A RESEARCH PROJECT SUPPORTED BY THE EUROPEAN COMMISSION UNDER THE FIFTH FRAMEWORK PROGRAMME AND CONTRIBUTING TO THE IMPLEMENT OF THE KEY ACTION "SUSTAINABLE MANAGEMENT AND QUALITY OF WATER" WITHIN THE ENERGY, ENVIRONMENT AND SUSTAINABLE DEVELOPMENT

EVK1-CT-2002-00106

REPORT

No. 4.2 , April 2004

Work Package 4, Delivery D12

WASTEWATER REHABILITATION TECHNOLOGY SURVEY

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CARE

CARE-S - Computer Aided REhabilitation of Sewer networks

COMPUTER AIDED REHABILITATION
OF SEWER NETWORKS

Work package 4

Rehabilitation technology information system

Report D12

Wastewater rehabilitation technology survey

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A INTRODUCTION

A.1 CARE-S project

The Computer Aided REhabilitation of Sewers network (CARE-S) project is funded by the European Community, under the fifth framework program and contributing to the implementation of the key action "sustainable management and quality of water". This project aims to establish a rational framework for sewer network rehabilitation decision-making. The work plan has been divided in several Work Packages, and tasks has been distributed among CARE-S partners. The WP's are:

WP1: Performance Indicators
WP2: Structural condition
WP3: Hydraulic capacity
WP4: Rehabilitation technologies
WP5: Socio-economic consequences
WP6: Multicriteria decision support
WP7: Wastewater network rehabilitation manager
WP8: End user testing
WP9: Dissemination
WP10: Administration

A.2 Work Package 4

CLABSA leaders WP4, which summarized objectives are:

- General survey of available techniques and contractors. Require information from international associations of trenchless technology. Analysis of experiences and results.
- Build a complete chart for the variety of methods in rehabilitation of sewers. Current state-of-the-art. Rates, range of applicability, limits and restrictions. Combine global and local approach.
- Evaluate cost of rehabilitation linked to the applied technology. Approach to some formulae of cost calculation.
- Present other valid alternatives for rehabilitation: redesign of sewers, operational methods.
- Criteria for choice-making of suitable techniques related to sewer problems.

To complete the criteria for wastewater network management, this work package will present appropriate measures to tackle various wastewater network problems.

There are a variety of methods to rehabilitate wastewater networks. The method to be chosen obviously depends on local conditions, such as the type of the problem, the size of the pipe etc. The rehabilitation costs are linked to the applied method and technology.

Two specific tasks have been defined:

Operational options (Task 4.1)
Some functional problems may be solved by operational methods rather than renovation or replacement, for example certain types of sedimentation, which may be handled by jetting. This task will present arguments for operational options or local redesign versus renovation and replacement.

This task will generate report D11, “Survey of operational options”

Structural rehabilitation (Task 4.2)
Rehabilitation of sewer and storm water networks includes system improvements (detention basins, separation of storm water etc) as well as renovation technology. During the last 20 years, there has been an extensive development of technologies for sewer and storm water rehabilitation. Today, a large variety of methods exist to meet problems in small sized as well as large sized pipelines. Several cities use renovation as their first priority measure against structural and hydraulic decline.

This task aims to analyze which measures are appropriate to meet various kinds of problems. A list of measures and problems they should apply to will be presented and used for the rehabilitation manager, considering their potential for pipe failure in one hand, and their characteristics leading to more or less social disturbance and annoyances on the other hand.

Also, attention will be brought to the innovative question of establishing the explicit links between the rehabilitation techniques (with or without trench) and the other aspects of the project: calibrate disturbances to the citizens (WP5), hydraulic benefits (WP3), mechanical benefits and durability (WP2), and economical issues (WP7).

This task will generate report D12, “Wastewater on rehabilitation technology survey”.

A.3 This document

Here it’s presented deliverable D12, that shows the results of task 4.2. The content of this document has been divided in several parts:

- *Part A* – Framework for WP4 CARE-S project and introduction.
- *Part B* – Description of the objectives of this document.
- *Part C* – Detailed description of Rehabilitation Technologies for pipes, manholes and lateral connections.
- *Part D* – Description and presentation of the Rehabilitation Techniques Chart, that summarizes the main characteristics of the RTs.
- *Part E* – Rehabilitation Technology Data Base. Description and end-user manual.
- *Part F* – Cost formula calculation and end-user manual.
- *Part G* – References.
- *Part H* – Annexes.

B OBJECTIVES

B.1 Report D12 objectives

The aim of this document is to present a description of all techniques and methods available for sewer rehabilitation, with their main characteristics.

To make the rehabilitation techniques (RTs) operative, they have been presented in different formats:

- Part C of this report presents a definition for each RT, together with a schematic outline of the installation process. This brief explanation aims to make more comprehensible the technique but does not intend to describe with detail the steps to follow. This task would exceed the intention of this document and would carry some problems, as the same RT may present slight differences among different contractors, installers or work conditions. A short list with some remarkable benefits and drawbacks of each technique is also presented, giving additional information and warning of possible problems during the works.
- Apart of this basic information for the RTs, Part D presents the RTs Chart. In this chart it can be found the complete list of RTs, together with a series of columns that contains their characteristics. This is an easy way to have a general view of the RTs, in particular this chart shows clearly the different categories in which the repair, renovation and replacement techniques have been divided. Even more, a color coding system allows to identify the suitable techniques for more common defects in just a glance.
- A list of over 70 RTs having each one of them more than 60 characteristics sums up around 4500 data. To be able to manage them, it becomes essential to store them in a Data Base structure. In this sense, a rehabilitation technologies data base (RTsDB) has been implemented, with some extra features, as an aided searching. This RTsDB will become part of the CARE-S Rehab Manager, but can be also used as a stand alone DB. RTs can be searched for some of their characteristics (applicability conditions).

It's convenient to remark that the rehabilitation methods are presented under their technical names, meanwhile commercial names have not been listed in this document. This pretends to aggregate in a single name all the techniques that, under different commercial names (that may vary even from country to country), are in fact the same technique, although sometimes they might present slight variations.

All rehabilitation methods found after literature and contractors survey are exposed in the document. A few of them are not fitted for sewerage, but they are still presented to provide a complete state-of-the-art in rehabilitation technologies, that it is also useful for other CityNet projects.

B.2 Process and methodology

The process of elaboration of this document and the tasks linked to it (RTs chart and RTsDB) by WP4 partners, can be summarized in the following steps:

- Elaboration of a list of RTs, separated according European Standard EN 752-5:1997, *Drain and sewer systems outside buildings*, in repair, renovation, and replacement[1].
- Searching for techniques and creation of sub-categories to gather them into uniform groups. As it has been mentioned above, a literature survey was made, but most information was found in internet.
- Simultaneously to this searching, a list of valuable characteristics for RTs was elaborated with the cooperation of WP4 partners. For this second list, it was discussed the information that was convenient to know from the RTs. Three categories were made to point the importance and content of the characteristics: applicability conditions or requirements; technology performance/characteristics and environmental impact and comments. As it'll be explained in detail in *Part D,* the first group of characteristics gather the characteristics that make a RT able or not to solve a defective sewer. The other two groups give general and useful (but not decisive) information about the characteristics of each RT. For each characteristic a first proposal of the output information was made: ranges, y/n, %, high/medium/low, etc.
- With these elements the chart was constructed, putting the RTs in rows and the characteristics in columns. The cells were filled with the contribution of WP4 partners.
- Next step was to export all this information into a data base (RTsDB). It was agreed, for better integration with the rest of CARE-S tools, to do it in MS Access. The RT Chart and the RTsDB follow the same scheme of information presentation. It was also implemented in this data base a searching system that allow, as it will be explained in *Part E,* searching through applicability conditions.
- Swindon meeting gave a new boost to this task, allowing an interchange of ideas, needs and requirements. The implementation of a color code to the RT Chart and the checking of all the characteristics meanings, as well as its related category (mainly it was decided what characteristics were going to be used by Multicriteria Decision System – applicability conditions – and which will remain as just general information) are practical results of the workshop.
- The RTsDB was checked by all WP4 partners to adapt the system to the different countries, and many implementation were made on it.
- The operational Methods were linked to this DB, as explained in the D11 report "Survey of operational options".

[1] The definitions of these three categories were first introduced in this standard, nevertheless they are clearly separated as the three branches of rehabilitation methods in the EN 13566-1 *Plastic piping systems for renovation of underground non-pressure drainage and sewerage networks*.

B.3 Rehabilitation techniques

Sewerage conduits are subjected to several conditions that may cause a variety of damages. As internal causes of sewer damage it can be can found:

- quality of flow, that may have low pH values (frequently with origin in industrial spillage), that disaggregates concrete pipes;
- hydraulic performance, that may cause stress for internal pressure;
- network age, that presents natural wasting for use along years of low maintenance investment;
- network construction time, because it becomes clear that in different countries (and cities) the infrastructure development has not been done with a good quality control of materials and/or constructive methods, usually these periods happened to meet after wars;
- sewer material, low quality materials usually linked post-war periods present a shorter lifetime than quality controlled materials, in particular, concrete is quite sensitive to this issue; and
- constructive methods, that carry associated trends to present some particular defects, as e.g. mining may lead to vault fissuring when soil over vault has not been well compacted and pipe works in pressure in rain events.

As external causes, it can be mentioned the

- traffic overloads, that may cause structural damages in shallow sewers;
- soil overloads, that may cause damages in deep and not properly designed sewers;
- root intrusion, that causes partial or total blockages, as well as fissuring or joint displacement;
- mines, war shelters and tunnels, that change the soil stress state;
- other buried services, that may affect directly to sewers, piercing them partially, causing blockages and hydraulic capacity decreasing;
- kind of surrounding soil, that may be chemically aggressive to some sewer materials;
- watertable that may cause several problems in pipes under it; and
- drinking water network spills that may wash out soil around pipes and also inflow in sewer network, causing different problems.

These causes of internal and external damages lead to diverse pathologies, like fissures, cracks, deformations, infiltrations, exfiltrations, obstacles, dislocation, abrasion, corrosion, pipe breakage and collapse.

The removal or even the prevention of this damage, can be achieved by sewer rehabilitation.

According to European standard EN 13566-1, the definitions for the three main groups in which sewer rehabilitation is divided are:

- *Repair*, rectification of local damage.
- *Renovation*, work incorporating all or part of the original fabric of the pipeline by means of which its current performance is improved.
- *Replacement*, rehabilitation of existing pipeline system by the installation of a new pipeline system, without incorporating the original fabric.

Similar definitions can be found in WRc “Sewerage Rehabilitation Manual”:

- *Repair*, rectification of damage to the structural fabric of the sewer and the reconstruction of short lengths, but not the reconstruction of the whole pipeline.
- *Renovation*, methods by which the performance of a length of sewer is improved by incorporating the original sewer fabric, but excluding maintenance operations such as root or silt removal.
- *Replacement*, construction of a new sewer, on or off the line of an existing sewer. The function of the new sewer will incorporate that of the old, but may be also include improvement or development work.

In the last decades, the rehabilitation technological market has developed quickly. This growth has been even more tangible in the development of trenchless technologies. Some of the today available technologies have been developed as adaptations of larger machinery. In this sense, some trenchless technologies have token profit from the important advances and experiences in “tunnel diggers”: tunnelings, shields, TMBs (Tunel Boring Machines), EPBs (Earth Pressure Balance) and mixed shields. Ideas and adaptation of these equipment have made possible the implementation and establishment of new techniques.

Other techniques have developed specifically for pipe installing, as consequence of urban services managers demand (operators of sewers, but also of water, electricity, gas, communications, etc.). Growth of cities, that increase their paved urban surface day by day, have make that technical development have inclined significantly for trenchless technologies, mainly because of their lower social cost.

The wide range of technologies that is presented in this document leave in urban network managers’ hands updated information about the state-of-the-art in pipes rehabilitation, that is presumed to be enough to give managers a suitable technical solution for most of the rehabilitation problems he could face. Nevertheless, still there are some technical lakes to solve a few specific problems. One of the most worrying problem, is the lake of a low-cost technique for laterals re-opening in no-man entry sewers.

We presume that next years will bring network rehabilitation responsible new techniques and improvements in the existing ones that provide even better solutions to rehabilitation problems.

C REHABILITATION TECHNIQUES

C.1 Repair techniques

C.1.1 Dig technologies

Digging techniques represent the most ordinary way for network rehabilitation, with a quite low technical development, when compared to most trenchless technologies. Nevertheless, one of its advantages is its versatility, that makes dig technologies be able to repair, renovate and replace sewers, manholes and laterals.

C.1.1.1 Open cut

C.1.1.1.1 Conventional trench

This method consists on the excavation of a trench, that permits the opencast access to existing sewer for repair. This technique is widely used also for renovation and renewal.

Process

- Removal of existing pavement, with manual and mechanic means. Transport of resulting products to a rubbish dump.
- Trench excavation using mechanical digging (or hand digging, if other urban services could be damaged). The trench is normally wide enough for operative to carry out repair works.
- Depending on the depth of the trench, local regulations and soil conditions, sloping and/or benching should be required to prevent risk of collapse. De-watering may also be required under watertable.
- If operation involves the substitution of a length of pipe, a layer of bedding material is laid along the bottom of the trench and the pipe laid on top. This material is usually selected soil, sand or concrete. The lengths of pipes are assembled in joints. Replacement of lateral connections, if necessary, are made and sealed.
- The trench is back-filled and compacted in layers if granulate material employed or, with concrete, to ensure adequate support around the pipe.
- Finally, the surface pavement is reinstated.

Benefits:

- ✓ Low level of operator skill required.
- ✓ Suitable for all pipe materials.
- ✓ Ability to overcome unknown obstructions.
- ✓ Other infrastructure can be rehabilitated or replaced at the same time, allowing for coordination of work and sharing of costs.

Drawbacks:
- The cost of the open cut method can be substantial compared to some newer technologies.
- Construction is usually longer than with most trenchless technologies due to the quantity of disturbance to other infrastructure and traffic, and the amount of reinstatement work required following the installation of the sewer.
- There are more safety concerns due to traffic issues on road rights-of-way, the number of excavations required, and the large equipment needed to perform the work.
- There can be disturbances to other surface and buried infrastructure.
- The social and economic costs of major open cut projects can be substantial during construction.
- Large volumes of earth works required (high transport costs).
- Risk of landslide, and consequently risk for operators.

C.1.1.2 Semi-open cut

C.1.1.2.1 Shoring and Trench box (modificated shoring)

Trench box and conventional shoring are presented together[2]. Trench box is a digging method that consists on the excavation of a trench and the protection of it by means of a couple of pre-cast parallel metallic sheets, separated by means of shores. This allows trenching in non-cohesive soils and digging more deep, keeping the security conditions, and saving sloping and benching. This method is also used for renovation and renewal, later described.

Process

The process is almost the same than for conventional trenching:

- Removal of existing pavement, with manual and mechanic means. Transport of resulting products to a rubbish dump.
- Trench excavation using mechanical digging (or hand digging, if other urban services could be damaged). The trench is normally wide enough for operative to carry out repair works.
- The trench wall is shored up to prevent risk of collapse, <u>or</u> the trench box is located. De-watering may also be required under watertable.
- A layer of bedding material is laid along the bottom of the trench and the pipe laid on top. Once the pipes are assembled and lateral connections made, the protections are moved away.
- Then, the trench is back-filled and compacted in layers if granulate material employed or, with concrete, to ensure adequate support around the pipe.
- Finally, the surface pavement is restored.

Benefits:
- ✓ Less surface occupied (working area required) than conventional trench method.
- ✓ Less earth excavation volume.
- ✓ More depth can be reached in secure conditions and without affecting the surface occupied.
- ✓ For important depths, costs are minor compared to conventional trenching.
- ✓ Low level of operator skill required.
- ✓ Suitable for all pipe materials.

[2] In fact, trench box is a modification of shoring. Trench boxes are intended primarily to protect workers from cave-ins, meanwhile shoring is primarily used for supporting the trench face, with wooden planks or metallic sheets.

- ✓ Ability to overcome unknown obstructions.
- ✓ In some cases, other infrastructure can be rehabilitated or replaced at the same time, allowing for coordination of work and sharing of costs.

Drawbacks:

- × The cost of the trench box or shoring methods can be higher compared to some newer technologies.
- × Construction can be longer than conventional trenching for shoring. In the case of trench box, little time to settling up would be minor than for digging slopes or benchings.
- × There are more safety concerns due to traffic issues on road rights-of-way, the number of excavations required, and the large equipment needed to perform the work.
- × There can be disturbances to other surface and buried infrastructure.
- × The social and economic costs of major open cut projects can be substantial during construction.
- × Large volumes of earth works required (high transport costs) although minor than for open trench.
- × Risk of landslide, and consequently risk for operators.

C.1.1.2.2 Concrete sheet pile

This method consist on the construction of a concrete wall in the earth, and a later digging of the soffit (intrados) soil. It's a common way of constructing subterranean infrastructures (parkings, tanks,…)

Process

- The process is usually made in lengths of wall from 2.6m to over 5 meters, depending on soil characteristics, and machinery used.
- Vertical digging of a narrow and deep trench. Digging machinery allows excavation for usual widths of 45-60-80cm (special machinery arrives to 100-120cm), and maximum depths over 25 m.
- Steel reinforcement, already mounted, is placed in the trench.
- Concrete is pumped in the trench.
- The process continues with the next length.
- Once the concrete sheetpile is finished and set up, the excavation can begin. In the case of linear infrastructures (e.g. sewers), the sheet pile is constructed along the infrastructure and in both sides. In this cases, the digging material is the soil between the walls (intrados or soffit space).
- Maximum depth of excavation is in function of sheet pile dimensions and soil characteristics.
- The access to sewer is now opencast. Any kind of repair can be done.

- Once repaired, the intrados is fulfilled with adequate material (earth, granulates..) and the surface pavement restored

Benefits:

- ✓ More adjusted and controlled working area required than trenching or shoring.
- ✓ Less earth excavation volume.
- ✓ Very far depth-limit, within secure conditions.
- ✓ For large depths, costs are minor compared to conventional trenching.
- ✓ Suitable in any kind of soil, although rocky soils increase the costs and the time.
- ✓ Suitable for all pipe materials.
- ✓ Ability to overcome unknown obstructions.
- ✓ In some cases, other infrastructure can be rehabilitated or replaced at the same time, allowing for coordination of work and sharing of costs.

Drawbacks:

- × Very high cost, because the material employed in wall construction is not retrievable. It's a bad waste if intrados has to be fulfilled after repair, as structural elements (walls) loose their sense.
- × Construction time is longer than trenching or shoring.
- × There are more safety concerns due to traffic issues on road rights-of-way, the number of excavations required, and the large equipment needed to perform the work.
- × There can be disturbances to other surface and buried infrastructure.

C.1.1.2.3 Sheet pile

This method consist on a row of interlocking, vertical pile segments or sheets, driven to form an essentially straight wall. If required, the sheet can be retrieved.

Process

The process is similar than for concrete sheet piling:

- Metallic (usually steel) sheets are vertically jacked in the soil, vibrating or striking them, with specialized machinery, and interlocked together.
- Once the sheet pile is finished, the excavation can begin. In the case of linear infrastructures (e.g. sewers), the sheet pile is constructed along the infrastructure and in both sides. In this cases, the digging material is the soil between the walls (intrados or soffit space).
- Maximum depth of excavation is in function of sheet pile dimensions and soil characteristics.
- The access to sewer is now opencast. Any kind of repair can be done.
- Once repaired, the intrados is fulfilled with adequate material (earth, granulates..)

- Metallic sheet can now be retrieved and the surface pavement restored

Benefits:

- ✓ As the structural element can be retrieved, costs are much minor than for concrete sheet piles.
- ✓ More adjusted and controlled working area required than trenching or shoring.
- ✓ Less earth excavation volume.
- ✓ Suitable even in hard soils and soft rocks.
- ✓ Suitable for all pipe materials.
- ✓ Ability to overcome unknown obstructions.
- ✓ In some cases, other infrastructure can be rehabilitated or replaced at the same time, allowing for coordination of work and sharing of costs.

Drawbacks:

- × Depths are usually not much deeper than 5-8 meters.
- × Strong vibration necessary to sheet jacking, so many disturbances are produced to nearby buildings and infrastructures.
- × Construction time is much shorter than for concrete sheet piling.
- × Not suitable for medium-hard rocky soils.
- × There are more safety concerns due to traffic issues on road rights-of-way, the number of excavations required, and the large equipment needed to perform the work.
- × There can be disturbances to other surface and buried infrastructure.

C.1.2 Trenchless technology

C.1.2.1 Robotic repairs

C.1.2.1.1 Injection in joints or cracks

Robotic options are larger each day. Specialized companies create and innovate new products specifically designed for sewers. Most of them consist on a CCTV equipment self propelled, in many cases with interchangeable repair devices.

Injection robots are able to grout mortar or polymers in the sewer.

Process

- CCTV sewer inspection detects the defect (joint, crack or fracture), giving its precise location and dimensions. In some cases, sewer has to be cleaned allow the access to robots.
- In many cases, the operation has to be done without running water, and so it’s necessary to cut the connections and water pumping.

- The robot is assembled with the proper devices for injection, and introduced in the sewer trough the manhole.
- The defective reparation is guided with the aid of a CCTV. It can be set in the same or in different robot, depending on robot performances.
- Robot devices do the grouting.
- Once repaired, the robot(s) are pulled out and the service restored.

Benefits:

- ✓ Very useful for small-localized sewer damages.
- ✓ No surface damage is produced. No dig required.
- ✓ Very low social cost, as few traffic disturbances, noise or dust produced.
- ✓ Relatively quick total working time compared with digging methods.
- ✓ No deep limit, and achieves longitudes of sewer up to 100m from one single manhole.

Drawbacks:

- × Not suitable for grave or generalized fractures.
- × High level of operator skill required.
- × Very specific machinery employed (robots).
- × Low operations performance.
- × Not suitable for all pipe materials.

C.1.2.1.2 Milling robot

The milling robot removes any roots which have penetrated, grinds off protruding lateral connections, and removes hard deposits such as concrete. With its interchangeable tools it can be used for milling, drilling or grinding.

Process

It's the same than for injection:

- CCTV sewer inspection detects the defect (root, protruding lateral, deposit…), giving its precise location and dimensions. In some cases, sewer has to be cleaned allow the access of the robots.
- In many cases, the operation has to be done without running water, and so it's necessary to cut the connections or water pumping.
- The robot is assembled with the proper devices for milling, and introduced in the sewer trough the manhole.
- The defective reparation is guided with the aid of a CCTV. It can be set in the same or in different robot.
- Once repaired, the robot(s) are pulled out and the service restored.

Benefits:

- ✓ Very useful for obstructions, root cutting, concrete deposits and protruding laterals.
- ✓ No surface damage is produced. No dig required.
- ✓ Very low social cost, as few traffic disturbances, noise or dust produced.
- ✓ Relatively quick total working time compared with digging methods.
- ✓ No deep limit, and achieves longitudes of sewer up to 100m from one single manhole.

Drawbacks:
- High level of operator skill required.
- Very specific machinery employed (robots).
- Low operations performance.
- Limited engine power.

C.1.2.1.3 Root cutting robot

The root cutting is a particular case of milling robot, with specific tool.

The process, benefits and drawbacks are the same than for milling robot. (See 1.2.1.2.)

C.1.2.1.4 Pointing

Pointing[3] is a method of repairing a brick sewer or manhole by the application of cement mortar where loss has occurred. Another member of the sewer repair robots is the pointing robot. This device, allows the robot to raking out the old mortar and then pressure pointing.

Process

It's the same than for injection:

- CCTV sewer inspection detects the defect (mortar missing in brick sewer), giving its precise location and dimensions. In some cases, sewer has to be cleaned allow the access of the robots.
- In many cases, the operation has to be done without running water, and so it's necessary to cut the connections and water pumping.
- The robot is assembled with the proper devices for pointing, and introduced in the sewer trough the manhole.
- The defective reparation is guided with the aid of a CCTV. It can be set in the same or in different robot.
- Once repaired, the robot(s) are pulled out and the service restored.

Benefits:
- ✓ No surface damage is produced. No dig required.
- ✓ Very low social cost, as few traffic disturbances, noise or dust produced.
- ✓ Relatively quick total working time compared with digging methods.
- ✓ No deep limit, and achieves longitudes of sewer up to 100m from one single manhole.

Drawbacks:
- If large surfaces require pointing, the process became very slow.
- High level of operator skill required.
- Very specific machinery employed (robots).
- Low operations performance.

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[3] Pointing method can be robotic or man-made, explained later.

C.1.2.1.5 Rerounding

Re-rounding is intended to re-shape a deformed sewers and restoring circular cross section. An expander[4] unit is used to re-round the pipe and install a metal or plastic clip which holds the pipe fragments in position. This technique is generally used prior to patch repair or relining.

Two main techniques exist, both relying on an expander to push the deformed sewer section back into shape.

Process using scrolled clips

- A stainless steel sheet or PVC clip is wrapped around an expander.
- The assembly is inserted into position in the sewer
- Expansion to the required diameter is carried out.
- The clip is left in position and the expander retracted.

The clip is not considered a complete repair, therefore a localized or manhole to manhole lining is normally applied after re-rounding.

Process using segmental re-rounders

- Consists of a short length of PVC pipe, made from six hinged segments.
- Assembly is collapsed to enable insertion into position into pipeline.
- Once in position, expansion is carried out using hydraulic jacks.
- Interlocking grooves in the longitudinal edges provide added strength.
- Polyethylene foam gasket on outer surface avoids grouting into place.

Benefits:
- ✓ Stainless steel or rubber couplings can also be expanded manually into position over leaking joints in man entry sewers.
- ✓ Segmental re-rounders can be used for clay or concrete host pipes of diameter from 600 to 2800mm.
- ✓ Can renovate entire length after re-rounding defective sections
- ✓ No surface damage is produced. No dig required.
- ✓ Very low social cost, as few traffic disturbances, noise or dust produced.
- ✓ Quick total working time.

Drawbacks:
- × Only suitable for circular sewers.
- × Some systems do not form a leak-proof repair.
- × High level of operator skill required.
- × Quite specific devices employed; nevertheless, the use of packers is each day more common.

[4] An expander, or *packer* is a cylindrical device that is able to increase its diameter, generally inflating with air (pneumatic), but sometimes mechanically. In man-entry sewers, this process can be done hand-made.

C.1.2.2 Short-liners (Patch repair)

C.1.2.2.1 Fiberglass and polymers

Short liners consist on a short length (1-3m) of fabric impregnated with resin, positioned over the defective section of the pipeline, to repair holes or fractured sections. These linings are made from the same types of materials as cured-in-place linings, typically glass or carbon fibre or polyester felt, impregnated with either an epoxy or polyester resin.

Process

- The liner is wrapped around a long flexible tube (packer or expander)
- The assembly is winched into the defective area of the sewer.
- The packer is inflated to push the repair lining against the internal wall of the sewer.
- The resin is cured (at ambient conditions, elevated temperature or by UV radiation).
- The packer is deflated and removed.

Various alternative method of curing of the system can be utilized depending on the combination of resin system. Ambient condition curing is the slowest (and cheapest), and UV light the quickest (process can be set up in minutes) but has a higher cost.

Benefits:
- ✓ Useful for small defects.
- ✓ Good quality control for factory prepared liners.
- ✓ Some can tolerate some infiltration during application.
- ✓ No surface damage is produced. No dig required.
- ✓ Very low social cost, as few traffic disturbances, noise or dust produced.
- ✓ Quick total working time.

Drawbacks:
- × Only suitable for circular sewers.
- × Poor quality control for site impregnated liners.
- × Shrinkage of liner during cure can result in displacement at lateral services.
- × High level of operator skill required.

C.1.2.2.2 Metallic

Another kind of short-liner is the metallic joint sealing, that involves the installation across the joint or defect of a metal band or clip faced with an elastomeric material which forms a seal with the inner surface of the pipe.

Process

It's the same than for rerounding

- A stainless steel sheet is wrapped around an expander.
- The assembly is inserted into position in the sewer

- Expansion to the required diameter is carried out.
- The clip is left in position and the expander retracted.

Benefits:
- ✓ Does not uses chemical, so it's environmental safe.
- ✓ Good quality control.
- ✓ Can be used in small as well as in large diameters.
- ✓ Can provide structural repair.
- ✓ No surface damage is produced. No dig required.
- ✓ Very low social cost, as few traffic disturbances, noise or dust produced.
- ✓ Fast installation times.

Drawbacks:
- × The cost of the materials is, however, higher than for cured-in-place methods.
- × The repair length is limited by the size of clip which can be inserted from a manhole, because the repair clips have no longitudinal flexibility.
- × Not suitable for non-circular sewers.

C.1.2.3 Man-made repairs

C.1.2.3.1 Masonry

Masonry or brick works consist on hand-made reparation with bricks and mortar. The bricklayer does the work inside the sewer, so one of the limitations for this method is that inside-repairs are only possible in man-entry sewers. Otherwise, dig technology can be used.

Process

- The sewer is cleaned, the water canalized in one small pipe of 200-300mm diameter (or pumped), and sewer length is provided with electric light.
- Usually, a preliminary task of demolition of damaged elements is necessary.
- The operative reconstructs the defective zone with bricks and mortar.
- The auxiliary installations are taken away, once the masonry work has set up.
- The sewer is back to service.

Benefits:
- ✓ Very adaptable method. Material is employed only where needed.
- ✓ Structural method.
- ✓ Sealing method.
- ✓ Quite simple (and cheap) devices and materials employed.
- ✓ No surface damage is produced. No dig required.
- ✓ Very low social cost, as few traffic disturbances, noise or dust produced.

Drawbacks:
- × Only suitable for man-entry sewers.
- × Many security and health measures to be observed.
- × Many powerman required, that can increase the cost.

C.1.2.3.2 Fill with mortar and plaster

Brick or masonry works have a roughness surface, so sometimes these surfaces are finished up with a coat of mortar (of 0.5cm thick aprox.), that reduces the roughness of the sewer, increasing its capacity and making difficult the placement of sediment deposits. Depending on material mixture proportion (less sand and more cement) and bricklayer’s work, the finished surface can be very smooth. This can be a good complementary action, after masonry work repair is finished. This technique is also used in concrete (reinforced or not) sewers.

Process

- The sewer is cleaned, the water canalized in small pipes (or pumped), and sewer length is provided with electric light.
- Usually, a preliminary task of demolition of damaged elements is necessary.
- The operative fills with mortar and plaster the sewer surface.
- The auxiliary installations are taken away.
- The sewer is back to service.

Benefits:
- ✓ Very adaptable method. Material is employed only where needed.
- ✓ Sealing method.
- ✓ Quite simple (and cheap) devices and materials employed.
- ✓ No surface damage is produced. No dig required.
- ✓ Very low social cost, as few traffic disturbances, noise or dust produced.

Drawbacks:
- × Only suitable for man-entry sewers.
- × Non-structural method.
- × Many security and health measures to be observed.
- × Many powerman required, that can increase the cost.

C.1.2.3.3 Pointing

As explained above, pointing is a method of repairing a brick sewer or manhole by the application of cement mortar where loss has occurred. Only can be done hand-made in man-entry sewers.

Process

- The sewer is cleaned, the water canalized in small pipes (or pumped), and sewer length is provided with electric light.
- Defective mortar between bricks is removed.
- Cement mortar is applied where mortar is missing or quitted (gaps between bricks)
- The auxiliary installations are taken away.
- The sewer is back to service.

Benefits:
- ✓ Very adaptable method. Material is employed only where needed.
- ✓ Sealing method.

- ✓ Enhances sewer structural performance (but difficult to measure)
- ✓ Quite simple (and cheap) devices and materials employed.
- ✓ No surface damage is produced. No dig required.
- ✓ Very low social cost, as few traffic disturbances, noise or dust produced.

Drawbacks:
- × Only suitable for man-entry sewers.
- × Many security and health measures to be observed.
- × Many powerman required, that can increase the cost.
- × Not structural method (but semi-structural)

C.1.2.3.4 Injection

Man-entry sewers allow hand-made injections, that consist in grouting with mortar (or other gel material) the voids existing in the extrados of the sewer.

Process

- The sewer is cleaned, the water canalized in small pipes (or pumped), and sewer length is provided with electric light.
- Once detected the zones to inject (can be done with radar detector), small drills are made.
- Mortar is grouted through the drills sequencely, to prevent voids in the injection.
- Drills are sealed and the advance continues until the end of the damaged zone.
- Sometimes, this operation is finished up plastering the sewer internal surface.
- The auxiliary installations are taken away and the sewer is back to service.

Benefits:
- ✓ Very useful for grave or generalized fractures.
- ✓ Structural and sealing technique.
- ✓ No surface damage is produced. No dig required.
- ✓ Very low social cost, as few traffic disturbances, noise or dust produced.
- ✓ Very quick total working time compared to digging methods.

Drawbacks:
- × Only suitable for man-entry sewers.
- × Possibility of environmental damage if grouting chemical material in sensitive zone.
- × Many security and health measures to be observed.
- × Difficult to measure in the project, if voids surveying with radar has not been done.

C.1.2.3.5 In situ invert repair

This technique is very useful for repairing collapsed inverts, and consists in reconstructing the concrete or brick invert sewers. In many cases, the performance of the sewer is adequate except for the inverts, usually the most wasted part of the sewer, because of the time, slope (water velocity) o chemical abrasive products poured to sewer networks.

Process

- The sewer is cleaned, the water canalized in small pipes (or pumped), and sewer length is provided with electric light.

- A preliminary task of demolition and extraction of damaged elements is done.
- The operative reconstructs the defective zone: makes sewer slope uniform and then reconstructs the invert with bricks and mortar. Otherwise, a formwork is placed to form the channel and the benchings and concrete is pumped it.
- The auxiliary installations are taken away, once the masonry or concrete work has set up.
- The sewer is back to service.
- The auxiliary installations are taken away and the sewer is back to service.

Benefits:
- ✓ Very useful for invert collapses.
- ✓ Structural and sealing technique.
- ✓ No surface damage is produced. No dig required.
- ✓ Very low social cost, as few traffic disturbances, noise or dust produced.

Drawbacks:
- × Only suitable for concrete or brick sewers.
- × Only suitable for man-entry sewers.
- × Many security and health measures to be observed.
- × Many powerman required, that can increase the cost.
- × Relatively slow process (quite slow if invert is reconstructed with bricks).

C.1.2.3.6 Pre-cast invert repair

The difference with “in situ invert repair” is that pre-cast technique uses precast elements, usually “half pipes”, to repair the invert. It’s ideally used if sewer performance is adequate, but benchings are not so correct, and channel is too wasted.

Precast elements are available in several materials, but plastic and stoneware are preferred, because of their longer durability to chemical agents and waste.

Process

- The sewer is cleaned, the water canalized in small pipes (or pumped), and sewer length is provided with electric light.
- A preliminary task of demolition and extraction of damaged elements is done.
- The operative reconstructs the defective with precast elements. Usually, there are assembled together or placed with mortar (stoneware half-pipe, tiles) or chemicals (plastic elements).
- The auxiliary installations are taken away and the sewer is back to service.

Benefits:
- ✓ Very useful for invert or channel collapses, when walls and crown of section remain in adequate performance.
- ✓ Sealing technique.
- ✓ Suitable for most sewer materials.
- ✓ No surface damage is produced. No dig required.
- ✓ Very low social cost, as few traffic disturbances, noise or dust produced.

Drawbacks:
- × Non structural technique, although it can enhance structural capability.
- × Only suitable for man-entry sewers.
- × Many security and health measures to be observed.

- Many powerman required, that can increase the cost.
- Relatively slow process, but not so much as "in situ" method

C.1.2.4 Grouting methods

C.1.2.4.1 Chemical stabilization (fill and drain systems)

Fill and drain methods are used for sealing cracks and cavities in structurally sound sewers by chemically treating a length of sewer between manholes. Chemical grouting is a technology primarily used for spot repairs to seal joints and non-structural cracks. Chemical grouting reduces or stops water infiltration and exfiltration. The chemical grout builds up an external, flexible, and impermeable mass in the soil surrounding the spot repair location. Chemical grouting is used primarily for cracks in pipes, at leaky joints, and in access holes.

Process

- A sewer section between manholes is isolated and cleaned.
- Manholes and laterals are closed off.
- A chemical solution is pumped into the sewer.
- This solution seeps through defects into the surrounding ground.
- The first solution is pumped out and a second introduced.
- Reactions between the two solution in the surrounding ground cause solidification and leakage prevention.
- The sewer is re-cleaned before being put back into service.

Benefits:
- ✓ It is a cost-effective method to stop water infiltration by filling voids and sealing fissures in fractured soil.
- ✓ It can prevent future structural damage.
- ✓ Can re-use unmixed chemicals.
- ✓ Provides structural enhancement (although difficult to measure) through the stabilization of the existing pipe fabric and the surrounding ground.
- ✓ Suitable for non-circular sewers.
- ✓ Mobile Equipment.
- ✓ May enhance capacity.
- ✓ No surface damage is produced. No dig required.
- ✓ Very low social cost, as few traffic disturbances, noise or dust produced.
- ✓ Quick total working time.

Drawbacks:
- There is the potential of ground water pollution (selection of grout type is a major consideration). Some companies have environmentally safe chemical solution.
- Chemical grouting is effective when used with other technologies.
- Size of sewer limited by volume.
- Difficult to isolate section to be treated where surface is irregular.
- Large volume of chemicals required.
- Difficult quality control.

C.1.2.4.2 Mortar stabilization

Mortar stabilization[5] is a common grouting method. It consists inject mortar slurry into the soil, and it's widely used in civil engineering to treat slump zones and cavities.

To properly map the cavities, several techniques may be used, among we highlight the SPT (standard penetration test) and the non-destructive test of ground penetrating test (GPR or georadar).

Process

- A drill is done to allow the grouting pipe to penetrate into soil. In unstable soils, the drillhole shall be stabilized with drilling fluid of bentonite or polymer slurry. The head of the drilling fluid shall be kept at a level high enough to ensure sufficient stabilizing capacity in the cased or uncased drillholes.
- Generally the contractor shall adopt slow pumping rates in order to maximize mortar intake and to ensure against occurrence of hydraulic fracturing. The pumping or mortar injection rate recommended is 0.03 m3 per minute or lower. The maximum limit pump-in pressures recommended is 1 bar (0.1 MPa) near structures. In the case of damaged sewers, this limit shall be reduced to 0.5 bar (0.05 MPa).
- Generally mortar injection shall commence around the perimeter of the treatment zone and then proceeding toward the center. Each hole shall be drilled and grouted before moving to the next hole. In the case of multiple cavities or multiple limestone layers in any drill hole, treatment shall proceed from the lowest cavity and completed for that cavity before proceeding to the next higher cavity.
- Operation is finished when shafts are back filled, compacted and repaved.

Benefits:

✓ Improves general soil stability.
✓ If it's carefully designed and taken on, can be an structural technique.

Drawbacks:

× There's risk of surface for settlement or heave over, so monitoring of surface is highly recommended.
× Doesn't repairs directly the sewer.
× Surface damage is produced and digging required, although only in few locations.
× Requires soil characterization.
× Difficult to measure in the project.
× To complete sewer repair, other techniques (like fissure sealing) are required.

C.1.2.4.3 Joint sealing [6]

<u>Sealer injection</u>

Technique for repairing leaky joints by injecting them with resin or grout, with the help of a packer, to prevent infiltration or exfiltration. There are numerous variations in packer design and

[5] In the rehabilitation techniques context, we refer to "mortar stabilization" when grouting is made from the inside of the sewer. If mortar injection is done from the outside, then we speak of "surrounding stabilization" (see 1.2.4.6).
[6] Joint sealing includes two different techniques: injection sealing and rubber joint.

sophistication, and most systems use either a two-part acrylic gel or a water-reactive polyurethane resin.

Process

- A packer with inflatable end elements is winched into position over the defective joint.
- The packer is inflated to form an isolated annulus around the defect. Air or water pressure is applied to the center section of the packer, and the rate of pressure loss through the joint is measured.
- If the loss exceeds a specified limit, a grout gel or resin is pumped from the packer into the annulus, and the joint is re-tested.
- Curing of the resin takes place with the packer in position.
- Packer is deflated and removed.

Benefits:

✓ Can check for leakage prior to injection of sealant.
✓ Mobile Equipment
✓ No surface damage is produced. No dig required.
✓ Very low social cost, as few traffic disturbances, noise or dust produced.

Drawbacks:

× Not suitable for non-circular sewers.
× It does not provide structural repair.
× Difficult quality control.

<u>Rubber joint</u>

A variant of this technique, primarily used in pressure applications, is the use of internal joint seals. The seal's flexibility ensures a bottle-tight seal around the entire pipe joint, while its low profile and graded edge allows water to flow without creating turbulence. Internal joint seals are made of EPDM (ethylene propylene diene monomer) synthetic rubber. This technique requires operatives to access the sewer to perform the work and, as such, pipe diameters of sufficiently large size are good candidates for this technology.

Process

- Bypass pumping is done in the affected length.
- The pipe joints must be completely cleared of debris and dust. Complete preparation of the area on either side of the joint is also required to accommodate the lip of the seal.
- Once the cleaning is completed, a Portland cement grout is used to fill the joint gap completely and made flush with the internal surface of the sewer.
- The area must be cleaned with a dry brush and coated with a lubricant soap compatible with the type of seal being used. The lubricant soap is only an aid for installing the seal.
- The seal is then placed in position, spanning the gap.
- Stainless steel retaining bands are then installed in the grooves of each seal. A hydraulic expanding device is used to apply the correct pressure to the retaining bands, thereby keeping the seal in place.

Benefits:

✓ This technology is specific to pipe joint issues.
✓ Minimal working space is required at the surface.
✓ It is a low-cost alternative.

✓ Very low social cost, as few traffic disturbances, noise or dust produced.

Drawbacks:
- × It can only be used in man-entry sewers.
- × It does not address other possible pipeline deficiencies.
- × Not suitable for non-circular sewers.
- × It does not provide structural repair.
- × Bypass pumping is required.

C.1.2.4.4 Resin injection

As seen in "injection" (1.2.3.4) injections consist in grouting with any gel material the voids existing in the extrados of the sewer. For no-man-entry sewers and plastic tubes, robot devices and different resins have been developed.

Process

- CCTV sewer inspection detects the defect (root, protruding lateral, deposit…), giving its precise location and dimensions. In some cases, sewer has to be cleaned allow the access of the robots.
- In many cases, the operation has to be done without running water, and so it's necessary to cut the connections or water pumping.
- The robot is assembled with the proper devices for grouting: first making small drills and then grouting resin through the drills.
- The defective reparation is guided with the aid of a CCTV. It can be set in the same or in different robot.
- Once repaired, the robot(s) are pulled out and the service restored.

Benefits:
- ✓ Sealing technique.
- ✓ No surface damage is produced. No dig required.
- ✓ Suitable for no-man-entry sewers.
- ✓ Very low social cost, as few traffic disturbances, noise or dust produced.
- ✓ Very quick total working time compared to digging methods.

Drawbacks:
- × Non structural technique.
- × Possibility of environmental damage if grouting chemical material in sensitive zone.
- × Many security and health measures to be observed.
- × Difficult to measure in the project, if voids surveying with radar has not been done.

C.1.2.4.5 Compacted filling

Compacted filling[7] is an auxiliary work for some dig operations. It consist in compacting the back filling in trenches or gaps. In sewer repair framework, compacted filling is usually referred to small dimension holes or gaps, in which soil may already exists, but it's not enough compacted.

[7] Compacted filling (known in Spanish as "retacado"), has some differences with standard compacting.

Sewers constructed in large depths (more than 6-8m) were often dug by mining technique; today newer trenchless techniques have displaced this method. During sewer mining, soil upwards the vault and behind the walls, should be compacted filling to avoid gapping between soil and sewer vault and walls. This gaps may cause sewer pathologies in the case that the sewer work in pressure, because internal over pressure is suppose to be compensated by surrounding soil. In the case of lacking of this compacted soil, sewer fissuring or cracking may be produced.

To prevent this pathology or to cure it, next process is followed:

Process

- For detecting gaps behind walls and vaults, most suitable inspection technique is georadar, but expertise detailed visual inspection may be enough in severe damaged sewers. In this case, a simple way of checking the correct pathology diagnosis is introducing a thin rod through the fractures, verifying that soil behind the wall is not compacted when rod penetrates effortlessly.
- Once the defective zone has been defined, several proceedings may be followed, but the general idea is that a part of the vault or wall is dissembled, to let soil dumping into gaps.
- This process must be done in thin layers, depending on kind of soil used for back filling this can be from 20cm to 50cm.
- After each filling layer, soil is compacted with compacting devices. There's a wide range of possibilities, depending on compacting degree required, soil used, vibration allowed, dimensions of soil to compact, etc.
- Once each layer has been compacted and compacted soil encircles the sewer, the wall or vault is reconstructed.
- Finally, fissures and cracks must be repaired, using specific repair technique.

Benefits:
- ✓ Structural and sealing technique.
- ✓ No surface damage is produced. No dig required.
- ✓ Very low social cost, as few traffic disturbances, noise or dust produced.
- ✓ Useful for deep sewer under the avobe described construction conditions.

Drawbacks:
- × Only suitable for man-entry sewers.
- × Walls or vault dissembling requires shoring, so sewer must be disconnected of the network to avoid water pulling shoring structures, during rainfall events.
- × Difficult to measure in the project, if voids surveying with radar has not been done.
- × Many security and health measures to be observed.
- × To complete sewer repair, other techniques (like fissure sealing) are required.

C.1.2.4.6 Surrounding stabilization

This technique consists on soil stabilization by means of grouting, usually with mortar slurry. Its used as curative as well as a preventive method when constructing "big" buried infrastructures, like train tunnels or trunk sewers.

This is an indirect repair technique, because it hardens and toughens the soil, but does not act directly to sewer. It's suitable for sewers constructed in unstable or unsound soils. In some cases, can be used as well as a kind of protection for building foundation during tunneling construction.

Process

- Once the treatment soil area is defined, a cluster of pit location is defined. Injections will be done from these holes, so they must be carefully distributed in the affected area. In the particular case of sewers, shafts should be distributed along sewer length and in both sides of it (zigzag distribution).
- Injection pits are dug to projected depth.
- Mortar slurry is grouted directly through injection drills made in the shafts, in the defined directions to cover all the corresponding area. From each shaft, one or several injection drills are made sequentially (new drill is made only after previous grouting is finished; only cased drills might be done previously, in some conditions)
- Process is repeated in all the injection shafts.
- Operation is finished when shafts are back filled, compacted and repaved.

Benefits:

✓ Improves general soil stability.
✓ If it's carefully designed and taken on, can be an structural technique.
✓ Can be used for no-man-entry sewers, but rarely will be the best solution for small diameters.

Drawbacks:

× Only suitable to stabilize soils, doesn't repairs directly the sewer.
× Surface damage is produced and digging required, although only in few locations.
× Requires soil characterization.
× Difficult to measure in the project.
× To complete sewer repair, other techniques (like fissure sealing) are required.

C.2 Renovation techniques

C.2.1 Dig technology

C.2.1.1 Open cut

C.2.1.1.1 Conventional trench

See 1.1.1.1

C.2.1.2 Semi-open cut

C.2.1.2.1 Shoring and Trench box (modificated shoring)

See 1.1.2.1

C.2.1.2.2 Concrete sheet pile

See 1.1.2.2.

C.2.1.2.3 Sheet pile

See 1.1.2.3.

C.2.2 Trenchless technology

C.2.2.1 Coating lining

C.2.2.1.1 Reinforced cemetitious

In consist in man-made plastering with special products (reinforced cementitious) the inside sewer surface. The surface must be adequately prepared to ensure good adhesion. A variety of modifications can be made to cement to modify its properties depending on desired coating effect.

Process

- The sewer is cleaned and dried. Connections temporarily cut.
- Sometimes, a preliminary task of demolition and extraction of damaged elements is necessary.
- Cementitious product is applied over sewer walls.
- After relatively short curing time, sewer is back to service.

Benefits:

- ✓ Can adapt to different requirements (chemical attack, abrasion, structural reinforcement, sealing…)
- ✓ Variations in cross section easily accommodated.

- ✓ Lateral connections relatively easy to handle.
- ✓ No surface damage is produced. No dig required.
- ✓ Very low social cost, as few traffic disturbances, noise or dust produced.

Drawbacks:
- × Only suitable for man-entry sewers.
- × Sewer surface needs to be carefully prepared to ensure bonding.
- × Control of infiltration required.
- × Many security and health measures to be observed.

C.2.2.1.2 Steel reinforced cement mortar spray[8]

<u>Man-made</u>

In man-entry sewers lining is normally carried out using a hand spray gun. The surface must be adequately prepared to ensure good adhesion. Systems are typically modified to provide some level of structural integrity. A variety of modifications can be made to cement to increase the mechanical properties and hence increase the structural capability of the coating.

Process (ferrocement)

- The sewer is cleaned and dried. Connections temporarily cut.
- Sometimes, a preliminary task of demolition and extraction of damaged elements is necessary.
- Layers of steel mesh are fixed to the existing pipe wall
- Mortar is applied over and through the mesh (gunite operation).
- A high strength liner that resist the growth of cracks is formed.
- If smooth roughness required, a manual process of finishing up can be done in man-entry sewers.

Benefits:
- ✓ Can offer structural reinforcement.
- ✓ Sealing technique.
- ✓ Variations in cross section easily accommodated.
- ✓ Lateral connections relatively easy to handle.
- ✓ Live flows can be negotiated in some cases.
- ✓ No surface damage is produced. No dig required.
- ✓ Very low social cost, as few traffic disturbances, noise or dust produced.
- ✓ Fast installation times.

Drawbacks:
- × Only suitable for man-entry sewers.
- × Sewer surface needs to be carefully prepared to ensure bonding.
- × Cross section decreases slightly (steel reinforcement plus mortar gunite can make 2-3cm thick).
- × Control of infiltration required.
- × Many security and health measures to be observed.
- × High level of operator skill

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[8] Method suitable for no-man-entry sewers (robot made) and in man-entry sewers (man made). Some gunite robots are prepared for intermediate size of sections (e.g. D=800mm) in which robot operator is transported by gunniting machine in a near horizontal position.

<u>Robot made</u>

In this method, cement mortar is applied to the pipe wall by the rotating head of a machine.

Process

- The sewer is cleaned and dried. Connections temporarily cut.
- The mortar is usually pumped through hoses to the lining machine as it is being applied.
- An initial coat of cement mortar is projected.
- Then a wire mesh that runs the complete length of the sewer is installed.
- A second coat of cement mortar is then added.
- After the mortar cures (approximately 24 hours), service is reestablished.

Benefits:

✓ Semi-structural and non-structural applications.
✓ Sealing technique.
✓ Variations in cross section easily accommodated.
✓ Most cement mortar lining equipment can accommodate small bends (less than 22.5°) and, depending on the diameter of the water main being lined, larger bends (up to 45°) can be accommodated.
✓ No surface damage is produced. No dig required.
✓ Very low social cost, as few traffic disturbances, noise or dust produced.
✓ Fast installation times.

Drawbacks:

× The semi-structural cement mortar application requires access by workers to install the wire mesh and, therefore, is only suitable for water mains of 600 mm diameter or greater.
× The application of the cement mortar requires a completely cleaned and dried pipe.
× Cross section decreases slightly.
× Access to customer homes and businesses is required to isolate every water service line, and to apply compressed air to clear the service connections after the lining process.
× Control of infiltration required.
× Epoxies and Polyurethane resin require curing time.
× Sewer surface needs to be carefully prepared to ensure bonding.
× Deformation of existing pipe can cause problems.
× Many security and health measures to be observed.
× High level of operator skill.

C.2.2.1.3 Fibers reinforced cement mortar spray

Manufacturers of reinforced cement or epoxy liners include fiber reinforced mortar, calcium aluminum mortar, polypropylene or glass reinforced.

The diverse fibers listed above are mixed with mortar in very low percentages, changing significantly the properties of the mortar. Workability, flexion and compression resistance, elastic module and other mechanical proprieties are modulated by the percentage and kind of fibers added.

Process

Process can be man-made or robot-made, and follows basically the same scheme than steel reinforced cement mortar spray, bit in this case, steel reinforced is not used.

Benefits:

- ✓ Fibers added to mortar can change its proprieties to accommodate to each project requirements.
- ✓ Semi-structural and non-structural applications.
- ✓ Sealing technique.
- ✓ Variations in cross section easily accommodated.
- ✓ Most cement mortar lining equipment can accommodate small bends.
- ✓ No surface damage is produced. No dig required.
- ✓ Very low social cost, as few traffic disturbances, noise or dust produced.
- ✓ Fast installation times.

Drawbacks:

- × The application of the cement mortar requires a completely cleaned and dried pipe.
- × Cross section decreases slightly.
- × Sewer surface needs to be carefully prepared to ensure bonding.
- × Many security and health measures to be observed in man-entry sewers
- × High level of operator skill.

C.2.2.1.4 Polymer lining

Application of a lining or coating by either a rotating head which is winched through the pipeline, or hand held spraying equipment which is used for lining sewer lengths and /or manholes. Materials usually sprayed to the inside walls are epoxy or polyurethane.

Process

- The pipeline is cleaned to remove encrustation and protrusions.
- Inspection of the main is carried out to ensure no infiltration and a relatively clean surface for adhesion of the coating. The host pipe must not have any pinholes or other possible leaks in the pipe wall.
- A two component resin is mixed under specified conditions and pumped though lines to a spinner head. The appropriate mixture and temperature of the resin and hardener is critical for durability and cohesiveness. Because of this, computerized machinery with heating devices is used in the application.
- The spinner head is winched through the main at a required speed.
- After lining, the ends of the water main are capped and the resin is allowed to cure for a specified time (normally 16 hours), at an ambient temperature (must be above 3° C).
- A uniform, smooth coating, typically 1mm thick is achieved.
- On completing the curing process the pipe should be inspected visually or by CCTV.

<u>Epoxy</u>
A variety of epoxy systems are available; all require extensive cure times at ambient temperatures. Most were developed for clean water applications, but some are used in a variety of sewer applications.

<u>Polyurethane</u>
Cure time of PU systems is much shorter than that of epoxy; however the quality of the cured resin system is much more sensitive to external conditions.

Benefits:

- ✓ There is very little loss of pipe diameter (2 mm) as a total thickness of 1 mm of epoxy is applied.
- ✓ The improved interior friction coefficient increases hydraulic capabilities.
- ✓ Laterals do not need reconnection.
- ✓ Water service connections to the newly relined water main do not have to be blown with air, as is the case for the cement mortar lining application method.
- ✓ Sealing technique.
- ✓ The method can accommodate a variety of diameters and cross section, and negotiate bends.
- ✓ No surface damage is produced. No dig required.
- ✓ Very low social cost, as few traffic disturbances, noise or dust produced.
- ✓ Relatively quick installation.

Drawbacks:

- × Non-structural rehabilitation method .
- × Requires careful control of mixing/speed of application.
- × Curing times *can* be significant.
- × A completely clean and dry water main is required.
- × Control of infiltration is required to prevent pre-cure lining disbandment or collapse.
- × Access to customer homes and businesses is required to isolate every water service line before the lining process begins.

C.2.2.2 Close-fit linings

Close fit sliplining involves inserting a thermoplastic tube that has been temporarily deformed to allow sufficient clearance for insertion into the host pipe. The tube is subsequently returned to its original shape and diameter, providing a close fit in the host pipe. The outside diameter of the tube is the same or slightly larger than the inside diameter of the host pipe These are normally structural liners manufactured from PE.

C.2.2.2.1 Swaged liners (swageling)

Installation is achieved by concentrically reducing the diameter of the liner and then reverting to its original shape after installation. The tube is passed through a set of dies (referred to as "swageling") or through an array of compression rollers, to reduce the tube diameter to allow for insertion by winching. The tube then reverts to its original dimensions once the winch tension is released, and in most cases, with the help of internal pressure. This technique is most successful when there are long runs with few connections, because of the time and cost of re-opening the laterals.

Depending on the reductions and the reversion technique, these systems can be divided in:

<u>Swage-line</u>

The pipe is pulled through a steel die at an elevated temperature. This method doesn't allow stopping.

<u>Die draw</u>

The pipe is pulled through a steel die Ambient. Diameter reduces from 6% to 10% without increasing its temperature. Natural relaxation on release of tension reverts the pipe to its original size. This process is only continuous (can't stop).

Rolldown

In this case, the pipe is pushed through hemispherical steel rollers at ambient temperature, that reduces the diameter up to a 10%. The reversion process is achieved using cold pressure water. This method can be discontinuous, allowing stops.

Process

- A insertion pit is dug to accommodate butt-fusion welding of pipes before the diameter reduction and during insertion.
- The diameter of the PE pipe is reduced by being either pulled or pushed through the reduction devices. This operation may require the use of a lubricant.
- Winch loads are variable depending on whether liner is pulled or pushed into deforming tool.
- Once the pipe has been introduced in the host pipe, the reversion process begins, either elevating the temperature, leaving at ambient temperature or using cold water.
- Lateral connections are reopened, and sewer is back to service.

Benefits:

- ✓ There is minimal loss of pipe diameter and no grouting requirement when compared to the traditional sliplining technique.
- ✓ The improved interior friction coefficient can increase hydraulic capabilities.
- ✓ Long lengths of structural liner can be inserted.
- ✓ Sealing technique.
- ✓ The liner can be selected to provide either full structural integrity or semi-structural integrity, depending on the condition of the host pipe.
- ✓ Some bends can be negotiated.
- ✓ There's no need of a completely clean neither dry sewer.
- ✓ Method can be applied even if infiltration exists.
- ✓ No grouting required.
- ✓ It is rapid and causes little disturbance to other utilities

Drawbacks:

- × Sufficient site space is required to accommodate butt-fusion welding of pipes before the diameter reduction and during insertion.
- × Only circular cross section pipes can be lined.
- × Obstructions, deformed host pipes, dimensional irregularities, alignment of the host pipe and displaced joints must be considered because they can inhibit lining process.
- × So, the host pipe needs surveying, cleaning, and preparation.
- × The energy required to reduce the pipe diameter increases with larger pipe sizes and greater wall thickness.
- × Manufactured pipe for insertion usually requires special extrusion dies due to non-standard pipe diameters.
- × Tight radius bends have to be cut out.
- × Lateral connections have to be excavated or robotically re-opened.
- × A single diameter liner cannot cope with a major size change in host pipe bore.

C.2.2.2.2 Folded liners (fold & form)

In this method, pipe section is passed through a re-shaping tool either on site or immediately after manufacture in the factory. Factory formed pipe is typically permanently formed into a U shape configuration. Folding the liner prior to installation can result in a large reductions in cross section which maximized the annular gap during insertion. Resultant lower winch loads enable longer lengths to be installed and tighter bends negotiated. The folded liner is then winched into the host pipe and re-rounded using a combination of heat and pressure and, at times, a device propelled through the liner. PE liners are preferred for pressure applications while PVC systems are mainly used for gravity sewers. It is most successful with few connections.

Process

- Site folded liners are welded immediately prior to installation.
- For some PVC liners, heating of the coil is required to soften the liner prior to insertion.
- New pipe is introduced in the old pipe with the help of winches.
- Containment tubes or sleeves are sometimes used to protect the liner during insertion and prevent rupture during re-rounding.
- Once sited on position, pipe reversion is carried out by pressurized steam, with hot or cold water or air, depending on material employed.
- PVC liners typically show some deformation into laterals, which enables easy identification of lateral connections, for robot opening (in no-man entry sewers).

Benefits:

- ✓ The site-folded technique is less sensitive to the variations in diameter or pipe with dimensional irregularities, when compared to the diameter-reduction technique.
- ✓ There is minimal loss of pipe diameter and no grouting requirement when compared to the traditional sliplining technique.
- ✓ Liner can be coiled for transportation depending on diameter.
- ✓ The improved interior friction coefficient may increase hydraulic capabilities.
- ✓ Long lengths of structural liner can be inserted.
- ✓ Both structural and non-structural systems available, depending on the condition of the host pipe.
- ✓ Sealing technique, and can also be structural.
- ✓ Some liners can be used in host pipes with bends up to 45°, with some internal wrinkling.
- ✓ There’s no need of a completely clean neither dry sewer.
- ✓ Method can be applied even if infiltration exists.
- ✓ It is rapid and causes little disturbance to other utilities

Drawbacks:

- × Site or cold factory formed liners, require restraining bands to hold the reduced cross-section.
- × Factory folded liners cannot be welded on site and therefore restrict the size and length of liner that can be supplied.
- × Sufficient site space is required to accommodate butt-fusion welding of pipes before the diameter reduction and during insertion.
- × Sometimes, the reversion process may not be completed fully.
- × The liner may move in relation to the host pipe due to stresses that may be developed in the liner (e.g., due to thermal expansion or contraction).
- × The liner cannot be used in bends of more than 45°.
- × For full structural applications, the folding and re-rounding process of the installed liner must be carefully monitored to avoid long-term liner problems.

- Pre-grouting may be necessary in damaged areas or where there are voids.
- Only circular cross section pipes can be lined.
- Host pipe needs surveying, cleaning, and preparation.
- Tight radius bends have to be cut out.
- Lateral connections have to be excavated or robotically re-opened.
- A single diameter liner cannot cope with a major size change in host pipe bore.

C.2.2.3 Sliplining

C.2.2.3.1 Continuous sliplining

Simple slip-lining typically comprises either a continuous or jointed discrete lengths of pipe are pulled or pushed through the existing pipe. Sliplining creates a new pipe inside the old sewer without a complete excavation.

PVC and HDPE (high density polyethylene) pipe is primarily used in sewer sliplining applications. With PVC pipes, joints are traditional push-on joints with a low profile bell. HDPE pipe are either butt fused (thermal process), or joined together by electrofusion in various possible lengths above ground, then inserted into the host sewer at entry pits.

A sliplined pipe substantially reduces the cross-sectional area of the pipe. However, the reduction in friction with the lined pipe compared to the previous, old unlined pipe can partially compensate for the reduced internal diameter. Hydraulic requirements must be considered carefully before selecting sliplining as a preferred alternative.

Grouting the gap between the new and the old pipe (annular space) is an important step in the sliplining process to maintain the structural stability of the new pipe.

Process

- Mandrel testing of the existing pipe is required to ensure the host pipe can accommodate the sliplining. Or even better, CCTV inspection can be made to map the ovality of the pipe.
- A nose cone is fitted to the leading end of the liner to prevent snagging and to aid attachment of the winch wire bond.
- A lead-in trench and rollers allows the liner to be inserted smoothly into the host pipe.
- Pipe lengths may be jointed into strings to form a continuous pipe, or jointed prior to insertion where only limited space is available.
- All external weld beads must be removed to facilitate insertion.
- The sliplined pipe is then reconnected to the existing sewer at both ends.
- Laterals need to be identified and remade prior to grouting.
- Grouting is generally required to fill the void between the new and old pipes.

Benefits:

- ✓ It is rapid and causes little disturbance to other utilities.
- ✓ It usually provides an improved friction coefficient for improved hydraulic performance.
- ✓ Depending on flows, installations can be done in live lines without bypass pumping.
- ✓ Low degree of skill required.
- ✓ Low social cost, as few traffic disturbances, noise or dust produced.

Drawbacks:

- Requires insertion pit.

- The sliplined pipe is usually sized so its outside diameter is at least 10 percent smaller than the inside diameter to allow for smooth insertion. This reduction, in association with the wall thickness of the pipe, leads to the loss of cross-sectional capacity.
- Sliplining requires a long assembly/lay down area.
- When short pipe sections are used, there is an increased cost in the jointing techniques.
- Because the liners used for sliplining do not turn through elbows, the alignment of the unlined pipe must be considered before selecting this technique.
- Poorly controlled grouting to the annular space can lead to buckling of the liner pipe.
- Flotation might be during grouting.
- Lateral connections have to be excavated or robotically re-opened.

C.2.2.3.2 Discrete sliplining

Jointed discrete lengths of pipe can also be used for sliplining applications. Discrete short sections of pipe are jointed either outside or inside the pipeline to form a continuous lining. These pipe lengths can be joined by collar or collarless methods, such as screw threads on the ends of the pipes, or snap-lock joints. This means shorter lengths of pipe can be inserted via the entry pit, and less working space is required at the surface of the job site.

This method can be used for man entry or non-man entry pipelines.

Process

The typical procedure is dependent on the pipe size and the materials used.

- Lateral connections are disconnected.
- Individual lining units are passed into the pipeline via manholes or special access shafts.

Man entry

- Lining begins from furthermost point.
- Units are positioned and joined.
- Small section lined, then grouted, before proceeding to next section.

Non-Man Entry

- Units joined in manhole or access shaft.
- Units are pushed or pulled into pipeline until entire length has been lined.

Reinforced materials

Glass reinforced plastic, glass reinforced cement and reinforced ferrocement can be used for pressure and gravity applications.

- Units are either cast, filament wound or centrifugally spun into pipe sections.
- Pipes are joined by spigot and socket or by collared butt joints. Some joints require additional sealing.

<u>Plastic materials</u>

Polyethylene or polypropylene units. Typically used for non-man entry applications.

- Jointed by threaded, push fit or snap fit joints; enables close fit with host pipe.
- Joints are sealed using an O-ring.
- Plastic pipes can be pre-molded to specialized dimensions for non-conventional shaped pipelines. They are typically 2m in length and are welded prior to winching into position.

Benefits:
- ✓ Quick insertion.
- ✓ Can accommodate large radius bends.
- ✓ Can line non-circular cross sections.
- ✓ causes little disturbance to other utilities.
- ✓ It usually provides an improved friction coefficient for improved hydraulic performance.
- ✓ Depending on flows, installations can be done in live lines without bypass pumping.
- ✓ Low degree of skill required.

Drawbacks:
- × Labor intensive jointing.
- × Reduction in pipe cross section may be significant.
- × May require grouting.
- × Safe access conditions for man entry required
- × Excavation to reconnect lateral may be necessary for non-man entry sizes.
- × When short pipe sections are used, there is an increased cost in the jointing techniques.
- × Lateral connections have to be excavated or robotically re-opened in no-man entry sewers.

C.2.2.3.3 Segmental sliplining

Pipe segments are prefabricated sections specifically for man-entry mains. They are constructed from two pieces, joined longitudinally and circumferentially, and can be made from glass reinforced cement (GRC), glass reinforced plastic(GRP), plastic reinforced concrete (PRC), concrete or reinforced gunite. Units are assembled manually prior to grouting of the annular gap.

Panel or section insert liners are used only where person entry to the sewer is available.

When panels are used, they are designed to form a close fit, with fixed spacers, then grouted in place. The panels are relatively light and are designed to pass through access holes.

Larger diameter sewers can be lined with sections rather than panels. These would be carried into the pipe and joined in situ. The sections should also be grouted in place.

Process

The process is the same than for man-entry sliplining

- Lateral connections are disconnected.
- Individual lining units are passed into the pipeline via manholes or special access shafts.
- Lining begins from furthermost point.
- Units are positioned and joined.
- Small section lined, then grouted, before proceeding to next section.

Benefits:
- ✓ These technologies can be applied for structural or non-structural purposes.
- ✓ The liner can be designed to match the original host pipe diameter, thereby minimizing the loss in capacity.
- ✓ The liner can be effectively laid to a required grade as individual pipes can be fixed within the host pipe by spacers.
- ✓ Sections easily cut to form connections.
- ✓ There is reduced infiltration.
- ✓ There is minimal disruption at the surface as access can take place from existing manholes.

Drawbacks:
- × Bypass pumping is required.
- × It is a labor-intensive technology, and so cost increases.
- × Requires grouting.
- × There is a loss of cross-sectional diameter in the existing pipe due to the installation of the panels or sections and the grouting space required.

C.2.2.4 Spirally wound lining

C.2.2.4.1 Spiral lining

A ribbed plastic strip is spirally or helically wound to form a continuous plastic liner which is held in position by either grouting or expansion of the liner. Can be manually wound in man-entry sewers.

Non-man entry sewers[9]

Process with a static winding machine

- Hydraulic winding machine positioned at bottom of manhole.
- Profiled strip containing is fed into winding machine to form a tube.
- Tube travels down host pipes as further turns of the helix are added.
- Large friction build up as pipe rotates; limits length of installation.
- Grouting of annular gap: ribbed external surface assists bonding.

  Adaptations to the technique:

  - Specially designed profiled strip fed into machine.
  - Locking wire prevents joints between adjacent turns from slipping.
  - Once installed, locking wire pulled to allow joints to slip; helix increases in diameter.
  - Produces a close fit spiral wound liner; eliminating need for grouting.

Process with a traveling winding machine

- A winding machine that travels down the host pipe as tube is created.
- Non-circular shapes can be formed using a winding cage.
- Steel reinforcements can be used for large diameters.
- Grouting of annular gap, ribbed external surfaces assists bonding.

[9] Process changes significantly depending on machinery used: static or traveling.

Benefits:
- ✓ In some case long lengths can be achieved.
- ✓ Changes in diameter can be accommodated.
- ✓ Slow bends can be accommodated with some techniques.
- ✓ Installation can be carried out under flow .
- ✓ There is minimal disruption at the surface as access can take place from existing access holes (manholes).

Drawbacks:
- × May require grouting.
- × Needs trained personnel to operate winding equipment.
- × Digging or robotic operations required for re-open lateral connections
- × Possible reduction in hydraulic capacity.
- × Can only line circular cross sections.

Man entry sewers

Process

- Liner strip fed into pipeline via existing access points.
- Profile arranged into helix in host pipe, locking strip hammered into joints.
- Integral rubber seals can be used to produce watertight joint.
- H section plates can be used to join coils.

or

- Interlocking profile edges on liner strip.
- Self powered winding machine can travel through pipe, can create non-circular sections.

Once installed

- Standard cement grout is injected through drilled holes in liner.
- Bracing may be fitted to prevent distortion.
- Drilled holes are plugged when grouting complete.
- Laterals are cut as the tube is installed, rapid hardening mortar used to create seal

Adaptations to techniques
  - Steel reinforcements to increase strength of tube.
  - Cutting profiles to accommodate size changes, then seal with H-section jointing plates and solvent adhesive.

Benefits:
- ✓ No need for over pumping.
- ✓ Can accommodate laterals.
- ✓ Can line non-circular cross sections.
- ✓ There is minimal disruption at the surface as access can take place from existing access holes (manholes).

Drawbacks:
- × Requires grouting.
- × Reduction in pipe cross section may be significant.
- × Safe access conditions for man entry required.

C.2.2.5 Cured-in-place lining (CIPP) (or soft reversion lining)

CIPP is frequently referred to as in situ relining. A fabric tube is impregnated with a thermosetting or ambient-curing polyester or epoxy resin before being inserted into the host pipe. The resin is then cured to produce a rigid pipe within the host pipe. The combination of the fabric material, with or without fibers, and the resin can be designed to produce a new pipe that has full structural capabilities or semi-structural capabilities.

Systems are generally supplied as an absorbent carrier felt which is impregnated with the resin matrix, a reinforcing layer is also incorporated depending on the particular system. Curing of the resin system is determined by the choice of resin system, but may be achieved at ambient or elevated temperature, using water, air or steam or by using ultra violet lamps.

Typical resins systems are Vinyl ester, Polyester, Polyurethane and Epoxy. Typical carrier felts are manufactured from Polyester, possibly reinforces with glass or carbon in a variety of fibre matrix orientations (e.g. Chopped strand or woven). An elastomeric or thermoplastic (PE/PVC) coating is normally incorporated on the felt, this is the surface in contact with the liquid flowing through the pipeline.

There are three main groups of CIPP systems. These are available independently or in combination: felt-based, woven hose, and membrane systems.

Felt-Based Liner System: This liner is made of non-woven polyester felt, coated on one face with a layer of elastomer. The felt-based liner can include reinforced fibers to provide full or semi-structural integrity of the liner. The resin used in this application also plays a large role in the structural integrity of the new liner. The liner is normally impregnated with the resin at the factory then transported to the site for installation. The transportation to the site frequently occurs in a refrigerated truck to prevent premature setting of the resin. For larger diameter liners, the resin is sometimes applied on site.

Woven Hose System: These liners normally offer a semi-structural system within the host pipe. The liner is very thin and the successful installation depends on the quality of the adhesive bond to the host pipe wall. As such, the quality of the cleaning done on the host pipe before insertion of the liner is of prime importance.

Membrane System: This liner system is inserted into the host pipe with an elastomeric membrane coated with resin. This system is suitable for non-structural sewer rehabilitation applications and is primarily used to offer internal corrosion protection. It can bridge very small pinholes and joint gaps.

Process

- First step is making a CCTV inspection in the host pipe, clean and if adherence with old sewer is wanted, dry it. If mechanical capabilities of new liner are strength enough, there's no need to force adherence.

Then, two main techniques exist for installation of the liner, inversion and winch installation:

<u>Inversion</u>

- In some cases a pre-liner is winched into position to contain the inverted liner.

- The end of the liner is clamped around a inversion ring and the liner is turned inside out (inverted) down the length of the pipe using air or water.
- Pressure applied to the inside of the pipe after lining, forces the liner to hold its shape of the host pipe while the resin system under goes its specified cure regime.

<u>Winch Installation</u>

- The collapsed liner is pulled through the length of the pipe, and inflated (for example using compressed air) and cured (for example using steam).
- Some liners have resin sandwiched between 2 plastic membranes to prevent the resin coming into contact with the environment.

An novel variation on the winch installation is to cast a polymeric liner into place, typically this process consist of the following stages:

- the liner consists of two sleeves with a resin based cement mortar sandwiched between them.
- A pre-liner is pulled through the length of the pipe.
- A tailor made studded HDPE in-liner is mechanically folded and pulled through the outer liner.
- Both section ends are sealed and the liner is inflated using water pressure.
- The annular void created by the studding is grouted to fix the liner permanently in place.

Benefits:
- ✓ Installation is relatively fast with minimal excavation required.
- ✓ It offers a choice of different resins to suit the application.
- ✓ The fabric material to be used can be tailored in the factory to suit the diameter of the host pipe.
- ✓ Non-circular sections can also be lined if required.
- ✓ CIPP liners can negotiate 90° bends within the host pipe.
- ✓ The system can accommodate very long lengths.
- ✓ It fits in very tightly to the host pipe, and resists thermal expansions or contractions.
- ✓ An improved interior friction coefficient may increase hydraulic capabilities.
- ✓ The reduction in cross section is minimized.
- ✓ Usually, no grouting required.
- ✓ It can be used in structural, semi-structural, and non-structural applications.
- ✓ CIPP is widely available.
- ✓ There is minimal disruption at the surface as access can take place from existing manholes.

Drawbacks:
- × Mixing of the resin may have to be carried out on site (in few cases).
- × Sizes smaller than 100 mm or larger than 600 mm have greater difficulty of installation.
- × Time must be allowed for curing of the resins.
- × Heat or steam is required for some systems.
- × Obstructions can inhibit lining process.
- × Lateral connections have to be excavated or robotically re-opened in no-man entry sewers.
- × Partial buckling and/or ovality may occur during installation.
- × For full structural applications, liner preparation and installation processes must be carefully monitored to avoid long-term liner problems.
- × Need for bypass pumping.
- × Medium-high level of operators skill required.
- × Sewer service must be disconnected, as well as high flow and laterals.
- × Control of infiltration required, depending on resin used.

- Set up cost are high, so it's not recommended for short lengths.
- Pre-grouting may be necessary in damaged areas or where there are voids.
- Safe access conditions for man entry required.

C.2.2.5.1 Ambient cure

Benefits:

- ✓ Very simple installation.

Drawbacks:

- Very slow curing process, forces disconnect laterals and by-pass water many hours.
- If diameter is medium or large (D>500mm), liner walls thickness is larger, and so curing process won't reach inner part of the layer.
- Out of use today

C.2.2.5.2 Hot water cure

Benefits:

- ✓ Simple installation, although requires cauldron.

Drawbacks:

- Slow curing process, nevertheless is quicker than ambient cure.

C.2.2.5.3 Steam or hot air cure

Benefits:

- ✓ Quite quick curing method.

Drawbacks:

- Requires special equipment.
- Risk of folding in large diameters. In this case, hot water curing is recommended.

C.2.2.5.4 UV cure

Benefits:

- ✓ Quickest curing method.

Drawbacks:

- Requires UV lamp robot, that makes high cost.
- If diameter is medium or large (D>500mm), liner walls thickness is larger, and so curing process may not reach inner part of the layer.

C.3 Replacement techniques

C.3.1 Dig technology

C.3.1.1 Open cut

C.3.1.1.1 Conventional trench

See 1.1.1.1.

C.3.1.2 Semi-open cut

C.3.1.2.1 Shoring and Trench box (modificated shoring)

See 1.1.2.1

C.3.1.2.2 Concrete sheet pile

See 1.1.2.2

C.3.1.2.3 Sheet pile

See 1.1.2.3.

C.3.1.2.4 Mole ploughing

Method of installing a pipeline by pulling a plough through the ground whilst a continuous length of flexible pipe is fed into the top of the plough and buried in suitable terrain from the tail. This method is useful for small diameters, so it's commonly used for installing water and irrigation mains, electrical and telecommunications ducting.

Adaptations to the system such as hoppers attached to the pipe box, enable bedding materials to be fed in during the process to surround the pipe.

Process

- A steel blade and pipe box are pulled through the ground using a tractor (or other pulling vehicle) and an additional winch unit.
- As the plough passes, the ground is opened creating a vertical hollow, allowing the pipe to be inserted.
- The pipe must be flexible enough to be fed over the top of the mole plough and guided into position through the pipe box.
- The slot cut by the plough is so narrow that it virtually closes over the cable, and few space work is required afterwards. 80% of the settlement is achieved by gravity and natural relaxation of the soil.
- In some cases a tracked vehicle or vibrating roller are used to assist ground compacting.

Benefits:
- ✓ Rapid installation rates.
- ✓ Low cost.
- ✓ Few disturbances to citizens.
- ✓ Suitable for the rural sides of the roads or highways.

Drawbacks:
- × Not suitable for hard or rocky soils.
- × Not suitable if surface is paved.
- × Other services will slow down the process.
- × Only short depth achieved (2m).
- × Only suitable for very small diameters and slightly flexible pipes.

C.3.2 Trenchless technology

C.3.2.1 On-line replacement

C.3.2.1.1 Pipe bursting percussive (pneumatic)

Pipe bursting methods[10]

Pipe bursting is a trenchless technology that replaces a sewer by breaking and displacing the existing pipe and installing a replacement pipe in the void created. The system uses a pneumatic, hydraulic, or static bursting unit to split and break up the existing pipe, compressing the materials into the surrounding soil as it progresses. The new replacement pipe is simultaneously pulled or pushed with the bursting head to fill the void created.

The leading or nose portion of the bursting head is often smaller in diameter than the existing pipe, to maintain alignment and to ensure a uniform burst. The base of the bursting head is larger than the inside diameter of the existing pipe to be burst, to fracture it. It is also slightly larger than the outside diameter of the replacement pipe, to reduce friction on the new pipe and to provide space for maneuvering the pipe. The bursting head can be additionally equipped with expanding crushing arms, sectional ribs, or sharp blades, to further promote the bursting efficacy.

It is possible to upsize to about 30 percent greater than the diameter of the existing pipe, but this depends on soil conditions, the proximity of other existing structures, and the depth of cover. The pulling force of the bursting unit must be maintained at a value less than the tensile strength of the replacement pipe to avoid overstressing the new pipe. The replacement pipe must be installed in one continuous length and, as such, butt-fused PE pipe is used in most cases. Service connections connected to the sewer to be rehabilitated must be excavated and exposed before starting the pipe bursting or surveyed to latter robotic re-opening.

Sometimes an external protective sleeve pipe is installed during the bursting process and the product pipe installed within this casing or conduit pipe. This is normally only considered for pressure pipe installations. Alternately, in gravity sewer applications, the wall thickness of the product pipe is increased to allow for external scaring of the pipe as it is pulled into place. The

[10] A general description of pipe bursting methods is done before specific characteristics for percussive pipe bursting are explained.

bursting operation can proceed either continuously or in steps, depending on the applied type of pipe bursting system. Before bursting, is convenient clean of sand or debris the pipe (the required pull force will be reduced), and the service connections must be located and disconnected. The system then is more successful when there are long lengths to rehabilitate with few connections.

Variations on this process are available for different host pipe materials. Typically, pipe bursting is used in brittle materials: cast iron, clay and concrete.

Process

- A cone ended bursting tool ("bursting head") is inserted into the existing pipe and forced through it, applying radial force to break open the pipe.
- The rear of the bursting head is connected to the new pipe, and the front end of the bursting head to either a winching cable or a pulling rod assembly.
- The bursting head and the new pipe are launched from the insertion pit
- The burster is powered of by pneumatics, hydraulics or by a pulling rod [11].
- The cable or rod assembly is pulled from the pulling or reception pit.
- Pipe fragments are pushed into surrounding soil.
- At the same time, the new pipe is pulled in the annulus left by the expanding operation.

Benefits:

- ✓ Cleaning of the existing pipe is not necessary, but recommended.
- ✓ Existing manholes can be used as launch pits.
- ✓ A larger diameter pipe can be inserted. This, in conjunction with the improved interior friction coefficient, can substantially increase the hydraulic capabilities of the new sewer.
- ✓ It provides full structural rehabilitation.
- ✓ Continuous pipe (HDPE) or discrete, joined pipe, such PVC can be used.
- ✓ Progress rates are greater than open cut.

Drawbacks:

- × Pit excavations are normally required to accommodate the replacement of pipe sections.
- × Ground surface heaving can occur if the depth of cover is too little or soil is un-compacted.
- × All sewer services must be excavated before bursting, and reconnected to the new sewer afterward.
- × Any rigid obstructions in the host pipe bedding will deflect the new pipe. This method is not recommended where grade is critical.
- × Over-pumping required

<u>Pneumatic Pipe Bursting</u>

Pneumatic pipe bursting is the most frequently used type of pipe bursting. In this method the bursting head is a cone-shaped soil displacement hammer. It is driven by compressed air, and operated at a rate of 180 to 580 blows /minute.

The percussive action of the bursting creates a small fracture with every stroke, and thus continuously cracks and breaks the old pipe. This action is combined with the tension from the winch cable, which is inserted through the old pipe and attached to the front of the bursting head. It keeps the bursting head pressed against the existing pipe wall, and pulls the new pipe behind the head. The air pressure required for the percussion is supplied from the air

[11] Depending on pipe bursting method employed: percussive, hydraulic or static, respectively.

compressor through a hose, which is inserted through the new pipe and connected to the rear of the bursting tool. The air compressor and the winch are kept at constant pressure and tension values respectively. The bursting process continues with little operator intervention, until the bursting head comes to the reception pit.

Benefits:
- ✓ Widely available and experienced method.

Drawbacks:
- × Vibrations may affect other nearby services, so all underground structures within one meter of the existing sewer should be rehabilitated must be excavated and exposed to avoid damage that may occur due to the forces being transmitted, and the displacement of soil, by this bursting technique.

C.3.2.1.2 Pipe bursting hydraulic

In the hydraulic expansion system, the bursting process advances from the insertion pit to the reception (pulling) pit in sequences, which are repeated until the full length of the existing pipe is replaced. In each sequence, one segment of the pipe (which matches the length of the bursting head) is burst in two steps: first the bursting head is pulled into the old pipe for the length of the segment, then the head is expanded laterally and the resultant perpendicular force breaks the pipe and forces the pipe fragments into the surrounding soil. The bursting head is pulled forward with a winch cable, which is inserted through the old pipe from the reception pit, and attached to the front of the bursting head. The rear of the bursting head is connected to the replacement pipe and also the hydraulic supply lines are inserted through the replacement pipe. The bursting head consists of four or more interlocking segments, which are hinged at the ends and at the middle. An axially mounted hydraulic piston drives the lateral expansion and contraction of the head.

Benefits:
- ✓ Hydraulic methods claim to have a more powerful bursting action than pneumatic, and there is little vibration to disrupt adjacent services.

Drawbacks:
- × Relatively higher cost than pneumatic pipe bursting.

C.3.2.1.3 Pipe bursting static

In the static pull system, the force for breaking of the existing pipe comes only from pulling the bursting head forward. The head is pulled by either a pulling rod assembly (TRS system) or a winch cable, which is inserted through the existing pipe and attached to the front of the bursting head. The tensile force applied to the bursting head is significant. The cone-shaped bursting head transfers this horizontal pulling force into a radial force, which breaks the old pipe and provides a space for the new pipe.

If a rod assembly is used for pulling, the bursting process is done in consecutive sequences, rather than continuously. Prior to bursting, the segmented rods are inserted into the old pipe from the reception pit. The rods are not very long, and during insertion they are threaded together to reach the bursting head at the insertion pit. There, they are attached to the front end of the bursting head, and the new pipe is connected to its rear end. In each sequence during the bursting, the hydraulic unit in the reception pit pulls the rods for the length of individual rods, and the rods are separated from the rest of rod assembly as they reach the reception pit.

If a winch cable is used instead of rods, the pulling process can be continuous. However, a typical cable system does not transmit as a large pulling force to the bursting head as a rod assembly.

Benefits:
- ✓ Very few vibrations.

Drawbacks:
- × Lower bursting power.

C.3.2.1.4 Controlled line and grade system (CLG)

CLG (Controlled Line and Grade) System is a pipe replacement method derived from pipe bursting methods, with ability to correct sags, humps or misalignments in existing pipelines.

Process

- A steel rod string that consists of short steel rods coupled together is inserted through the existing pipe, along its entire length.
- The rod string is precisely aligned to the desired line and grade in insertion and reception pit and anchored in tension
- A light cement slurry is pumped in to fill the pipeline and any open voids around it.
- Once the cement slurry is cured (between 4 to 24 hours), a bursting head and a replacement pipe are attached to one end of the rod string.
- The rod is then pulled out towing the new pipe behind it. A bentonite lubricant may be supplied to reduce the pulling force required for the operation.
- The bursting advances through the cured slurry, encountering equal resistance from the cement, existing pipe and ground envelope at all points around its face and circumference. Because of that, the bursting head is not as likely to be deviated from its path and is less affected by sags, misalignments and undulations in the old sewer pipeline
- The cured light cement provides the support and a shield against shards from the old burst pipe, rocks and harmful objects in the pipe zone.

The described method is modified under the following conditions:

- When larger pipes are being replaced (generally 400mm and larger), a boring tool is substituted for the bursting head.
- If the existing pipe is deviated to the extent that a straight axis through the pipe lies partly outside the pipe, special rods equipped with cutting edges along their length are combined with standard rods to make a steel rod string. The rod string is positioned at correct line and grade in insertion and receiving pits, but is forced into a curved shape to accommodate line deviation. When the rod string is anchored in tension, rods with cutting edges press against the inside wall of the sewer pipe – under the crown in the case of sag. The rod string is then rotated, forcing the cutting edges to cut through the existing pipe wall and surrounding ground until the rod string is straightened out at the desired correct line and grade.

Benefits:
- ✓ This method is recommended where grade is critical.
- ✓ Able to correct sags, humps and misalignments.
- ✓ Slurry fills voids and other defects, increasing the structural strength of the pipe.
- ✓ Cleaning of the existing pipe is not necessary.
- ✓ Existing manholes can be used as launch pits.
- ✓ A larger diameter pipe can be inserted.

Drawbacks:
- × Pit excavations are normally required to accommodate the replacement of pipe sections.
- × Ground surface heaving can occur if the depth of cover is too little or soil is un-compacted.
- × All sewer services must be excavated before bursting, and reconnected to the new sewer afterward, or surveyed by CCTV, closed and reopened after rehabilitation.
- × All underground structures within one meter of the existing sewer to be rehabilitated must be excavated to avoid damage that may occur due to the force being transmitted, and the displacement of soil, by the bursting operation.
- × Higher cost and time operation than for other pipe bursting techniques.
- × Over-pumping required.

C.3.2.1.5 Pipe splitting

Pipe splitting system is used for pipes that are not brittle, like some plastics, steel and ductile iron. Instead of the bursting head, the system uses a splitter, which cuts the existing pipe along one line and opens it out, rather than fracturing it.

The splitter consists on a pair of rotary slitter wheels, which make the first cut, a hardened sail blade on the underside of the splitter, which follows, and an expander, whose conical shape and off-centered alignment force the split pipe to expand and unwrap.

The unwrapping of the pipe is smooth, without generating hoop stresses or longitudinal bending in the pipe walls, that could cause high pulling forces and jamming. The splitting and unwrapping of the existing pipe creates a hole immediately behind the splitter large enough to allow the new pipe to be pulled in. The old pipe dislocates to a position above the hole and the replacement pipe, thus protecting the new pipe from damage.

Process

- The splitter is inserted into the existing pipe and pulled through it by either a wire rope or steel rods.
- The rear of the expander is connected to the new pipe.
- The splitter and the new pipe are launched from the insertion pit
- Old pipe is opened out and unwrapped into surrounding soil.
- At the same time, the new pipe is pulled in the annulus left by the expanding operation.

Benefits:
- ✓ Usable in ductile pipes.
- ✓ Cleaning of the existing pipe is not necessary.
- ✓ Existing manholes can be used as launch pits.
- ✓ A larger diameter pipe can be inserted.
- ✓ Continuous pipe (HDPE) or discrete, joined pipe, such as PVC can be used.
- ✓ Progress rates are greater than open cut.

Drawbacks:

- Pit excavations are normally required to accommodate the replacement of pipe sections.
- Ground surface heaving can occur if the depth of cover is too little or soil is un-compacted.
- All sewer services must be disconnected before splitting, and reconnected to the new sewer afterward.
- There is little vibration to disrupt adjacent services.
- Over-pumping required

C.3.2.1.6 Pipe eating

Pipe eating is a technique based on microtunneling[12] in which a defective pipe is excavated in-situ together with the surrounding ground to make a path for a larger pipeline. The micro-tunneling shield machine will usually need some crushing capability to perform effectively. The replacement pipes are connected to the back of the tunneling shield. The defective pipe may initially be filled with grout to improve steering performance of the shield machine. The pipe fragments can be removed by either vacuum excavation or by slurry pumping.

The system has a cutting head and a shield section:

- The cutting head has cutting teeth and rollers that cut the pipe, and cutting arrangements close to the edge of the shield that cut the ground to the required diameter to take the new pipe. The cutting head is cone-shaped, which puts the material of the old pipe into tension and thus reduces the heavy wear of cutting teeth.
- The shield section carries the cutting head and its hydraulic motor system.

The head and shield are launched from a drive pit, where a thrust frame is located. It provides a thrust that is applied on the cutting head through the new pipe to push the head and shield forward through the ground.

The existing defective pipeline is crushed and removed through the new pipeline by the circulating slurry system. The new pipe may follow the line of the old pipe on the entire length, or may cross the elevation of the old pipe on a limited segment only..

The system is remotely controlled and guided with a surveyed laser line from the drive pit, and prepared to "eat" whatever is in the way, the old pipe or the ground only.

For equipment that uses slurry spoil disposal, the shield has a packer which projects ahead of the shield and seals off the section to enable slurry pressure to be maintained. In these system live flows can be accommodated through the packer.

Process

- A microtunnelling shield is adapted to allow the existing pipeline to be broken up and removed.
- The shield has a larger diameter than the existing pipeline and contains a device to crush the fragments of pipe to facilitate their removal from the shield.
- It is moved along the route using hydraulic jacks, located in the drive shaft.
- Replacement pipes are connected to the back of the shield.
- A new pipe is simultaneously installed by jacking it behind the microtunneling machine.

[12] Microtunneling is explained in 3.2.3.7

Benefits:
- ✓ This method permits in-line replacement and upsizing of sewers with reduced potential for disturbing paved surfaces or adjacent utilities.
- ✓ No fragments from the old pipe are left in the ground.
- ✓ It enables sagging sewers to be realigned.
- ✓ Some systems allow the wastewater to be pumped through the shield during installation, thus eliminating the need for a bypass.
- ✓ Steering is possible within limits, and can follow the alignment of existing pipe.

Drawbacks:
- × The method is not suitable for the replacement of metallic or thermoplastic pipes.
- × It can be costly in comparison with pipe bursting.
- × Laterals must be removed.
- × Working space is needed above ground for ancillary construction equipment.
- × Drive and reception pits are required.

C.3.2.1.7 Pipe reaming

Pipe reaming is a modified back reaming method used in directional drilling[13], which is specially adapted for pipe replacement. The reamer has cutting teeth, which grind and pulverize the existing pipe through a “cut and flow” process, rather than a compaction.

Process

- The pilot drill string is inserted through the existing pipe.
- A specially designed reaming tool is attached to the drill string and pulled back through the pipe, while simultaneously installing the new pipe.
- The pipe fragments and the excess material from upsizing are carried with the drilling fluid to manholes or reception pits, and retrieved with a vacuum truck or slurry pump for disposal.

Benefits:
- ✓ This method permits in-line replacement and upsizing of sewers
- ✓ Reduced disturbing in paved surfaces or adjacent utilities.
- ✓ No fragments from the old pipe are left in the ground.
- ✓ It enables sagging sewers to be realigned.
- ✓ Steering is possible within limits, and can follow the alignment of existing pipe.
- ✓ Cleaning of the existing pipe is not necessary.

Drawbacks:
- × The method is not suitable for the replacement of metallic or thermoplastic pipes.
- × It can be costly in comparison with pipe bursting.
- × Laterals must be removed.
- × Drive and reception pits are required.

C.3.2.1.8 Pipe crushing (implosion)

Pipe crushing is a replacement method based on static pipe bursting. In this case, the old pipe is not “exploded-out”, but “imploded-in”. In the "implosion" system, the bursting tool consists of

[13] For horizontal directional drilling, see 3.2.3.2

two parts: a crushing head, which breaks the existing pipe and forces the pipe fragments inwards into the pipe void, and a steel cone, which pushes the crushed pipe fragments and soil outwards, making room for the new pipe**.** The crushing head is cylinder-shaped, and slightly larger than the existing pipe. Inside the cylinder, there are steel blades, which extend radially from the center and fracture the old pipe, as the head is pulled forward.

Process

- The bursting tool is inserted into the existing pipe and forced through it.
- The crushing head and the new pipe are launched from the insertion pit.
- The pulling is done with a rod assembly, as in the static pull system, that is pulled from the pulling or reception pit.
- Pipe fragments are pushed outwards through the cone.
- At the same time, the new pipe is pulled in the annulus left by the crushing operation.

Benefits:
- ✓ Cleaning of the existing pipe is not necessary.
- ✓ No fragments from the old pipe are left in the ground.
- ✓ A larger diameter pipe can be inserted. Pipe capacity can be maintained or increased.
- ✓ It provides for full structural rehabilitation.

Drawbacks:
- × The method is not suitable for the replacement of metallic or thermoplastic pipes.
- × Pit excavations are normally required to accommodate the replacement of pipe sections.
- × Ground surface heaving can occur if the depth of cover is too little or soil is un-compacted.
- × All sewer services must be excavated before bursting, and reconnected to the new sewer afterward.

C.3.2.1.9 Pipe ejection (modified pipe jacking)

Pipe ejection (or modified pipe jacking) is a pipe replacement system, in which the unbroken existing pipe is removed from the ground, while the new pipe is simultaneously installed. The old pipe is broken into pieces only as it completely exits out of the ground. This techniques are applicable only for pipes with sufficient remaining thrust capacity to withstand the push forces. They are used on shorter replacement sections to avoid high frictional resistance.

In pipe ejection, the replacement pipe pushes out the old pipe. A jacking frame is placed into the insertion pit, as well as the replacement pipe, which is installed in segments. The jacking frame and the insertion pit are sized to fit the length of individual pipe segments.

Process

- Excavation of the bore is carried out from the jacking shield which consists of a steel cylinder. Excavation can be carried out by hand, mechanical excavators or remote controlled tunneling shields.
- The new pipe is placed against the old pipe, and as the new pipe is jacked, the old pipe is pushed toward a reception pit or manhole.
- At the reception pit, the existing pipe is broken into pieces and removed.
- Forward movement is achieved by hydraulic jacks in the drive shaft that react against a thrust wall in the shaft.

- Spoil may be removed by auger flight, slurry pumping, and for man entry constructions by skip trucks and conveyers. Auger flight is preferred for short drives and slurry pumping for long drives especially in the presence of groundwater.

Benefits:
- ✓ Can be used in structural applications.
- ✓ Sealing technique.
- ✓ Only pit damage done in surface pavement. Pit dimension can be important in large diameters.
- ✓ No fragments from the old pipe are left in the ground.
- ✓ Noise and traffic disruption less than conventional trenching.

Drawbacks:
- × Pipes with significant structural damages are not adequate for this method, because pipes must have enough remaining thrust capacity to withstand the push forces.
- × Thorough site investigation required.
- × High level of operator skill.

C.3.2.1.10 Pipe extraction (modified static pull)

Pipe extraction[14] (modified static pull) is pipe replacement systems, in which the unbroken existing pipe is removed from the ground, while the new pipe is simultaneously installed.

In pipe extraction, the replacement pipe is pulled in place of the old pipe. An extraction machine is placed into one pit, and the replacement pipe is fed from the other. The tool assembly consists of a centralizing device, pull plates, and a cylindrical expander or plug, which allows the system to handle both size-for-size replacement and upsizing.

Process

- Excavation of the bore is carried out from the jacking shield which consists of a steel cylinder. Excavation can be carried out by hand, mechanical excavators or remote controlled tunneling shields.
- A pulling device (a pulling rod assembly) is inserted through the existing pipe.
- It’s attached to the extraction machine on one end, and a tool assembly, which is connected to the replacement pipe, on the other end.
- The new pipe is placed against the old pipe, and as the new pipe is jacked, the old pipe is pulled toward a reception pit or manhole.
- At the reception pit, the existing pipe is broken into pieces and removed.
- Spoil may be removed by auger flight, slurry pumping, and for man entry constructions by skip trucks and conveyers. Auger flight is preferred for short drives and slurry pumping for long drives especially in the presence of groundwater.

Benefits:
- ✓ Can be used in structural applications.
- ✓ System allows up-sizing pipe diameter.
- ✓ Sealing technique.

[14] Pipe extraction follows basically the same idea than pipe ejection, but pulling the old pipe instead of pushing it.

- ✓ Only pit damage done in surface pavement. Pit dimension can be important in large diameters.
- ✓ No fragments from the old pipe are left in the ground.
- ✓ Noise and traffic disruption less than conventional trenching.

Drawbacks:

- × Pipes with significant structural damages are not adequate for this method, because pipes must have enough remaining thrust capacity to withstand the pull forces.
- × Thorough site investigation required.
- × High level of operator skill.

C.3.2.1.11 Pipe pulling

Pipe pulling is a method of replacing small diameter service pipes by attaching a new pipe to it and pulling it through the ground. This technique is particularly appropriate for lead service pipes.

The new pipe is attached to the existing pipe, which is pulled through.

Process

- The method utilizes a winch cable fitted with a metal cone that grips the internal wall of the old pipe. Some systems have a series of cones to distribute the pulling force along the length of the pipe.
- The replacement pipe is attached to this end of the cable, allowing it to be pulled in place as the old pipe is removed.
- The pulling device that provides the force to pull the old pipe out of the ground is a winch, attached to the other end of the cable.

Benefits:

- ✓ Replacement pipe can be PVC or PE
- ✓ Only pit damage done in surface pavement
- ✓ No fragments from the old pipe are left in the ground.
- ✓ Quick system.
- ✓ Noise and traffic disruption less than conventional trenching.

Drawbacks:

- × Only suitable in very small diameters (up to 25 mm).
- × The small diameters of the service pipes can make it difficult to insert the winch cable.

C.3.2.2 Off-line replacement non steered

C.3.2.2.1 Rod pushing (Thrust Boring)

Directional Rod Pushing is a conventional earth boring system. This method forms a pilot bore by driving a closed pipe head with rigid attachment from a launch pit into the soil which is displaced.

Process

- Launch pit is dug.
- Head pipe is pushed through the soil, with the help of the rigid attachment thrusting, creating a bore.
- The pipe is replaced meanwhile the bore is done

Benefits:
- ✓ Low cost
- ✓ Fast and simple set up.
- ✓ Replacement pipe can be PVC or PE
- ✓ Only pit damage done in surface pavement
- ✓ Noise and traffic disruption less than conventional trenching.

Drawbacks:
- × Not suitable for hard soils.
- × Very limited steering and monitoring capability. If steered, a locator will be necessary.
- × Only suitable for short lengths and small diameters.

C.3.2.2.2 Impact moling pneumatic hammer

Impact moles consist of an enclosed steel tube containing an air-powered piston (also referred as the striker) that strikes the nose of the tool driving it forward. A bore, into which a small diameter new pipeline can be pulled, is formed by displacing and compacting the soil laterally. The friction between the ground and the mole body prevents the mole from rebounding backwards. Repeated impacts of the piston advance the whole unit through the ground. It is an unsteered boring device. There is no rigid connection between the mole and the insertion pit, and the progress of the mole relies upon the frictional resistance of the ground for its overall forward movement. Hence the performance of the mole is high dependent on the type and conditions of the ground.

Fixed and moving headed moles are available, driven by pneumatics and/or hydraulics. It is claimed that the moving head types impart all the energy into pushing the head into the ground, whereas for the fixed headed types the internal impact has to overcome friction and move the body at the same time. Adaptations to standard moles are available that cope with different types of ground.

The hammering action can either be a simple striking of the piston onto the forward end of the unit or a two-stage action of a specially designed moving head. Compressed air repeatedly propels the piston against the rear of the chisel head assembly. This first compresses the pre-tensioned steel spring, which forces the chisel head assembly forward independently of the main casing. The first impact creates a pilot bore. Then, the same continuous force thrusts the main casing ahead. The second impact expands the borehole to its final diameter.

Non-steerable moles[15] typically involve the excavation of two pits: an insertion pit and a receiving pit. After the careful alignment of the mole in the insertion pit, the tool is expected to advance through the ground in a straight line. A single person can operate the mole.

Process

- A launch pit is excavated, typically 1.5m long and 1m deep to launch the mole.
- A reception pit is excavated of sufficient size to remove the mole.

[15] Steerable moles studied in 3.2.2.4.

- A launching cradle sets the line and level of the mole in the launch pit.

There are two main methods, depending on soil conditions:

- Usually the mole is launched first and creates an unsupported bore.
- Then, the mole is removed from the receiving pit and the new pipe is attached to an air hose and pulled into the bore (the most popular mode of operation) or the pipe is sometimes pushed into its place.

Or

- A product pipe is directly towed into the bore during the boring procedure, if soil conditions are not suitable for unsupported borehole.

Benefits:
- ✓ Low operational costs.
- ✓ Only pit damage done in surface pavement
- ✓ Accurate for lengths up to 10m.
- ✓ Minimum skill required.
- ✓ Quick system.
- ✓ Noise and traffic disruption less than conventional trenching.

Drawbacks:
- × Only for small diameters.
- × Non-steerable method.
- × Cannot be steered around obstructions.
- × Can only be used in compactable soils.
- × Ground investigation essential.

C.3.2.2.3 Impact moling hydraulic hammer

The main difference between hydraulic and pneumatic hammer moling is that the first bores with an hydraulic head.

The process, benefits and drawbacks are the same than for impact moling pneumatic hammer, adding next:

Benefits:
- ✓ Produces less vibrations, and so less disturbance to other utilities nearby.

C.3.2.2.4 Steerable moling

<u>Steerable moles</u> is an impact moling technique in which the tracking head (mole) can be drove.

Process

The general process for steerable moles is the same than for “impact moling pneumatic hammer”.

The operation requires a two-man crew: the tracker operator and the mole operator.

A walkover tracking system is used, as in directional drilling industry, where one operator walks the bore route with a walkover locator device and monitors the progress of the tool in the ground. The information provided to them by the tracking system is the tool head position, depth, pitch, and roll. (Pitch is the inclination of the mole expressed in percentage of slope. Roll is the rotational position of the mole nose, commonly referred to as a “clock face”. The 12-hour clock configuration is the basis for steering: up is 12 o-clock, down is 6, left is 9 and right is 3.) . It is recommended that the tracking operator marks the bore path on the ground with flags or spray paint. The most important task for the tracker operator is to detect horizontal deviation from the planned bore and to communicate this information to the operator of the mole. Although tracker can monitor vertical deviation as well, it is usually easier for mole operator to detect the need for the pitch correction.

The other operator is a tool operator who implements the required course corrections using the guidance controls. The mole operator at the launch point has the control unit with continuous display of pitch and roll. The resolution of the pitch sensor is much better than the resolution of depth measurement available to the tracker, so the operator is the one to detect the need for the pitch correction and immediately corrects it. The operator does all the steering according to the planned route. To make the rotation he applies the torque to the air hose from the surface. When changing the borepath direction, the operator simply adjusts the roll in desired direction, producing either horizontal or vertical deviation. The rotation of the mole body, which is required during steering, is often difficult because of the friction between the mole and the soil, and a friction sleeve inside which the mole body rotates is recommended. Such a sleeve can reduce the overall friction by up to 90%.

Benefits:
- ✓ Mole may be launched from the surface or from a pit.
- ✓ Steerable method. Can be steered around obstructions.
- ✓ Low operational costs.
- ✓ Quick system.
- ✓ Noise and traffic disruption less than conventional trenching.

Drawbacks:
- × Only for small diameters.
- × Can only be used in compactable soils.
- × Ground investigation essential.

C.3.2.2.5 Pipe ramming (impact ramming)

Pipe ramming is a trenchless method for installation of steel pipes or casings, in which a pneumatic tool is used to hammer the pipe or the casing into the ground while the excess soil from creating the borehole is removed to the surface.

The method is frequently used under railway and road embankments. Pipe ramming is typically used for horizontal installations, but can also be applied for vertical projects, such as piling driving or micro-piling.

Process

- The method typically requires excavation of two pits.
- A pneumatic hammer based on the designs of an impact mole is attached to the casing.
- A nose cone is attached to minimize damage to the casing (usually steel pipe).

- The casing is lined up in the desired direction and pneumatic hammer placed behind it.
- The entire casing may be rammed at once or sections added during the operation. The choice depends on the available space for an insertion pit setup and ground conditions. When shorter pipe segments are rammed, the ramming tool drives each pipe segment for its length through the ground, and then returns back to the tool's original position for the new segment that is to be welded or mechanically attached to the previous segment already in the ground.
- Pipe is driven into the ground with repeated percussive blows.
- The front end of the casing may be closed or open depending on pipe diameter, a cutting ring may be welded if the end is left open.
- Lubrication may be required for open ended cutters,
- The soil core which forms in the steel casing may be removed using an auger, compressed air or jetting.
- After installation the product pipe is pulled through the casing.

In addition to new installations, pipe ramming can be combined with directional drilling and used to free the product pipe during pullback (or the drill pipe during pilot hole boring or reaming) if it gets stuck due to hydrolock or differential pressure sticking.

Benefits:

- ✓ Thrust plates or blocks in the insertion pit are not required.
- ✓ This method is most valuable for installing larger pipes over shorter distances (less than 20 meters) and for installations at shallower depths, compared to HDD.
- ✓ Can save both total installation time and costs under favorable conditions, compared to other trenchless methods such as augering and directional drilling.
- ✓ It is suitable for all ground conditions except solid rock.
- ✓ Little or no soil disruption.
- ✓ Little disruption to traffic.

Drawbacks:

- × The method is non-steerable.
- × Not suitable for soil containing boulders
- × Ground investigation essential.

C.3.2.2.6 Auger boring

Auger boring is the process of simultaneously jacking casing through the earth between two pre-sunk shafts while removing the spoil inside the encasement with a rotating flight auger. The casing supports the surrounding soil as spoil is systematically removed. Systems are generally un-steerable therefore best suited to cohesive or stable soils. There are two types of auger boring: track type and cradle type.

The track type method consists of a track system, machine, casing pipe, cutting head, and augers. The boring operation is cyclic, as pipe segments and auger flights are added after a prescribed auger flight length is installed. Thrust is developed by hydraulic rams located at the rear of the boring machine. One end attaches to the end of the boring machine while the other attaches to lugs connected to the track system. No rotation is applied to the casing as it is jacked through the soil by hydraulic thrust rams located at the rear of the machine. Lubrication is used to reduce skin friction and to aid with soil cutting and transport. An additional common measure to reduce skin friction includes an over excavation in the order of 25 mm to 50 mm. Pipe diameters range from 200 mm to 1200 mm, and overall installation lengths are typically limited to 100 m.

In the cradle-type auger boring method, the boring machine and the complete casing auger system are held in suspension by construction equipment (i.e., side booms, excavators, or cranes) as the boring operation is executed. There is no requirement for any thrust structures; however, the entire casing length must be assembled outside the launching pit before beginning the boring operation, with the complete auger and cutting head unit placed inside the casing. The entire system is then lowered into position in the bore pit via cranes. Once the desired line and grade of the casing are established, the boring process is performed in a continuous manner until completed.

Free boring, where a casing is not used is also available for small diameter pipes (50-150mm) where damage due to a collapsed bore will be less significant.

Process

- A helically wound auger flight contained within a steel casing is attached to a cutting head.
- The rotating action of the auger flight simultaneously rotates the cutting head, which removes soil from the bore
- The cutting head and augers are powered from the drive pit.
- Most systems contain pipe jacking equipment which allows the casing to be moved forward as the cutter progresses.
- The casing forms a bore for the product pipe to be inserted.

Benefits:
- ✓ The technology is well established and widely available.
- ✓ The steel casing remains in the bore after the drilling operation is complete; it can be used as a conduit or as the host pipe.
- ✓ Little or no soil disruption.
- ✓ Little disruption to traffic.

Drawbacks:
- × Steering capability is very limited after installation is initiated.
- × Not suitable for soil containing boulders or very soft clay/organic ground.
- × Ground investigation essential.

C.3.2.3 Off-line replacement steered

C.3.2.3.1 Guided auger boring

A variation on directional drilling is guided boring. This technique utilizes a similar process to directional drilling and was developed initially for electric cables and is commonly used for installation of pumped sewers of less than 300mm diameter. The guided steerable drilling head is capable of following tight curves and can install up to 100m lengths.

Steering is achieved through articulation of the casing near the cutting head. This is controllable from the drive pit

This is similar to microtunneling, but in guided auger boring the guidance mechanism actuator sited in the drive shaft (e.g. a hydraulic wrench which turns a steel casing with an asymmetric face at the cutting head). The term may also be applied to those auger boring systems with rudimentary articulation of the casing near the head activated by rods from the drive pit.

Process

The same than for auger boring.

C.3.2.3.2 Horizontal directional drilling (HDD)

Horizontal drilling, frequently referred to as HDD (horizontal directional drilling), is a pipeline installation technique involving drilling in a shallow arc using a steerable drilling head. Typically used for long installations and pipe diameters greater than 300mm, up to 1200mm. The technique consists of several stages for installation. First, a pilot bore is made with a suitably sized drilling rig. The bore is steered to create an initial hole at the required line and grade. Successive reamers are then pulled back to enlarge the hole diameter to the desired size. During the last stage of the reaming, the service pipe is pulled back into the bore.

Most sewer force mains installed by this method are continuously welded PE pipe, although steel, ductile iron and PVC have also been used. Gravity sewer installations are also possible.

Process

- A rotating steerable hollow drill of 80-140mm is launched from the surface at an angle of 8-15º to drill a pilot hole under the obstacle.
- A fluid jet cutter or mud driven cutter is used depending on soil type.
- A washover pipe of approximately 140mm diameter is drilled over the pilot string and follows behind the drill head.
- Alternate drilling in the pilot string and the washover pipe until the exit point is reached.
- The pilot string is retracted and the bore enlarged by a rotating barrel reamer attached to and pulled back by the washover pipe.
- Subsequent reaming until the required diameter is achieved.
- The new pipe is assembled and tested above ground.
- It is attached to the reaming head via a swivel joint and pulled though the newly created cavity (at the same time as final reaming) using the pullback capacity of the drilling rig.

A survey pack can be located behind the cutting head ensures that an accurate path is maintained.

Benefits:
- ✓ Rapid installations.
- ✓ Long distances with relatively large diameter.
- ✓ There is reduced disruption to surface operations, such as major thoroughfares, railway tracks, rivers, buildings, and trees.
- ✓ There is less disruption to buried infrastructure compared to the open cut method.
- ✓ Printout of line and level available.
- ✓ It allows for a new sewer alignment.

Drawbacks:
- × Requires a large site "footprint": space requirements for HDD rigs can range from a 30m wide by 45m long entry plot for a 300m, crossing up to 60 wide by 90 long area for crossing of 900 or more meters.
- × On the pipe side of the crossing sufficient temporary space should be rented to allow fusing and joining the polyethylene carrier pipe in a continuous string.
- × Exact pipe alignment can be difficult to attain, although still fairly accurate.

- Equipment has difficulty operating in granular soils. Cobble and gravel seams might cause difficulties during the pilot bore and pullback stages.
- Ground investigation is essential.
- On large installations, large quantities of drilling mud are used creating the potential risk of frac-out and costly slurry management actions (i.e., recycling, containment, and disposal).
- HDD requires consistent and good soil conditions (e.g., firm clay, boulderless cohesive tills) for good performance.

C.3.2.3.3 Guided drilling (mini-HDD)

The Industry distinguishes between mini-HDD and conventional HDD, which is sometimes referred to as maxi-HDD. Mini-HDD rigs can typically handle pipes up to 300mm and are used primarily for utility construction in urban areas. Long crossings with large diameter pipe needs bigger, more powerful equipment and drill rig.

Process

The process is the same than for HDD, but HDD machines have significantly larger pullback forces.

Benefits:
- ✓ Rapid installations.
- ✓ There is reduced disruption to surface operations, such as major thoroughfares, railway tracks, rivers, buildings, and trees.
- ✓ There is less disruption to buried infrastructure compared to the open cut method.
- ✓ Printout of line and level available.
- ✓ It allows for a new sewer alignment.

Drawbacks:
- Only for diameters of 300mm or smaller.
- Entry and exit elevation differences in excess of 15 m are not recommended.
- Exact pipe alignment can be difficult to attain, although still fairly accurate.
- As pipe diameter increases, large volumes of drilling fluids must be pumped requiring more/larger pumps and mud-cleaning and storage equipment.
- Equipment has difficulty operating in granular soils. Cobble and gravel seams might cause difficulties during the pilot bore and pullback stages.
- Ground investigation is essential.
- Mini-HDD requires consistent and good soil conditions (e.g., firm clay, boulderless cohesive tills) for good performance.

C.3.2.3.4 Conventional pipe jacking

A technique for installing a pipe through a bore, created by a shield machine which is hydraulically jacked from a drive shaft. Some steering of the shield is possible to ensure correct alignment, however initial alignment is obtained by laying the pipes sections on guide rails prior to jacking. During jacking the alignment is checked against a fixed reference point.

Sequential thrusting of sections of the pipeline is possible using intermediate jacking stations. This enables longer lengths to be installed.

Jointing systems must be flush with the pipe wall and strong enough to withstand jacking forces.

Process

- Excavation of the bore is carried out from the jacking shield which consists of a steel cylinder.
- Excavation can be carried out by hand, mechanical excavators or remote controlled tunneling shields.
- The product pipe is connected to the back of the tunneling shield and further sections added as installation progresses.
- Forward movement is achieved by hydraulic jacks in the drive shaft that react against a thrust wall in the shaft.
- The process must be carried out continuously to avoid excessive gripping of the pipe by the surrounding soil.
- Spoil may be removed by auger flight, slurry pumping, and for man entry constructions by skip trucks and conveyers. Auger flight is preferred for short drives and slurry pumping for long drives especially in the presence of groundwater.

Benefits:
- ✓ Can be used in structural applications.
- ✓ Sealing technique.
- ✓ Only pit damage done in surface pavement. Pit dimension can be important in large diameters.
- ✓ Noise and traffic disruption less than conventional trenching.

Drawbacks:
- × Thrust plates or blocks in the insertion pit are required.
- × Thorough site investigation required.
- × Soil characteristics determine pipe material.
- × High level of operator skill.

C.3.2.3.5 Low load pipe jacking

A pipe jacking method variant, in which separate provision is made to carry the jacking load, the pipe being installed carrying little or none of the jacking force.

C.3.2.3.6 Thrust jacking

Pipe jacking method variant in which a pipe is jacked through the ground without mechanical excavation of material from the front of the pipeline.

C.3.2.3.7 Microtunneling

A technique for installing non-man entry pipelines using a steerable, remote control pipe jacking technique. Micro-tunneling is different than full tunneling in that the process uses a remotely controlled boring machine combined with the pipe jacking technique to install pipelines directly.

Microtunneling is a process that uses a remotely controlled Microtunnel Boring Machine (MTBM) combined with the pipe jacking technique to directly install product pipelines underground in a single pass, from 300mm to 3600mm in diameter. Microtunneling has evolved to describe a tunneling process where the workforce does not routinely work in the tunnel. Line and grade tolerances of two centimeters are the standard.

This technique can be economically competitive with direct burial when depths exceed 6 meters due to the costs of deep trench excavation and trench support. This method is cost effective when faced with unstable soil conditions and work below the groundwater level. These conditions increase the risk of surface settlement during a direct burial or conventional tunnel installation. These conditions also increase liability for all parties with regard to property damage and personal injury.

The increased pipe wall thickness required for jacking pipe provides a longer service life of sewers installed. Manufacturing and quality control standards are higher for jacking pipes than for buried pipes.

Improved steering precision is achieved when a theodolite based guidance system is used instead of the traditional laser guided system. This theodolite system can provide an as-built location of the pipeline at every 3 cm. The system can also be designed to do curved pipe jacking.

One weakness of FRPM (Fiber Reinforced Plastic Mortar) pipe is a lower jacking force capacity when compared to other pipe materials of the same internal diameter. Historically, larger diameter pipe and inter jack stations are used to achieve long drive lengths. Inter jack stations are jacks placed inside the tunnel to provide additional jacking capacity or to provide a more even distribution of the jacking capacity. Inter jack stations are not practical in pipe diameters less than 1 meter, as they must be dismantled and removed from the pipeline when jacking is complete.

Process

- The remote control tunnelling machine consist of a shield which is used to excavate a bore.
- The tunnelling machine is pushed horizontally into the ground from the drive pit by hydraulic jacks.
- A range of cutting heads is available for the tunnelling shield; these may be fitted with blades, picks or disc cutters depending on soil conditions.
- In addition to the techniques common to pipe jacking for spoil removal, vacuum pressure is also used to suck spoil away from the head and back to tanks on the surface.

Benefits:

- ✓ Curved bores can be produced.
- ✓ Line and level of pipe can be controlled.
- ✓ Safe tunneling option under favorable conditions, because workers and the public are not directly exposed to hazardous conditions.

- ✓ Less noise and traffic disruption than conventional trenching.
- ✓ Precise installation.
- ✓ Also suitable in wet conditions and marine crossings.
- ✓ Faster rate of progress than conventional tunneling.

Drawbacks:
- × Large pits necessaries, depending on diameter
- × Thorough site investigation required.
- × Boulders can halt installation.
- × High capital cost of equipment
- × Requires highly skilled operatives.

C.3.2.3.8 Minitunneling

Mini tunnels are constructed in sizes from 1000 to 3000 mm diameter. All of the hydraulic and electric power for the operation is located outside the shaft.

The operator sits in the front of the shield and operates the valves and controls of the tunnel excavator machine and the segment erector. All of the hydraulic and electric power for the operation is located outside the shaft. The tunnel machine is connected to the power supply by cables that are mounted on the inside of the new tunnel. Conveyors or muck cars are used to remove the spoil from the tunnel. The muck cars may be battery operated. These cars are also used to bring the new pipe segments to the front of the tunnel where they are installed. Three identical concrete segments with radially and axially integrated tongue and groove are combined as a pipe. The length of each segment is between 60 and 75 cm depending an the diameter of the pipe.

In this application the driving shield has an open face. In some cases the tool for soil excavation is a drag bucket. Protected by the driving shield a pipe made of pre-fabricated segments, or tubbings, is installed. The pipe, exclusively provides the counterpressure for the further shield driving process. So the difference between this building method and others is that the pipe is not jacked through the soil by large hydraulic forces. Once the segments have been installed the pipeline does not move any longer.

Process

- Identical segments with tongue and groove compression gaskets are assembled together to form a pipe. This pipe may be made in a circle or other shape as required.
- The tunnel is constructed by repeatedly connecting these segments together to make the next pipe in the tunnel.
- Before the next pipe in the tunnel is made, hydraulic cylinders push against the last pipe installed and advance the tunnel shield through the ground.
- After the tunnel shield is advanced the hydraulic cylinders are retracted and the next set of pipe segments installed to make the next pipe.
- The process is then repeated.
- After the pipe in the tunnel is installed, the annulus is grouted.

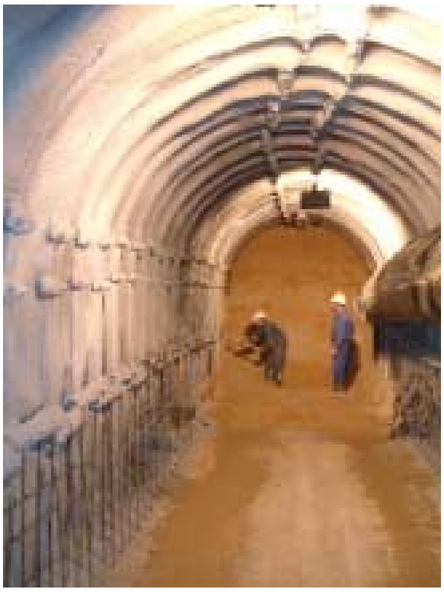
Benefits:
- ✓ Mini tunnels can be installed in most types of ground conditions.
- ✓ Loads on the pipe are reduced because the soil above the pipe is not disturbed.

- ✓ Small access shafts can be used (4m of diameter pit), which reduces disruption at the surface.
- ✓ House connections can be re-connected during the construction phase.
- ✓ After the tunnel is installed the tunnel shield can be taken apart and removed from the tunnel: a reception shaft is not necessary for all installations.
- ✓ All work is measured and checked by a laser. The precision of the tunnel installation is ± 1 cm
- ✓ Reinforced concrete segments are not always required because the construction method significantly reduce the stress on the pipeline segments.
- ✓ Curved bores can be produced.
- ✓ Line and level of pipe can be controlled.
- ✓ Little noise and traffic disruption compared with conventional trenching.

Drawbacks:
- × Not able for plastic pipes, commonly FRPM[16] pipes used.
- × Requires grouting.
- × Thorough site investigation required.
- × The soil around the tunnel is decisive for the load carrying capacity and so determinate the strength necessary for segments.
- × High capital cost of equipment.
- × Many security and health measures to be observed.
- × Requires highly skilled operatives.

C.3.2.3.9 Tunneling

Full tunneling is a construction method of excavating an opening beneath the ground without continuous disturbance of the ground surface and of sufficient diameter to allow individuals to access and erect a ground support system at the location of the material excavation. Full tunneling is a technique normally used for very deep installations. Although primarily used for new installations, applications have been included for rerouting existing sewers.



Benefits:
- ✓ There is a high level of accuracy due to the laser-guided installation.
- ✓ There is continuous tunnel support.
- ✓ The method is applicable in deep sewer installations.

Drawbacks:
- × Tunneling needs a minimum depth of cover.
- × A tail tunnel is required for effective spoil removal (full tunneling).
- × It is expensive for short stretches.
- × Extensive geotechnical information is required.
- × The potential exists for ground settlement.
- × Many security and health measures to be observed.
- × High-level operator experience is needed.

[16] Fibers Reinforced Polyester.

C.3.2.3.10 Shield tunneling

Shield tunneling is one of the most powerful and technically advanced systems in tunnel excavation. Shield tunneling involves many systems that have been developed in the last decades. The systems has grown adapting to different necessities, as excavation in granular soils, under high water head, in heterogeneous soil conditions and other difficulties.

The parts of the tunneling system include:

- Shield
- Hydraulic system
- Cutting head designed for specific soil conditions
- Operator Controls
- Transport system for removing spoil and bringing segments to the front of the tunnel

Depending on the soil condition and the difficulties to be expected, optimum excavation techniques will be used in each of the systems listed above.

One of the major advances accomplished in this field was with the introduction of shields of the pressurized type, which allow tunnels to be constructed in all types of soils including sands under high water head. These include the slurry shield and the Earth Pressure Balance (EPB) shield. The first technique makes use of a bentonite slurry to stabilize the working face of the tunnel. The EPB shield was developed a decade later: in this case, face support is obtained by retaining the spoils in the working chamber so that sufficient confining pressure is reached. Compressed air has also been used successfully in some projects to support the working face of the shield, but this technique is essentially limited to the less pervious categories of soils. Additional improvements have been made to the shield tunneling technique over the most recent years, particularly in terms of machine size and ground motion control.

Large Tunnel Boring Machines (TBM) are now common, and shields with diameters up to 14 m and over have been manufactured for projects. These advances have allowed the shield technique to be extended to a larger scope of project conditions, including motorway tunnels that currently require openings in the order of 12 m to be excavated.

Such advances have been accompanied with significant technological improvements that allow a more appropriate management of adverse conditions to be obtained, when tunneling in difficult grounds. The introduction of foams in EPB shields allows a more appropriate control to be achieved of ground deformations at the working face and, in turn, of tunneling induced settlements. Similarly, large diameter TBMs can be equipped with a secondary internal cutting wheel to help excavate through sticky clays. The introduction of advanced back-filling processes at the shield tailpiece has also strongly contributed to significantly reduce the potential for tunneling induced settlements in providing a means for limiting the amount of ground movement into the tail gap.

From a more general standpoint, several developments have been devoted to the design of “mixed-shields” that would be capable of handling a variety of heterogeneous materials, which are often found in urban areas and usually result in major tunneling difficulties. Even though the “universal machine” is yet to be invented, concepts such as the “mixed-shield” can help in adjusting to the variety of grounds encountered along a tunnel alignment, particularly at shallow depth.

Advances in the shield technology have allowed significant improvements to be made in terms of ground motion control, and tunneling induced settlements can now be kept under relatively low values in comparison with previous records. Significant experience has also been gained over the past years in shield operation know-how. As a result, and provided an appropriate machine is selected and skillful workmanship is available, high performances should be expected for most shield tunneling jobs, with limited impact on the environment, compared to open trench digging.

Ground collapse may, however, be experienced - even when using the most elaborate machines- in situations where unexpected conditions are encountered, or when face pressures fail to be maintained at the design level. Some attempts have been made to anticipate and prevent localized face collapse through a more systematic real time use of shield parameters recorded during tunneling. The system termed CATSBY allows all recorded data to be either stored, or used to estimate some pre-established key parameters that could, in turn, provide some indication of the ground-structure interactions associated with the tunneling process. These include pressures in the muck chamber, as well as characteristics of the thrust resultant acting on the tunnel face. Measurements are taken at regular intervals (typically every 3 minutes), and each parameter is characterized in terms of mean value and standard deviation. These data can be used by the shield operator to check that mean values remain within acceptable levels and that no sharp changes occur in the time response of pre-established key parameters. The concept can be applied to a variety of project conditions, and is designed with sufficient flexibility to allow adjustments to be made as required in the course of the project.

One particular difficulty to be emphasized with shield tunneling is the operation of the machine through the entrance and exit shafts, as these junctions usually result in reduced confining pressures in the surrounding ground, which could lead to critical conditions in grounds such as water-bearing soils with low cohesion. Break-in/Break-out transition zones need to be introduced in these areas; these should serve five main purposes:
(1) Ground support in the direction perpendicular to the opening;
(2) Face reinforcement to ensure ground stability ahead of the shield, using a confining pressure limited to the thrust reaction capacity;
(3) Ground support in the vault to limit decompression effects, so that settlements can be controlled despite reduced confining pressures;
(4) Control of water pressures and water ingress, so that blow-in and flood can be prevented;
(5) Guidance to the TBM along the first meters of drive, to prevent sinking of the machine to occur.

Several treatment solutions have been made available to cope with these difficulties; in particular, techniques based on partial ground substitution have proven to be fully efficient in soft water-bearing grounds.

Process

- The excavator digs up the soil and carries it to a conveyor belt.
- The shield is driven forward by means of the hydraulic cylinder. The advance rate for each pipe is between 60 and 75 cm. The completed pipe in the tunnel serves as a thrust wall for the hydraulic cylinders pushing the tunnel shield.
- The hydraulic cylinders are retracted to make room for the installation of the next segments, which make up the pipe.
- After the new pipe is installed and grouted the hydraulic cylinders push the tunnel shield forward.

Benefits:
- ✓ System for large diameters.
- ✓ There is a high level of accuracy due to the laser-guided installation.

- ✓ There is continuous tunnel support. Shield tunneling is suitable in unstable ground conditions.
- ✓ The method is applicable in deep sewer installations.

Drawbacks:

- × High costs.
- × High-level operator experience is needed.
- × Tunneling needs a minimum depth of cover.
- × A tail tunnel is required for effective spoil removal (full tunneling).
- × It is expensive for short stretches.
- × Extensive geotechnical information is required.
- × Potential exists for ground settlement.
- × Many security and health measures to be observed.

C.4 Manhole rehabilitation

Man holes are the chambers with removable cover constructed on a drain or sewer to permit entry by personnel [EN 752-1].

Manhole rehabilitation technologies:

- Dig technologies.
- Preformed manhole units
- Concrete liners: poured in place.
- Liners: Cured in place pipe (soft reversion lining).
- Cementious coatings. Sprayed, pumped or troweled.
- Polymer coatings. Sprayed, pumped or troweled.
- Cementious grouts.
- Polymer grouts.
- Mechanical seals or inserts.
- Protective systems (for new manholes).

C.5 Lateral connections rehabilitation

Lateral connections are understood to be the pipes that lead the wasted waters from the particular buildings to the public sewer, as well as the connection itself.

Techniques for these pipes rehabilitation are the same than for sewer rehabilitation, only limited by the minimum size available of the technique. Many technologies have been adapted to minor sizes. A brief list of specific techniques for lateral pipes restoration is presented. These techniques are explained in their respective section.

Lateral pipes rehabilitation technologies:

- Dig technologies. [see 1.1.x.x]
- Cured in place pipe (soft reversion lining). [see 2.2.5.x]
- Folded liners (fold and form pipe). [see 2.2.2.2]
- Swaged liners (deformed and reformed pipe). [see 2.2.2.1]
- Pipe bursting (hydraulic, pneumatic). [see 3.2.1.1-3]
- Pipe splitting. [see 3.2.1.5]
- Pipe pulling. [see 3.2.1.11]
- Coatings. [see 2.2.1.x]
- Fill and drain systems. [see 1.2.4.1]

D REHABILITATION TECHNIQUES CHART

D.1 RT Chart description

As it was explained before, the chart began with a list of RTs, separated according European Standard EN 752-5. Several subdivisions were quickly made, amongst it's remarkable the category "dig or trenchless", that rapports core information of the method.

Together with this, another list of valuable characteristics for RTs was elaborated with the cooperation of WP4 partners. For each characteristic the output information is presented in ranges, y/n, %, high/medium/low, codes or similar.

With these elements the chart was constructed, putting the RTs in rows and the characteristics in columns. The cells were filled with the contribution of WP4 partners.

D.2 Columns - Characteristics

Characteristics of the RTs have been divided in clusters, identifying clearly those characteristics that are decisive for the election of the technique fron those that give useful but not decisive information. Groups are:

D.2.1 Applicability conditions or requirements

Under this area it has been listed characteristics of the technique that make it suitable or not to solve a determinate problem in the sewerage network. These characteristics deals with the technique ability to cope with a sewer defect, the size, shape, materials, working constrictions and others that may reject the RT.

These characteristics are used by Multicriteria Decision System to offer the end-user only the Rts that are suitable to solve its particular problem, before ranking them.

Applicability conditions fields are:

D.2.1.1 Kind of defect solved

Obviously, one of the most important characteristics of a technique in order to decide about its suitability, is if it can solve the sewer defect appropriately. To achieve this purpose, possible defects in sewers have been classified according to standard EN-13508-2 Condition of drain & sewer systems outside buildings; Visual Inspection coding system.

The defects considered in the chart are:

- Related to the fabric of the pipeline:
  - BAA, deformation
  - BAB, fissure
  - BAC, break / collapse
  - BAD, defective brickwork or masonry
  - BAE, missing mortar
  - BAF, surface damage
  - BAG, intruding connection
  - BAH, defective connection
  - BAI, intruding sealing material
  - BAJ, displaced joint
  - BAK, lining defect
  - BAM, weld failure
  - BAN, porous pipe
  - BAO, soil visible through defect
  - BAP, void visible through defect

- Related to pipeline operation:
  - BBA, roots
  - BBB, attached deposits
  - BBC, settled deposits
  - BBD, ingress of soil
  - BBE, other obstacles
  - BBF, infiltration
  - BBG, exfiltration
  - BBH, vermin

The rehabilitation technologies are referred to all these defects according if they are suitable (index “2”), conditionally suitable (index “1”) or not suitable (index “0”).

When a RT is indexed as *suitable* it means that the technique is appropriate to solve the defect, and it’s usually employed to that aim. RT is adequate and reasonable to solve the defect in a cost-benefit context, i.e., its use is not disproportionate to the defect.

If a RT is considered as *conditionally suitable* it means that the technique may be able to solve the problem under specific conditions or it’s reasonable in determinate cases. Depending on the seriousness of the defect, the technique may be a good solution or just unsuitable. For instance, sliplining may be a good solution for used for breaks (BAC), but if breaking is large or sewer is collapsed, this technique is not usable under normal conditions. Also, contitionally suitable is linked to techniques that in general seem disproportionate to solve a defect, for example missing mortar (BAE) in masonry man-entry sewers can be “solved” with liners, but probably pointing is a more cost-benefit optimized option. In conclusion, RTs classified as conditionally suitable are techniques that can’t be discarded as a possible technical solution, but its convenience must be checked for the specific conditions of each case.

The techniques considered *non suitable* to solve a determinate defect are those whose application in normal conditions is not possible or the cost-benefit is very disproporcionate.

D.2.1.2 Technology applicable to sewers/manholes/laterals

This characteristics informs about the suitability of the RT to be applied to different parts of the asset. Manholes and lateral connections (from houses or gullies) are also parts of the network that require rehabilitation, even that in general these does not suffer the same loading conditions that the sewer itself.

Most of the techniques are suitable for sewers, but a few of them only are used in small diameters (250 mm or smaller), and so these are considered to be only useful for lateral connections.

D.2.1.3 Diameter of existing sewer

Indicates the minimum and maximum size, in millimeters, the technique can cope with. These measures may be vary in local markets, as not all the sizes (diameters) are available in all the regions. The measures here exposed are intended to be the extreme values of the European market. It must be advised that the development of the rehabilitation techniques market is quick, and presented values may not be always updated in some cases.

When this characteristic is marked as “min” or “max”, it means that the applicability of the technique is independent of the minimum/maximum size of the sewer.

1600mm has been establish as the minimum size for man-entry sewers, and consequently all the man-made repairs mark this size as minimum. Other local regulations (more restrictive or permissive) about working in confined spaces should be implemented by the end-user to better adjustment of suitable man-made technologies. This can be done easily in the Rehabilitation Technology Data Base.

Regarding replacement techniques, they are not influenced by the diameter of the existing sewer. In these cases, this value indicates the sizes the technique can achieve (diameter/size of the ***new*** sewer).

D.2.1.4 Shape and visitability of existing sewer

Four categories have been distinguished: *circular, non-circular, man-entry, no man-entry.*

All the techniques are suitable for circular pipes, but some of them cannot adapt to rectangular, or ovoid sewers or with vault. As this kind of sections is quite usual in many locations, this is a decisive characteristic to be included in applicability conditions.

It’s defined as **man-entry** the sewer that measures 160cm high or more and 60 cm of wide. As it has been explained before, local regulations may change these values, and the end-user should adjust this in the Rehabilitation Technology Data Base.

Shape and visitability are independent variables, and according to previous definition, circular pipes are only considered man-entry for diameters of 1600mm or over. Even though, it’s usual to consider pipes of 1500mm as “man-entry”. For inspection purposes, minor measures of sewer may be considered fair, and so it can be introduced the concept of **partly man-entry** sewers, with a minimum measures of 100cm high and 50cm wide. These conduits may admit visual inspections in favorable conditions (low flow, not steep).

For rehabilitation works inside the sewer, this should be man-entry.

D.2.1.5 Suitable material of existing sewer

Many rehabilitation techniques are only suitable for specific sewer materials, as fragile (or at least not-ductile), and consequently some techniques will be discarded if the existing sewer material is not listed.

Replacement techniques inform in this field the material for renewal sewers; in this case, this is , in general, not a decisive condition.

Materials considered are coded according to next list:

1	stone
2	brick
3	vitrified clay
4	concrete
5	reinforced concrete
6	asbestcement
7	ferro-cement
8	glassfibre-reinforced cement (GRC)
9	grey cast iron
10	ductile cast iron
11	steel
12	stainless steel
13	plastic
14	polyvinylchlorid (PVC)
15	polyethylene (PE)
16	epoxy resin
17	polyester resin
18	polyester felt
19	glass-reinforced plastic (GRP)
20	glass fibre
21	polymer concrete (PRC)
22	basalte
23	polypropilene (PP)
24	any
25	no new pipe

D.2.1.6 Structural or sealing technique

Most, but not all, rehabilitations technologies are designed to be watertight, and this is one of the main characteristics of any flow conduit, that avoids infiltration and exfiltration.

The other major characteristic of a conduit, and of any structure, is that it must be able to support the design loads, i.e., it must be structurally resistant.

This field of the chart gives this important information where techniques are characterized as if they are able to increase significantly the structural strength of the conduit, and also if the technique avoids infiltration, exfiltration, exudation and other undesirable phenomena of fluid transfercence.

D.2.1.7 Diameter or cross section after rehabilitation

One of the reasons that lead to the rehabilitation of a sewer may be a poor hydraulic capacity. In other occasions, the hydraulic performance needs to be improved due to different reasons. That's because it's important to know the change in the cross section of the sewer after rehabilitation.

This characteristic has been characterized as *not changed*, when the rehabilitation works does not influence in the sewer internal size; *increased,* if the section is significantly improved its diameter; or *reduced*, for the rehabilitation techniques that usually have as consequence a reduction of sewer cross section.

In this sense, it must be remarked that due to the large variety of installers, materials and conditions even for the same technique, it's almost impossible to asses an exact value for this characteristic. For example, cured in place techniques, even if they use the same curing system, present considerable pipe thick variation depending on pipe diameter and pressure design. Different manufacturer present also significant variations for similar conditions. As consequence of this, the simplification made grouping the changes in simple categories is convenient.

Some techniques may be marked as combinations of these factors, if the result depends on existing sewer size, manufacturer (of the new pipe), etc. Seems reasonable that a technique that reduces in 10cm the existing sewer diameter could be considered as a significant reduction of cross section in a 150mm pipe, but may be not be important (if it's carefully done) in a 2500mm main.

D.2.1.8 Need to cut off temporally the service connection

It's important to know if the technique requires to stop the flow of the lateral connections to be carried out. This interruption of service may be sometimes impossible, others inconvenient, so that this characteristic may become sometimes a decisive factor for the sewerage manager.

D.2.1.9 Application under groundwater level or leakage admissible

This field provides the information of the requirements of watertightness of the RT under two different scopes:

- If the technique is applicable under the watertable. In this sense, trench technologies are considered as suitable, because, in general, the water in the trench can be evacuated by means of small pumps, and working in this conditions is acceptable and even quite usual, as this does not represent a technical problem.

- If significant infiltration is admissible during rehabilitation works. This aspect is more addressed for no-dig technologies.

D.2.1.10 Suitable kind of soil

Soil surrounding does not compromise the suitability of most rehabilitation techniques, but in few cases, techniques should be carried out in favourable soil conditions. This can be different for diverse techniques, and so drilling technologies require cohesive soils, but present very low performance in rocky soils.

This does not intend to force sewerage manager to invest in large geological data collection campaigns in a master plan phase. More simple information is only requested, and experience and knowledge of the territory by managers is usually enough for the purposes of this selection.

The soils have been divided in a very simple way, depending on its hardness:

- Soft,
- Medium,
- Hard,
- Any

And combination of these factors.

D.2.1.11 Working area required

Urban areas in general, and city centers in particular, are in European countries very busy and quite often it is difficult to find space to carry out the works[17]. Rural areas does not have this problem. This parameter pretends to point an idea of the room required for the work, under usual conditions and rehabilitated lengths.

The information of the area required is completed with the number of locations in which this area is divided. Some techniques allow or require distribute the working area in several sites, usually two manholes or access pits.

The categories are:

- Small, for occupied area less than $100m^2$
- Medium, for areas between 100 and $300m^2$
- Large, for areas between 300 and $800m^2$
- Whole length, for occupied space over $800m^2$ and for trench technologies.

[17] This has motivated the successful development of so many trenchless techniques, specially in the last decades.

D.2.2 Technology performance

Next columns of the chart provide additional information of the rehabilitation techniques. This information is not considered to be decisive, under normal conditions, for the selection of the technique as “suitable” to solve a determinate problem. However, these data give very useful information for ranking the techniques, as gives parameters that allow calculation of important data, as for example an estimation of work duration, the requirement of auxiliary works, etc.

D.2.2.1 Maximum length from each location

This parameter provides an estimation of the maximum length of sewer that each technology is able to rehabilitate from one single working location (usually, a manhole or an access pit). This gives an idea of the number of working locations required in works of special length. Value is given in meters, and **measured only in one direction from the location,** i.e., downstream or upstream. As rehabilitation techniques works are generally independent of the sense (direction), in most cases the length of pipe able to be rehabilitated from one location is the double of the “maximum length from each location” given value.

Results presented are estimation, and different manufacturers may provide different values. Even more, the same rehabilitation technique may vary, and usually do, the working length depending on the pipe diameter: bigger diameter, shorter length. This is marked in the chart with a value in parenthesis.

Some repair techniques affect very short lengths, and in consequence a minimum length of one meter has been imputed. On the other side, rehabilitation methods with virtually no technical limitation, as for example trenching methods or man-made repairs, have been catalogued as *unlimited*, that should be understood only in that sense.

D.2.2.2 Performance of the technology

The performance of the rehabilitation technologies is the average length of rehabilitated conduit per day. This value has been estimated from diverse sources, and includes the standard auxiliary works required by rehabilitation. For example, the performance of a trenching method includes the time for digging, lying the pipe, backfilling and compacting. This characteristic does not include the time required for any special operation before or after the works themselves, like pavement demolition or reinstatement, scaffold of other infrastructures or auxiliary constructions or operations not directly linked to the installation works. In the case of conduits that require latter reopening of lateral connections (see D.2.2.8) this work is not included in the rehabilitation technology itself, and shall be calculated separately.

The performance has been calculated as an average, consequently, particular works, or installers, may increase or decrease significantly this time depending on their skill or technical improvements to be more competitive, but strongest variations may come from factors external to the rehabilitation technology, like working time restrictions due to traffic cut off, breakdowns, pace of materials supply[18] and a wide variety of unexpected problems.

For simplicity reasons, this value has been calculated for usual pipe sections. Large sections (diameters) may require more time to be installed, and small ones can usually be placed quicker. In general, this simplification should be good enough for the purposes of use of this characteristic, that is to provide an idea of the duration of works, for social cost assessment.

In favorable conditions, daily peaks of performance are expected to be higher than average values presented.

In some cases, particularly in repair methods, the values are more difficult to assess, as rehabilitated length depends also of the actual state of degradation of the sewer itself, and not only of the technique. Also, few techniques are not measurable in length of conduit per day [m/d], because its own characteristic (e.g. slurry injection) or because the performance varies remarkably with the size of the sewer section or diameter (e.g. masonry works or concrete sheet pile). In these cases, performance is given in appropriate units, as expressed in the “comments” box in the Rehabilitation Technology Database (injection in m^3 of slurry injected per day; masonry and concrete sheet pile in m^2 of placed material per day).

D.2.2.3 Material of new sewer

This characteristic provides the most common type of material used by the rehabilitation technology. This is quite clear for renovation and replacement techniques, in which there is a new pipe, or at least a coating (new material) in the existing conduit. In the case of repaired pipes, there are some cases in which the technique does not provide new material to the pipe (milling or root cutting techniques) or the material provided does not became a significant part of the existing sewer (grouting methods). In these last cases, the value of this field is null.

The material of the new sewer is of significant importance in order to know the new roughness of the sewer inside, which is an important parameter for the calculation of the sewer hydraulic capacity.

D.2.2.4 Hydraulic performance after rehabilitation

The rehabilitation technologies may produce a marked difference in the hydraulic capacity of a conduit. As it’s well known, the hydraulic capacity of a single conduit is determined by 3 factors:

- The cross section: the size (area) and shape (hydraulic radius) of the sewer may change form the original conditions (also from the actual conditions) by the use of most rehabilitation technologies. Some techniques are specifically developed to restore the free area of the cross section, like the root cutting methods, or the milling robot; also the rerounding techniques have been developed to correct the circular cross sections that have become ovoid. But there are many techniques that in fact reduce the existing cross section, although usually this reduction is only in some millimeters, and thanks to

[18] This is particularly important in techniques that require intensive quantity of materials, for example sheet pilling of concrete.

the decreased roughness of the new pipe material, the global effect in the hydraulic capacity can be considered null.

- The roughness: is due to inner surface material. Most renovation techniques use plastic pipes (HDPE, PVC, polymers, etc.), so that concrete and brick pipes reduce their original roughness while plastic pipes keep similar values. Some techniques use concrete as new material; in these cases, concrete old pipes restore its original roughness. Concrete solutions are not usual in old plastic pipes.

- The slope: in general, slope can only be changed in off-line replacement methods. Other rehabilitation technologies do not change this paramenter, and thenthe influende in the hydraulic capacity is null, except for off-line replacement methods and CLG system. CLG (controlled line and grade) is a on-line replacement technology that allows small changes in the direction and grade of the sewers, generally intended for correcting sags. This technique is not very common.

As a final consideration, it should be pointed that the objective of a rehabilitation is not to provide more hydraulic capacity to a sewer length that is under-dimensioned, but to give back the original level of service to a deteriorated conduit, including also the hydraulic level of service. So, rehabilitation is not to increase the hydraulic capacity, but to restore the lost capacity.

D.2.2.5 Digging requirements

The growing importance of trenchless methods is indisputable. It's advantage is more in the side of social cost reduction, thanks to the absence, or drastical recuction, of the space occupied by works, particularly in earth works. This figure expresses the excavation activities during the works, described by means of three parameters, surveyed for each rehabilitation technology:

- *Surface works*: that include any kind of pavement demolition, excavation, etc. that affect the surface ground. Techniques that operate usually from the manholes (service entries) don't cause surface works in this sense.

- *Access pit*: rehabilitation technologies that require the digging of a restrained size hole in the ground, affecting the surface locally. Includes the requirement of enlarging manholes for the installation of the new pipe or works achievement. In some cases, two pits are required, one for each end of the pipe. Pit size depends on technique, diameter and depth. This operation is access a usual for pipejacking and sliplinning techniques

- *Dig or trench*: general excavation required, decentralized, along the pipeline (trenching) or affecting large areas.

D.2.2.6 Need of previous cleaning

One of the usual operations done before rehabilitation works is the sewer cleaning. This is also done prior to inspection and characterization of conduit defects, specifically in small no man entry sewers, where visual inspection can only be done with CCTV robots.

A clean sewer is required by some techniques which effectiveness may be affected by attached deposits and dirt over pipe walls in different grades. Cleaning operations have been divided into categories:

- *No cleaning* required to carry out the works
- Light cleaning necessary before starting the works
- Heavy cleaning must be done prior to develop the rehabilitation
- Heavy clean and dry, for those techniques that can't be used in wet pipes.

This cleaning operation should be considered when assessing direct cost.

D.2.2.7 Need of digging for reconnecting laterals

Lateral connections are the conduits that connect the sewer network with the buildings and inlets. If these connections are done along the pipeline and not in the manholes, access to connection points is limited, even more in no man entry sewers. When rehabilitating a pipeline, it's usual to cover these connection points, sometimes to ensure that the main conduit is going to keep more or less dry, and sometimes because the new pipe just blocks out them.

The reconnection of these lateral connections can be achieved with the help of a drilling robot in no man entry sewers (and its consequent increase of prices), or it can be hand-made by operatives inside the sewer, if the size of the conduit is big enough.

But some techniques, as the trench and the replacement methods don't allow this later reopening, either because the new conduit is on a different line ("off-line") or because the technique damages the connection points, that must be reconstructed (e.g. pipebursting). In these cases, there are no many options for reconnecting, but digging.

The chart and the database inform about this condition.

D.2.2.8 Requires later re-opening of laterals connections

This characteristic, that could appear as redundant, comparing to "Need of digging for reconnecting laterals", provides a significant new note regarding reconnecting laterals operations.

In this case, it's studied if the rehabilitation technology blocks out the lateral connections or not. If it does not, then no further operation is required to accomplish the rehabilitation works. If the technique blocks the connections, then, a later task of reopening them is required. As explained before, this reopening can be hand-made, robotic or digging. This makes extra charges and time consumption, that must be considered for direct and indirect cost calculation.

D.2.2.9 Possibility of work interruption

It's convenient to know if the works during a rehabilitation can be stopped, because there are several external agents that may affect them. Other activities in the same location of the project may make more attractive a technique that gives the possibility of being temporally interrupted.

D.2.2.10 Requires man in underground

Unfortunately, accidents, pile-up and fatal in most events, prove that sewer networks are a high risk asset. Safety and health must be then the first priority in rehabilitation works. Safety should be considered from the very first instance, that is in the planning and projecting tasks.

This aspect has been included in the chart and database, that provide information whether the technique requires operatives working inside the sewer. It should be advised that trench technologies have been also considered as “man in underground”, because its linked high risk, in spite of the protections (shoring, sheet piles) that can reduce it. Tasks developed in short periods of time in manholes or access pits have not been considered as high risk activities, and consequently the database of rehabilitation technologies says that these doesn’t require man in underground (even that partially they do).

D.2.2.11 Curvature allowed

Sewer network is usually projected as straight lines or with small curvatures, trying to disturb the hydraulic flow the less the best. But city plot, other infrastructures, defective construction or bad design, cause that the real network present turns. If these changes of direction are done in manholes, maintenance and rehabilitation operations are easier to be done.

Some rehabilitation technologies are quite flexible to sharp changes of direction (like trenching or grouting). Others, are able to cope with small curvatures, although these turns be not accessible (manholes), like linings and steered techniques. But several technologies are only able to construct straight pipelines, and this must be considered when studying the convenience of a technique to solve a rehabilitation case.

It becomes necessary to remark that the degree of curvature allowed depends on the diameter gap of the new pipe regarding the old one. If this ring gap is large, the degree of curvature can be increased.

The database provides basic information of this aspect, pointing techniques that allow small degrees of curvature during the works and those that are only valid to construct straight pipelines.

D.2.2.12 Night works

This characteristic is an important issue in order to assess the social cost of rehabilitation works. The reason is obvious: during the night the traffic disturbance caused by lanes closing, streets closed, etc. is lower, and so it is the indirect costs. Then, rehabilitation technologies are classified as “night technology” when it is possible to develop the works in night periods, remaining the surface with no significant disturbances during the day.

D.2.2.13 Estimated lifetime of rehabilitated pipe

Sewers lifetime is difficult to asses, because installation, working conditions, soil, pressure frequency, and many other factors make a noticeable influence in this lifetime. Statistical studies are then hard and, by the moment, not very much reliable. Considering also that different installers for the same technique might provide different lifetimes for the sewers, and that some techniques are difficult to compare, it has been decided to leave this field in blank, so the end-user is able to assess this value based on his local experience.

D.2.3 Environmental impact

Environmental characteristics are assessed providing additional information for indirect costs calculation. Next characteristics are measured in a very basic scale, and it's not necessary to say that different local conditions, manufacturers and installers may cause greater or lower impacts

D.2.3.1 Structural impact on the surrounding buildings or networks

In densely built areas, as most of European city centers are, the underground is occupied by many urban services, and most times urban networks run in parallel and cross each other along the streets. Digging a trench or using a soil aggressive technique (techniques that make heavy vibrations in the ground and/or compact the soil) can damage the infrastructures nearby, including the foundations of the buildings.

D.2.3.2 Environmental impact of materials and Works

Basic and general assessment of the environmental impact caused directly by the works, including the materials employed. Techniques are classified as none, low, mid or grave impact, and its combinations.

D.2.3.3 Impact on groundwater quality

It becomes essential to know if the rehabilitation technology is potentially dangerous for the groundwater when this water is used as a resource. There are techniques (grouting, injection of chemicals) that have been rejected in specific conditions due to its pollution potential, that can cause contamination of the watertable or soil close to the sewer.

D.2.3.4 Acoustic pollution. Noise

Acoustic pollution produced by earth works and machinery during rehabilitation is an important issue for social cost assessment. This parameter can also be combined with "night technologies" to rule out rehabilitation technologies that could be done by night, but are not suitable because of the noise.

D.2.3.5 Air pollution. Dust

Works usually produce air pollution, essentially dust produced by earth works. In general, pollution due to exhaust of machinery is minor. Trenchless solutions are more environmental friendly in this aspect. Dust causes citizens complaints, and so it's convenient to consider this impact when working in urban areas.

applicability conditions or requirements | technology performance / characteristics | environmental impact | comments

	class, according to EN 752-5	Dig or trenchless	class_1	class_2	RT_name	RT_code
REHABILITATION OF SEWERS	repair. *Methods of rehabilitation in which the structure of the old sewer is conserved with bare rectification of damages, simply to maintain performance levels and extend service life ("conservation")*	dig technology: external repair	open cut		conventional trench	1.1.1.1
			semi-open cut	narrow trenching	shoring and trench box	1.1.2.1
					concrete sheet pile	1.1.2.2
					steel sheet pile	1.1.2.3
		trenchless technology: internal repair	robotic repairs		injection in joints or cracks	1.2.1.1
					milling robot	1.2.1.2
					root cutting robot	1.2.1.3
					pointing	1.2.1.4
					terrounding	1.2.1.5
			short -liner installed with packers or man-made		short-liner fiberglass and polymer	1.2.2.1
					short-liner metallic	1.2.2.2
			man-made repairs		masonry	1.2.3.1
					fill with mortar and plaster	1.2.3.2
					pointing	1.2.3.3
					injection	1.2.3.4
				small repair (channel and/or benching)	in situ repair	1.2.3.5
					pre-cast repair	1.2.3.6
			grouting (injection) methods	inside	chemical stabilisation (fill and drain systems)	1.2.4.1
					mortar stabilisation	1.2.4.2
					joint sealing	1.2.4.3
					resin injection	1.2.4.4
				outside	compacted filling	1.2.4.5
					surrounding stabilisation	1.2.4.6
	renovation. *Methods of rehabilitation in which all or part of the original fabric of a pipeline is incorporated to the new structure and its current performance is improved*	dig technology: total or partial reconstruction of the same structure of the sewer from the outside	open cut		conventional trench	2.1.1.1
			semi-open cut	narrow trenching	shoring and trench box	2.1.2.1
					concrete sheet pile	2.1.2.2
					steel sheet pile	2.1.2.3
		trenchless technology: continuous relinings	coating lining		reinforced cement/epox	2.2.1.1
				spray lining (projected)	steel reinforced cement mortar spray	2.2.1.2
					fibres reinforced cement mortar spray	2.2.1.3
					polymer lining	2.2.1.4
			close-fit lining		swaged liners (swagelining)	2.2.2.1
					folded liners (fold & form lining)	2.2.2.2
			sliplining	with continuous pipe	continuous sliplining	2.2.3.1
				with long pipes	discrete sliplining	2.2.3.2
				with short pipes	segmental sliplining	2.2.3.3
			spirally wound lining		spiral lining	2.2.4.1
			cured-in-place lining (CIPP) (or soft reversion lining)	thermal cure	CIPP hot water cure	2.2.5.1
					CIPP steam cure	2.2.5.2
					CIPP UV cure	2.2.5.3
					CIPP ambient cure	2.2.5.4
	replacement. *Methods of rehabilitation in which a new sewer replaces the old one, either "on" or "off" -but besides- the existing line, without incorporating the original fabric. Performances are improved ("renewal" or "substitution")*	dig technology	open cut		conventional trench	3.1.1.1
			semi-open cut		trench box	3.1.2.1
				narrow trenching	concrete sheet pile	3.1.2.2
					steel sheet pile	3.1.2.3
					mole ploughing	3.1.2.4
		trenchless technology	on-line replacement (destruction of old pipe)	pipebursting (pipecracking)	pipebursting percussive (pneumatic)	3.2.1.1
					pipebursting hydraulic	3.2.1.2
					pipebursting static	3.2.1.3
					Controlled Line and Grade system (CLG)	3.2.1.4
					pipe splitting	3.2.1.5
					pipe eating	3.2.1.5
					pipe reaming	3.2.1.7
					pipe crushing (implosion)	3.2.1.8
					pipe ejection (modified pipe jacking)	3.2.1.9
					pipe extraction (modified static pull)	3.2.1.10
					pipe pulling	3.2.1.11
			off-line replacement - non steered		rod pushing	3.2.2.1
				impact moling	pneumatic hammer	3.2.2.2
					hydraulic hammer	3.2.2.3
					steerable moling	3.2.2.4
					pipe ramming (impact ramming)	3.2.2.5
					auger boring	3.2.2.6
			off-line replacement - steered		guided auger boring (guided boring)	3.2.3.1
				directional drilling	horizontal directional drilling (HDD)	3.2.3.2
					guided drilling (mini HDD)	3.2.3.3
				pipe jacking	conventional pipe jacking	3.2.3.4
					low load pipe jacking	3.2.3.5
					thrust jacking	3.2.3.6
					microtunnelling	3.2.3.7
					minitunnelling	3.2.3.8
					tunnelling	3.2.3.9
					shield	3.2.3.10

For kind of defect solved: 0 = non-suitable, 1 = conditionally suitable, 2 = suitable
y/n = yes or no, depending on conditions

E REHABILITATION TECHNIQUES DATA BASE

E.1 RT data base description

The result of the rehabilitation technologies survey has produced over 50 different techniques, and for each one of them 30 characteristics have been defined. This makes quite a pretty amount of information that must be organized properly to make it usable and useful.

CARE-S target requires, among other large amount of information and calculations, access to the available techniques and their main characteristics. This information must be available in a dynamic way, that is, data must be stored in a easy to query file, organized and arranged. This is an important issue, because the aim of this surveying task is not just to establish a list with the state-of-the-art of rehabilitation technologies, but provide a useful tool to other tasks developed in the CARE-S project.

The information was collected in a chart in a first instance (see previous chapter), and latter exported to a database. A database file makes possible a dynamic inquire from the Multi Criteria Decision Tool created in the CARE-S project, providing the list of techniques able to solve a specific defect in the sewer or drainage system, under defined environment conditions and dimensions (see Applicability conditions or requirements). This database also provides data for the calculation of socio-economic costs, like the environmental costs (see Environmental impacts), the disturbance to citizens (working area required, time to develop the works, etc.) and others (see Technique rates and characteristics).

The software used is MS access, due to its availability (it's the most common database software, attainable from any end-user), its compatibility with other tools of CARE-S project and the possibility of providing this database as a stand alone tool. The database can be updated with new techniques or characteristics easily, giving the end-user the possibility to adjust this tool to his experience and local requirements.

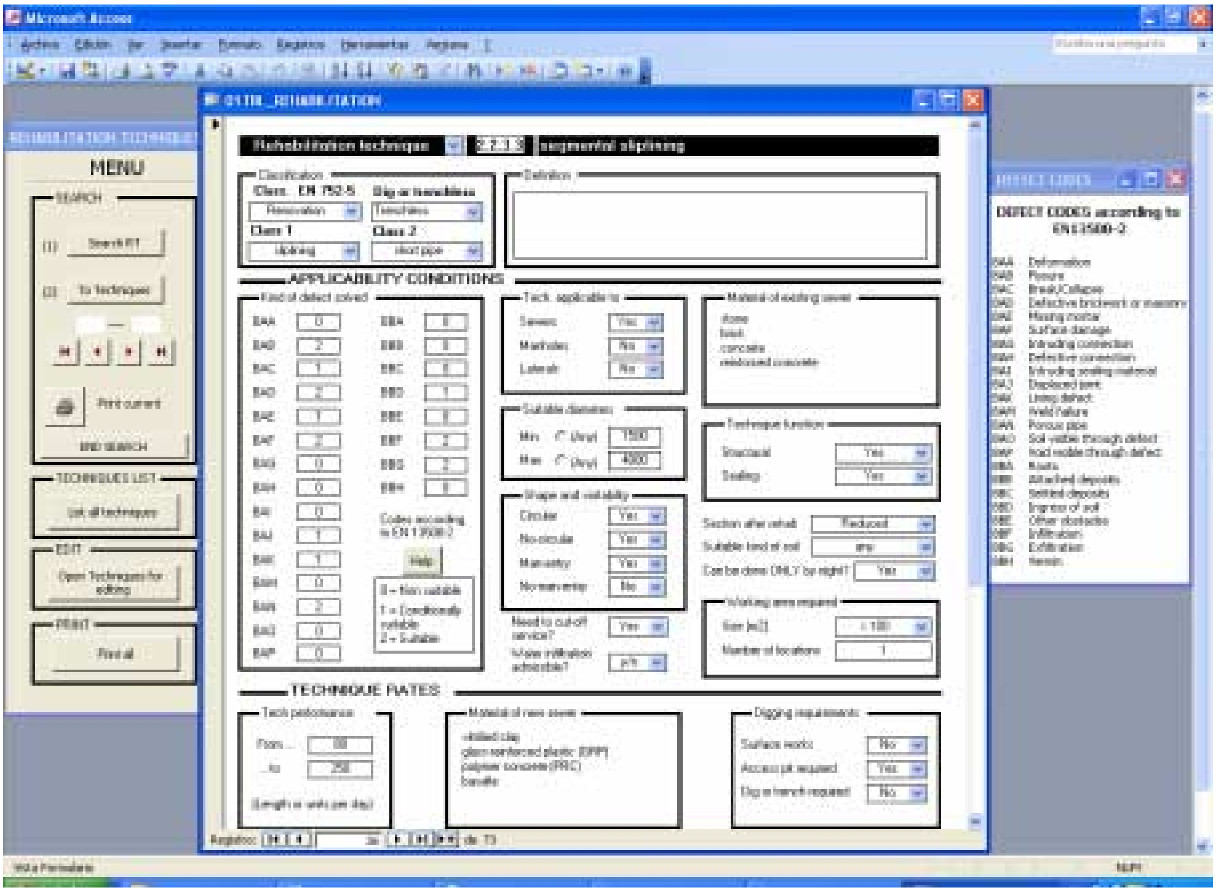


Figure 1. View of the Rehabilitation technologies database. From left to right, the menu box, partial view of a rehabilitation technique card and the helping defect codes list box.

E.2 User manual for the rehabilitation technologies DB

E.2.1 General description: The Rehabilitation & Operational Technologies database

The overall target of the CARE-S project is to help to rehabilitate “the right sewer, at the right time, with the right technology”. This requires, among other things, access to information about available techniques and their main characteristics. This information must be available in an organized and arranged way, making it possible to perform queries. Data should also be dynamic (easy to edit), as technology is constantly developing. The Rehabilitation and Operational Technologies database (**ROTs DB**) (including information about operational methods) was constructed to serve this purpose.

The database is fairly simple to use, especially with the help menu. A useful feature to search for techniques is available from the specifically designed **search engine**. The **list** facility offers quick access to each rehabilitation technology. The **print** and **edit** features have also been developed to improve the ease of use of the database for users unfamiliar with MS Access.

E.2.2 Scope of application

The tool was created for two main purposes:

- To use as a stand-alone tool for access to information about rehabilitation technologies, and
- To be the information source on rehabilitation technologies for use in the Multi Criteria Decision Tool for selection of technologies

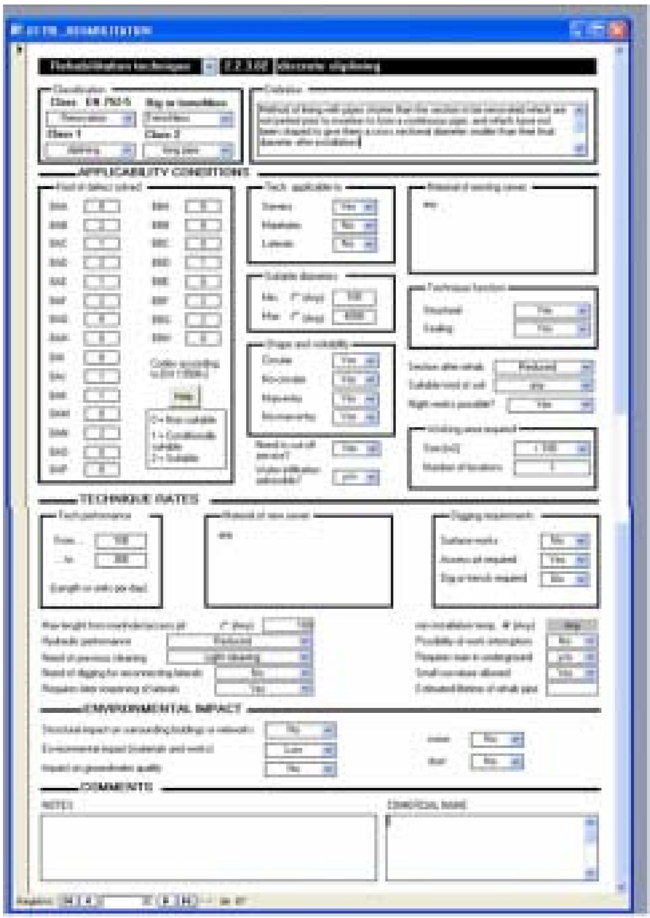
For the latter point, a list of techniques is suggested which are able to solve (a) specific defect(s) in the sewer or drainage system, under defined environment conditions and dimensions (see Applicability conditions or requirements). This database also provides data for the calculation of socio-economic costs, like the environmental costs (see Environmental impacts), the disturbance to citizens (working area required, time to develop the works, etc.) and others (see Technique rates and characteristics).

E.2.3 Data

In order to use the ROTs DB, the user must have MS Access installed on their computer.

Basically, this is a data-provider tool. It can, and should, be modified according to end-user preferences and utility specific information, as information about available technologies and their characteristics may differ from one country to another. It can also be updated with techniques which are not present in the DB.

Complete information of each technique is stored in single files (or "file cards"). The structure and meaning of each field is explained in the report D12 (Rehabilitation technology survey).



E.2.4 How-to guide

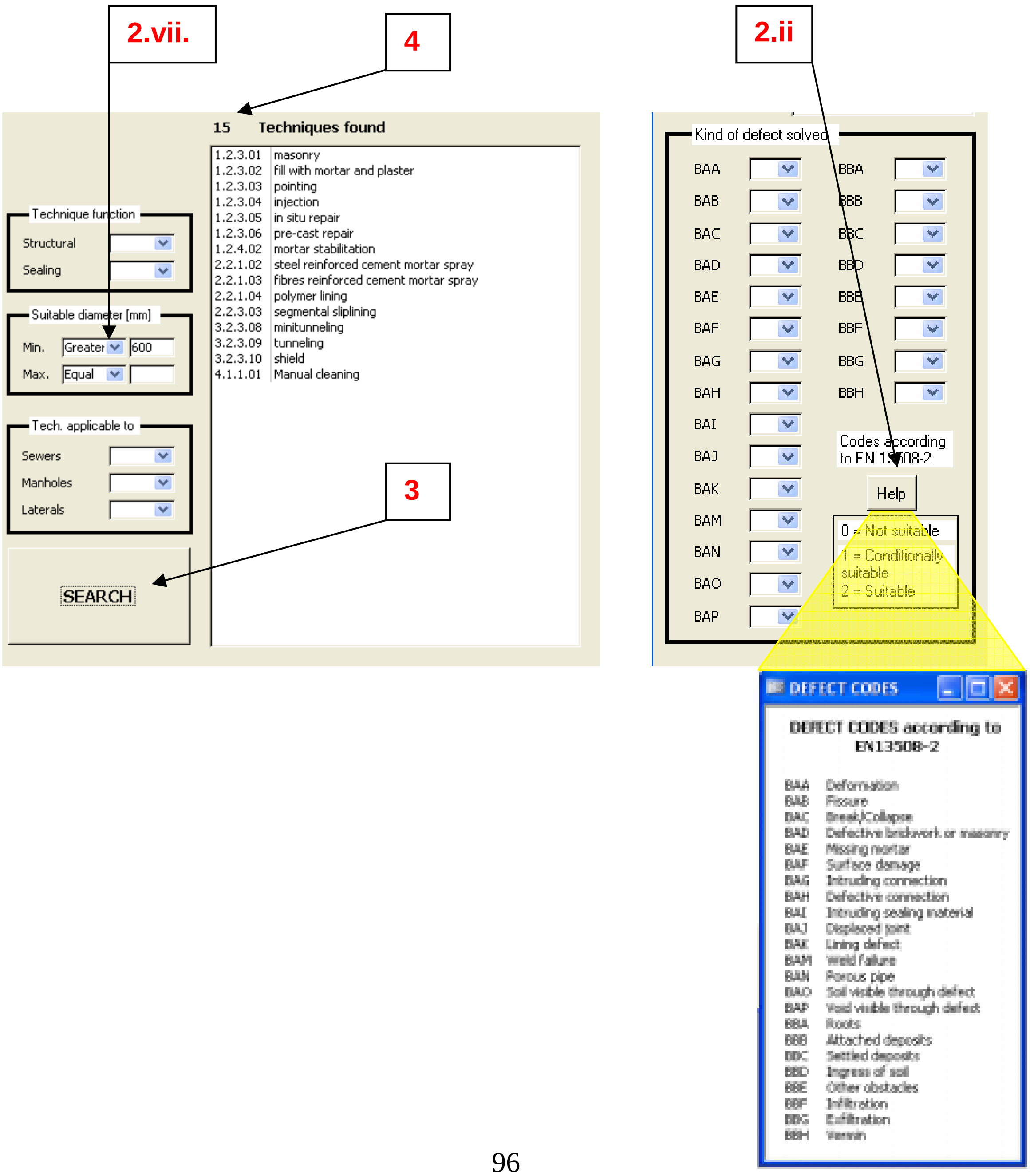
In the following, a step by step guide is presented of the functions and menus of the database.

Search engine:

1. Click the *search button* on the menu. The search form window opens.
2. Fill in the form with your search requirements. Please note that:
   i. The more criteria you enter , the less techniques you find. Start with broad search criteria and narrow them down.
   ii. **Kind of defect solved**: click "help" button in the box and a list of the codes and their short name will pop up.
   iii. Searching for no more than two defects is recommended (few techniques are able to solve many defects).
   iv. Note that "1" indicates that the technique is "conditionally suitable" to solve the defect, which means that it will not in general be the most cost-effective technology (but under some conditions this could change)
   v. and "2" means "suitable", which in general is the most cost-effective technique.
   vi. Logical operators are not allowed in this criterion, so "chain search" is recommended when searching for techniques "1" or "2" regarding a defect.
   vii. **Suitable diameter**: use the logical operators' boxes for wide searching. "Min." and "Max." are the minimum and maximum diameter the technology can rehabilitate. So, searching for technologies able to rehabilitate pipes larger than 600mm, <u>do not use</u> "max greater 600", <u>but rather</u> "min greater 600".

viii. Searching for technologies able to work only in a defined range does not make as much sense as it may seem. E.g.: techniques that solve defects of pipes where diameter is 300<D<600mm. The command would be “min greater 300” & “max minor 600”. In this case no technique is found!! The reason: techniques solving problems for pipes greater than 300mm can also solve pipes greater than 600mm. Tip: in such cases, just search for the minimum diameter (“min greater 300”).

3. After filling in your requirements, you can now click on *search button*.
4. The list of techniques matching your search criteria will appear. In the top left, you can see the number of techniques found. Just double click over one of then to access the complete information of the technique.
5. If a warning message appears, instead of the list, with “no technique found”, try to search with fewer criteria.



List facility:

For quick access to a technique in the DB, the list facility has been developed. To use it:

1. Click on “List all techniques” on the menu box.
2. Double click the desired technique to go to its file.

Edit facility:

When accessing the rehabilitation files using the search engine or the list facility, data are not made editable, in order to avoid information damage.

To edit the rehabilitation files, you can use the edit function. Please, note that Access does not allow the “undo” function, so a back-up of the database before editing is recommended.

Print facility:

The “Print all techniques” function allows an operation that can otherwise be done opening and printing all the techniques one-by-one.

F COST FORMULA CALCULATION

F.1 Rehabilitation technologies cost assessment

One of the most important criteria to choose a technique is obviously its direct cost. Unfortunately, this becomes also the most difficult task. The difficulties come from the fact that each sewer work is different: the working conditions change, the suppliers and the general construction costs may differ depending on regions and time. So it's clear that the aim of assessing the direct cost for rehabilitation technologies is to give a tool for **guidance and comparison** purposes only.

The Cost Tool presented inside the CARE-S project is based in few cost drivers that are used by a reduced collection of formulae. Each one of the formulae is suitable for a group of rehabilitation technologies with similar cost behavior (trench, robotic, man-made, injection, etc.). This tool has an open formulation, so that the end-user can check the default prices and the factors used to assess the cost, and change any of them to adjust it to the local conditions.

F.2 Cost formula calculation

Cost assessment for the rehabilitation technologies has been achieved in different ways, according to the data available for each technology:

- *Regression over final cost of works done.* If enough data were available, it has been possible to calculate a regression formula. Due to a lack of incomplete information in most of the data, this calculation has been possible in few techniques.

- *Regression over installers price.* Some installers have provided their prices for their techniques for different diameters and conditions. These prices are not really their final offer to a determinate work, but a basis price. It can vary significantly depending on working conditions and boundaries, and of course of the competitors for the tender.

- *Cost drivers.* This option has been used when rehabilitation cost depend clearly on determinate factors (drivers) like, materials price (concrete, plastic), working surroundings, depth, pipe length, number of existing connections, etc. Then the final cost is assessed by comparison with default conditions and multiplying factors. In the Cost Tool, user can add new cost drivers, change default costs or multiplying factors.

- *Project price formula.* Wherever insufficient data to use previous methods have been obtained, it has been considered a better option to construct the price as it is done in a project. Some basic prices have been fixed in the Cost Tool, but of course these can be changed by the user to adapt them to local conditions and experience.

Unfortunately, there are some techniques for which no valid cost formula has been reached. The cause can be the novelty of the method (E.G. Control Line and Grade system), its rare use for sewer pipes (e.g. mole ploughing), or in some cases the complexity of the works, that require an specific study of the cost for each location (e.g. tunneling with shields).

Finally, just warn once more time that next formulae are just a guidance, obtained from data of different countries and consequently may present a significant dispersion regarding to single local conditions.

F.2.1 Conventional trench

Cost driver formula:

Cost = (default cost * diameter * depth + Σdrivers) * length

COST DRIVER	VARIABLE	VALUE
Depth	Depth < 1.5 m	1
	< 3	2
	< 4.5	3
	< 6	4
	≥ 6	5
Presence of hard rock (yes)	Diameter < 300 mm	40
	< 700	70
	≥ 700	120
Difficult soil (yes)	Diameter < 300 mm	7
	< 700	15
	≥ 700	25
Working surroundings	Street	50
	City	50
	City + street	100
Reinstatement of pavement /surface	Street	120
	Grass	60
Dewatering (yes)	Diameter < 500 mm	30
	< 1000	40
	≥ 1000	50

F.2.2 Shoring and trench box

Project price + cost driver formula:

Cost = *"conventional trench cost"* + 30*length*depth*2

Shoring price = 30 €/m2 ; 100% shored

F.2.3 Concrete sheet pile

Project price formula:

Single (discrete – boring holes) pilling = 50 + 4/3 depth * 2 * length

Sheet pile = 170* length* depth + 70* length

Digging + earth transport + dumping = 11* length* diameter *width, if depth < 4m
20* length* diameter *width, if depth > 4m

$Cost_a$ (discrete piling) = Single pilling + (Digging + earth transport + dumping)

$Cost_b$ (sheet piling) = Single pilling + (Digging + earth transport + dumping)

F.2.4 Injection

Project price formula:

Cement Slurry cost = concrete cost*1.5

Injection equipment renting = 973 €/day (aprox yield 3 – 4 tn/day)

Cost = (concrete cost*1.5 + 375)* volume of cracks

F.2.5 Robot

Project price formula:

Basic price = 200€/h robot renting (strong variations in different countries)

F.2.6 Short liners

Regression form installers prices:

Cost = (0.5213*diameter+291.84) length

Not checked for pipes over 1000mm diameter

F.2.7 Man-made repairs

Project price formula. The basis are:

Masonry = 50€/m^2
Invert channel = 75€/m (semicircuplar piedes D=300mm, installation excluded)
Concrete works = 100€/m^3 (includes material and manpower)

Average cost for invert repairs = 180 €/m

Average cost for invert + vault repairs = 250 €/m

Only for man-entry sewers

F.2.8 Cured in place pipes (CIPP)

Regression over final cost of works:

Cost = 537+109*Length+235*number_of_Service_Connections+17*Diameter

For small diameter pipes.

Regression over installers price:

Cost = $(74.145\ e^{0.0017*\text{diameter}})$*length

Not checked for pipes over 1200mm diameter

F.2.9 Horizontal directional drilling (HDD)

Regression over installers price:

Cost = (1.3086*diameter+8.1905)*length

Not checked over 500mm diameter

F.3 User manual for the rehabilitation technologies DB

F.3.1 General description: Rehabilitation cost tool

The cost tool is designed to obtain rehabilitation costs depending on the characteristics of the pipe and type of technology that has been selected.
The tool provides, for every pipe that will be passed to it, two costs that can be interpreted as the extremes of a possible cost interval or two different costs of the selected rehabilitation technology depending on specific conditions (winter / summer costs, night / day costs, using end- user or hired workers).

The cost tool is based on excel spreadsheets and macros and it is fully user definable: rehab technologies, cost drivers, cost formulae and default values can be edited by the user. This is needed because several local factors can influence both the costs and the dependencies between costs and driver factors that influence the costs. This aspects will allow the user to change the structure of the tool depending on his specific needs.

Opening the Excel file, the system asks for **a password that is "wp4"**. The password is not limiting any activity and it was defined only for avoiding accidental modifications to the spreadsheet macros.

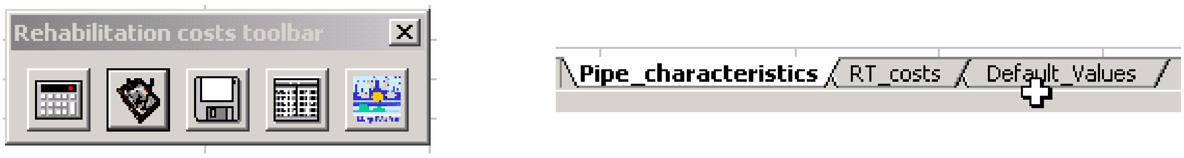


Figure 1: buttons and spreadsheets that are available in rehabilitation cost tool
Three worksheets should be visible for the user and a toolbar with five buttons (Figure 1). The first worksheet ("Pipe characteristics") is used to input pipe data according to the cost drivers that are defined by the user or by CARE-S default.

F.3.2 Scope of application

The scope of the cost tool is to provide costs or cost ranges to the other CARE-S tools. The tool can be run as a stand-alone Excel application, in order to allow the user to evaluate rehabilitation costs for single technologies or projects, and inside the CARE-S prototype in order to compare different rehabilitation projects on economic basis.

F.3.3 Data Input

Basically, the cost tool has been developed with the same philosophy of rehabilitation technologies database. As it has been constructed in Excel, it can be easily modified according to end-user preferences. In particular, it can be updated with new techniques, drivers and formulae, giving the end-user the possibility to adjust this tool to his experience and local specific conditions (climate; local salaries and construction material costs, etc).

Pipe data have to be copied in the spreadsheet “Pipe Characteristics” following the scheme defined in the headers. This operation can be done manually by the user or provided automatically by CARE-S Rehab manager.

Data can have blank spaces (for example when data about some pipe characteristics are missing). In those cases, the tool will use default values that are contained in the “Default Values” spreadsheet (Figure 3).

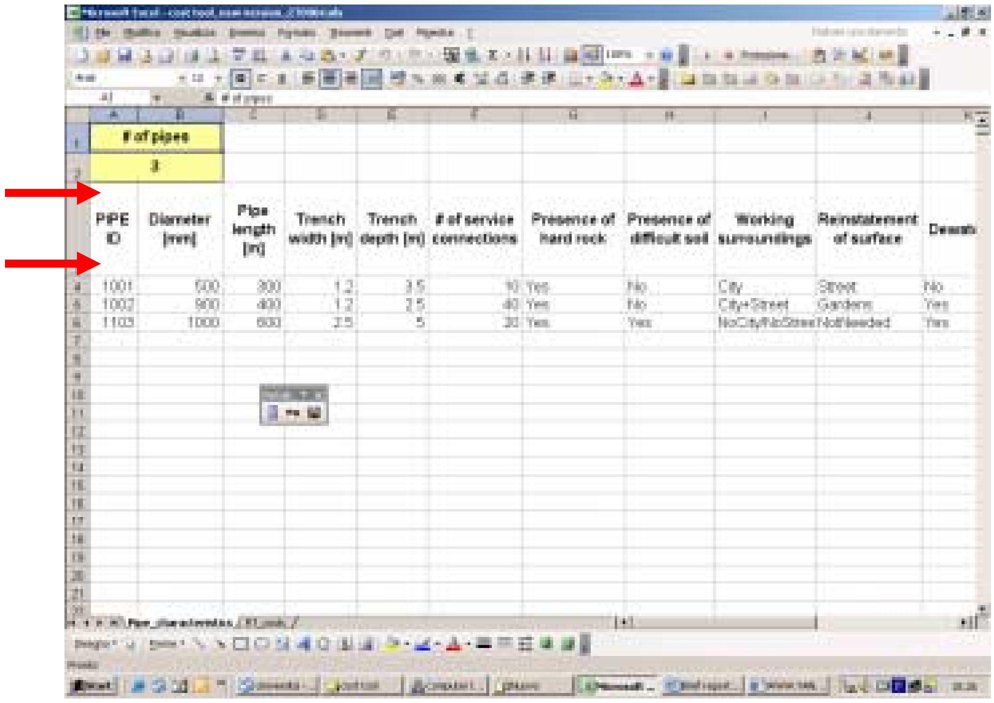


Figure 2: Pipe characteristics spreadsheet

In the second row, this spreadsheet counts automatically the number of pipes that are entered. This is essential for the definition of the “RT_costs” spreadsheet because fixes the number of times the tool has to be run in order to obtain the rehab costs.

The “Default Values” spreadsheet contains the cost driver values that the tool will use in case pipe data are missing the specific information. The user can modify the “default values” depending on the characteristics of the analysed network and of catchment. The user can also modify or add single information to the “pipe characteristics” spreadsheet before running the cost tool.

								DEFAULT VALUES			
Diameter [mm]	Pipe length [m]	Trench width [m]	Trench depth [m]	# of service connections	Presence of hard rock	Presence of difficult soil	Working surroundings	Reinstatement of surface	Dewatering	Default project unit cost (€/m)	Volume of cracks [m3/m]
600	300	1.2	3.5	10	Yes	No	City	Street	No	600	1.2

Figure 3: The default values table

F.3.4 Result presentation

After entering the available pipe data and the default values, the user has to click on the "computation" button (the calculator in the toolbar in figure 1) and the results should be written in the "RT_costs" spreadsheet in form of the following table (figure 4)

PIPE ID	Rehab ID	Rehab Techology	Rehab cost 1 (€)	Rehab cost 2 (€)
1001	1.1.1.1	conventional trench	72000	108000
1001	1.1.2.1	shoring and trench box	135000	202500
1001	1.1.2.2a	concrete sheet pile (single)	153860	230790
1001	1.2.1.2	milling robot	600000	900000
1001	1.2.1.3	root cutting robot	6000	9000
1001	1.2.3.1	masonry	28274	42411
1001	1.2.3.4	injection	138600	207900
1001	1.2.3.6	pre-cast repair	54000	81000
1001	1.2.4.2	mortar stabilization	138600	207900
1002	1.1.1.1	conventional trench	48000	72000
1002	1.1.2.1	shoring and trench box	111000	166500
1002	1.1.2.2a	concrete sheet pile (single)	153860	230790
1002	1.2.1.2	milling robot	600000	900000
1002	1.2.1.3	root cutting robot	6000	9000
1002	1.2.3.1	masonry	42410	63615
1002	1.2.3.4	injection	207900	311850
1002	1.2.3.6	pre-cast repair	54000	81000
1002	1.2.4.2	mortar stabilization	207900	311850
1103	1.1.1.1	conventional trench	117000	175500
1103	1.1.2.1	shoring and trench box	297000	445500
1103	1.1.2.2a	concrete sheet pile (single)	550000	825000
1103	1.2.1.2	milling robot	1200000	1800000
1103	1.2.1.3	root cutting robot	12000	18000
1103	1.2.3.1	masonry	94245	141368
1103	1.2.3.4	injection	138600	207900
1103	1.2.3.6	pre-cast repair	108000	162000
1103	1.2.4.2	mortar stabilization	138600	207900

Figure 4: Result presentation

The results table contains every pipe (first column) and every rehab technology that can be computed with the available information (second and third column) with the relative costs (two columns in general containing day/night costs or Summer/Winter costs or the extreme values in a possible cost interval).

F.3.5 Cost tool default data files and customization

As the tool is totally user definable, costs selection will be a user decision and the relative formula will be added by the user in the "RT_formulae" definition spreadsheet.

The "tablet" button in the toolbar (the second button in figure 1) allows for the definition of cost drivers and formulae. Clicking on it, a new spreadsheet is revealed in the workbook ("RT_formulae").

The spreadsheet is composed by two parts: the first table (on the left) contains the cost drivers (Figure 5) with a maximum number of variable equal to 20; the second table (on the right) contains cost formulae (Figure 6) with a maximum number of 100 techniques (considering two possible costs for each of them, such as day/night or summer/winter). Every element is definable by the user or it can be adopted as CARE-S default.

	COST DRIVERS													
Name	Diameter [mm]	Pipe length [m]	Trench width [m]	Trench depth [m]	# of service connections	Presence of hard rock	Presence of difficult soil	Working surroundings	Reinstatement of surface	Dewatering	Equip. hourly rate (€/h)	Av. work rate (m/h)	Default project unit cost (€/m)	Volu o cra [m3
Type	Float	Float	Float	Float	Float	List	List	List	List	List	Float	Float	Float	Flo
List						Yes	Yes	No City/No Street	Not needed	Yes				
						No	No	Street	Gardens/Grass	No				
								City	Street					
								Street+City						
Demo Value	500	300	1.2	3.5	10	Yes	No	City	Street	No	100	300	600	5
Operation	Default	Default	Default	Default	Default	Default	Default	Default	Default	Default	Default	Default	Default	Def

Figure 5: Cost drivers table

In the cost drivers table, every cost driver has:

- a “Name”
- a “Type” (FLOATING point number or a State coming out from a LIST): this option can be used for distinguish numeric variable (such as diameter, length, width, etc.) from list variables (such as need for dewatering, working surrounding, etc.). Lists can contain up to ten elements.
- a “Demo Value” that is used in the formulae table to obtain a numerical result allowing the operator to test formula consistency during editing phase
- an “Operation” state that can be “default” (if the cost driver is defined by CARE-S) or “save” (if the cost driver is user defined). This switch is used for selecting the use of CARE-S defaults or for defining new variables and values.

The cost drivers are copied in the RT formulae table (Figure 6) and they can be used for defining new formulae for cost computation. The RT formulae table has the following structure:

- two columns showing Rehabilitation technique codes and names (on the top of the list, there is a “Default” command that returns the default CARE-S list of technologies); the user can modify technologies names, codes or adding new ones; the maximum number of technologies is equal to 100 (CARE-S default list is containing 76 technologies at the moment)
- the central part of the table is used for intermediate computing of factors that compose the total cost (coefficients that strictly depend on one or some factors can be edited and computed in the spreadsheet area and then multiplied for obtaining the final cost).
- In every table row, a “Default” switch can be used for returning CARE-S default formulae or “user-defined” ones that can be manually written in the last two columns using the same syntax as usual Excel.
- the last two columns are used for total cost computation with two possible formulae that can define a range (as someone asked in the very beginning of this cost tool) or a summer/winter cost

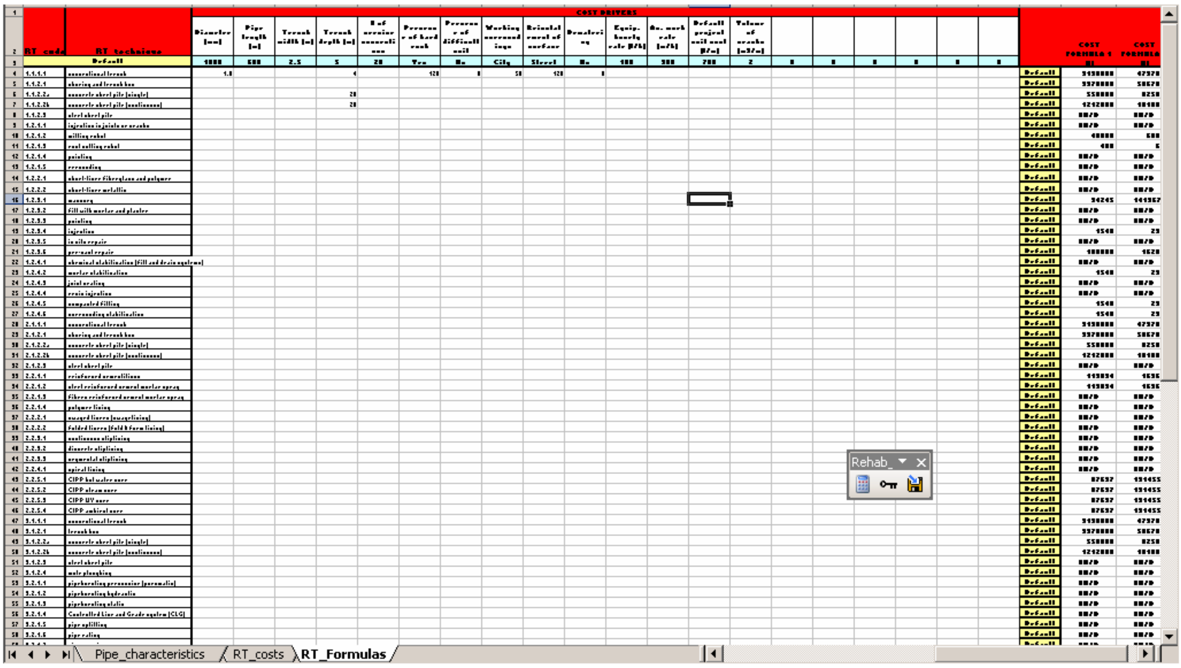


Figure 6: Cost Formulae table

The third button in the toolbar displayed in figure 1 is the "save" button (with a diskette icon). The "RT_formulae" spreadsheet disappears and the user returns to "RT_cost" spread sheet.

F.3.6 Cost tool file management and copy/paste procedures

The fourth button in the toolbar (with a spreadsheet icon) will start the "file manager" tool. As the information about cost formulae and cost drivers can be changed by the user, a tool is needed for helping the user to copy and paste formulae between different cost tool files. If the user wants to take the formulae from another project or generally from other cost tool files that he has used in the past, he can run the file manager as it will be described in the following.

Figure 7 shows the "File manager" form that is constituted by a selection box and four buttons. At the beginning only two of them are active: the "Remove" and the "Select" buttons. The "Select" button opens a file box in order to select the files that the operator wants to use for loading or saving cost formulae. Vice versa, the "Remove" button is used for cancelling a file from the dropdown list of possible selections.

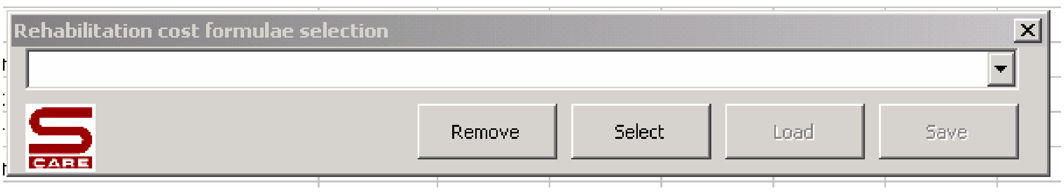


Figure 7: File manager

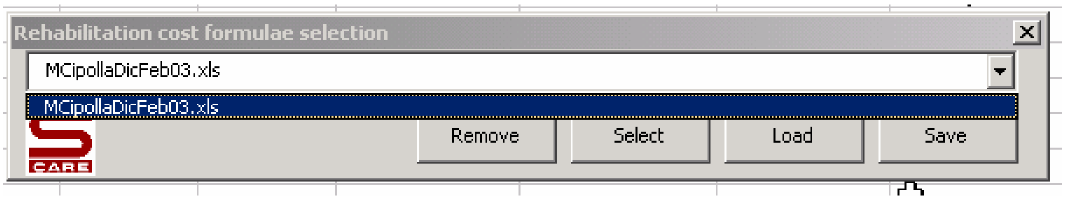


Figure 8: Dropdown selection list of cost tool files

When a file is selected, it appears in the dropdown list and the “Load/Save” buttons are activated (Figure 8).
The “Load” button is used to load the formulae collected in the selected file into the present file.
The “Save” button is used to save the formulae collected in the present file to the selected one.

F.3.7 Accessing to DAYWATER database

The last button on the right part of the toolbar (displaying a daisy and some buildings) gives access to the DAYWATER database of BMP costs. This option has been provided through an agreement between CARE-S and DAYWATER project in order to give to the user a wider range of urban drainage management options.

F.3.8 How-to guide

Next, a step by step guide is presented with the functions developed in the data base, and available in the menu.

Computing rehabilitation costs:

6. If used as a stand alone tool, copy pipe information in the “Pipe Characteristics” spreadsheet. If used inside the Rehab Manager, verify that information has been correctly copied in the “Pipe Characteristics” spreadsheet. Blank spaces define unavailable information. **The cost tool works even if some information is missing.**
7. Verify default values in “default values” spreadsheet because they will used in case the specific information about the pipe is missing
8. Click on the Computation button (the first button on the left of the toolbar displaying a calculator)
9. The results are provided in the “RT costs” spreadsheet

Modifying cost drivers and formulae:

3. Click on “Editor” button in the toolbar (the second from the left displaying a tablet). The “RT formulae” spreadsheet is revealed.
4. Go to the “RT formulae” spreadsheet and modify cost drivers (Figure 5) including new variables or modifying the existing ones. As an example: introduce a new variable called “Need for dust reduction”

i. Introduce a new variable called “Need for dust reduction” (Figure 9).
ii. Define it as a List
iii. Introduce two possible values: “Yes” and “No”
iv. Put “No” as Demo value

v. Select “Save” in the Operation row

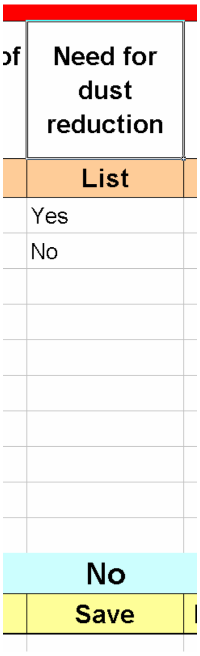


Figure 9: example of a new cost driver

5. Go to the cost formulae table on the right of the “RT Cost” spreadsheet (Figure 6) and modify the cost formulae for every needed technology

G REFERENCES

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- http://www.apwa.net/
- http://www.awwa.org/
- http://www.csiro.au/
- http://www.epa.gov/
- http://www.hrwallingford.co.uk
- http://www.infraguide.gc.ca/
- http://www.istt.com/
- http://www.latech.edu/tech/engr/ttc/index.html
- http://www.microtunneling.com/
- http://www.no-dig.com/
- http://www.trenchlessdataservice.com/
- http://www.tttechnologies.com
- http://www.ukstt.org.uk/
- http://www.wef.org/

H ANNEX 1: RTS VS DEFECTS

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prEN 13508-2 Conditions of drain and sewer systems outside buildings Part 2: Visual inspection coding system						ATV-Advisory Note M143 Part 2 : Optical Inspection	
Drains and sewers							
BA Codes relating to the fabric of the pipeline						Code	Characterisation
Main code		Characterisation 1		Characterisation 2			
BAA	Deformation	A	vertical			LB(E,F)(O,U,L,R)nn	deflection
		B	horizontal			D–(O,U,L,R)nn	deformation of plastic pipes
BAB	Fissure	A	surface crack			SR(B,E,F)(O,L,R)	fissure in cut-out hole
		B	crack				
		C	fracture				
				A	longitudinal	RL(E,F)(O,U,L,R)nn	longitudinal fissure
				B	circumferential	RQ(E,F)(O,U,L,R)	circumferential fissure
				C	complex	RS(E,F)(O,U,L,R)	complex
				D	helical		
						RC(E,F)(O,U,L,R)nn	fissure in joint
						RX(E,F)(O,U,L,R)	homocentric fissure
BAC	Break/Collapse	A	break				
		B	missing			BS(B,E,F)(O,U,L,R)	missing part of pipe
		C	collapse			BT(B,E,F)	collapse
BAD	Defective brickwork or masonry	A	displaced				
		B	missing			BK(B,E,F)(O,U,L,R	missing brick
		C	dropped invert				
		D	collapse			BT(B,E,F)	collapse
				A	another layer of brickwork or masonry visible		
				B	nothing is visible		
BAE	Missing mortar						
BAF	Surface damage	A	increased roughness				
		B	spalling (break in away of small fragments from the surface of the fabric				
		C	visible aggregate				
		D	aggregate projecting from surface				
		E	missing aggregate				
		F	visible reinforcement				
		G	reinforcement projecting from surface				
		H	corroded reinforcement			C-(B,E,F)(O,U,L,R)	corrosion
		I	missing wall				
		J	corrosion products on surface				
		K	other surface damage				
				A	mechanical damage	V-(E,F)(U,L,R)	mechanical abrasion
				B	chemical attack-general (e.g. corrosion of reinforcement)	C-(B,E,F)(O,U,L,R)	corrosion
				C	chemical attack - biochemical attack due to sulphuric acid - damage above the water level		
				D	chemical attack - attack by wastewater - damage below the water level	C-(B,E,F)(O,U,L,R)	corrosion
				E	cause not evident		
BAG	Intruding connection		A connecting pipe projecting into the pipeline			SE(E,F)(O,L,R)nn	a connecting pipe projecting into the pipeline
BAH	Defective connection	A	the position of the connection is incorrect			SN(E,F)(O,L,R)	botched-up connecting pipe
		B	there is a gap between the end of connecting pipe and the main pipe				
		C	there is a partial gap (around part of the circumference of the connecting pipe) between the end of connecting pipe and the main pipe				
		D	the connecting pipe is damaged			AR(B,E,F)(O,U,L,R)	fissure in connecting pipe
		E	the connecting pipe is blocked			A-D(O,U,L,R)	the connecting pipe is blocked
						S-D(O,L,R)	the cut-out hole is blocked
						AU-(O,U,L,R)	blanking connecting pipe
						SU-(O,L,R)	blanking cut-out hole
		Z	other				

BB Codes relating to the operation of the pipeline							
BBA	Roots	A	tap root				
		B	independent fine roots			HP-(O,U,L,R)mn	Ingrown roots
		C	complex mass of roots				
BBB	Attached deposits	A	encrustation			HI(E,F)(O,U,L,R)mn	encrustation
		B	grease				
		C	fouling				
		Z	other				
BBC	Settled deposits	A	fine (e.g. sand, silt);			HDSmn	settled deposits (sand)
		B	coarse (e.g. rubble, gravel); .			HDGmn	settled deposits (gravel)
		C	hard or compacted material (e.g. concrete)			HF	compacted settled deposits
		Z	other				
BBD	Ingress of soil	A	sand				
		B	peat				
		C	fine material (e.g. clay, silt)				
		D	gravel				
		Z	other				
BBE	Other obstacles	A	dislodged brick or masonry unit lying in invert				
		B	pieces of broken pipe are lying in the invert				
		C	another object lying in the invert				
		D	protruding through the wall			HE(E,F)(O,U,L,R)mn	obstacles
		E	wedged in the joint				
		F	entering through a connection/junction pipe				
		G	external pipes or cables built through pipeline				
		H	built into the structure				
BBF	Infiltration	A	sweating				
		B	dripping			W-F	inflow
		C	flowing			W-G	infiltration
		D	gushing				
BBG	Exfiltration		Visible leakage of flow out of the pipeline				
BBH	Vermin	A	rat				
		B	cockroach				
		Z	other				
				A	in the pipeline		
				B	in a connection		
				C	in an open joint		
				Z	other		
Others:						W-Smn	dammed subsurface water
BC Inventory codes							
BCB	Point repair	A	pipe replaced				
		B	localised lining				
		C	injected mortar				
		D	other injected sealing material				
		E	hole repaired				
		Z	other trenchless repair method				
BCC	Curvature of sewer	A	left				
		B	right				
				A	up		
				B	down		
BD Other Codes							
	-						

			Codes relating to the fabric of the pipeline															Codes relating to the operation of the pipeline							
	Code according to prEN 13508-2 :		BAA	BAB	BAC	BAD	BAE	BAF	BAG	BAH	BAI	BAJ	BAK	BAM	BAN	BAO	BAP	BBA	BBB	BBC	BBD	BBE	BBF	BBG	BBH
	Technology		Deformation	Fissure	Break/Collapse	Defective brickwork or masonry	Missing mortar	Surface damage	Intruding connection	Defective connection	Intruding sealing material	Displaced joint	Lining defect	Weld failure	Porous pipe	Soil visible through defect	Void visible through defect	Roots	Attached deposits	Settled deposits	Ingress of soil	Other obstacles	Infiltration	Exfiltration	Vermin
REPAIR	conventional trench	1.01	2	1	2	1	0	0	2	2	0	0	0	2	2	2	2	0	0	0	2	0	2	2	-
	trench box	1.03	2	1	2	1	0	0	2	2	0	0	0	2	2	2	2	0	0	0	2	0	2	2	-
	concrete sheet pile	1.04	1	1	1	1	0	0	1	1	0	0	0	1	1	1	1	0	0	0	1	0	1	1	-
	sheet pile (steel)	1.05	2	1	2	1	0	0	2	2	0	0	0	2	2	2	2	0	0	0	2	0	2	2	-
	injection in joints, cracks or fractures	1.06	0	2	0	1	2	1	0	1	0	1	0	0	0	1	1	0	0	0	1	0	2	2	-
	milling robot (mortar, pipes, joints...)	1.07	0	0	0	0	0	0	2	1	0	0	1	0	0	0	0	2	1	1	0	1	0	0	-
	root cutting robot (repair/operational)	1.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	-
	pointing	1.09	0	1	0	2	2	1	0	1	0	0	1	0	0	1	1	0	0	0	0	0	2	2	-
	rerounding	1.10	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
	connection restoration	1.11																							-
	fiberglass & polymer	1.12	0	2	1	1	0	1	0	0	1	1	2	1	1	2	2	0	0	0	2	0	2	2	-
	metallic	1.13	1	0	0	0	0	0	0	0	2	1	1	1	0	1	1	0	0	0	1	0	2	2	-
	masonry or bricks works	1.14	1	2	1	2	1	2	0	0	0	0	0	0	0	1	1	0	0	0	1	0	1	1	-
	fill with mortar and plaster concrete or brick walls or vaults	1.15	0	2	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	-
	pointing	1.16	0	2	0	1	2	1	0	1	0	0	0	0	0	1	1	0	0	0	1	0	2	2	-
	injection in joints, cracks or fissures	1.17	0	2	0	1	2	1	0	1	0	1	0	0	0	1	1	0	0	0	1	0	2	2	-
	in situ repair (concrete and mortar)	1.18	0	2	1	2	2	2	1	1	1	1	2	0	0	1	1	0	0	0	1	0	1	1	-
	precast repair (with precast elements made of gres, plastic, ...)	1.19	0	2	1	2	2	2	0	1	0	1	2	0	1	1	1	0	0	0	1	0	1	1	-
	chemical stabilisation (fill and drain systems)	1.20	0	2	0	0	0	0	0	0	0	0	0	0	2	1	1	0	0	0	0	0	2	2	-
	mortar stabilization	1.21																							-
	joint sealing	1.22	0	1	0	0	0	0	0	1	1	1	0	1	0	1	1	0	0	0	1	0	2	2	-
	resin injection	1.23	0	2	0	1	0	0	0	1	0	1	1	0	0	1	1	0	0	0	1	0	2	2	-
	compacted filling with structural regeneration through the extrados	1.24	0	1	1	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	2	0	1	1	-
	surrounding soil stabilization	1.25	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	1	1	-
	patch repair	1.26	0	2	1	1	0	1	0	0	1	1	2	1	1	2	2	0	0	0	2	0	2	2	-
RENOVATION	conventional trench	2.01	1	1	2	0	0	0	1	2	0	0	0	0	0	0	2	0	0	0	1	0	2	2	-
	trench box	2.03	1	1	2	0	0	0	1	2	0	0	0	0	0	0	2	0	0	0	1	0	2	2	-
	concrete sheet pile	2.04	1	1	1	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	1	0	1	1	-
	sheet pile	2.05	1	1	2	0	0	0	1	2	0	0	0	0	0	0	2	0	0	0	1	0	2	2	-
	reinforced, cementitious	2.06																							-
	steel reinforced cement-mortar spray	2.07	0	2	2	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	-
	fibres (steel, glass) reinforced cement-mortar spray	2.08	0	2	2	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	-
	polymer lining	2.09	0	2	1	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	-
	swaged liners (swagelining)	2.10	0	2	1	0	1	2	0	0	0	1	1	0	2	1	1	0	0	0	1	0	2	2	-
	folded liners (fold & form lining)	2.11	0	2	1	0	1	2	0	0	0	1	1	0	2	1	1	0	0	0	1	0	2	2	-
	continuous sliplining	2.12	0	2	1	0	1	2	0	0	0	1	1	0	2	0	0	0	0	0	1	0	2	2	-
	discrete sliplining	2.13	0	2	1	2	1	2	0	0	0	1	1	0	2	0	0	0	0	0	1	0	2	2	-
	segmental sliplining	2.14	0	2	1	2	1	2	0	0	0	1	1	0	2	0	0	0	0	0	1	0	2	2	-
	spiral lining	2.15	0	2	1	2	1	2	0	0	0	1	1	0	2	0	0	0	0	0	1	0	2	2	-
	hot water cure	2.16	0	2	1	1	1	2	0	0	0	1	2	0	2	0	0	0	0	0	1	0	2	2	-
	steam cure	2.17	0	2	1	1	1	2	0	0	0	1	2	0	2	0	0	0	0	0	1	0	2	2	-
	UV cure	2.18	0	2	1	1	1	2	0	0	0	1	2	0	2	0	0	0	0	0	1	0	2	2	-
	ambient cure	2.19	0	2	1	1	1	2	0	0	0	1	2	0	2	0	0	0	0	0	1	0	2	2	-
	assembled precast elements or panels	2.20	0	2	1	1	1	2	0	0	0	1	2	0	2	0	0	0	0	0	1	0	2	2	-
REPLACEMENT	conventional trench	3.01	1	2	2	1	0	2	1	2	0	1	0	1	2	2	2	0	0	0	2	1	2	2	-
	mole ploughing	3.02	1	2	2	1	0	2	1	2	0	1	0	1	2	2	2	0	0	0	2	1	2	2	-
	trench box	3.03	1	2	2	1	0	2	1	2	0	1	0	1	2	2	2	0	0	0	2	1	2	2	-
	concrete sheet pile	3.04	1	2	2	1	0	2	1	2	0	1	0	1	2	2	2	0	0	0	2	1	2	2	-
	sheet pile (steel)	3.05	1	2	2	1	0	2	1	2	0	1	0	1	2	2	2	0	0	0	2	1	2	2	-
	pipebursting percussive (Pneumatic)	3.06	1	2	2	0	0	2	0	0	0	1	0	0	2	2	2	0	0	0	2	1	2	2	-
	pipebursting hydraulic	3.07	1	2	2	0	0	2	0	0	0	1	0	0	2	2	2	0	0	0	2	1	2	2	-
	pipebursting static	3.08	1	2	2	0	0	2	0	0	0	1	0	0	2	2	2	0	0	0	2	1	2	2	-
	System)	3.09	1	2	2	0	0	1	0	0	0	0	0	0	2	2	2	0	1	1	1	1	2	2	-
	pipe splitting	3.10	1	2	2	0	0	2	0	0	0	1	0	0	2	2	2	0	0	0	2	1	2	2	-
	pipe eating	3.11	1	2	2	0	0	2	0	0	0	1	0	0	2	2	2	0	0	0	2	1	2	2	-
	pipe reaming	3.12	1	2	2	0	0	2	0	0	0	1	0	0	2	2	2	0	0	0	2	1	2	2	-
	pipe crusing (implosion)	3.13	1	2	2	0	0	2	0	0	0	1	0	0	2	2	2	0	0	0	2	1	2	2	-
	pipe ejection (modified pipe jacking)	3.14	0	1	0	0	0	2	0	0	0	1	0	0	1	1	1	0	0	0	1	1	2	2	-
	pipe extraction (modified static pull)	3.15	0	1	0	0	0	2	0	0	0	1	0	0	1	1	1	0	0	0	1	1	2	2	-
	pipe pulling	3.16	0	1	0	0	0	2	0	0	0	1	0	0	1	1	1	0	0	0	1	1	2	2	-
	rod pushing	3.17																							-
	pneumatic hammer	3.18																							-
	hydraulic hammer	3.19																							-
	steerable moling	3.20																							-
	pipe ramming (impact ramming)	3.21																							-
	auger boring	3.22																							-
	guided auger boring (guided boring)	3.23																							-
	horizontal directional drilling (HDD)	3.24																							-
	guided drilling (mini-HDD)	3.25																							-
	conventional pipe jacking	3.26																							-
	low load pipe jacking	3.27																							-
	thrust jacking	3.28																							-
	microtunnelling	3.29																							-
	minitunnelling	3.30																							-
	tunnelling	3.31																							-
	shield	3.32																							-

Legend:

suitable	2	data will be filled	(yellow)
conditionally suitable	1	replacement in **new** line	(red)

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