing water mains are similar to the costs of new construction but with additions for reconnections and filling or otherwise making safe the old main.

Water undertakings that have a large number of mains in need of renewal will probably obtain more favourable costs than those given in Table 2, particularly if they are able to plan an even workload over a three to five year period.

#### 4.3. COSTS OF RENOVATION

##### 4.3.1. Introduction.

The actual cost of renovating a water main can only be determined by studying each particular job in detail and estimating the cost of each stage. It is anticipated that current research will provide cost guidelines for water undertakings.

Set out in Tables 3 and 4 are the estimated costs of relining a 300 m length and a discontinuous length in excess of 2 km of 150 mm diameter main with cement mortar or bitumen.

In addition, comparable data is included for the thermoplastic pipe insertion (slip lining) technique. It must be stressed that these latter data have not been collated from actual jobs but have been produced from a purely synthetic model: the justification for their inclusion is that the process is the only structural renovation technique currently available.

##### 4.3.2. Cement lining of a 150 mm diameter main.

The example is based on the assumptions given in paragraph 4.2 above and the following:

- (a) The pipe is laid on level ground.
- (b) This will require three or four passes of the scraper.
- (c) The two valves occur within the pipeline length.



- (d) Ten of the services (20 per cent) will become blocked and therefore require excavation.
- (e) Temporary supply is provided by tanker.
- (f) The main will be out of service for 24 hours.
- (g) The cost of the scraping and cement relining are based on figures quoted by one contractor.

**Table 2. Typical cost/metre of renewing 300 m\* of cast iron water distribution mains**

Diameter (mm)	100	150	200
	£	£	£
Breakout and temporary reinstatement	2.67	3.00	3.35
Lay and joint pipe	2.52	2.82	3.15
Test, flush sterilize	0.08	0.08	0.09
Permanent reinstatement	9.03	10.11	11.31
Connect services	3.63	3.63	3.63
Fit valves	0.13	0.14	0.14
Fit hydrants	0.26	0.28	0.29
Connect junction	0.70	0.80	0.86
Transfer main supply	1.05	1.17	1.26
Water undertaking attendance	0.09	0.09	0.09
Seal and grout old main	0.46	1.03	1.84
Valve and hydrant boxes	0.51	0.51	0.51
Pipe and joints	3.08	4.55	11.29
Valves	0.31	0.48	1.42
Hydrants	0.55	0.55	0.55
Ferrules and service pipe	0.91	0.91	0.91
Hydrant tees	0.13	0.23	0.75
Bends	0.10	0.16	0.67
Rubber rings	0.02	0.03	0.06
<b>TOTAL COST/METRE</b>	<b>26.23</b>	<b>30.57</b>	<b>42.17</b>

\* The renewal cost/metre for a discontinuous length in excess of 2 km is not expected to be different from that quoted for a 300 m length.

In this example, in addition to pipes and joints the most significant costs are permanent reinstatement and connection of services.

**Table 3. Cost of cement mortar lining 150 mm diameter main**

Item	Cost/metre	
	300 m £	≥ 2 km £
Excavate, backfill and temporarily reinstate pits at start and end of pipe	0.29	0.29
Remove section of pipe at start and end of pipe	0.01	0.01
Excavate, remove and replace valve, temporary reinstatement	0.46	0.46
Excavate, remove blockage and reinstate at 20 per cent of house connections*	0.71	0.71
Recondition and coat valves by hand	0.03	0.03
Flexible couplings	0.13	0.13
Provide temporary supply by tanker for 24 hours	0.07	0.07
Water undertaking attendance	0.13	0.13
Scrape and cement mortar line	3.60	3.60
Move contractor's equipment to site	3.33	0.50
Permanent reinstatement:		
1. End pits	0.48	0.48
2. Valve pits	0.32	0.32
<b>TOTAL COST/METRE</b>	<b>9.56</b>	<b>6.73</b>

\* Where 'blow back' is not possible.

The significant costs, in this example, are the scraping and lining process itself, and the initial setting up costs.

**Table 4. Cost of scraping and bitumen lining 150 mm diameter main**

Item	Cost/metre	
	300 m £	≥ 2 km £
Excavate, temporarily, and bitumen line. Supply all fittings as required.	6.00	4.00
Water undertaking attendance	0.13	0.13
Provide temporary supply for 8 hours	0.04	0.04
Permanent reinstatement of 6 m <sup>2</sup> every 100 m length	0.70	0.70
<b>TOTAL COST/METRE</b>	<b>6.87</b>	<b>4.87</b>

Costs are only available for the complete work by the contractor on site.

4.3.3. Bitumen lining of a 150 mm diameter main.

The costs for bitumen lining are based on those quoted by one contractor. The particular contractor undertakes all excavation and temporary reinstatement, all pipe cutting and supplies all the fittings required. Normally the contractor would expect a job to be 1.5 to 4 km minimum length.

4.3.4. Pipe insertion into a 150 mm diameter main.

The cost data shown in Table 5 have been produced using a purely synthetic model to quantify the expected cost sensitive aspects of the operation.

Table 5. Cost of pipe insertion (slip lining) into 150 mm diameter main

Item	Cost/metre	
	300 £	≥ 2 km £
Excavate, backfill and temporarily reinstale lead-in and tie-in pits	0.19	0.19
Excavate, remove and replace valves and hydrants including backfill, temporary reinstatement and new fittings	2.33	2.33
Excavate, remove and reconnect services using appropriate fittings: temporary reinstatement included	2.50	2.50
Excavate, remove and replace junctions: cost of fittings and temporary reinstatement included	0.79	0.79
125 mm Class D HDPE pipe (no handling charges included)	4.23	4.07
Clear obstructions and draw in liner	4.42	4.42
Radiographic testing of welds	1.67	1.67
Test flush and sterilize main	0.08	0.08
Water undertaking attendance	0.09	0.09
Temporary water supply by tanker for 8 days	0.57	0.57
Move contractor's equipment to site	3.33	3.33
Permanent reinstatement at £12.24/m <sup>2</sup>		
1. Lead-in and tie-in pits	0.18	0.18
2. Valves and hydrants	0.12	0.12
3. Services	1.20	1.20
4. Junctions	0.12	0.12
TOTAL COST/METRE	21.82	18.83

In this example, significant costs are for excavation and replacement of valves and services, the liner, its handling into the existing main, and setting up.

## 5. CONCLUSIONS

Eight renovation processes have been considered:

- Bitumen lining
- Cement mortar lining
- Thermoplastic pipe insertion
- Insituform
- In situ resin coating (train method)
- Membrane lining
- In situ resin coating (spray method)
- Fibre reinforced cement lining

### Bitumen lining

The process has been used for non-structural renovation of water mains. The main attraction is the cost of the process; in the example given it is approximately 20 per cent of renewal. In addition, the main can be reintroduced into service the same day. The major disadvantage of the process is the lack of durability of the lining.

### Cement mortar lining

The process has been used since the mid 1930s as a solution to non-structural problems. The cost is attractive; in the example given, it is approximately 25 per cent that of renewal. The major disadvantage of the process is that the main has to be out of service for 24 to 48 hours. However, with our present knowledge, cement mortar lining is the most satisfactory alternative to renewal as a solution to non-structural problems.

### Thermoplastic pipe insertion

The process is the only currently available structural renovation technique. It has been used successfully in the gas, petrochemical and sewerage industries. Synthetic cost modelling has indicated that the cost of the process is approximately 65 per cent of renewal. The technique appears attractive for use in urban areas with dense traffic where the partial excavation can significantly reduce disruption with respect to open trench work. The major disadvantage is the significant reduction in pipe bores.

### Insituform

The technique has been used to renovate sewers. However, with respect to water distribution pressures, the process must be classified as non-structural and from actual job costs is expected to be expensive compared with renewal.

#### In situ resin coating (train method)

The technique has been used successfully for the non-structural lining of long lengths of pipe for the petrochemical industry. The major process advantages are the small reduction in pipe bore and the fact that long lengths, 2 to 5 km, can be coated in a single run. With respect to water distribution, two major disadvantages are apparent; the inability to line lengths with service connections, and the long duration of disconnection (approximately 10 days). The technique shows potential for non-structural renovation of mains laid in rural areas where the number of service connections is small. Costs are not currently available.

#### Membrane lining

The process appears to be a simple and cost-attractive non-structural renovation technique. Some development is required before its application to water mains can be contemplated. Costs are not available.

#### In situ resin coating (spray method)

The technique has been shown to be sufficiently attractive for the non-structural renovation of water mains particularly where the frequency of service connections is high. Significant development work is required. Costs are not available.

#### Fibre reinforced cement lining

Available information suggests that, by the introduction of fibres into cement mortar, linings of sufficient strength to withstand internal pressurization and external loading can be produced. Costs are not available.

## 6. FUTURE WORK BY WRC

Research at WRC Medmenham Laboratory is to be concentrated in three areas:

1. Assessment of the durability and economics of operation of bitumen and cement mortar lining.
2. Investigation of the potential of fibre reinforced cement for structural and non-structural renovation.
3. Monitoring of developments in other processes and, where appropriate, the organization of trials.

## ACKNOWLEDGEMENTS

The Water Research Centre acknowledges the information supplied by the industrial concerns mentioned in the report and the assistance given by members of the National Water Council Standing Committee on Sewers and Water Mains. It is also indebted to Mr M. Goulding formerly of Manchester Corporation Waterworks and now Consultant to Tate Pipe Lining Processes Limited for the information which makes up a significant part of the Section dealing with cement mortar lining.

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3. CLARE, H. J.                    Private communication. Pilkington Brothers Limited, St. Helens, 1976.