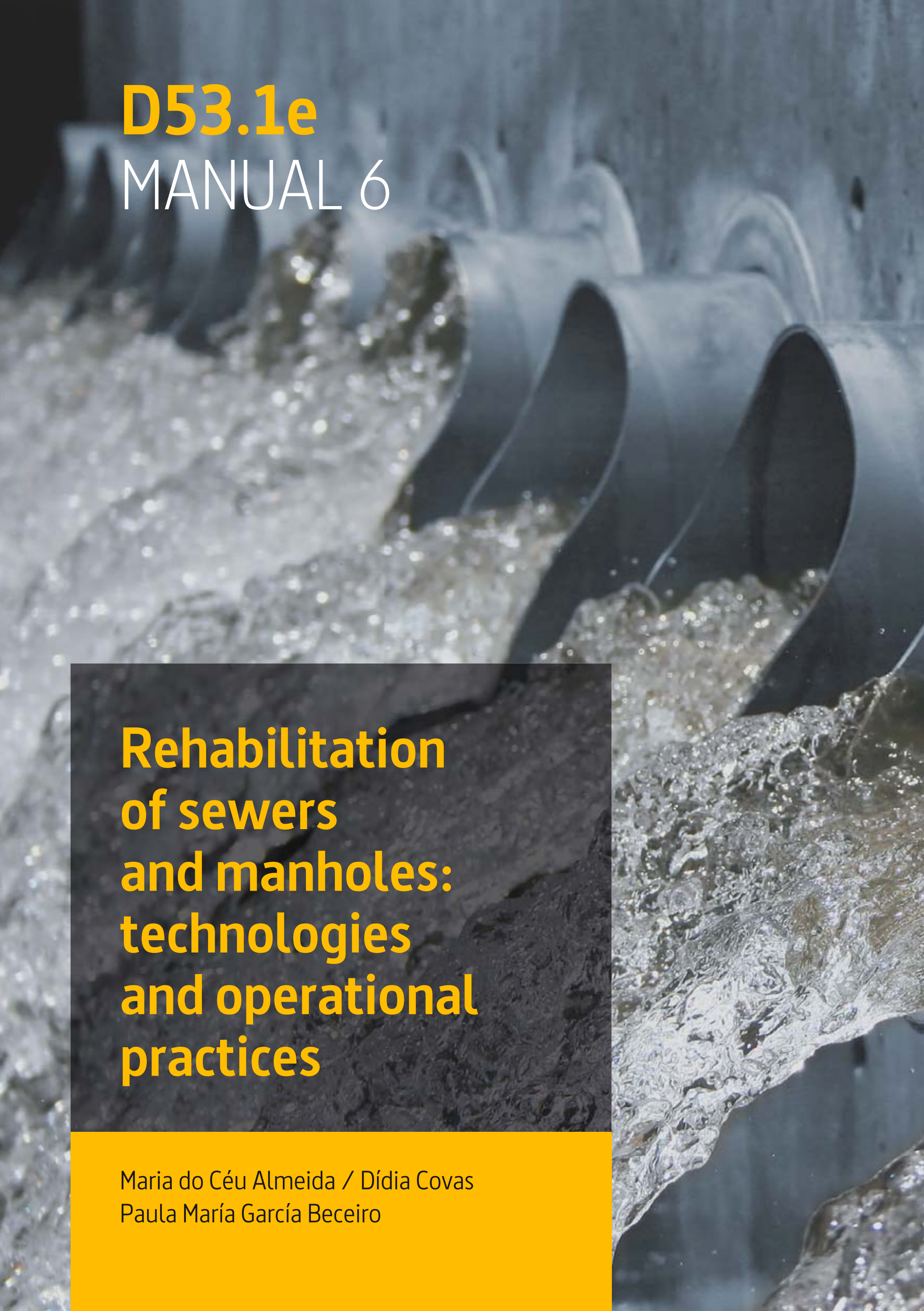

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MANUAL 6

Rehabilitation of sewers and manholes: technologies and operational practices

Maria do Céu Almeida / Dídia Covas
Paula María García Beceiro

Rehabilitation of sewers and manholes: technologies and operational practices

Authors:

Maria do Céu Almeida, LNEC – National Civil Engineering Laboratory
Dídia Covas, IST –Instituto Superior Técnico, Universidade de Lisboa
Paula María García Beceiro, LNEC – National Civil Engineering Laboratory

Reviewers
Rita Ugarelli SINTEF - Stiftelsen SINTEF
Ana Galvão, IST –Instituto Superior Técnico, Universidade de Lisboa

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1 Introduction

1.1 Scope

The scope of the current TRUST manual is the identification and organisation of best-practice and rehabilitation techniques of sewers and manholes at the operational level.

This manual presents a service-oriented portfolio of rehabilitation techniques, based upon a thorough assessment of the existing and emerging offers in sewer systems. It provides an overview and guidance to professionals on available rehabilitation techniques for sewer systems, focusing on sewers and manholes given their importance for the overall infrastructure. However, some of these techniques can be applied to other components such as drains and laterals. It presents as well operational practices to support rehabilitation and repair strategies.

This is the sixth volume of a series of manuals developed in scope of the TRUST project (www.trust-i.net). The other volumes include the global framework of infrastructure asset management (Manual 1), specific guidelines for policy-making at a national or regional level (Manual 2) and for strategic and tactical planning at the utility level (Manuals 3 and 4) well as a portfolio of rehabilitation techniques of water mains and storage tanks (Manual 6).

1.2 Document structure

The document has three chapters, being the first the present introductory chapter.

Chapter 2 focuses on the rehabilitation technologies for sewers and manholes mains, including the classification of the technologies, the non-structural and structural renovation techniques, the replacement techniques and a methodology for selecting the technique. **Chapter 3** provides an overview of operational practices often used in rehabilitation interventions

1.3 Target public

This manual is targeted for water professionals (Cabrera *et al.*, 2011):

TARGET GROUP	PROFILE	NEEDS AND EXPECTATIONS
Water professionals: Technical staff	Control all the technical aspects of urban water systems other than management Technical formation to be expected Close profile to the scientific community	Expect technical content with details for practical uses Particularly technical documents; no research details necessary

Rehabilitation technologies for sewer systems

2

2.1 Introduction

Rehabilitation of components of sewer systems is essential to ensure the overall systems as well as individual components performance. Additionally, the useful life of components can often be extended by timely action to correct either defects or deterioration resulting from various factors.

The rehabilitation activities can be driven by the need to improve the performance of the system or individual components in terms of: structural behaviour (e.g. increase of structural capacity); hydraulic behaviour (e.g. reduction of the roughness or of infiltration) and environmental behaviour (e.g. reduction of exfiltration of sewage to adjacent ground).

Existing bibliography on rehabilitation of sewer systems is extensive. A structured classification of the different techniques, providing information on the main characteristics and application potential is presented in this report, largely based in existing standards (e.g. EN 12889:2000, CEN 2000b; EN 15885:2010/prA1, CEN 2010a; EN 14654-2:2013, CEN 2013;

ISO 11295:2010, ISO 2010) and other recognised references (e.g. Stein, 2001).

The selection of the technique to be used in each specific case depends on the local conditions and the methodological guidance is based on specific criteria for supporting the selection of the most appropriate techniques.

2.2 Classification of rehabilitation techniques for sewers and manholes

The rehabilitation techniques, adopted in order to improve the current system or component performance, are commonly classified into three types: **renovation**, **replacement** and **repair**, as adopted in the standard EN 15885:2010/prA1 (CEN, 2010a).

Renovation consists in the intervention in an existing system component incorporating totally or partially the existing material (EN 752:2008, CEN 2008a).

Replacement involves the construction of a new component of the system which adopts the function of the disabled component (EN 752:2008, CEN 2008a).

Repair consists in the rectification of local anomalies (EN 752:2008, CEN 2008a).

Some rehabilitation techniques are also applied outside the context of rehabilitation, particularly, in maintenance activities or for preventive purposes (e.g. material protection in order to avoid the posterior degradation), usually repair or renovation techniques.

In the following table, the adopted classification to the rehabilitation techniques of the components of sewer systems is presented. The main references for the different types of techniques are: EN 12889:2000 (CEN, 2000b) and EN 1610:1997 (CEN, 1997) standards for replacement techniques; and, EN 15885:2010/prA1 (CEN, 1010a) and ISO 11295:2010 (ISO, 2010) standards for renovation and repair techniques. This classification is primarily intended for sewer systems, but it has been harmonised with the classification proposed for water supply systems on the common features applicable (Alegre and Covas, 2010).

In the next chapters the main characteristics, conditions of application, advantages and disadvantages of each rehabilitation technique family for sewers are presented. For each technique the applicability into manholes and the specific techniques that are applied in these components are also referred. The abbreviations used for materials are specified in annex 1.

Additionally to the previously mentioned standards, other specific standards for design concepts and principles are referred to when applicable, including EN 752:2008 (CEN, 2008a), EN 14801:2006 (CEN, 2006), EN 13689:2002 (CEN, 2002c), EN ISO 11296-1:2011 (CEN, ISO, 2011a) and EN 1916:2002/AC: 2008 (CEN, 2008b) standards.

Classification of rehabilitation techniques

TYPE	TECHNIQUES	
Repair	Repair by injection	
	Repair with cured-in-place patch	
	Repair with trowelled material	
	Repair by sealing with internal mechanical devices	
	Repair with lateral connection collar	
	Other repair techniques	
Renovation	Lining with continuous pipe	
	Lining with close-fit pipe	
	Lining with cured-in-place pipe	
	Lining with discrete pipes	
	Lining with spirally wound pipe	
	Lining with formed in place	
	Lining with pipe segments	
	Lining by sprayed, trowed or cast-in-place material	
Replacement	Open cut or trench replacement	
	Semi-open cut replacement	
	Unmanned trenchless replacement	Non-steerable techniques: - Soil displacement techniques - Soil removed techniques
	Manned trenchless replacement	Steerable techniques: - Microtunnelling - Pilot jacking with pipe bore - Directional drilling

2.3 Repair techniques

The repair techniques are those intended to rectification of local damage, and the majority are trenchless techniques. Most of these techniques do not improve the integrity or the structural resistance of the component and are designed to fix specific problems associated with local anomalies in the material, with infiltration and exfiltration, reduction of the roughness on surfaces, among others. Several of these techniques are also applicable for manholes.

Repair techniques families considered herein are:

- repair by injection sealing;
- repair with cured-in-place patch;
- repair with trowelled material;
- repair by sealing with internal mechanical devices;
- repair with lateral connection collar;
- other repair techniques.

In the following sections, each family of techniques is briefly described including an overview of the main characteristics, conditions of application, advantages and disadvantages, and relevant standards. The main references are the EN 15885:2010/prA1 (CEN, 2010a) standard and Stein (2001).

In the case of reinforced concrete, the repair of cracks is especially important to control the potential corrosion of reinforcement bars that can develop without significant outward evidence.

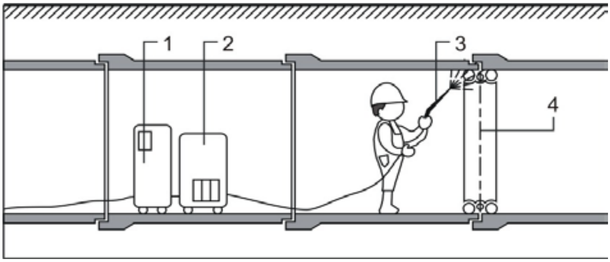
Given the continued development of processes and variety of application possibilities, an exhaustive description of existing techniques is not carried out. Instead, this overview is mainly based in techniques considered in existing normative documents. Other repair techniques that are not detailed in this document can be found in literature (e.g. Stein, 2001) and on the internet.

2.3.1 Repair by injection

This family of techniques consists in the repair by injection of non-retractable grout in local anomalies. These repairs can be subdivided in:

- repair by grout injection by robotic means;
- repair by grout injection by manual means, in man-entry sewers, usually using an injection pump;
- repair by grout fill injection, used for filling voids in the pipe material or adjacent soil associated with joints or cracks.

The schematic representation of these alternatives is presented in the following figures:



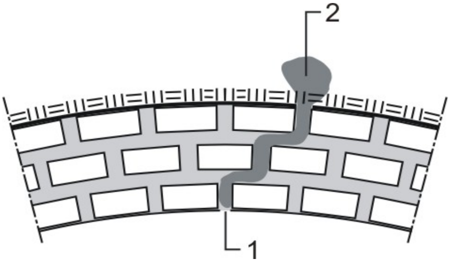
Legend

1 – Control panel

2 – Injection pump

3 – Injection lance

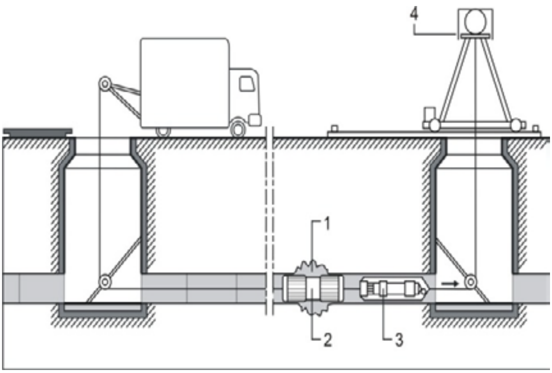
4 – Packer



Legend

1 – Point of injection

2 – Filled void



Legend

1 – Section to inject

2 – Packer

3 – CCTV

4 – Winch

For the application of this family of techniques, usually the pipe to be rehabilitated must be out of service, free of obstructions or flow, and cleaning is required before execution of the repair. Usually, in non-man-entry sewers, repair is monitored with CCTV.

The main characteristics and conditions of application of **repair by grout injection by robotic means**, based in the EN 15885:2010 (CEN, 2010a) standard are summarized as follows:

FEATURES	DESCRIPTION	
Relevant standards	EN 15885:2010/prA1 (Wastewater).	
Materials	Epoxy resins (EP) or others, and cementitious mortars not retractable.	
Applications	Non pressure pipes. Applicable for manholes, drains and laterals.	
Geometric characteristics	Cross sectional shape	Circular and non-circular
	Diameter range (mm)	150 to 750
	Maximum length (m)	200 m
	Execution of bends	-
Performance	- Restoration of the local tightness and reduction of infiltration. ☺ - Hydraulic capacity is not reduced. ☺ - Improvement of environmental performance if there exfiltration in anomaly to be repaired. ☺ - Abrasion and chemical resistance depend on material.	
Installation characteristics	- Filling void in joints, fissures and connections of drains, laterals or sewers. ☺ - Applied by robots under CCTV control. - Repair does not resist surcharging pressure. ☹ - Repair resists external water pressure. ☺ - Minimal surface working space required. ☺ - Access is possible via manholes. ☺ - The technique does not rely on adhesion to host pipe. - Flow diversion is required. ☹	

Legend: ☺ Main advantages; ☹ Main disadvantages.

The main characteristics and conditions of application of repair by grout injection by manual means are presented, based in the EN 15885:2010/prA1 (CEN, 2010a) standard are summarized as follows:

FEATURES	DESCRIPTION	
Relevant standards	EN 15885:2010/prA1 (Wastewater).	
Materials	Grout retractable or not, cementitious or polymer.	
Applications	Non pressure pipes. Applicable for manholes.	
Geometric characteristics	Cross sectional shape	Circular and non-circular
	Diameter range (mm)	Man-entry sewers
	Maximum length (m)	1200 m
	Execution of bends	-
Performance	- Tightness improved locally. ☺ - Hydraulic capacity is not reduced. ☺ - Improvement of structural behaviour due to restoration of the integrity of the pipe or amelioration of the behaviour of the surrounding soil. ☺ - Improvement of environmental performance if exfiltration occurred in defect to be repaired. ☺ - Abrasion and chemical resistance depends on material.	
Installation characteristics	- Filling void in joints, fissures and connections of drains, laterals or sewers. - Holes are made in the pipe for injection and control. - Pressure applied in the injection is controlled in function of the material resistance of the existing pipe. ☺ - Spacing of injection holes to ensure continuity of void filling. - Minimal surface working space required depends on the equipment but not generally significant. ☺ - Access is possible via manholes. ☺ - The technique does not rely on adhesion to host pipe. ☺ - Flow diversion is required. ☹	

Legend: ☺ Main advantages; ☹ Main disadvantages.

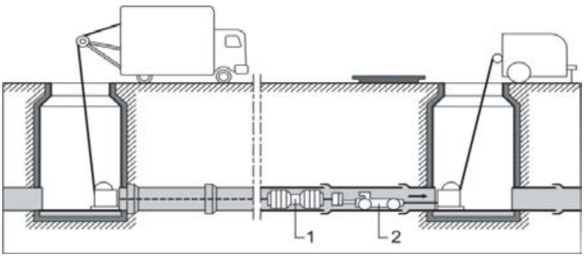
The main characteristics and conditions of application of repair with injection grouting, based in the EN 15885:2010/prA1 (CEN, 2010a) standard are summarized as follows:

FEATURES	DESCRIPTION	
Relevant standards	EN 15885:2010/prA1 (Wastewater).	
Materials	Epoxy resins (EP) or others, and cementitious mortars non retractable.	
Applications	Non pressure pipes. Applicable for manholes, drains and laterals. Not applicable in lining pipes.	
Geometric characteristics	Cross sectional shape	Circular and non-circular
	Diameter range (mm)	Minimum 150
	Maximum length (m)	200 non-man-entry; 1 000 man-entry
	Execution of bends	-
Performance	- Restore of the tightness locally and reduction of infiltration. ☺ - Hydraulic capacity is not reduced. ☺ - Improvement of environmental performance if exfiltration occurred in defect to be repaired. ☺ - Improves structural integrity of the pipe/ground set. ☺ - Chemical resistance depends on material.	
Installation characteristics	- Filling void in fissures or joins. - Applied by robots in non-man entry sewers under CCTV control. - Repair does not resist surcharging pressure. ☹ - Repair resists external water pressure. ☺ - Minimal surface working space required. ☺ - Access is possible via manholes. ☺ - The technique does not rely on adhesion to host pipe. ☺ - Flow diversion is required. ☹	

Legend: ☺ Main advantages; ☹ Main disadvantages.

2.3.2 Repair with cured-in-place patch

This family of techniques consists in the repair of local anomalies through placement of patches and short sleeves which are cured-in-place. In some cases, structural strength can be improved on site. These techniques can be applied in joints, radial fissures, longitudinal fissures and local anomalies with fragmented material. Schematic representation of this technique is shown as follows:



Legend

1 – Packer

2 – CCTV

For the application of this family of techniques, usually the pipe to be rehabilitated must be out of service, free of obstructions or flow, and cleaning is required before execution of the repair. In non-man-entry sewers, the monitoring of the repair work is usually carried out with CCTV.

The main aspects of application of **repair with cured-in-placed** technique are presented. The main characteristics and conditions of application are shown of cured-in-place patch repair are summarized as follows:

FEATURES	DESCRIPTION	
Relevant standards	EN 15885:2010/prA1 (Wastewater)	
Materials	Epoxy resins (EP) or others, and cement mortars non retractile	
Applications	Non pressure pipes. Applicable for manholes, drains and laterals.	
Geometric characteristics	Cross sectional shape	Circular and non-circular
	Diameter range (mm)	Minimum 100 (by robotic means in non-man-entry sewers)
	Maximum length (m)	200 m (non-man-entry sewers)
	Execution of bends	Possible in not sharp bend
Performance	- Restore of local tightness locally and reduction of infiltration. ☺ - Hydraulic capacity is not reduced. ☺ - Improvement of environmental performance if exfiltration occurred in defect to be repaired. ☺ - Abrasion and chemical resistance depend on material.	
Installation characteristics	- Mechanical or leak sealing function. - Applied by robots in non-man-entry sewers under CCTV control. ☺ - Repair does not resist surcharging pressure. ☹ - Repair resists external water pressure. ☺ - Minimal surface working space required. ☺ - Access is possible via manholes. ☺ - The techniques rely on adhesion to host pipe, the preparation of pipe surface is required. ☹ - Flow diversion is required. ☹	

Legend: ☺ Main advantages; ☹ Main disadvantages.

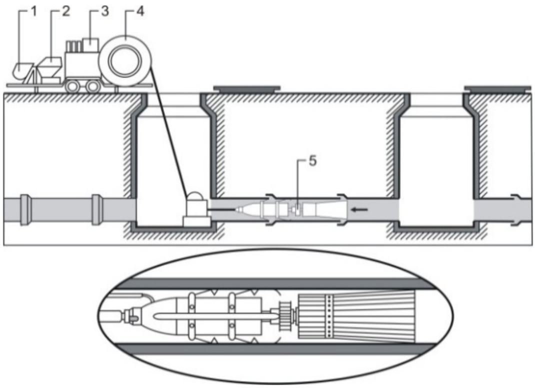
2.3.3 Repair with trowelled material

This family of techniques consist in the repair by coating, with or without reinforcement (reinforcement bars), by trowelling material. These techniques allow improving the resistance to physical, chemical and biological agents that act in the inner pipe surface. In some techniques the structural strength is improved with the repair. Other techniques allow improving the tightness of the pipe. The coating thickness depends on the material and the diameter, but can be as low as 1 mm. The curing process depends on the coating material.

For the application of this family of techniques, usually the pipe to be rehabilitated must be out of service, free of obstructions or flow, and cleaning is required prior to the execution of the repair. The application of the inner coating requires that the inner wall of the pipe is completely clean and polished and, in some cases, also dried; in some cases, for instance in case of local deterioration due to corrosion, rectification of the surface might be necessary. Locating of laterals and application of plugs to connections can be necessary prior to coating, being pigs removed after the curing process. If plugs are not used, the laterals must also be cleaned after pipe repair is concluded. In non-man-entry sewers, the location of laterals and monitoring of the repair work is usually carried out with CCTV.

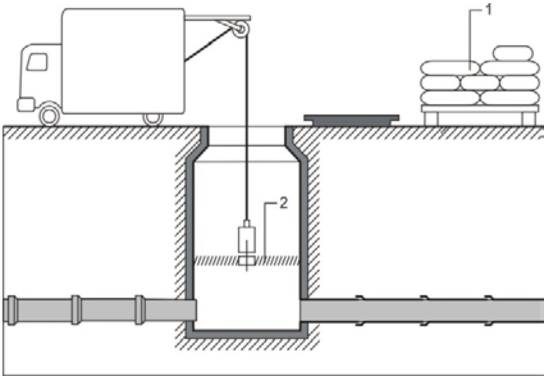
The coating can be applied by mechanical means (typically by winching or by a robot) or by manual means, depending on the diameter and length of the pipe to be rehabilitated. In other cases, coating can be applied with a rotary spray head inserted at the end of a hose, being the material spread on the inner surface of pipe. Examples of repair with trowelled material techniques are shown as follows, using a robot and by manual application, respectively.

(a)



Legend
1 – Mixer
2 – Pump
3 – Generator
4 – Cable and hose drum
5 – Spray machine

(b)



Legend
1 – Materials reservoir
2 – Spray machine

In some cases, after application of the coating, the pipe section is isolated to allow curing to occur, for a period ranging from 12 to 24 hours. This time can be significantly lower for special grouts.

The main characteristics and conditions of application of repair with trowelled material are presented, based in the EN 15885:2010/prA1 (CEN, 2010a) standard and Stein (2001), are summarized as follows:

FEATURES	DESCRIPTION	
Relevant standards	EN 15885:2010/prA1 (Wastewater).	
Materials	Cementitious or polymer grout (cement, epoxy, UP, PU, (silicates or mixtures). Reinforcement with glass fibre or for application of metallic meshes (man-entry sewers).	
Applications	Non pressure pipes. Pressure pipes. Applicable for manholes, drains and laterals.	
Geometric characteristics	Cross sectional shape	Circular and non-circular
	Diameter range (mm)	Minimum 150 (by robotic means in non-man-entry sewers)
	Maximum length (m)	200 m (non-man-entry sewers)
	Execution of bends	Possible
Performance	- Improvement of the hydraulic and mechanical performance. ☺ - Structural resistance increased is possible. ☺ - Reduction of hydraulic capacity is not significant (depends on the thickness of the coating). - Abrasion and chemical resistance depend on material.	
Installation characteristics	- Use of reinforcement in man-entry pipes. - Applied by robots in non-man-entry sewers under CCTV control. - Repair does not resist surcharging pressure. ☹ - Repair resists external water pressure. ☺ - Minimal surface working space required. ☺ - Access is possible via manholes. ☺ - The techniques rely on adhesion to host pipe, the preparation of pipe surface is required. ☹ - Reconnection of laterals is required depending on the specific technique. - Flow diversion is required. ☹	

Legend: ☺ Main advantages; ☹ Main disadvantages.

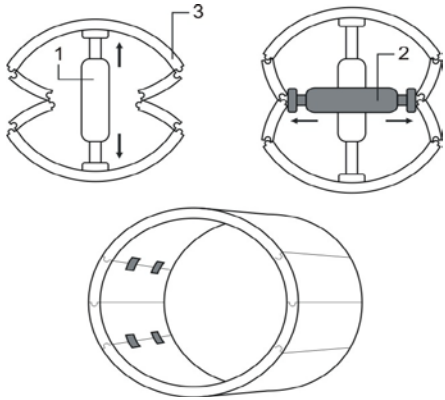
Main advantages of this family of techniques are its suitability for long pipe lengths, for different existing pipe wall materials and for different coating thicknesses.

The main disadvantages include: the required preparatory work for the application of the coating; the diversion of flow; and, some techniques of this family are especially suitable for circular cross sections. The quality of the repair depends on the proper execution and control of the processes.

2.3.4 Repair by sealing with internal mechanical devices

This family of techniques consist in the placement of elements in order to proceed with the sealing of local anomalies, such as joints or radial fissures, which are positioned and held in place by mechanical means. Besides to the mechanism, these techniques incorporate a sealing process. These techniques improve the pipe tightness provided that the damaged area is fully covered by the materials that ensure sealing. Depending on the technique reduction of the cross section can occur and, in some locations, this may result in deposits upstream of the repaired length.

For the application of this family of techniques, usually the pipe to be rehabilitated must be out of service, free of obstructions or flow, and cleaning is required before execution of the repair. The application requires that the inner wall of the existing pipe must have a smooth and uniform surface. The rectification of the existing pipe surface can be carried out in order to smooth the surface and reduce the protruding thickness of repair. If required, filling of voids in the material or adjacent soil should be carried out prior to grout injection. In non-man-entry sewers, the application and monitoring of the repair work is usually carried out with CCTV. The repair placement is made by mechanical means in order to ensure the application of the pressure required is shown as follows:



Legend

1 – Vertical jack

2 – Horizontal jack

3 – Element to be repaired

The main characteristics and conditions of application of repair using mechanical devices are presented, based in the EN 15885:2010/prA1 (CEN, 2010a) standard and Stein (2001)), are summarized as follows:

FEATURES	DESCRIPTION	
Relevant standards	EN 15885:2010/prA1 (Wastewater).	
Materials	Elastomeric sealing. Steel rings (stainless steel, aluminium), UPVC.	
Applications	Non pressure pipes. Pressure pipes.	
Geometric characteristics	Cross sectional shape	Circular
	Diameter range (mm)	Minimum 150 (by robot means in non-man-entry sewers)
	Maximum length (m)	200 m (non-man-entry sewers)
	Execution of bends	Possible
Performance	- Improved tightness of pipe. ☺ - Abrasion and chemical resistance depend on material.	
Installation characteristics	- Fixing to existing pipe by mechanical means. - Preparation of pipe surface is required. ☹ - Applied by robots in non-man-entry sewers under CCTV control. - Reduction of hydraulic capacity is not significant (local reduction of the diameter). - Repair resists surcharging pressure. ☺ - Repair resists external water pressure. ☺ - Minimal surface working space required. ☺ - Access is possible via manholes. ☺ - The techniques rely to adhesion of host pipe; the preparation of pipe surface is required. ☺ - Reconnection of laterals is required depending on the specific technique. - Protruding on the surface in the existing pipe requires repair. ☹ - Flow diversion is required. ☹	

Legend: ☺ Main advantages; ☹ Main disadvantages.

The main advantages of these repair techniques are the applicability to a wide range of pipe diameters and eliminating local problems of tightness.

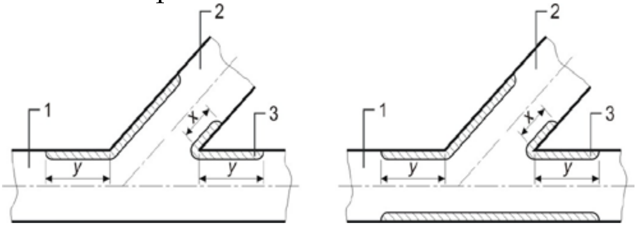
The main disadvantages include: the required preparatory work for the application of this family of techniques; the diversion of flow; and, this family of techniques is only suitable for circular cross sections. The quality of the repair depends on the proper execution and control of the processes.

2.3.5 Repair with lateral connection collar

This family of techniques is intended to repair the lateral connections, without opening trench, using a collar or tee piece that includes internal sealing of the pipe. Depending on the process, repair with sleeves impregnated with cured resin in place or using plastic materials that are fixed locally by fusion or with grout can be carried out. Depending on the technique reduction of the cross section can occur and, in some locations, this may result in deposits upstream of the repaired length.

For the application of this family of techniques, usually the pipe to be rehabilitated must be out of service, free of obstructions or flow, and cleaning is required prior to the execution of the repair. The application requires that the inner wall of the existing pipe must have a smooth and uniform surface. The rectification of the existing pipe surface or removal the protruding lateral can be carried out. If required, filling of voids in the material or adjacent soil should be carried out prior to grout injection. In non-man-entry sewers the application and monitoring of the repair work is usually carried out with CCTV.

The possible configurations of repair with lateral connections collar were presented as follows.



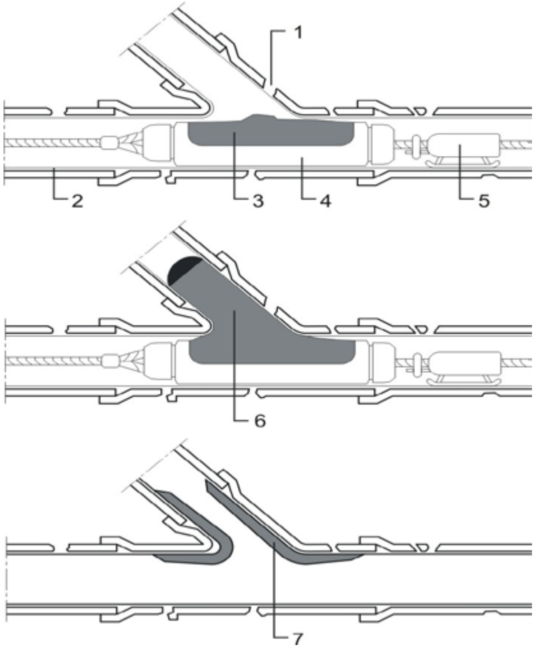
Legend

1 – Main pipe

2 – Lateral pipe

3 – Collar

In the next figure, examples of these techniques using robotic means are shown.



Legend

1 – Damaged lateral

2 – Coating

3 – Impregnated sleeve

4 – Packer

5 – CCTV

6 – Inflated sleeve

7 – Completed application

The main characteristics and conditions of application of repair with lateral connection are shown as follows, based in EN 15885:2010/prA1 (CEN, 2010a) and Stein (2001).

FEATURES	DESCRIPTION	
Relevant standards	EN 15885:2010/prA1 (Wastewater)	
Materials	Plastics (PE, PVC) or resins with thermic curing process, thermosetting resins (EP, UP). Glass fibre reinforcement.	
Applications	Non pressure pipes. Applicable for manholes.	
Geometric characteristics	Cross sectional shape	Laterals: circular; main pipes: various
	Diameter range (mm)	Non man-entry pipes: 150 to 800 (by robotic means) Possible manual application in man-entry pipes Laterals: 100to 200
	Maximum length (m)	200 m (Non-man-entry pipes)
	Execution of bends	-
Performance	- Improved tightness of pipe. ☺ - Improve flow when protruding connections are removed (obstruction). - Abrasion and chemical resistance depend on material.	
Installation characteristics	- Fixing to existing pipe through sleeve cured in place, or adhesion with fusion or grout. - Preparation and cleaning of sewers and lateral are required. ☹ - Applied by robots in non-man-entry sewers under CCTV control. - Repair does not resist surcharging pressure. ☹ - Repair resists external water pressure. ☺ - Minimal surface working space required. ☺ - Access is possible via manholes. ☺ - The techniques rely to adhesion of host pipe, requires preparation of pipe surface. ☹ - Flow diversion is required. ☹	

Legend: ☺ Main advantages; ☹ Main disadvantages.

The main advantages of these repair techniques are the applicability to a wide range of pipe diameters and eliminating local problems of tightness and obstruction due to laterals.

The main disadvantages include: ensuring the adhesion between the materials and the existing pipe; the required preparatory work; and, the flow diversion. The quality of the repair depends on the proper execution and control of the processes.

2.4 Renovation techniques

The renovation techniques consist in the intervention of a component at existing sewer system, incorporating all or part of the original material in order to improve its current performance. The majority are trenchless techniques. In most of these techniques the integrity or the structural resistance can be improved. Renovation techniques families considered herein are:

- lining with continuous pipe;
- lining with close-fit pipe;
- lining with cured-in-place pipe;
- lining with discrete pipes;
- lining with spirally wound pipe;
- lining with formed in place pipe;
- lining with pipe segments;
- lining by sprayed, trowed or cast-in-place material.

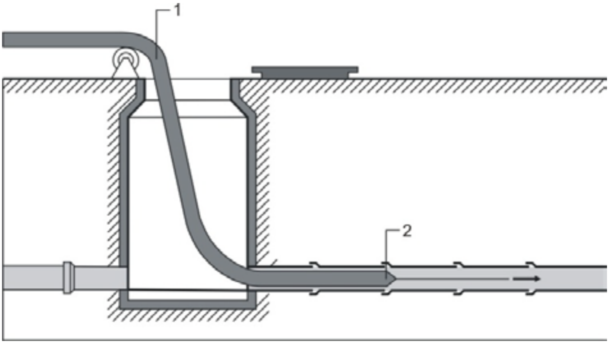
In the following sections, each family of techniques is briefly described including an overview of the main characteristics, conditions of application, advantages and disadvantages, and relevant standards. The main references are the EN 15885:2010/prA1 (CEN, 2010a) standard and Stein (2001).

2.4.1 Lining with continuous pipe

This family of techniques consists in the insertion of a long, flexible and continuous pipe in the existing sewer. The pipe is made continuous prior to insertion. In the insertion, the excavation of an access pit is usually required. Placement is carried out by pulling through a pulling head inserted in the pipe, in which a force is applied from the downstream manhole or access pit.

The renovation is carried out in the total length between manholes or access pits constructed for this purpose, or in the length to be rehabilitated.
The diameter of the lining pipe remains unchanged, being smaller than the diameter of the existing pipe. The annular space between the pipes is typically filled with a filling material such as a grout. Filling is recommended to allow fixing the new pipe, avoiding the entrance and circulation of water, dangerous gases and soil in the annular space, promoting the uniform transfer of loads along the pipe and helping to prevent the collapse of the existing pipe.

The protection and lubrication of the lining pipe during the insertion should be provided. Locating of laterals and application of plugs to connections can be necessary to avoid the entrance of filling material. The **lining with continuous pipe technique** is shown as follows:



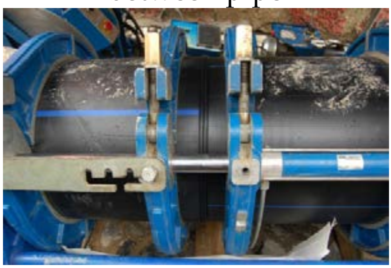
Legend
1 – Lining pipe
2 – Pulling head

The continuous pipe can be supplied on coils by the manufacturer or can be obtained by welding lengths of pipes prior to the insertion according to the diameter and the length that is to be renovated.

For the application of this technique, usually the section to be rehabilitated must be out of service and free of obstructions or flow. The process of lining with continuous pipe **by welding** is shown as follows, as recommended by Stein (2001):

Introduction of lining pipe into existing pipe

Execution of the weld between pipe



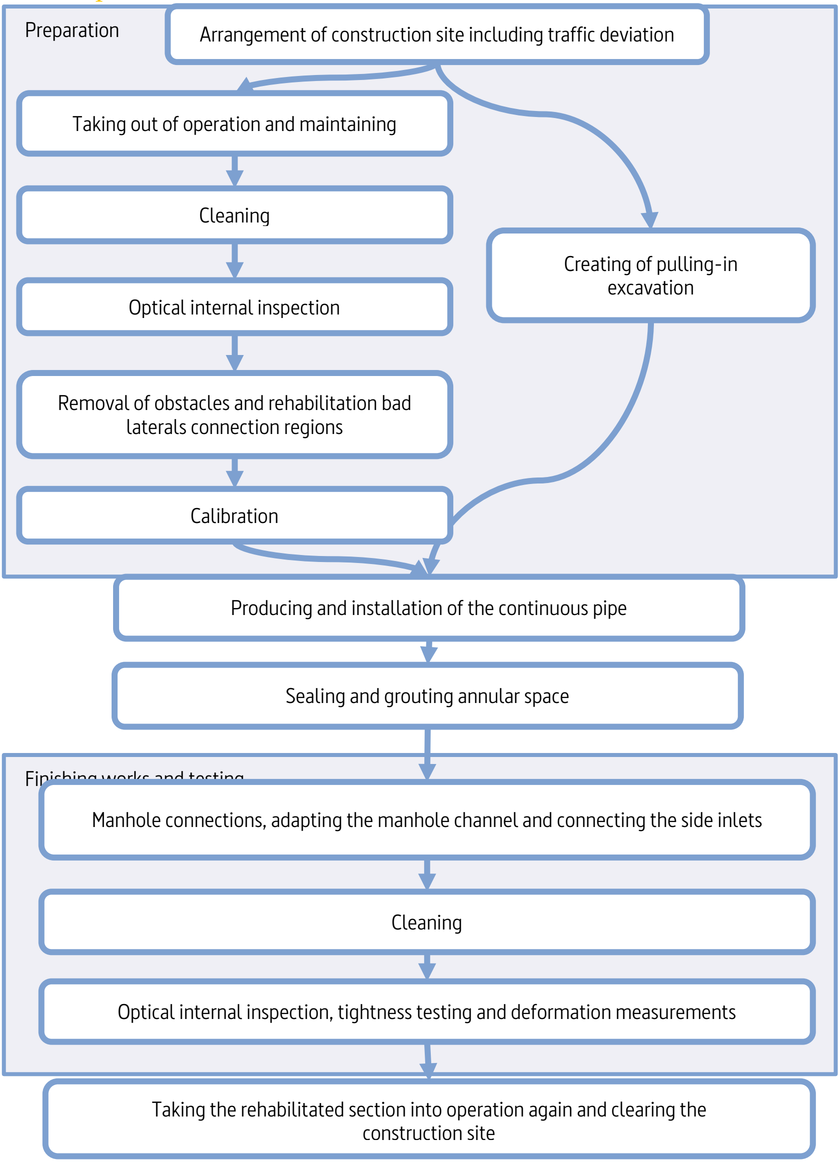
Insertion by pulling

Pulling head and access pit

The main advantage of this family of techniques is the possibility of increasing the structural capacity of the existing pipe. In concordance with WRc (2001), the advantages include the rapid insertion of the pipe and the lining is capable of accommodating large radius bends. The main characteristics and conditions of application of lining with continuous pipe are presented as follows, based in the ISO 11295:2010 (ISO, 2010) and EN 15885:2010/prA1 (CEN, 2010a) standards.

The main disadvantage is the significant loss of the cross section leading to reduce the hydraulic capacity in section; usually the reduction of roughness is not enough to compensate the reduction of cross section. A weakness of this technique is the welding process that must be duly executed and monitored by trained personnel according to the relevant quality control procedures. The limitations in the application on bends are not usually relevant in sewers, the curves and connections are realized in manholes. In accordance with WRc (2001), disadvantages include: flotation during the grouting can occurs; the excavation of an access pit is usually required for the introduction of the lining pipe; trained personnel is required for the execution of welding joints; and, difficulty of the reconnection of laterals.

Diagram of typical sequence of works in lining with continuous pipe technique



FEATURES	DESCRIPTION	
Relevant standards	EN 15885:2010/prA1, EN ISO 11296-1:2011 (Wastewater). ISO 11295:2010 (General).	
Materials	PE, PE-X, PP	
Applications	Non pressure pipes. Pressure pipes. Not applicable for manholes.	
Geometric characteristics	Cross sectional shape	Circular, non-circular cross section possible
	Diameter range (mm)	100 to 2000
	Maximum length (m)	300
	Execution of bends	Variable
Performance	- Significant loss of hydraulic capacity due to the reduction of cross section, despite de reduction of roughness. ☹ - Structural rehabilitation is possible. - Abrasion and chemical resistance depend on material.	
Installation characteristics	- Continuity of the pipe prepared prior to insertion. - Insertion possible by pushing or pulling. - Surface working space required: • reduced for the small diameters, supplied on coils. ☺ • high for larger diameter for storage and execution of the continuous pipe in place. ☹ - Access to the existent pipe requires local excavation in one end. - The technique depends of the coating adherence on the pipe inner surface. ☺ - Flow diversion is required. ☹ - The annular space is typically grouted. ☹ - Reconnection of laterals usually requires local excavation. ☹	

Legend: ☺ Main advantages; ☹ Main disadvantages.

2.4.2 Lining with close-fit pipe

This family of techniques consist in the insertion of a continuous and flexible pipe for which the cross section is reduced to facilitate the installation inside the existing pipe. The cross section is reverted after installation to provide a close fit to existing pipe, without annular space between the pipes.

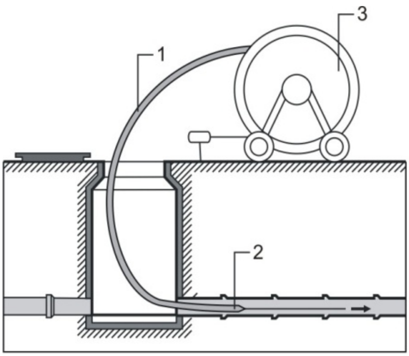
This technique has two possible methods depending on the type of deformation and reversion after installation applied in the lining pipe:

- lining with folded pipe: The pipe is longitudinally folded in the manufacturing plant or on site, obtaining a cross section reduction until 40%. After the placement in the final position, the pipe is reverted by application of heat and/or pressure. The reduction of cross section allows the insertion of the lining pipe into existing pipe through manholes, without require local excavation. The most used materials are PE and PVC.
- lining with deformed pipe: The cross section is reduced through the application of temporary diametrical compression on site, with or without to application of heat, prior to installation into existing pipe. The reduction of cross section obtained is around 10%, remaining the circular shape in the cross section. The reversion process occurs by relief of the compression force, the cross section gradually returns to the initial dimension. The most used material is PE.

The installation is usually performed by pulling. The pipe is connected to the pulling head in which a force is applied.

The application is carried out in total length between manholes, or in larger sections through intermediate manholes. In some cases, the excavation of an access pit is usually required. Schematic representations to this techniques family are shown in the following figures.

For the application of this family of techniques, usually the pipe to be rehabilitated must be out of service, free of obstructions or flow. The application requires that the inner wall of the existing pipe must have a smooth and uniform surface to ensure the complete reversion of the deformation or the reduction of the cross section, and the adjustment of the pipe. The phasing of works of this techniques family are similar to lining with continuous pipe (Stein, 2001), shows in as follow.



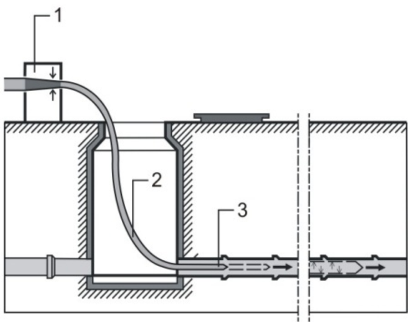
Lining with folded pipe

Legend

1 – Folded pipe

2 – Pulling head

3 – Drum trailer with folded pipe



Lining with deformed pipe

Legend

1 – Cross section reduce device

2 – Pulling head

3 – Lining pipe

In case of the existing pipe presents deformations or positional deviations, the application presents a major difficulty.

The main advantages in this family of techniques are the possibility of increasing the structural capacity of the existing pipe, rapid installation, grouting is not required and the lining is capable of accommodating large radius bends (WRc, 2001). The main disadvantages include: limitations in non-circular section; local excavation to the reconnection of laterals is required; and, deformations or positional deviations of existing pipe can cause problems.

The main characteristics and conditions of application of **lining to close-fit pipe technique** are shown as follows, based in the ISO 11295:2010 (ISO, 2010) and the EN 15885:2010/prA1 (CEN, 2010a) standards:

FEATURE	DESCRIPTION	
Relevant standards	EN 15885:2010/prA1, EN ISO 11296-1:2011, EN ISO 11296-3:2011 (Wastewater). ISO 11295:2010 (General).	
Materials	PE, PE-X, PP, PRP (polyester-reinforced PE), UPVC.	
Applications	Non pressure pipes. Pressure pipes. Not applicable for manholes.	
Geometric characteristics	Cross sectional shape	Circular, in general, and non-circular in folded pipe
	Diameter range (mm)	Folded pipe: 100 to 500 Reduced pipe: 200 to 1500
	Maximum length (m)	500
	Execution of bends	Some techniques allow
Performance	- Small reduction of the section, increase of flow capacity due to the reduction of roughness. ☺ - Structural rehabilitation is possible. ☺ - Abrasion and chemical resistance depends on material.	

Installation characteristics	- The cross section of the lining pipe is reduced by mechanical or termo-mechanical means (in the manufacturing plant or on site), then is inserted in the existing pipe and the cross section back to initial shape and size by relief of the installation forces or application of pressure and/or heat - Surface working space: • minimum in the case of lining with folded pipe. ☺ • sufficient space is required in the local place for place for the storage of the pipes and the installation in the case of deformed pipe. ☹ - Access: • in lining with folded pipe access is usually though manholes. ☺ • in lining with deformed pipe local excavation is required. ☹ - The technique does not rely to adhesion of host pipe. ☺ - Flow diversion is required. ☹ - No grouting is required. ☺ - Reconnection of laterals generally requires local excavation in pressure pipelines. Reconnection is possible from inside in gravity pipelines.

Legend: ☺ Main advantages; ☹ Main disadvantages.

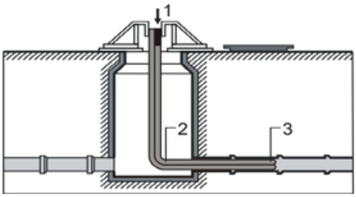
2.4.3 Lining with cured-in-place pipe

This family of techniques consists in the insertion of tube or flexible sleeve impregnated with a thermosetting resin which produces a pipe after resin cure, in the existing pipe. Different types of **lining with cured-in-placed techniques** are commercially available depending on the installation method.

These techniques are classified into two methods:

- insertion by inversion: The introduction of the flexible pipe or sleeve is made by inversion through the application of internal pressure with water or air. The curing process of resin is performed by heating water or air and the concurrent pressure application.
- insertion by winching: The pipe is inserted in the existing pipe using a winch and a cable in which the tube is pushed along the pipe to be rehabilitated. The reversion process is similar to the insertion by inversion; the tube is filled with water or air.

The combinations of methods are also possible. The number of procedures commercially available is extensive, can be also applied in drains and manholes. The representation of this rehabilitation technique family is showed as follows:



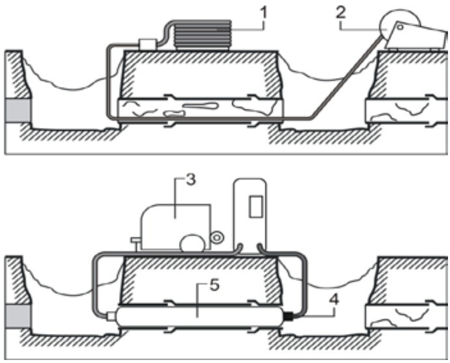
Insertion by inversion

Legend

1 – Applied pressure for inversion

2 – Lining pipe

3 – Inversion face



Insertion by winching

Legend

1 – Lining pipe

2 – Winch

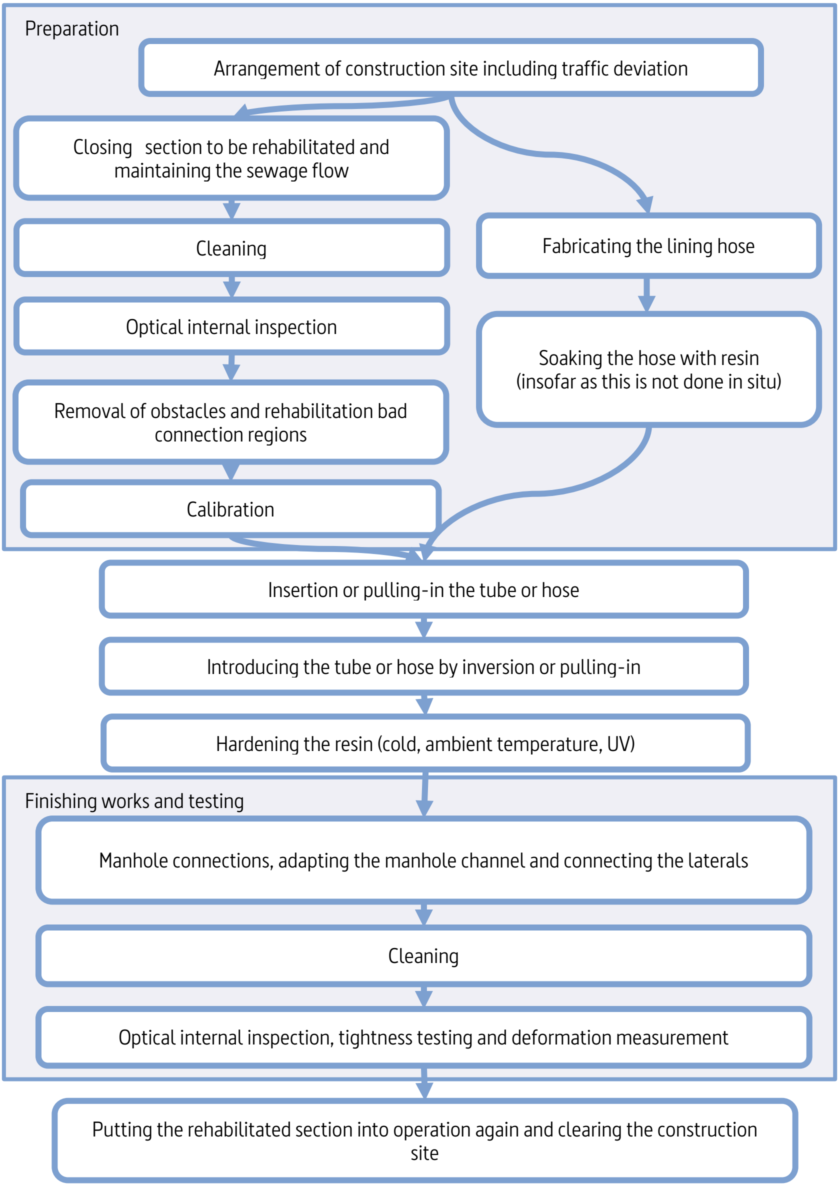
3 – End packer

4 – Curing equipment

5 – Final pipe

The application is carried out in total length between manholes, or in larger sections through intermediate manholes. In some cases, the excavation of an access pit is usually required. For the application of this technique, usually the section to be rehabilitated must be out of service and free of obstructions or flow. The process of **lining with cured-in-placed pipe technique** is shown as follows, as is recommended in Stein.

Diagram of typical sequence of works in lining with cured-in-place pipe technique



The application requires that the inner wall of the existing pipe must have a smooth and uniform surface and the complete curing process of the resin applied. The infiltration of groundwater can negatively affect the resin curing and should be avoided by the application of sealant or a membrane to confine the product.

Measures to protect the personnel (e.g. breathing) due to the toxic vapours are required in the application of this technique (e.g. solvents). These measures may include the need for forced ventilation or protective masks with appropriate filters, among others (Stein, 2001).

The differences between the insertion **by inversion or winching** are shown as follows:

Flexible sleeve prepared to insertion

Plastic protection

Beginning of inserting of sleeve

Sleeve insertion

Pipe in curing process

Rehabilitated pipe

Lining with cured-in-placed pipe installed by inversion is illustrated as follows:

In concordance with WRc (2001), the main advantages of this technique family include: the rapid installation; the lining is capable of accommodating large radius bends or in minor deformations; grouting is usually not required; this family of techniques is suitable for cases with variable cross section; and, the lateral connections can be carried out from inside, avoiding the excavation for the replacement. Additionally, the reinforcement of the structural strength in the existing pipe and the hydraulic capacity can be improved.

The main disadvantages according to WRc (2001) include: trained personnel is required; previous control of infiltration is required; reconnection of laterals may require sealing; and, significant preliminary work costs.

The main characteristics and conditions of application of lining with cured-in-placed pipe technique are shown as follows, based in the ISO 11295:2010 (ISO, 2010) and the EN 15885:2010/prA1 (CEN, 2010a) standards:

FEATURE	DESCRIPTION	
Relevant standards	EN 15885:2010/prA1, EN ISO 11296-1:2011, EN ISO 11296-4:2011 (Wastewater). ISO 11295:2010 (General).	
Materials	A composite consisting of a reinforced or unreinforced flexible pipe or sleeve impregnated with thermosetting resin (e.g. PU or EP), which can include optional internal or external membranes or coatings.	
Performances	Non pressure pipes. Pressure pipes. Applicable for manholes.	
Geometric characteristics	Cross sectional shape	Circular and non-circular cross section Possible variation in the cross section
	Diameter range (mm)	100 to 2 800
	Maximum length (m)	Installation by inversion: 600 Installation by winching: 150
	Execution of bends	Execution is possible in significant degrees of curvature.
Performance	- Small reduction of the section, increase of flow capacity due to the reduction of roughness. ☺ - Regarding of invert is not possible. - Structural rehabilitation is possible. ☺ - Abrasion resistance depends on the wall structure. - Chemical resistance depends on the type of resin.	

Installation characteristics	- Insertion of the flexible tube, prior the curing, can be achieved by: • inversion; • winching; • combination of methods. - The curing process can be initiated or accelerated by the application of heat (hot water, steam or electrical heating elements), UV radiation or ambient temperature. - Surface working space is usually reduced, varies with technique. ☺ - Access to existing pipe though the manholes or small excavation. ☺ - Structural resistance does not rely on the adhesion to host pipe. ☺ - Flow diversion required. ☹ - No grouting is required. ☺ - Reconnection of lateral from inside is possible. ☺

Legend: ☺ Main advantages; ☹ Main disadvantages.

2.4.4 Lining with discrete pipes

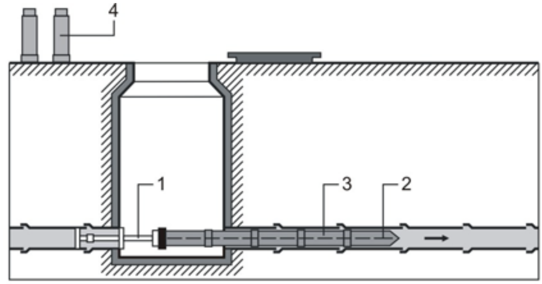
This family of techniques consists in the insertion of short length of pipes which are jointed to form a continuous pipe one by one during insertion. The section of pipe must be shorter than the pipe to be rehabilitated. The cross section of pipe remains unchanged during the procedure and the installation can be carried out through the following methods:

- installation by pulling: The first section pipe is connected at the pulling head in which a force is applied to pull the discrete pipes that are being joined in the manholes, according to type of join e.g. by welding or fitting (different types of existing joins). The partial displacement is equal to the segment length.
- installation by pushing of discrete pipes that are being joined in the manholes according to type of joint e.g. by welding or fitting (different types of existing joins). The partial displacement will be equal to the segment length.
- installation by individual pipe placement on site, being the joins made in situ.

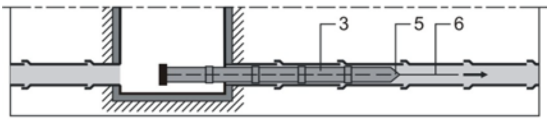
The application is carried out in the total length between manholes, or access pits constructed for this purpose, or in the length that needs to be renovated. The diameter of the inserted pipe remains unchanged, being smaller than the diameter of the existing pipe. The annular space is usually grouted with a filling material such as a grout. Filling is recommended to allow fixing the new pipe, avoiding the entrance and circulation of water, dangerous gases and soil in the annular space, promoting the uniform transfer of loads along the pipe and helping to prevent the collapse of the existing pipe.

Locating of laterals and application of plugs to connections can be necessary to avoid the entrance of filling material. In figure 4.9 this rehabilitation technique is shown.

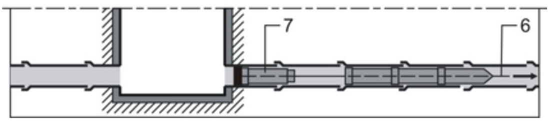
For the application of this family of techniques, usually the pipe to be rehabilitated must be out of service, free of obstructions or flow. These techniques are similar to lining with continuous pipe technique. The typical phasing **lining with discrete pipe** is similar to that shown in following figure, as recommended by Stein (2001).



(a) Installation by pushing



(b) Installation by pulling



(c) Installation by individual pipe placement

Legend

1 – Pushing device
2 – Pushing guide
3 – Joined lining pipe
4 – Discrete pipes stock
5 – Pulling head
6 – Winch cable
7 – Discrete pipe

The main advantage of this family of techniques is the possibility of increase the structural strength in the existing pipe. In concordance with WRc (2001), the advantages of this family of techniques include the rapid insertion of the pipe and the lining is capable of accommodating large radius bends.

The main disadvantage is the significant loss of the cross section leading to reduce the hydraulic capacity in section; usually the reduction of roughness is not enough to compensate the reduction of cross section. The limitations in the application on bends are not usually relevant in sewers, the curves and connections are carried out in manholes. In accordance with WRc (2001), the disadvantages include: flotation during the grouting can occurs; excavation of an access pit is usually required for the introduction of the pipe; trained personnel is required for the execution of welding joints; and, significant difficulty of the reconnection of laterals that usually require excavation.

The main characteristics and conditions of application of lining with discrete pipe technique are shown as follows, based in the ISO 11295:2010 (ISO, 2010) and the EN 15885:2010/prA1 (CEN, 2010a) standards.

FEATURE	DESCRIPTION	
Relevant standards	EN 15885:2010/prA1, EN ISO 11296-1:2011 (Wastewater) ISO 11295:2010 (General).	
Materials	Plastics (PE, PP, UPVC, GRP), metallic (Steel and ductile iron), concrete and clay.	
Performances	Pressure pipes. Non pressure pipes. Applicable for manholes.	
Geometric characteristics	Cross sectional shape	Circular and non-circular cross section
	Diameter range (mm)	Installation by pulling or pushing: 100 to 600 Individual placement: 600 to 4000
	Maximum length (m)	150
	Execution of bends	Installation by pulling or pushing: no Individual placement: with large radios
Performance	- Significant reduction of hydraulic capacity due to the reduction of cross section, despite de reduction of roughness. ☹ - Structural rehabilitation is possible. ☺ - Abrasion and chemical resistance depend on material.	
Installation characteristics	- The type of joint is significant feature of each technique. Pipe joins can be locked or unlocked. - Surface working space required without particular constraints. ☺ - Access to the existing pipe generally can be done through manholes for the discrete pipes with smaller length but requires local excavation to larger segment pipes and for the installation by individual pipe placement. - The technique does not rely to adhesion of host pipe. ☺ - Flow diversion is required for the installation. ☹ - The annular space is typically grouted. ☹ - Reconnection of laterals usually requires local excavation. ☹	

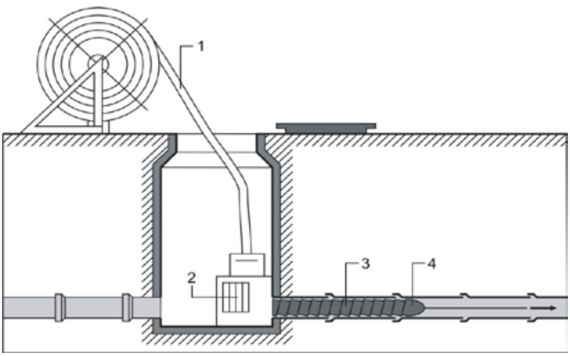
Legend: ☺ Main advantages; ☹ Main disadvantages.

2.4.5 Lining with spirally-wound pipes

This family of techniques consists in the construction of a new pipe with a profile strip which is supplied in spirally wound. The installation of spirally-wound can be achieved through several procedures including fitting and sealing or welding. The adjustment to the existing pipeline may not be complete, being the annular space grouting mortar required in many techniques of this family.

Filling is recommended to allow fixing the new pipe, avoiding the entrance and circulation of water, dangerous gases and soil in the annular space, promoting the uniform transfer of loads along the pipe and helping to prevent the collapse of the existing pipe.

The renovation is carried out in the total length between manholes or in the length to be rehabilitated. Locating of laterals and application of plugs to connections can be necessary prior to coating to avoid the entrance of filling material. Schematic representation of **lining with spirally-wound pipes technique** is shown as follows:



Legend

1 – Plastics strip to be spirally wound

2 – Winding machine in the manhole

3 – Spirally-wound lining pipe

4 – Guidance head (where applicable)

For the application of this technique, usually the section to be rehabilitated must be out of service and free of obstructions or flow. These techniques are similar to the lining with continuous pipe technique. The typical phasing of the works with this procedure is similar to that shown in figure 4.3, as recommended by Stein (2001), although usually local excavation are not required. The works can be carried out in manholes.

The main characteristics and condition of application of lining with spirally-wound pipes are shown as follows, based in the ISO 11295:2010 (ISO, 2010) and the EN 15885:2010/prA1 (CEN, 2010a) standards.

FEATURE	DESCRIPTION
Relevant standards	EN 15885:2010/prA1, EN ISO 11296-1:2011 (Wastewater). ISO 11295:2010 (General).
Materials	PE, PP, UPVC, GRP
Performances	Non pressure pipes. Applicable for manholes.
Geometric characteristics	Cross sectional shape: Circular and non-circular Diameter range (mm): 200 to 1200 Maximum length (m): 100 Execution of bends: Possible
Performance	- Significant reduction of hydraulic capacity due to the reduction of cross section, despite de reduction of roughness. ☹ - Structural rehabilitation is possible. ☺ - Abrasion and chemical resistance depend on material.
Installation characteristics	- Lining pipe formed on site by spirally winding a strip, which is joined and sealed by solvent welding or mechanic means. - Individual winching machines can produce a wide range of diameters. - Surface working space required without particular constraints. ☺ - Access to the existing pipe generally can be done through manholes. - The technique does not rely to adhesion of host pipe. ☺ - Flow diversion is required for installation. ☹ - The annular space is typically grouted. ☹ - Reconnection of laterals in non-man-entry pipes usually requires local excavation; reconnection from inside by robotic means is also possible. ☹

Legend: ☺ Main advantages; ☹ Main disadvantages.

In concordance with WRc (2001) and Stein (2001), the main advantages of this technique family include the rapid installation and the lining is capable of accommodating bends.

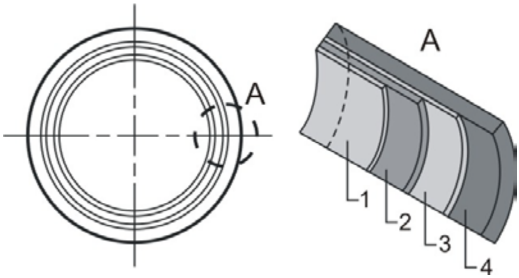
The disadvantages include trained personnel is required for specific equipment, significant loss of the cross section leading to reduce the hydraulic capacity in section; and, difficulty of the reconnection of laterals that usually requires local excavation.

2.4.6 Lining with formed in place pipe

This technique consists in the construction of the new pipe in place through the placement of an internal pre-coating (internal plastic layer); placement of an external coating on the inner surface (external plastic layer) with studs to ensure the annular space; and, injection with high resistance grout between these layers. In some of these techniques the internal pre-coating is not used. However, the pre-coating presents some advantages such as the limitation of the annular space and the reduction of grout required to avoid losses in the existing pipe; and, in long term, the grout is protected against the corrosion by external agents. The pre-coating is specially recommended with high groundwater levels. In exceptional cases a third coating on the inner surface, prior the placement of the internal pre-coating, is applied to control the tightness of the rehabilitated pipe without grouting. In other cases with higher requirements, a third coating with studs is applied over the first, both of the same type, with grouting (Stein, 2001).

The installation of coatings is usually carried out by winching, and then pressure is applied to ensure the placement in the wall of the existing pipe. The application of pressure can be performed with air or water.

The renovation is carried out in the total length between manholes or in the length to be rehabilitated. Locating of laterals and application of plugs to connections can be necessary prior to coating to avoid the entrance of filling material. The schematic representation of **lining with formed in place pipe technique** is shown:



Legend

1 – Internal plastic layer with integral profile or studs for anchorage

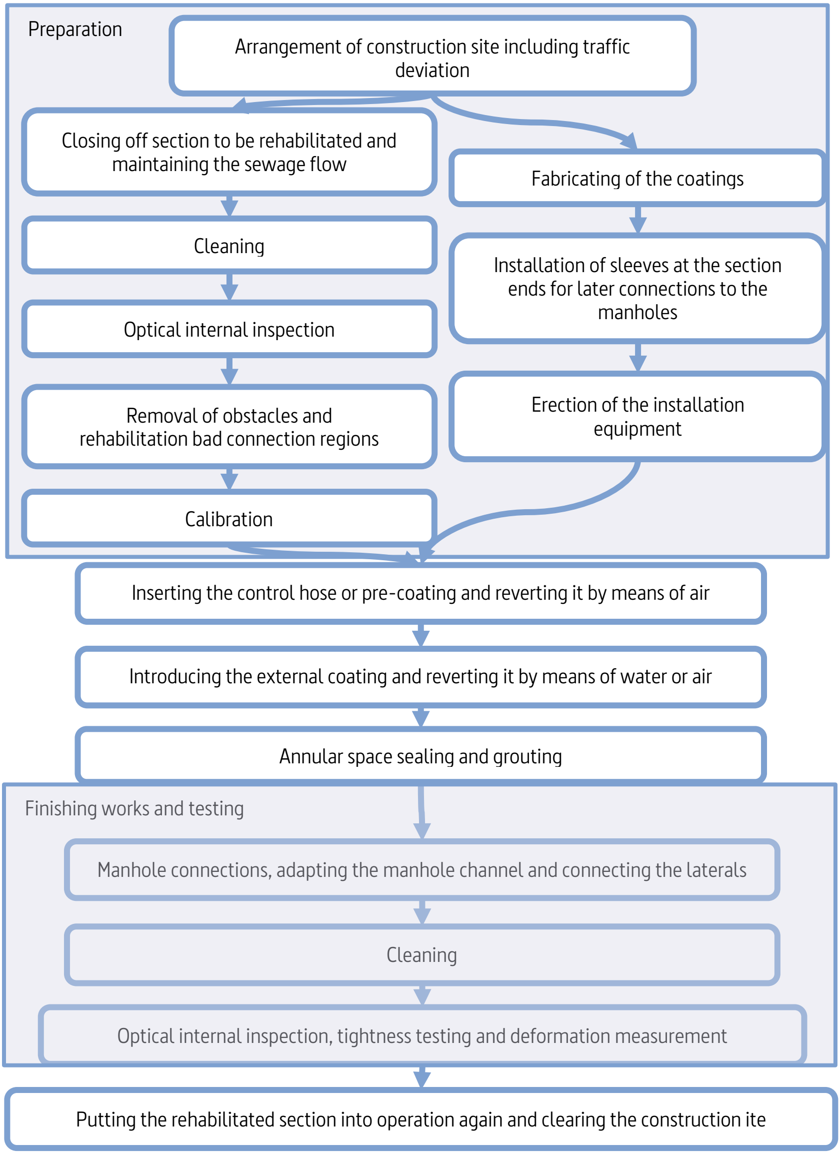
2 – Grout with optional reinforcement

3 – External layer if applicable

4 – Existing pipe

For the application of this family of techniques, usually the pipe to be rehabilitated must be out of service and free of obstructions or flow. The typical sequence of works in lining with formed in place pipe technique is similar to the process presented as is shown as follows, as recommended by Stein (2001).

Diagram of typical sequence of works in lining with formed in place pipe technique



In accordance with WRc (2001), the main advantage of this family of techniques is to be suitable for different types of cross section. The disadvantages include: trained personnel and specific equipment are required.

The main characteristics and condition of application of lining with formed in place pipe are shown as follows, based in the EN 15885:2010/prA1 (CEN, 2010a) standard.

FEATURE	DESCRIPTION	
Relevant standards	EN 15885:2010/prA1 (Wastewater).	
Materials	PE, UPVC and cementitious grout.	
Performances	Non pressure pipes. Applicable for manholes.	
Geometric characteristics	Cross sectional shape	Circular and non-circular
	Diameter range (mm)	200 to 2000
	Maximum length (m)	200
	Execution of bends	Possible
Performance	- Reduction of hydraulic capacity due to the reduction of cross section, despite de reduction of roughness. ☹ - Structural rehabilitation is possible. ☺ - Abrasion resistance depend on material and chemical resistance depends on the material of coating in contact with the flow.	
Installation characteristics	- Surface working space required without particular constraints. ☺ - Access to the existing pipe generally can be done through manholes. - The technique does not rely to adhesion of host pipe. ☺ - Flow diversion is required and absence of infiltration. ☹ - Reconnection to laterals can be performed from inside if pre-coating is used.	

Legend: ☺ Main advantages; ☹ Main disadvantages.

2.4.7 Lining with pipe segments

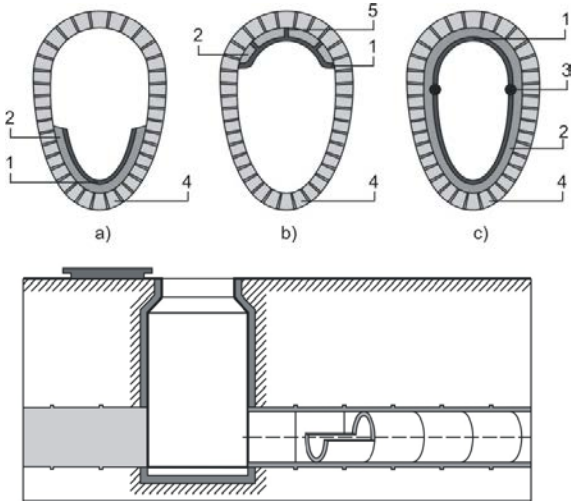
In this family of techniques the renovation is performed using self-supporting or non-self-supporting prefabricated segments which are introduced in the existing pipe through manholes, openings or local excavations. The existing pipe is suitable for any type of cross section. The installation of prefabricated segments can be carried out by manual means, with or without auxiliary equipment for the transport or fixing (Stein, 2001). The renovated pipe will present longitudinal and transversal joins. The different procedures are shown in in the following figure.

- partial segment lining at invert;
- partial segment lining at crown;
- full segment lining, with or without grouting.

The renovation with pipe segments is particularly suitable to restore or improve the abrasion resistance and chemical or biological attacks in the existing pipe: and, in some cases improve the resistance to external loads. This family of techniques may also be useful to restore the tightness or the slope of the surface.

For the application in the cases of full renovation or renovation of the invert, usually the pipe to be rehabilitated must be out of service and free of obstructions or flow. This technique is similar to the lining with continuous pipe. The typical phasing of the works with this procedure is similar to lining with continuous pipe.

A schematic representation of the **lining with pipe segments** is presented in the following pictures:



Legend

1 – Lining pipe segments
2 – Grout
3 – Longitudinal joints
4 – Existing pipe
5 – Anchors

The main characteristics and condition of application of lining with pipe segments are shown as follows, based in the EN 15885:2010/prA1 (CEN, 2010a) standard.

FEATURE	DESCRIPTION	
Relevant standards	EN 15885:2010/prA1 (Wastewater).	
Materials	Plastics (PE, PP, UPVC, GRP), GRC, polymer concrete (PC), clay, ductile iron and concrete.	
Performances	Non pressure pipes. Applicable for manholes.	
Geometric characteristics	Cross sectional shape	Circular and non-circular
	Diameter range (mm)	Man-entry sewer until 4000
	Maximum length (m)	No limit
	Execution of bends	Bends with larger radius

FEATURE	DESCRIPTION
Performance	- Hydraulic performances: • full segment lining: significant reduction of hydraulic capacity due to cross section reduction, despite the reduction in roughness. ☹ • partial segment lining at invert: can improve open channel flow. ☺ • partial segment lining at crown: no significant improvement in the hydraulic capacity. ☺ - Structural enhancement: • full segment lining: structural renovation is possible. • partial segment lining at invert: no significant improvement. • partial segment lining at crown: stability and resistance can be improved - Abrasion and chemical resistance depend on material in contact with flow.
Installation characteristics	- Jointing typically by either mechanical interlock or welding. - Lining pipes segments prefabricated or shaped in place. - Mechanical link to host pipe using grouting, gluing or anchoring is required. - Surface working space required without constraints, but space for segments storage is necessary. ☺ - Access via manholes is possible, local excavation at one end in larger sections. - In partial segments lining techniques adhesion to host pipe is decisive. ☺ - The technique does not rely to adhesion of host pipe. ☺ - Flow diversion is required in full segment lining and partial segment lining at invert. ☹ - Grouting of annular space is required. - Reconnection of lateral is possible from inside.

Legend: ☺ Main advantages; ☹ Main disadvantages.

In accordance with WRc (2001), the main advantages of this family of techniques include be suitable for different types of cross section and reconnection of laterals are easily handled. These techniques allow the reinforcement of the structural capacity of the existing pipe and trained personnel is not required.

According the same reference, the main disadvantages include: laborious process of joining; a system for the positioning of lining pipe segments during grouting; and, requires safe conditions in the man-entry into sewer.

2.4.8 Lining by sprayed, trowed or cast-in-place material

In this family of techniques the renovation is carried out by coating. The different existing methods are the followings:

- sprayed by mechanical means;
- sprayed by manual application;
- cast-in-place.

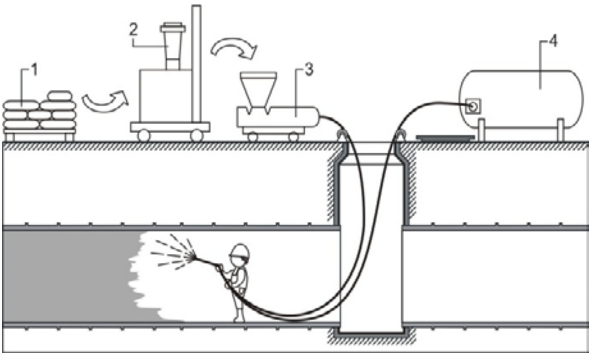
In any method, the reinforcement or the reinforcement bars on the surface can be applied which will be embedded in the coating. For the application of this family of techniques, the pipe to be rehabilitated must be out of service and free of obstructions and roots or flow. In case of infiltration, this should be controlled by the application of the suitable sealing prior to coating in order to ensure the adhesion to the existing pipe (WRc, 2001). If the surface is severely degraded, for example by chemical attacks, the surface layer of the material must be removed. The material thickness applied depends on the diameter and the type of material, may also depend on the technique and the requirements for the reinforcement of the structural strength.
In renovation **by manual application**, reinforcement meshes are usually applied prior to the application of the coating sprayed on the inner pipe surface. In the lining by cast-in-place, the formwork is placed in the pipe and concrete is injected in the space between the pipe surface and the formwork.

The existing pipe is suitable for any type of cross section and this family of techniques can be applied in variable cross sections.

In renovation by robotic means, the monitoring and the quality of the execution of the renovation work is usually carried out with CCTV.

The epoxy coating is an interesting alternative for small diameters due to allow the application of small thickness. However, this practise is mainly intended for the protection of the material, for example, by the action of aggressive chemical or biological agents. After the application, wait to the finalization of the curing process is required and the drying time depends on the process and the equipment used.

A schematic representation of lining by sprayed is represented. The typical phasing of the works for this procedure is similar to The typical phasing of the works with this procedure is similar to lining with continuous pipe.



Legend

1 – Mortar package

2 – Mixing machine

3 – Pump

4 – Compressor

The main characteristics and conditions of application for lining with sprayed, trowed or cast-in-place are shown as follows, based in EN 15885:2010/prA1 (CEN, 2010a) standard.

FEATURE	DESCRIPTION	
Relevant standards	EN 15885:2010/prA1 (Wastewater).	
Materials	Cementitious mortars, concrete, polymer resins. Possible reinforcement with steel or glass fibres.	
Performances	Non pressure pipes. Applicable for manholes.	
Geometric characteristics	Cross sectional shape	Circular and non-circular
	Diameter range (mm)	Manual application: man-entry sewers With robot: 200 a 600
	Maximum length (m)	Manual application: hundreds of meters, variable with technique With robot: 100
	Execution of bends	Possible
Performance	- Increased hydraulic capacity is possible. ☺ - Rehabilitation of structural integrity is possible with manual methods. ☺ - Abrasion and chemical resistance depend on the material of the coating in contact with flow.	
Installation characteristics	- Applicable in full or partial section. ☺ - Formwork is usually used in manual application. - Manual application requires sufficient working space for the execution of works including sufficient height for operative to stand upright. ☹ - Thickness of material applied is adapted to the pipe condition or limited by the characteristics of the resin. - Minimal surface working space required. ☺ - Access to the existing pipe can be done by manholes, excavation only in case of larger equipment. ☺ - Is necessary to ensure the material adhesion to host pipe (preparation of material usually required, especially polymers). ☹ - Flow diversion is required. ☹ - Reconnection to laterals is not affected by sprayed material, is possible from inside. ☺	

Legend: ☺ Main advantages; ☹ Main disadvantages.

In accordance with WRc (2001) and Stein (2001), the main advantages of this family of techniques is to be suitable for different types of cross section, be relatively independent of the length to be renovated, a variable thickness of coating can be applied and the reconnection to laterals are easily handled. The structural capacity of the existing pipe can be strengthened.

According to the same reference, the main disadvantages include: properly preparation of the surface in the existing pipe; control of the infiltration is required; requires close supervision; and, trained personnel is required.

2.5 Replacement techniques

The replacement techniques are those in which the construction of a new system component, on or off the line of an existing one, is carried out, adopting the function of the disabled component. This family of techniques includes trench or trenchless techniques. In the majority of these techniques, the reinforcement of the integrity and structural resistance can be improved. **Replacement techniques** families considered herein are:

- open cut or trench replacement;
- semi-open cut replacement;
- unmanned trenchless replacement;
- manned trenchless replacement.

In the following sections, each family of techniques is briefly described including an overview of the main characteristics, conditions of application, advantages and disadvantages, and relevant standards. The main references are the EN 1610:1997 (CEN, 1997) and the EN 12889:2000 (CEN, 2000b) standards.

Other techniques of construction in manned trenchless replacement, including the replacement using the in-situ concrete method or with prefabricated pipes are not detailed in this document. For further details about these techniques, abundant bibliography can be consulted for instance Stein (2001).

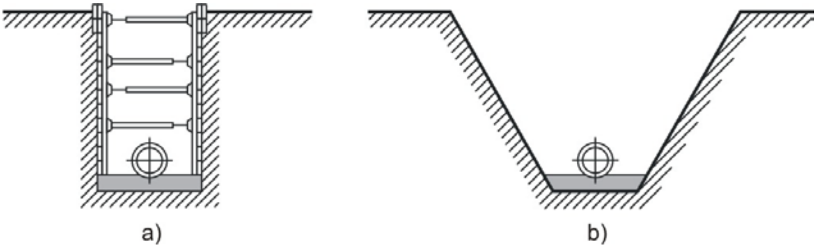
2.5.1 Open cut replacement

The open cut replacement has been the most used method for rehabilitation interventions in sewers and manholes. This family of techniques is comparable with construction of a new sewer.

The replacement can be carried out in the original alignment of the existing pipe or in alternative alignment; in the latter, the existing sewer is kept in operation while the new pipe is constructed.

In these techniques, the opening of trench is excavated in the alignment provided, ensuring the requirements of the project during the execution of works which depend on the local conditions. Some of the factors that can vary are: the depth of the excavation, the type of ground, local traffic, the water level or the existence of others infrastructures.

This family of rehabilitation techniques is schematically represented in the following figures, being (a) vertical wall trench, (b) trench with embankments



Examples of replacement interventions using the open cut method are presented as follows. The works must be performed in accordance with the EN 1610:1997(CEN, 1997).

The main characteristics and condition of application of open cut replacement are presented as follows, based in the EN 1610:1997 (CEN, 1997) standard and Stein (2001).

FEATURE	DESCRIPTION	
Relevant standards	EN 1610:1997 (Wastewater).	
Materials	Various according to design specifications.	
Performances	Non pressure pipes. Pressure pipes. Applicable for manholes.	
Geometric characteristics	Cross sectional shape	Circular and non-circular ☺
	Diameter range (mm)	No specific limitations ☺
	Maximum length (m)	No specific limitations ☺
	Execution of bends	No specific limitations ☺
Performance	- Increase of hydraulic capacity is possible. ☺ - Total rehabilitation of structural integrity. ☺ - Abrasion and chemical resistance depend on the material in contact with the flow.	
Installation characteristics	- Applicable to the total replacement of the pipe or only at the crown in cases of localized damage in that area, depending on the material. ☺ - Prefabricated or in-place pipe. - High surface working space required. ☹ - Negative impacts associated with the application and the high occupation of the public space: noise, vibration, commerce, road and pedestrian circulation, etc. ☹ - Cost increases with the depth of the installation. ☹ - Flow diversion is required. ☹ - Reconnection to laterals by excavation.	

Legend: ☺ Main advantages; ☹ Main disadvantages.

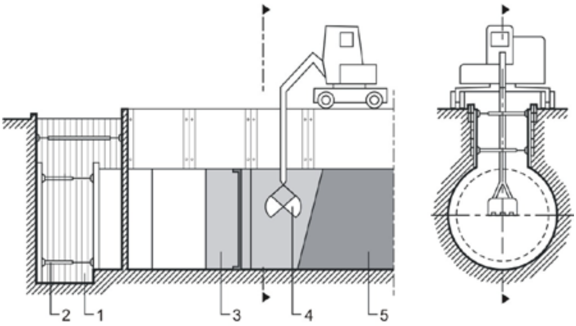
In accordance with Stein (2001), the main advantages of this technique are the flexibility in terms of the dimensions adopted, cross sectional shapes, materials, geological and hydrological conditions, depth, among others. The requirements of the new pipe may differ from the requisites of the existing pipe. In regions of contaminated soil, the soil can be removed at least in part. Open cut replacement is the most advantageous method if, simultaneously, other infrastructure works are carried out, particularly on pavements.

According to the same author, the main disadvantages include: important surface working space is required; social and economic conflicts; and, disturbances in the operation of other infrastructures can occur. The opening of the trench may adversely affect neighbouring structures and infrastructures. In consolidated urban areas the cost of the works can increase due to the adoption of the required measures for the removal of the excavated material, ensure the traffic deviation, the removal and replacement of the pavement, the placement of crossings for pedestrians or vehicles, and, the maintenance of the flow in the lateral connections to the existing pipe.

2.5.2 Semi-open cut replacement

The **semi-open cut replacement** is applied in man-entry sewers and consists in the excavation of a reduced trench in the misalignment of the existing pipe in which the existing pipe is gradually removed. The new pipe is gradually pushed through the entry shaft where the equipment is installed for the introduction. A bulkhead at the end of the bottom ring prevents the ingress of soil and the water; this technique can be applied without the need to lower the groundwater level. The width of the trench depends on the equipment available and the depth of the excavation (Stein, 2001). In this method, the replacement is done in the original alignment of the existing pipe.

Schematic representation of this rehabilitation technique is shown as follows. The works must be performed according to the EN 1610:1997 (CEN, 1997) standard.



Legend
1 – Abutment
2 – Hydraulic jack
3 – Working pipe
4 – Cutting shoe
5 – Existing pipe

Longitudinal Section Transversal Section

The main characteristics and conditions of application of semi-open cut replacement are shown as follows, based in the EN 1610:1997(CEN, 1997) standard and Stein (2001).

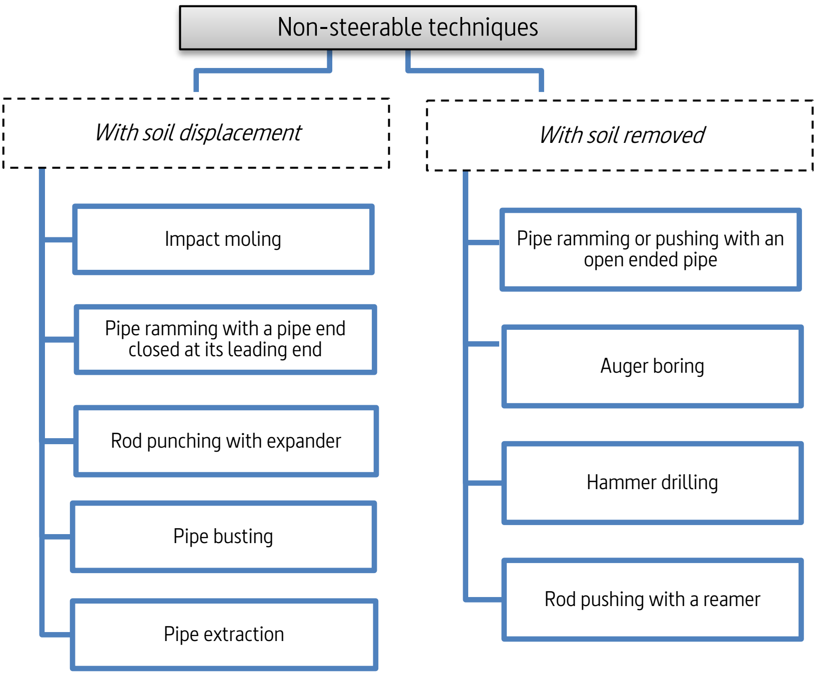
FEATURE	DESCRIPTION	
Relevant standards	EN 1610:1997 (Wastewater).	
Materials	Various according to design specifications.	
Performances	Non pressure pipes. Pressure pipes.	
Geometric characteristics	Cross sectional shape	Circular and non-circular ☺
	Diameter range (mm)	Man-entry sewers
	Maximum length (m)	200
	Execution of bends	Possible
Performance	- Increase hydraulic capacity is possible. ☺ - Total rehabilitation of structural integrity. ☺ - Abrasion and chemical resistance depend on material in contact with the flow.	
Installation characteristics	- Surface working space required for implementation of specific works is smaller than in the open cut method. The excavation of an access pit is usually required in order to install the equipment and insert the new pipe. - Negative impacts associated at the installation and occupation of the public space is smaller than the open cut method. ☹ - Depth of installation limited to about 1.5 m. ☹ - Flow diversion is required. ☹ - Reconnection to laterals by excavation. - Applicable in situations with high groundwater level with no need to lower. ☺	

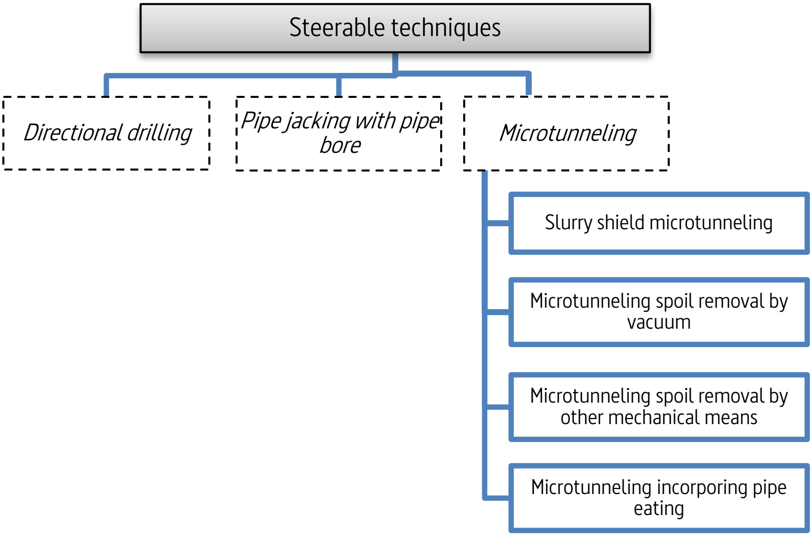
Legend: ☺ Main advantages; ☹ Main disadvantages.

2.5.3 Unmanned trenchless replacement

In the family of **unmanned trenchless replacement techniques** the new pipe is installed with the aid of steadily, percussive or vibrating applied forces, from an entry shaft to an exit shaft or other reception point. The soil is displaced or removed from the face (EN 12889:2000, CEN 2000b).

This family of techniques can be classified **in steerable and non-steerable techniques**. In following figures, the unmanned trenchless replacement, non-steerable and steerable techniques, are presented, respectively.





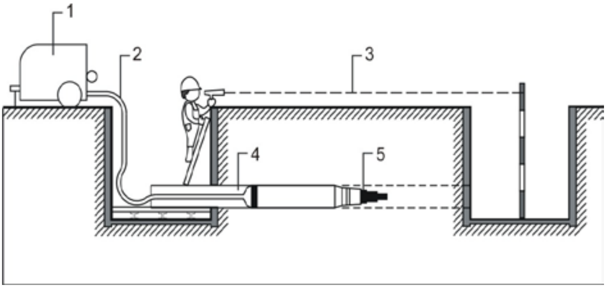
The selection of the technique depends on such factors as the accuracy of the alignment (planimetry and altimetry), the proximity of other structures and infrastructure, the external diameter, the length, the geological and hydrogeological conditions and the depth.

The **non-steerable techniques** are suitable in situation in which accurate alignment is not required.

The main non-steerable techniques with soil displacement are the followings, based in the classification detailed in the EN 12889:2000 (CEN, 2000b) standard:

- impact moling: Percussion hammer within a casing is used (cylinder with tapered nose or stepped head) to travel the ground. The pneumatic or hydraulic hammer displaces the soil and the movement relies on the frictional resistance of the ground. The pipe is pushed or pulled.
- pipe ramming with a pipe closed at its leading end: A steel casing with a closed end is ramming using a percussive hammer.
- rod pushing with an expander: A rigid pilot rod crosses the ground driven by percussion system. Thereafter, the new pipe is installed by pushing or pulling behind an expander.
- pipe bursting: Introduction of an expander of same or greater diameter than the existing pipe which is pulled causing the burst of the existing pipe and the displacement of the surrounding ground, the new pipe is displaced together with the head.
- pipe extraction: The existing pipe is extracted by pulling or pushing, and simultaneously replaced by the new pipe. This method is suitable only if structural strength of the existing pipe is sufficient to resist the application of the forces.

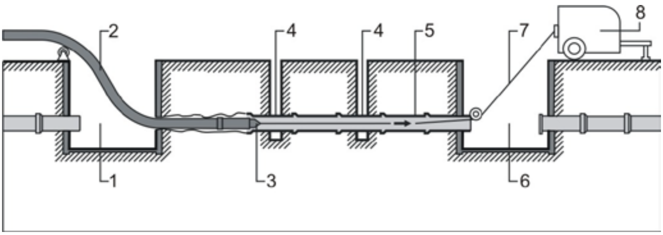
Unmanned trenchless replacement: scheme of soil displacement techniques with impact moling



Legend

1 – Compressor
2 – Compressed air hose
3 – Line of sight
4 – Casing
5 – Percussive hammer

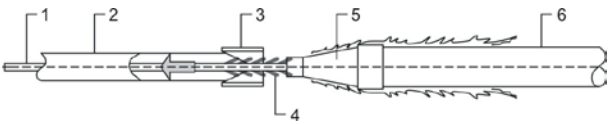
Unmanned trenchless replacement: scheme of soil displacement technique with pipe bursting



Legend

1 – Entry shaft
2 – New pipe
3 – Bursting body
4 – Laterals
5 – Existing pipe
6 – Exit shaft
7 – Winch cable
8 – Winch

Unmanned trenchless replacement: detail of soil displacement technique with pipe bursting



Legend

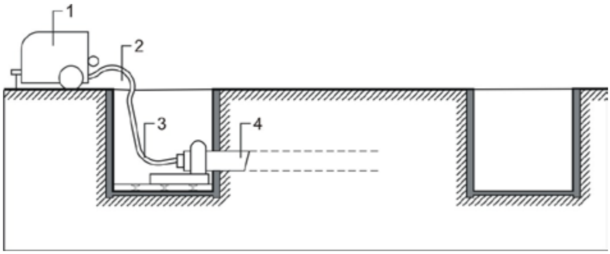
1 – Winch cable
2 – Existing pipe
3 – Expander
4 – Steel blades
5 – Bursting body
6 – New pipe

In the non-steerable techniques with soil removed, the main techniques are the following, based in the classification detailed in the EN 12889:2000 (CEN, 2000b) standard:

- pipe ramming or pushing with an open ended pipe: The drilling is carried out by driving a steel casing with an open end using a percussive hammer or pushing device. The spoil is removed by augering, jetting, compressed air or high pressure water.
- auger boring: The excavation is carried out by a rotating cutting head attached to an auger which continuously removes the spoil. The pipe is pushed simultaneously with the auger.

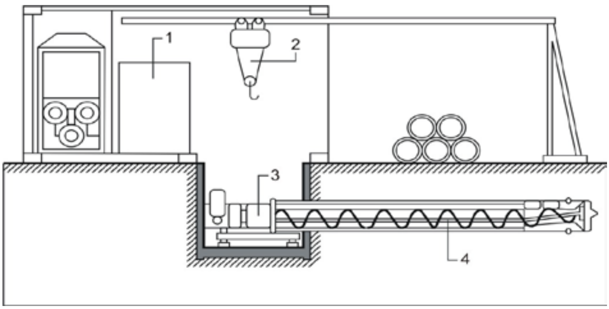
- hammer drilling: The drilling is performed using a percussive hammer with a cutting head. The spoil is removed mechanically by jetting or compressed air.
- rod pushing with a reamer: Soil is displaced by a rigid pilot rod being the new pipe installed by pulling it behind a rotating reamer.

Unmanned trenchless replacement: scheme of pipe ramming or pushing with an open ended pipe technique



Legend
1 – Compressor
2 – Compressed air hose
3 – Percussive system
4 – Driving pipe

Unmanned trenchless replacement: scheme of auger boring technique



Legend
1 – Power unit
2 – Host
3 – Pushing/ boring system
4 – Cutting head with auger

In the different steerable techniques, the main techniques are the following, based on the classification of EN 12889:2000 (CEN, 2000b).

- microtunnelling: Steerable drilling in a single pass with remote control. The pipe is installed directly behind the microtunnelling machine. Different techniques are included depending on the method of spoil removal.
- microtunnelling with auger spoil removal;
- slurry shield microtunnelling;
- microtunnelling spoil removal by vacuum;
- microtunnelling spoil removal by other mechanical means;
- microtunnelling incorporating pipe eating: The existing pipe is removed together with surrounded soil.
- pipe jacking with pipe bore: Microtunnelling is constructed in several phases. In the first phase a steered rigid pilot pipe is accurately installed by compression. In subsequent phases, the pilot bore is enlarged by compression. The pipe is then installed by compression with soil displacement or soil removal.
- directional drilling: A pilot bore is drilled using a steerable drilling head pushed by flexible rods. The bore is then enlarged by reamers up to the diameter required for the sewer and then the pipe is pulled or pushed into place.

Entry shaft: Installation of equipment

Cutting head

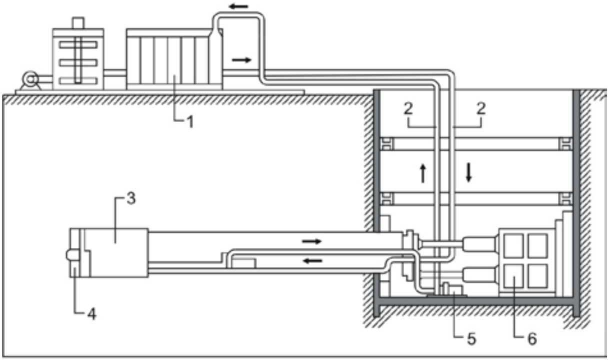
Emplacement of pipe section

Start to push the pipe section

Push the pipe section

Exit shaft: arrival of the cutting head

Application of the technique of slurry shield microtunnelling



Legend

1 – Slurry tank
2 – Slurry pipeline
3 – Lining ring
4 – Cutting head
5 – Pump
6 – Jacking device

The main characteristics and conditions of applications of the unmanned trenchless replacement are presented as follows, based in the EN 12889:2000 (CEN, 2000b) standard and Stein (2001).

FEATURE	DESCRIPTION	
Relevant standards	EN 12889:2000 (Wastewater), EN 14457:2004, EN 1916:2002/AC:2008.	
Materials	Steel, DCI, GRP, PE, PVC, PP, GRP, reinforced concrete, depending on the technique.	
Performances	Non pressure pipe. Pressure pipe.	
Geometric characteristics	Cross sectional shape	Circular
	Diameter range (mm)	Variable with technique
	Maximum length (m)	Variable with technique
	Execution of bends	Variable with technique
Performance	- Increase of hydraulic capacity is possible. ☺ - Total rehabilitation of structural integrity. ☺ - Abrasion and chemical resistance depend on material in contact with the flow. ☺	
Installation characteristics	- Not require preparatory work of cleaning. ☺ - Allows the construction of new pipes without opening trench or increase of existing pipe diameter. ☺ - Significant surface working space is required for the implementation of specific works and the storage of pipes. The excavation of an access pit is usually required in order to install the equipment and insert the new pipe. - May interfere with neighbouring structures and infra-structures (e.g. old buildings). ☹ - The flow diversion is required during the installation of pipe. ☹ - Reconnection to laterals by excavation. ☹	

Legend: ☺ Main advantages; ☹ Main disadvantages.

2.5.4 Manned trenchless replacement

The main method in the **manned trenchless replacement techniques** is the pipe jacking.

The pipe jacking technique consists in the installation of the new pipe from an entry shaft into an exit shaft with the aid of steadily forces by means of hydraulic jack. The application of forces allows the installation of the pipe through the ground; the excavated material is supported by the pipe and the soil is removed from the face. The most important functional parts of this method are (Stein, 2001):

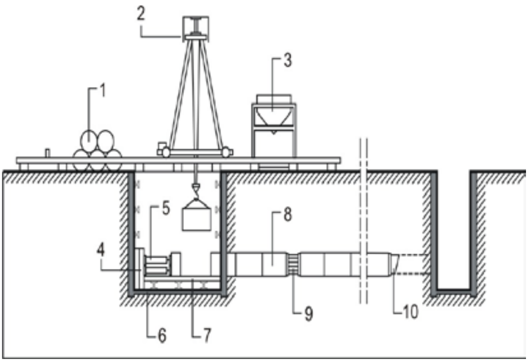
- cutting shoe or shield, which allow the removal of the soil and the existing pipe;
- jacking element or jacking pipe;
- intermediate jacking station;
- main jacking station.

The ground and the existing pipe are removed manually, mechanically or using a hydraulic jack.

These techniques are generally steerable and allow the installation in a straight line or through slight curve.

In figure 5.13 schematic representation of this rehabilitation technique is presented. The works must be performed according to the EN 1610:1997 (CEN, 1997) standard.

Representative scheme of pipe jacking technique



Legend

1 – Jacking pipe storage
2 – Hoist
3 – Separation plant
4 – Abutment structure
5 – Main jacking station
6 – Concrete base
7 – Guide frame
8 – Jacking pipe
9 – Intermediate jacking station
10 – Cutting shoe or shield

In accordance with Stein (2001), the main advantages are the increase of the cross section is possible, the occupation of the external space is limited to the access areas, the noise and gases are reduced, the existing pipe and the possible contaminated soil are removed.

The main disadvantages according the same reference are: cutting and posterior reconnection of laterals; the space required for the placing of the entry and exit shaft; and, reinforcement of the entry shaft to absorb the jacking forces is required. In this technique, a continuous control of the alignment is required. In the case of high groundwater levels, may be necessary to lower the groundwater level.

The main characteristics and conditions of application of manned trenchless replacement techniques are shown as follows, based in the EN 12889:2000 (CEN, 2000b) standard and Stein (2001).

FEATURE	DESCRIPTION	
Relevant standards	EN 12889:2000 (Wastewater); EN 14457:2004; EN 1916:2002/AC:2008.	
Materials	Steel, DCI, reinforced concrete.	
Performances	Non pressure pipes. Pressure pipes.	
Geometric characteristics	Cross sectional shape	Circular
	Diameter range (mm)	Man-entry pipes
	Maximum length (m)	Variable
	Execution of bends	Limited
Performance	- Increase of hydraulic capacity is possible. ☺ - Total rehabilitation of structural integrity. ☺ - Abrasion and chemical resistance depend on material in contact with the flow.	
Installation characteristics	- Allows the construction of new pipes without opening trench or increase of existing pipe diameter. ☺ - Surface working space is required for the implementation of the start and target excavations and the storage of pipes. The excavation of two access pit is required. - May interfere with neighbouring infra-structures. ☹ - The flow diversion is required when a pipe is installed. ☹ - Reconnection to lateral by excavation. ☹	

Legend: ☺ Main advantages; ☹ Main disadvantages.

2.6 Specific techniques for manholes

In addition to the above described techniques, which are suitable for renovation, replacement and repair in manholes, as indicated in table 2.1, specific techniques for the rehabilitation of local anomalies in these components are available.

The main specific local anomalies of manholes are:

- anomalies associated with the manhole top, especially with the ring, frame and cover, including positional deviations;
- anomalies on ladders or steps rungs for access.

The likelihood of the occurrence of these problems is high and can imply important consequences for the safety of persons, on public roads and for the personnel in charge for the operation and maintenance of the systems.

These local anomalies, if not accompanied by other problems in manholes which involve major works, are usually rectified by repair techniques.

These specific repair techniques are:

- replacement of ladders and steps;
- replacement of covers, rings and joints;
- repair of manhole chamber;
- levelling the manhole top.

The replacement of elements is a common practise that should be used considering the quality of the material and the specifications of the relevant standards. The repair of the manhole can be carried out with the techniques presented in the previous sections according to the type of anomalies observed.

2.6.1 Height levelling of manholes tops

The height levelling of manholes tops can be made with or without removal of the cover.

The first case can be applied when the frame, where it is embedded, and the cover are damaged. The removal of the cover allows the placement of support rings to raise the height, levelling of top or the wear of the material to rectify a protruding manhole top on the pavement. Special equipment to cut a section with the diameter slightly larger than the manhole can be required. The use of non-retractable grouts allows the sealing of the joints.

The height levelling of manhole tops without removal involves: the release of the frame by mechanical means; the raise of the manhole top the distance required; and, the placement of spacers and non-retractable grouts to ensure the sealing.

2.7 Technique selection

In the selection of the rehabilitation technique to be adopted in each case, the following should be considered (ISO 11295:2010, 2010; WRc, 2001):

- assessment of the deficiencies of current performance (anomalies) of the existing component;
- identification of the requirements for the desired functional performance in the components of the system (hydraulic, structural, environmental and operational performance);
- identification of the rehabilitation options which are technically feasible taking into account the functional performance required, based in the performance requirements and in the local conditions (e.g. traffic, occupation of public space, simultaneity with works in other infrastructures);
- comparison of the costs for the viable techniques and final selection of the technique to be applied.

A summary of the recommended sequence for the selection of the rehabilitation technique is presented as follows (WRc, 2001):

	INFORMATION ABOUT	ACTION
Technical selection	Operational and environmental conditions	Remove unsuitable materials
	Existing sewer dimensions and hydraulic requirements	Check hydraulic capacity
Operational	Installation issues: access, location, traffic control	Eliminate unsuitable techniques
	Compatibility with company policies	
Structural design	Structural integrity requirements	Determine minimum requirements and undertake structural design
Cost		Produce cost estimates for the remaining techniques
		Finalise choice of technique
Contract		Produce contract

The summary of conditions for application of rehabilitation techniques presented in this report is shown as follows:

TECHNIQUE	Reinforcement of structural strength	Flow capacity	Tightness	Cross section	Typical range of diameters (mm)	Typical maximum length (m)	Execution of bends	Surface working space	Application
RENOVATION									
Lining with continuous pipe	↑	↓	↑	C/O	100 - 2000	300	P	+/++	L/R
Lining with close-fit pipe	↑	→	↑	C/O	100 - 500 200 - 1500 100 - 2800	500	P	+/++	L/R
Lining with cured-in-place pipe	↑	→	↑	C/O		600 150	P	+	L/R/V
Lining with discrete pipes	↑	↓	↑	C/O	100 - 600 600 - 4000 200 - 1200 200 - 2000 until 4000	150	-	+	L/R/V
Lining with spirally-wounds pipe	↑	↓	↑	C/O		100	P	+	L/V
Lining with formed-in-pace pipe	↑	↓	↑	C/O		200	P	+	L/V
Lining with pipe segments	↑	↓→	↑→	C/O		-	-	+	L/V
Lining by sprayed, trowed or cast-in-place material	↑→	↑	↑→	C/O	Man-entry; Robot: 200 - 600	- 100	P	+	L/V
REPLACEMENT									
Open cut replacement	↑	↑	↑	C/O	-	-	P	+++	L/R/V
Semi-open cut replacement	↑	↑	↑	C/O	Man-entry	200	P	+++	L/R
Unmanned trenchless replacement	↑	↑	↑	C	-	-	P	++	L/R
Manned trenchless replacement	↑	↑	↑	C/O	Man-entry	-	-	++	L/R
REPAIR									
Repair by injection sealing	→	→	↑	C/O	Man-entry; Robot: 150 - 750	1200 200	-	+	L/V
Repair with cured-in-placed patch	→	→	↑	C/O	Man-entry; Robot: Min 100	- 200	P	+	L/V
Repair with trowelled material	↑	→↑	↑	C/O	Man-entry; Robot: Min 150	- 200	P	+	L/R/V
Repair by sealing with internal mechanical devices	→	→	↑	C	Man-entry; Robot: Min 150	- 200	P	+	L/R
Repair with lateral connection collar	→	↑	↑	C/O	Man-entry; Robot: 150 - 800	- 200	-	+	L/V

Legend: ↑ possible increase / performance improvement; → maintain; ↓ decrease.
C – circular; O – other; P – possible; L – non pressure pipes; R – pressure pipes; V – applicable for manholes.
+ reduced; ++ medium; +++ high.

In the case of replacement techniques, the technical specifications can include the intended levels of performance, while in the renovation and repair techniques limitations exist depending on the technique.

The EN 15885:2010/prA1 (CEN, 2010a) standard proposes performance levels for the different families of renovation and repair techniques in terms of the required functions with the application of the technique, including:

- structural integrity: stabilisation or reinforcement of the structural strength in the existing pipe (external and internal loads capacity);
- hydraulic performance: providing sufficient hydraulic capacity (e.g. reduction of the roughness);
- separation of the fluid transported and the inner surface of the existing pipe (e.g. avoid the corrosion);
- tightness of the pipe: sealing of existing pipe to avoid infiltration and exfiltration;
- impact on site: disturbances associated with the execution of works.

In the following tables are specified the criteria and the proposed levels of performance are specified and, the typical levels associated with the different renovation and repair techniques.

PERFORMANCE LEVELS ON STRUCTURAL INTEGRITY: EXTERNAL LOADS

PERFORMANCE LEVEL	CHARACTERISTICS
S4	Resists groundwater and internal negative pressure (short term)
S3	S4 + resists groundwater and internal negative pressure (long term)
S2	S3 + absorbs or resists to ground and traffic loading
S1	S2 + absorbs or resists to ground movements

PERFORMANCE LEVELS ON STRUCTURAL INTEGRITY: INTERNAL LOADS

PERFORMANCE LEVEL	CHARACTERISTICS
P4	Provides internal barrier layer
P3	P4 + long-term hole and gap spanning at design pressure
P2	P3 + where liner has independent ring stiffness (not dependent on the adhesion to the host pipe)
P1	P4 + long-term independent pressure resistance to design pressure (DP)+ can survive internally or externally induced (burst, bending or shear) failure of host pipe

HYDRAULIC PERFORMANCE LEVELS

PERFORMANCE LEVEL	CHARACTERISTICS
H2	Reduced performance
H1	Performance equal or increased

SITE IMPACT LEVELS

PERFORMANCE LEVEL	CHARACTERISTICS
W4	High surface working space or high excavation for construction of access
W3	Significant surface working space or significant excavation for construction of access
W2	Moderate surface working space or limited excavation for construction of access
W1	Minimum surface working space, excavation for construction of access is not required.

ACCESSIBILITY TO THE PIPE LEVELS

PERFORMANCE LEVEL	CHARACTERISTICS
NM	Non-man-entry
NE	Man-entry

TYPICAL PERFORMANCE LEVELS FOR RENOVATION AND REPAIR TECHNIQUES

TECHNIQUE	STRUCTURAL INTEGRITY: EXTERNAL LOADS	STRUCTURAL INTEGRITY: INTERNAL LOADS P	HYDRAULIC PERFORMANCE H	SITE IMPACT (DIAMETER DEPENDENT) W	MAN ENTRY
Lining with continuous pipe	S1	P1	H2	W3	NM
Lining with close-fit pipe	S1	P1	H1	W1 to W3	NM
Lining with cured-in-place pipe	S1	P2	H1	W1 or W2	NM
Lining with discrete pipes	S1	P1	H2	W1 or W2	NM
Lining with spirally-wound pipe	S1	P4	H2	W1	NM
Lining with formed-in-place pipe	S2	P4	H2	W1 or W2	NM
Lining with pipe segments	S2	P4	H2	W2	ME
Lining with sprayed, trowelled or cast in place material	S2	P4	H1	W1	NM or ME
Repair techniques	Technique dependent	Technique dependent	Technique dependent	W1	ME

The selection of the techniques depends on the associated costs and on the several factors mentioned above. The costs of the trenchless techniques tend to be lower than the replacement with open trench. However, the costs vary depending on the availability of the technique on site and with the required length or with the diameter, among others.

Operational practices for sewer systems

3

3.1 Operational procedures

The execution of the rehabilitation works often involves a set of procedures such as preparatory work (e.g. inspection, cleaning, flow diversion), tests, inspections, measurements and adequate functional tests during execution of works (e.g. quality control or checking of the functionality of components) and monitoring of operation. These operational procedures include:

- visual inspection or inspection using other methods;
- inspection and monitoring of the discharge points to the receiving water;
- measurements of flow and rainfall;
- smoke and tracers tests;
- tightness testing with water or air;
- cleaning of components.

In the following sections, the different operational procedures for the tightness test with water or air and the cleaning of the components are presented.

3.1.1 Tightness testing with water or air

PRE-INSTALLATION TEST OF COMPONENTS

Pipes, manholes, inspection chambers, fittings and joins used in sewers or drains must resist an internal hydrostatic pressure test without water leaks (EN 476:2011, CEN, 2011, for non-pressure sewers; NP EN 773:1999, CEN, 1999, for pressure sewers). In the case of join tightness depending on internal pressure, an additional external hydrostatic pressure test or partial vacuum test must be carried out.

In accordance with the EN 476:2011 (CEN, 2011) standard, the tightness test is carried out at ambient temperature and the components must resist a pressure test of 0 to 50 kPa.
In the case of pipes, these should be filled with water and fully purged of air. The method, period and test requirements are specified in the relevant products standards.

In the case of joints between two pipes or between a pipe and an element of the manhole or the inspection chamber base, the test must be carried out on two pipes or components joined. This test must include testing for angular deflection and shear force, or a combination of both, under hydrostatic pressure. Where appropriate, the shear force should be replaced by diametrical deflection. The combination of tests is specified in the relevant products standards.

In manholes and inspection chambers that are intended to be installed at depths greater than 2 m, the vertical element and the base of the manhole in the installation must be tested such as pipes. Joints between vertical elements should be tested such as mentioned above, without application of angular deflection, shear force and diametric deflection.

Inspection chambers that are intended to be installed at depth of less than 2 m must be tested by filling with water. The method, period and test requirements are specified in the relevant products standards.

In the case of fittings, the method, period and test requirement are specified in the products standards.

POST-INSTALLATION TEST OF COMPONENTS

The procedures and requirements for the test of pipes in non-pressure sewers and in pressure sewers are referred in the EN 1610:1997 (CEN, 1997) and EN 805:2000 (CEN, 2000a) standards, respectively, within the scope of pressure tests, being the water loss method one of the basic test methods.

Tightness of pipes, manholes and inspection chambers in free surface flow conditions can be tested with air or water. The test can be performed prior to execution of trench filling, but should be done after conclusion of works.

If the groundwater level during the test is above the crown of the pipe, a test to determine the infiltration can be required.
In general, the air test includes the followings steps:

- placement of adequate pigs (airtightness);
- application of pressure and measurement of the pressure drop, according to the specifications of the standard;
- the pressure drop must be lower than the values specified in the standards for the different materials to be considered in conformity;
- In case of significant deviations, the water test method should be used.

The water test is carried out by filling of the component until the pressure specified in the standard. The acceptance depends on the volume of water that must be added to restore the initial level over a period of 30 minutes.

3.1.2 Cleaning

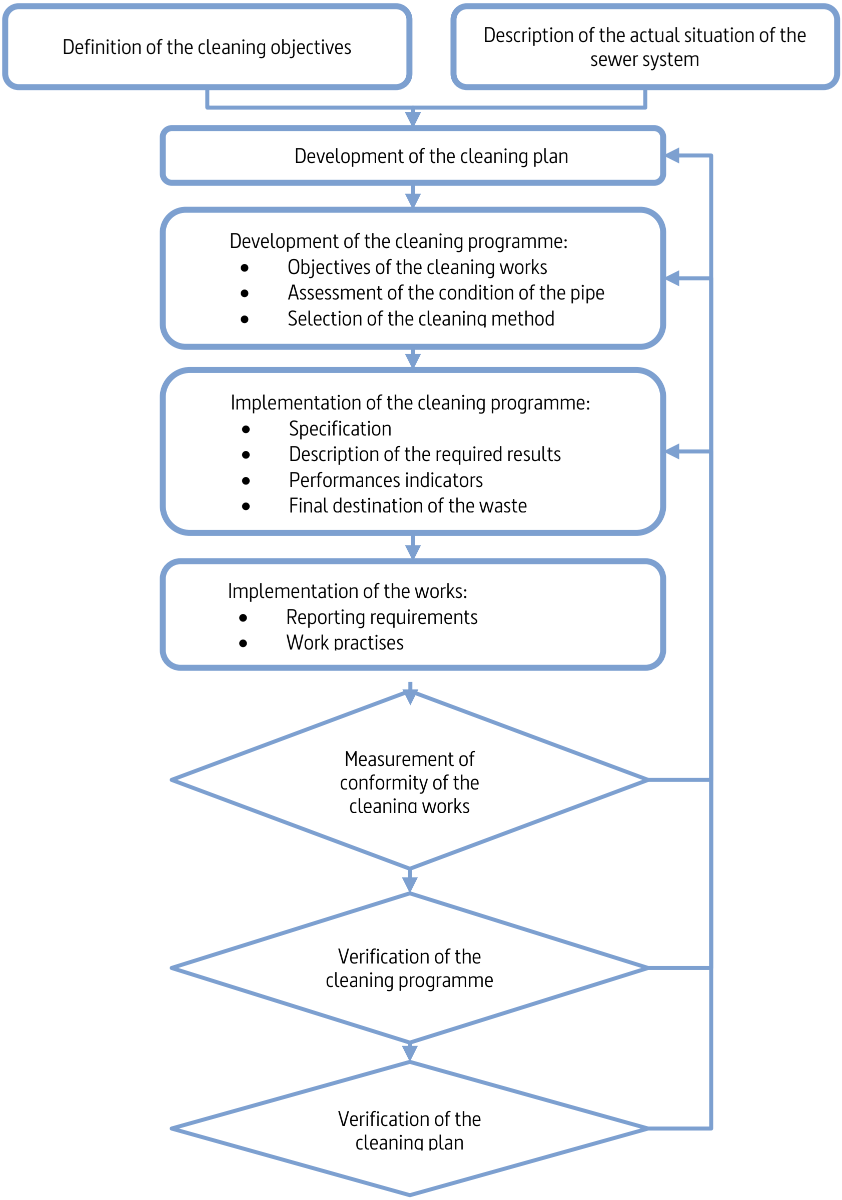
MANAGEMENT OF THE CLEANING OPERATIONS

The general principles of management and control of cleaning operations in sewers and drains presented herein are based in the standard EN 14654-1:2014 (CEN, 2014), within the scope of the overall management of sewer system.

For the purpose of this document, the cleaning operations, which are described in the next sections, are framed in the preparatory works required for the rehabilitation. Regular cleaning operations need during rehabilitation works should be identified and incorporated in the cleaning programme of the sewer system responsible utility.

According to the above mentioned standard, for the management of the cleaning operations the steps presented in the following figure can be considered.

Management of sewer cleaning operations



SPECIFICATION OF CLEANING WORKS OBJECTIVES

In the rehabilitation work, the cleaning operations are usually required prior to executing inspection works or to prepare a component of the system to be rehabilitated, with the exception of the replacement techniques in which the pipe is removed or eliminated; the works of renovation require the prior preparation of the pipe to be rehabilitated. In some solutions, the effectiveness of the rehabilitation technique depends on the adhesion of the materials to the inner wall of the existing pipe. In others cases, specific conditions for the insertion of the pipe in the existing pipe are required to avoid damage in the inserted pipe.

In the case of additional regular cleaning operations are required to improve the performance of the system or component, these processes should be incorporated in the cleaning programme of the entity and the objectives should be specified.

ASSESSMENT OF THE CONDITION OF THE PIPE PRIOR TO CLEANING WORKS

An evaluation of the conditions of the pipe prior to the cleaning works should be carried out to identify the followings aspects:

- the extent of the deposits or obstructions in the pipe or in the laterals;
- the nature of the deposits expected (e.g. sand, silt, grease);
- the amount of deposits which are to be removed;
- the structural condition and the type of material of the pipe.

INFORMATION TO BE PROVIDED

The information to be provided to the person carrying out the cleaning operations should include:

- the localisation and extent of the section of pipe to be cleaned;
- the localisation of the manholes which provide the access;
- restrictions on access to the site of the manhole or inspection chamber (including traffic restrictions, removal of vehicles of the road, the need of off-road vehicles, land ownership);
- restrictions on access into the manholes or inspection chambers (e.g. diameter of manholes);
- the depth of manholes;
- the type of the deposits expected;
- the size of the pipes and laterals;
- known hazards (including hazards from trade effluents, drop pipes);
- the flow rate and flow depth in the pipes;
- environmental restrictions such as noise, odour, vibrations;
- traffic managements requirements;
- restrictions on working methods;
- restrictions on temporary stopping where this could cause flooding or pollution;
- the localisation of pumping installations and other structures which could be adversely affected by cleaning operations;
- restrictions on the disposal of deposits.

SELECTION OF THE CLEANING METHOD

The cleaning techniques and the equipment to be used can be selected according to the following aspects:

- the nature of the deposits or obstacles to be removed;
- the dimensions of pipes or laterals;

- the ranges of water depths, velocities and flows;
- the distance from the manhole or inspection chamber to the furthest point to be cleaned;
- restrictions on access to the manhole or inspection chamber (including traffic restrictions, removal of vehicles of the road, the need of off-road vehicles, land ownership);
- whether access is available from the downstream manhole or inspection chamber;
- the type of material of the pipes;
- the structural condition of the pipes or laterals;
- environmental restrictions such as noise, odour, vibrations;

FINAL DESTINATION OF WASTE

The final destination of the waste of cleaning is referred in the national legislation and the restrictions must be properly defined in the contract.

SUPERVISION OF THE CLEANING OPERATIONS

In the supervision of the cleaning works, specifications for this purpose must be established prior to start. The description of the intended results, the requirements for reporting and method for evaluation of results should be included in the specifications.

A report shall be submitted by the contractor to the client on completion of the cleaning work, allowing a first inspection of these works. The cleaning report should contain the following aspects:

- the location, date and time of the works;
- the name of the contractor and the operative who carried out the work;

- an estimate of the state of the sewer before the work commenced;
- the cleaning techniques used;
- the type and amount of the deposits removed;
- condition of the sewer after cleaning.

The methods of the conformity assessment of the results must be specified in the contract and can include, for example, visual inspection of the sediment depths at manholes, visual inspection of the sediments in the pipes, directly or by CCTV means, inspection using sonar techniques. In case of the existence of roots or other obstacles, the visual inspection of the sewer is particularly important.

In the contract must also be referred if the assessment should be carried out throughout the system or just a sample. In the second case, the method considered for the sampling must be defined. In the case of existence of non-conformities must be rectified in accordance with the contract.

IMPLEMENTATION OF WORKS

The cleaning works should be carried out in order to prevent discharge of the coarse material and debris into the downstream sewer system. The deposit must be removed from the sewer and should have an appropriate final destination.

The cleaning works must begin from upstream to downstream. Where a supply of water is required, measures should be taken to avoid contamination of any drinking water supply and to avoid unacceptable impact on the pressure supplied to the other users.

The entire personnel must be trained in accordance with the recommendations of the EN 752:2008 standard (CEN, 2008a).

All work must be carried out in accordance with the requirements and the health and safety regulations. Despite of hazards usually associated to works in sewers, special risks associated with the equipment employed on the sewer cleaning should be dealt with by implementing adequate safety measures. The high pressure water jetting equipment must follow the requirements specified in the EN 1829-1:2010 standard (CEN, 2010b).

CLEANING METHODS

In the following sections, the most commonly used cleaning methods are described, which can be used separately or in combination.

FLUSHING

This technique consists in the placement of a barrier to the flow upstream of the length to be cleaned (e.g. gate or flushing valve) in order to retain a significant volume of water which is released to create a large wave. Care should be taken to ensure that there is no personnel in the downstream sewer during operation. This technique is suitable for non-hardened deposits which are generally retained in the sewer system.

JETTING

This technique consists in the application of a water jet to remove obstructions, sediments and attached deposits. Works should be carried out from a downstream manhole or inspection chamber. Maximum safe working pressures to avoid damage will vary according to the material, the condition of the pipe and the type of nozzle of the equipment. This method is usually applied in sewers with small diameter and low flow rates (EPA, 1999).

The water jet equipment can be classified in two families: higher pressures and lower flows (210 - 340 bar and 0.5 – 2.5 l/s) or lower pressures and higher flows (100 - 210 bar and 2.0 – 3.0 l/s). The jet is directed at the walls and bottom of the pipe.

Care should be taken when introducing the nozzle as it can cause impact damage to the pipe when the pressure is started. Additionally, the nozzle should be kept moving at all times in order to limit the potential for damage to the fabric of the sewer. The rewind rate of the jetting hose for sediment removal should be typically between 100 mm/s to 200 mm/s. The nature of sediments to be removed and the minimization of the risk of damage to the pipe should be considered in the selection of the nozzle.

HIGH PRESSURE WATER JETTING WITH SUCTION

This technique consists in the combination of water jetting delivering high flow rates of water combined with suction to remove deposits from the sewer. Where this equipment is incorporated in a single vehicle this is termed combined jetting. This combination sometime includes the re-circulation of water allowing higher flow rates of water to be used.

The following pictures show the execution of cleaning with high pressure water jetting with suction.

WINCHING

This technique involves pulling a tool by means of a cable between two adjacent manholes, usually a tool of type and dimensions adequate to sewer size and deposits type. Measures should also be taken to minimise the risk of damage of abrasion between the winch cable and the fabric of the manhole, as well as on sewers and laterals. The size of the tool should be increased successively to the maximum for the size of the pipe. The tension on the winch cable should be monitored and the direction of working is generally two-way. This technique can be applied in large sewers and allows the removal of large amounts of deposits.

RODDING

In this technique, a tool placed on the end of a flexible tube is pushed through the pipe. The tool has a rotating movement to remove the deposits and roots (EPA, 1999). This method is generally only suitable for pipes less than 250 mm of diameter and less than 2 m depth for removal the blockages. The type of tool selected relate to the nature of deposits.

REMOTE CONTROLLED EQUIPMENT

A variety of remotely controlled equipment is available including chain flails, mechanical root cutters, and robotic controlled high-pressure water cutters. The selection of the equipment depends on the nature of the deposits and the material of the sewer.

CLEANING BALLS OR SCOURING PLATES

In this method, a small plate or ball is allowed to move down the sewer. The diameter of the plate or ball used must slightly smaller than the size of the pipe. The increased flow velocity as the flow passes the moving obstruction loosens the sediments and moves them downstream. Cleaning balls are generally beaded to maximise the localised turbulence to release the deposits. It is not possible to remove the loosened deposits from the sewer.

This method is suitable to be used in larger diameter pipes, and is generally used where other methods are not practicable. Due to the potential health and safety risks, the use of methods involving operations personnel entering the sewer should be minimised.

The excavation by mechanical means can be done using excavators or purpose made vehicles that push or sweep forward to a collection point. The equipment should be protected to minimise the risk of explosion when mechanical excavation is used.

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Rehabilitation of sewers and manholes: technologies and operational practices

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