An Introduction to Trenchless Technology Piping

(+Türkçe Özet)

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An Introduction to Trenchless Technology Piping (With Appendix B / Ek B ile: Summary In Turkish/ Türkçe Özet, Kazısız Teknolojiler ile Boru Döşemeye Giriş)

ISBN 978-625-00-0325-1 ISBN 978-605-74001-0-9 (eBook)

GülMat. Publishing Co. Certification Nu : 49388

September 2021

The registered company address is: Fazılpaşa Cad. No:8 Kat:4 Zeytinburnu / İstanbul

Free of Charge

(Ücretsizdir)

This book was published by the support of Atlas Study Abroad

(Bu kitap Atlas Yurtdışı Eğitim Danışmanlığının katkılarıyla basılmıştır)

Acknowledgements

I would like to convey my sincere appreciation to Dr. Mohammed Najafi, the director of the Center for Underground Infrastructure Research and Education (CUIRE) in the Department of Civil Engineering at The University of Texas at Arlington/USA, who has published many books on the exciting fields of trenchless technology. We extracted and used much information from his valuable studies in this book. Many sources and unclear documents, pictures, graphs were also used. On this occasion, I would like to offer my best wishes and thanks to all contributors (especially ISTT managements). I salute them with indeptedness.

I want to pay special tribute to Mr. Mustafa Bayraktar (M.Sc.) who was a very special contributer. I also want to thank Mr. Haşim Çayır (M.Sc.), my research assistant at Fatih Sultan Mehmet Vakıf University, who helped me to complete this book. I would like to acknowledge the support of all my students, especially Mr. Oğuzhan Keskin (B.Sc) and Mr. O. Burak Kılıç (B.Sc.).

I would like to acknowledge patience and support of my family and dedicate this book to my wife Gönül and, my grandsons Enis Furkan, Emir Deniz and Yusuf Kerem.

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He received his B.Sc and M.Sc from İstanbul Technical University, and Ph.D. from Manchester University/UK. His research has been widely published in scientific-technical journals and professional-trade conference proceedings. He has been a consultant and expert witness in many establishments, companies and technology projects. He can be reached at f.yilmaz@fsm.edu.tr.

PREFACE

(In the name of ALLAH, the most merciful, the most compassionate)

The first reason for the preparation of this book is to share recent developments experienced in underground infrastructure technology with readers. It is the fact that innovative methods are becoming main route in underground piping constructions, renevations and rehabilitations. The second reason is to give awareness of trenchless technology in civil engineering and environmental engineering societies and world communities as well as the Turkish community.

The development of new equipment and method and increased level of equipment sophistication and capabilities are driving forces of trenchless technology. A safe and successful trenchless project depends on skills, training and experience of operators, field personal and project inspectors. This book will be of use for all parties in a trenchless project as it provides planning, design, construction, inspection and project management concepts.

The book begins with an overview of buried pipe history, new developments, pipe soil interaction and continues comparison of open-cut and trenchless (No-Dig) method of pipe installation. A description of trenchless installation methods, including conventional pipe jacking, utility tunneling, horizontal earth boring (horizontal auger boring, horizontal directional drilling, microtunneling, pilot-tube microtunneling, pipe ramming and pipe moling) are covered. This book includes characteristics and applications, capabilities and limitations of trenchless installation methods.

Information will be helpful to utility owners and design / consulting engineers to properly select appropriate trenchless installation methods based on their project specifics and site conditions. This book covers them and includes a summary of safety considerations and potential risk/impact to pavements and adjacent utilities.

Existing pipeline renewal and replacement methods are also covered in this book. It includes planning and design process, method applicability, and descriptions of different renewal and replacement methods. Cured-in-place pipe,

pipe bursting, sliplining, modified sliplining, coatings and linings, close-fit pipe, thermoformed pipe, lateral joints and renewal, localized repairs and grouting and trenchless replacement methods are main headings. To help with planning and method selection process, this book includes a decision support system for both gravity and pressure pipeline. Partially deteriorated and fully deteriorated pipes, and overview of emerging design concepts are also given. Water piping, pipe properties, selections and comparisons are also given at the last part of this book. The list of sources, trenchless technology glossary of terms as well as Turkish Summary of the field are provided at the end of this book.

It is hoped that such a book will be useful to Civil, Environmental and Materials Engineering students, civil engineers and others who are interested in getting basic information on trenchless technology.

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(September 2021)

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CHAPTER 1

1. New Pipeline Installations

1.1 Buried Pipe History and New Developments

The history of buried pipes started about 2500 B.C., when the Chinese delivered water through bamboo pipes. In some Mediterranean countries, clay pipes supplied water to villagers. In ancient Greece, pipelines and tunnels were constructed to distribute water in urban areas. From A.D. 100 to 300 in Rome, with plenty of low-cost slave labor, pipes become the guts of the infrastructure for the emperor and elite. Water was delivered to Rome in aqueducts and distributed to the mansions of the elite and to their luxurious Roman baths. The aqueduct of Valens in İstanbul (Turkish Bozdoğan-Valens Su Kemeri) was a Roman aqueduct system built in the late 4^{th} Century AD to supply water. The “fall of Rome” may have been brought about, in part, by distributing lead pipes. The acidic water of Rome dissolved lead from the pipes. The elite were lead-poisoned. Lead caused impotence, and the few successful pregnancies produced heirs who were imbeciles [1,2].

Americans and Europeans made pipes by boring logs and block of wood. Najafi[1] in his book, describes historical developments. *“Later they made wooden pipes from carefully sawed staves held together by steel hoops. Some old wooden stave pipes are still in service. Iron had been known since 1000 B.C., but before the Renaissance, iron was used mostly the make spears, swords and shields. In A.D. 1346, iron was used to make guns. These guns became the inspiration for iron pipe -the dream of “ingeniators” (the ingenious ones) - because of the demand for water in the burgeoning cities and because iron was stronger than bamboo or clay. Iron pipes became reality in England in 1824 when James Russell invented a device for welding iron tubes (gun barrels) together into pipes. Costly, handmade, iron pipes supplied gas for gas lambs in the streets and the dwellings of the elite. In 1825, Cornelius Whitehouse made long iron pipes by drawing flat strips of hot iron through a bell-shaped die. The urban way of life changed. Community expanded into metropolis. The “guts of the city” became steel pipes for water and clay pipes for sewerage.”*

The evolution of pipes was by trial and error. Old days, drainpipes were clay or concrete-both rigid. Flexible pipes (steel pipes, polymeric pipes, glass reinforced plastic pipes) have been used generally for transmission of water.

Milestones (with related Figure 1.1):

i) Before 2500 B.C. open canal water transmission system was implemented. The first water transmission through wood engraving pipe was tried in China. The pipes belonging this period were made of wood (such as bamboo).

ii) Clay is one of the most ancient piping materials, with the earliest (before 2500 B.C.) known example coming from Babylonia-Mesopotamia (birthplace of pipes). In the U.S., vitrified clay pipe (with a salt glazing applied to both the pipe's interior and exterior surfaces) was the material of choice for a lot of sewers by the 1880’s-1900’s. Clay pipe was very heavy by nature. Delivering it required the availability of either rail or water transport. Until those systems developed, clay pipe plants were created in many towns, wherever there was a need and an adequate supply of clay. Nowadays, vitrified clay pipe is used generally for sanitary sewer systems [1].

iii) The copper pipe was first used at 3000 B.C. by Egyptians intensively in cities for the transmission of water and wastewater. In all periods of history, copper alloys such as bronze (Cu-Sn) and brass (Cu-Zn) were also used in pipes.

iv) Lead pipes were intensively used in settlements of the ancient ages (from 2500 B.C.). The lead was vastly found in the nature, because of its low melting temperature it is easy to produce and give shape.

v) Marble pipe is used for centuries during and after the era of Rome and Byzantine (300 AD). Remarkably thin pipes were manufactured through stone engraving. The usage of marble pipes was limited because of their fragile property and the difficulty of assembling.

vi) The first usage of cast iron pipes were in Germany (1455), France (1664) and USA (Philadelphia-1804). These gray iron pipes served for centuries. Large scale use occurs in 1800's. First samples were made of sand casting. These iron pipes had wall thickness of 20 mm.

vii) After the invention of Portland cement in 1824, the concrete pipes were manufactured cheaper and more efficient way. Starting from this period (1840's) the concrete pipes have been mostly used in the wastewater systems.

viii) The steel pipes (solid wall, 1880's) manufactured after the progress of big iron blast furnace and steel making furnace processes. The first pipe samples which were obtained by the joining of the metal sheets appeared in 1700's. The steel pipes provide the property of wrought materials which the cast iron pipes do not have. The sample of this group is seamless pipes (Mannesmann) and its endurance is very high.

ix) Corrugated (ribbed) wall steel pipes provide price advantage comparing to the thick steel pipes. Its expected service life is rather short. Its durability can be prolonged by coating. Cheap spiral welded steel pipes (interior-exterior coated) entered into the market in 1920's. Corrugated steel pipe could be used as culverts, conduits and drainpipes.

x) Plastic polyvinylchloride (PVC) pipe was accidentally manufactured in 1920's. The first PVC pipe factory was established in 1930. The advantages of PVC are its lightness, resistance, and its chemical endurance. Its estimated durability is above 50 years.

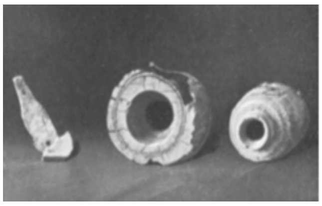
xi) Asbestos cement (1940's, AC) pipes are light concrete pipes which consist of the fibers of asbestos with the cement. The asbestos pipes are fragile, and their impact resistances are low. During the stages of production and repairing it causes problem for human health.

xii) The first manufacturing of plastic composite (glass reinforced polymer-GRP) pipe started in Sweden and Switzerland in 1956. GRP was manufactured commercially in 1980's. Because of its advantages and flexibility of production it is used in many industrial areas. GRP is more expensive when it is compared with concrete and plastics.

xiii) The first high density polyethylene (HDPE) plastic pipe was produced in 1960 after the progress in production methods and technologies. Right after, low weighted ribbed plastic pipes were produced and started to be used in agricultural areas. HDPE pipes (solid wall) intensively started to use in wastewater and drinking water systems starting from the mid-1970's.

xiv) The ductile iron (DI) pipe which was invented accidentally during Second World War has superior features comparing to the gray cast iron (CI). Ductile iron with nodular graphite crystals shows high resistance, high ductility, resistance against impacts and corrosion. The wall thickness of the centrifugally cast ductile iron pipes (1970's, DIP) decreased to 6 mm. The life and durability of the ductile iron pipes can be expected more than 100 years.

xv) Concrete composite (fiber reinforced concrete-FRC) pipe technology was developed in the 1980's to produce a lighter, longer and stronger "concrete" pipe that was also asbestos free. Fibres of cellulose are added to traditional cement materials to form a structurally strong composite. FRC pipes are referred in transmission of wastewater and they have durability under 50 years.



i)

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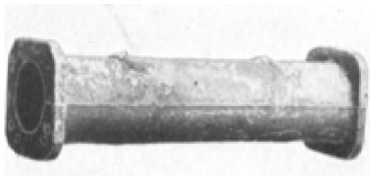


vi)

FIGURE 1.1 Pipes i) Wooden (such as bamboo) pipe. ii) Clay pipe and fitting, iii) Copper pipe, iv) Lead pipe, v) Marble pipe, vi) Cast iron pipe, vii) Concrete pipe, viii) Steel pipe (solid wall), ix) Corrugated (ribbed) wall steel pipes, x) Plastic polyvinylchloride (PVC) pipe, xi) Asbestos cement (AC) pipe, xii) Plastic composite (glass reinforced polymer-GRP) pipe, xiii) High density polyethylene (HDPE) plastic pipe, xiv) Ductile iron (DIP) pipe, xv) Concrete composite (fiber reinforced concrete-FRC) pipe. *(Source: sewerhistory.org and Yilmaz, 2009)*

New Developments

Trenchless technologies (TT) are an alternative to drilling and blasting (D&B) methods used in traditional manual construction also known as "hand mining" in rock or soil. TT significantly reduces the cost of application, makes them use in crowded areas and is much more effective and results can be obtained in a very short time.

International Society for Trenchless Technology (ISTT) was established in September 1986 with a goal of advancing the science and practice of trenchless technology for public benefit through education, training, study and research [3]. ISTT has 27 affiliated societies. Since 1990, when, by the establishment of the North American Society for Trenchless Technology (NASTT), the trenchless technology industry started and organized in the United States. Since then major accomplishments have been made and the organizational activities have been broadened. Germany has always been leading country in Europe on No-Dig applications and the German Society for Trenchless Technologies (GSTT) was formed in 1990. Turkish Society for Infrastructure and Trenchless Technology (TSITT, AKATED) was established at 2010. Since then, many accomplishments have been achieved in Turkey.

At the beginning, horizontal directional drilling equipments (HDD) and microtunnelling boring machine (MTM) manufacturing were attractive trenchless methods. Nowadays, new techniques and materials furnished the technology and increased scope of applications [4].

Najafi[1] put forward stratejik vision in his book. *"Utility ownersproject engineers, and contractors should consider the existing and experienced methods, and those alternative methods that will be available or under development. Further, it should be noted that underground pipeline construction and renewal projects present many risks. There is no guarantee that the methods presented in this book will be successful at all times and at all project and site (surface and subsurface) conditions. Moreover, there is no recommendation of the proprietary methods, pipe materials, and brand names mentioned in this book. The specified method characteristics, diameter range, maximum installation, typical application, and accuracy are based on project and site conditions. Type at equipment used, and experience and training of the crews and the operators are additional facts. Design engineers, project owners, contractors, government agencies, and all other parties involved in trenchless technology projects should consider the risks. Methods successfully used in some applications may not be applicable in other conditions due to change in project, site, and soil. Design engineers and pipeline owners need to be involved in the selection of appropriate trenchless methods for their specific project conditions and do not leave the trenchless method selection entirely to the contractors. Therefore, everyone involved in a trenchless technology construction and renewal should keep abreast of latest developments."* Many of the proposed developments given below are being tested by TT companies: a) Conventional rotary cutting head with an ultrasonic drill, which will pulverize rock with high-frequency sound waves, b) Autonomous robotic boring, cleaning and lining machines, c) Quick detection and self avoiding options from obstacles such as previously laid pipes, cables, the foundations of buildings and even buried boulders, d) Faster move, compacting the spoil into bricks and use those as lining material with a 3D printer, e) Navigate and steering by using various sensors including, crucially, ground-penetrating radar. f) Physical as well as remote inspection and managing the systems, g) Innovative pipeline renewal methods and better materials in all areas of water, sewer, gas and oil applications. As a final word, trenchless technology is developing at a fast rate [2,5,6].

1.2 Open-Cut Method of Pipe Installation

Najafi[1] in his book, describes open cut installation clearly.*"The conventional method for construction, replacement, and renewal of underground utilities has been trenching or open cut, an indirect method of pipeline installation. Open-Cut (OC), or trench excavation is a narrow excavation (in relation to its length) made below the surface of the ground. In general, the depth is greater than the width, but the width of a trench (measured at the bottom) is not greater than 5m. Open-cut methods involve digging a trench along the alignment of the proposed pipeline, supporting trench walls (or sloping sides of the trench), constructing bedding or foundation, placing the pipe sections in the trench, embedding the* *pipe sections, and backfilling the trench and compacting operations (Figure 1.2). Open-cut construction covers:*

a) managing the traffic flow,

b) trench excavation and shoring,

c) dewatering (if needed),

d) backfilling and compaction,

e) reinstatement of the surface (ground and pavement). Last four stages may amount to 70 percent of the total cost of the project."

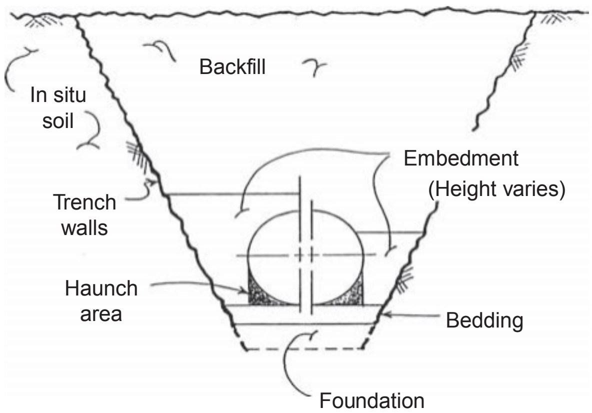


FIGURE 1.2 Open-cut installation. *(Source: Howard, 2002)*

Open-cut methods include higher "social cost". Social cost (general public) means traffic disruptions, noise and dust. Social cost (environmental impacts) also means higher carbon emissions due to higher fuel consumptions. Social cost (safety hazards of trenching) covers accidents, falls into trench. Social cost also covers damage to trees and tree roots. Social cost leads reduction in service life of pavement due to manipulations. Social cost also comprises the damages of existing utilities (structural hazards).

Trenchless technology (TT) is a process for construction, renewal, and replacement of underground pipelines and utilities with minimal surface and subsurface disruptions. Trenchless technology method (also called No-Dig) provides more opportunities for direct installation of pipelines and ducts. In the trenchless technology installations, the loads on the pipe are considerably less and more uniformly distributed around the pipe surface, resulting in minimum pipe deflections. Figure 1.3 illustrates a comparison of pipe loads in trenchless and open-cut methods [1].

Trenchless installation methods significantly reduce the amount of;

a) surface excavation,

b) digging,

c) alignment,

d) supporting,

e) embedding,

f) backfilling,

g) compaction,

h) pavement replacement.

In the trenchless installation method, the most costly item is the pipe installations, usually estimated on a linear meter (foot) bases, while in the open-cut method excavation, backfilling, pavement replacement, shielding and shoring are the major cost items and estimated on a cubic meter or square meter basis.

Trenchless methods are becoming increasingly important as utility pipes for water, gas, and telecommunications and storm and sanitary sewers.

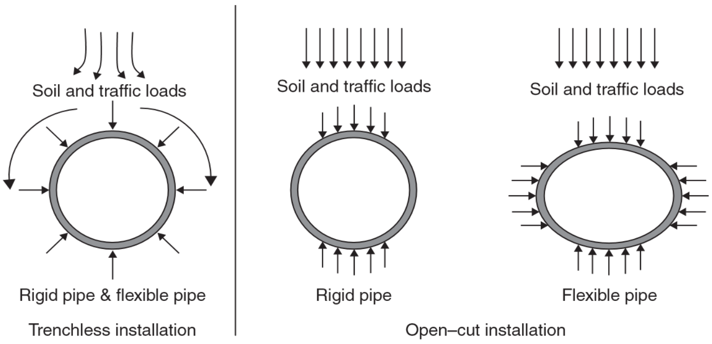


FIGURE 1.3 Comparison of pipe loads in trenchless and open-cut methods. (Source: *Najafi, 2010)*

Trenching (OC) and Trenchless (TT) are alternative methods in many areas (For example: Construction, Figure1.4).

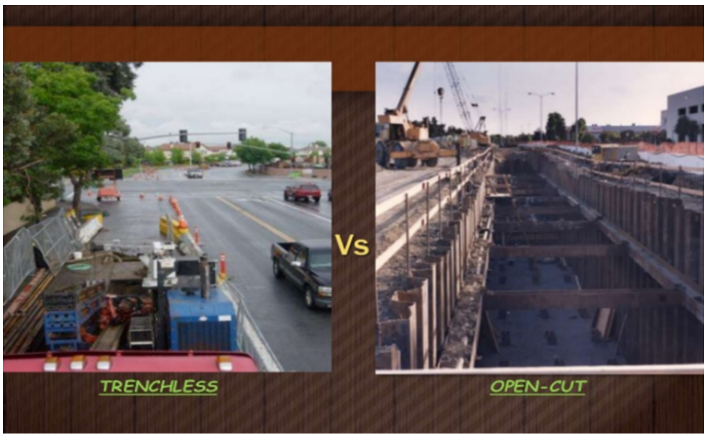


FIGURE 1.4 Comparison of trenchless and open-cut methods. *(Source: fppt.com)*

Case study made by Professor J. Hoelterhoff (German Society for Trenchless Technology Member) for Berlin is exciting [6,7]. Research covers Berlin's (3,4 million population) 26 years Trenchless Technology (TT) experience. More than 780 km of collective and house service connection sewer pipes were constructed by using TT (mainly microtunelling) in between 1980 and 2006. Approximate saving of construction costs was totalling of 67 million Euro. This money was used for other waterwork activities. Negative impacts avoided by TT included:

- 2,4 million cubic meter soil excavation,
- Digging up and restoring 1,3 million square meter of road surface,
- Transporting 198.000 truckloads of soil through the city,
- Extracting 212 million cubic meter of ground water (equal to Berlin's yearly water supply),
- 3 times more carbon dioxide emissions of the construction equipment used in the open construction method,
- Damage of trees (Figure 1.5).

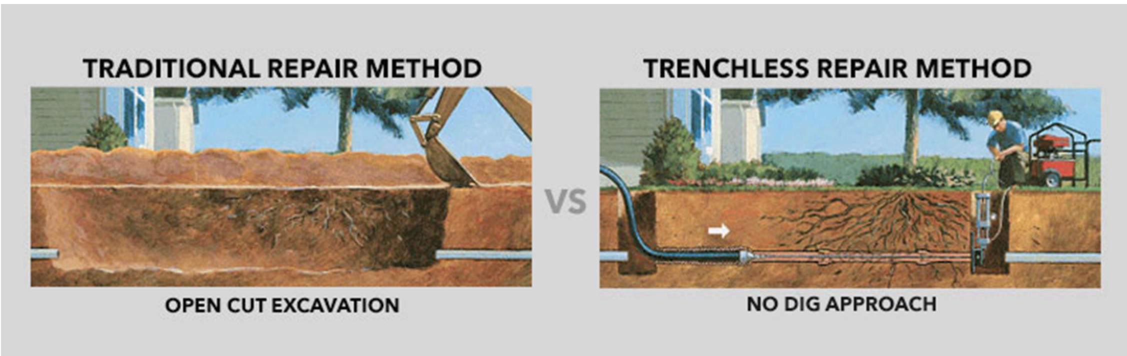


FIGURE 1.5 Comparison of traditional repair and trenchless repair method. (*Source: www.greensplumbingco.com/services/traditional-sewer*)

OC methods involve time consuming excavations and other activities. No doubt that TT is favourable method although in some application OC is main route.

1.3 Comparison of Construction Operations

Table 1.1 comprises detailed construction operations and differences of two main methods of trenchless and open-cut.

According to Professor Najafi[1] these are reality. *"Owing to its many benefits, trenchless construction has become the method of choice to replace traditional open-cut pipeline installations. Through trenchless construction a better-quality pipe is installed, permanent soil and traffic loads on the pipe are reduced, which results in extending the pipe's service life and lowering life cycle cost of the project."* Comparison of trenchless and open-cut has again favorable in trenchless side in the area of renewing/replacement. Many researches were made and construction outputs published for comparisons [3, 8-10].

TABLE 1.1 Comparison of Construction Operations for Open-Cut and Trenchless Technology Methods[a]. *(Najafi, 2010)*

Construction Operations	Open-Cut	Trenchless
Route surveying	Yes	Yes
Land and easement acquisitions	Yes	Yes
Mobilizing equipment and personnel	Yes	Yes
Preparing the right-of-way (ROW) (cleaning and grubbing)	Yes	Maybe[b]
Transporting and storing pipe and other materials	Yes	Yes
Topsoil stripping	Yes	No
Grading	Yes	No
Stringing (transporting and laying of pipe on the ROW)	Yes	Maybe[b]
Transporting welding machines and other equipment to site	Yes	Yes
Welding, ultrasonic, and x-ray checking of welds	Yes	Yes
Installing protective coating at pipe joints	Yes	Yes
Testing pipe for external coating integrity	Yes	Yes
Trenching (including shoring, sloping or shielding)	Yes	No
Dewatering	Yes	Yes
Lowering pipe into trench or shaft/pit	Yes	Yes
Installing block valves and terminus equipment	Yes	Yes
Hauling select soil	Yes	No
Backfilling	Yes	No
Compacting backfill soil	Yes	No
Disposing extra soil	Yes	No
Leak testing (hydrostatic testing) and/or internal inspection	Yes	Yes
Reinstatement of ground	Yes	Maybe[b]
Final inspection	Yes	Yes
Demobilizing equipment and personnel	Yes	Yes
Installing cathodic protection facilities	Yes	Yes
Preparation of as-built	Yes	Yes

[a]Trenching, backfilling, dewatering and reinstatement of ground make up 70% of cost for open-cut projects.
[b]Required for certain types of horizontal directional drilling, pipe bursting, and continuous sliplining methods.

1.4 Trenchless Technology (No-Dig) Methods

Najafi[1] developed a general approaches to trenchless methods. *"Since mid-1980s, many developments have occurred in the trenchless equipment and methods. These developments include manufacturing more powerful directional drilling (HDD) equipment, utility location and tracking tools, more sophisticated microtunneling (MT) equipment, and more capable pipe-ramming, horizontal auger-boring (HAB), and tunneling equipment, as well as better pipe materials and proprietary joints. In the area of renewing deteriorated and old pipelines, developments have been in pipeline inspection technologies, pipe bursting, and new pipeline renewal methods in all areas of water, sewer, gas, and oil applications."*

TABLE 1.2 Primary and Alternative Applications for Trenchless Technology Methods. *(Najafi, 2010)*

Application	Primary Trenchless Technology Methods	Possible Trenchless Technology Methods[a]
Installation of a New Pipe		
Gravity pipe (sanity and storm sewers)	Conventional pipe jacking (CPJ), utility tunneling (UT), microtunneling (MT)	Horizontal directional drilling (HDD)
Pressure pipes (water, gas, and oil)	Horizontal directional drilling (HDD)	Conventional pipe jacking (CPJ), utility tunneling (UT)
Road and railroad crossings	Horizontal auger boring (HAB), pipe ramming (PR)	Horizontal directional drilling (HDD)
Cables and telecommunications	Mini horizontal directional drilling (Mini-HDD)	Piercing method (PM)
Renewing an Existing Pipe		
Gravity pipes (sanity and storm sewers)	Cured-in-place pipe (CIPP), sliplining (SL), modified sliplining (MSL)	Close-fit pipe (CFP)
Pressure pipes (water, gas, and oil)	Close-fit pipe (CFP), cured-in-place pipe (CIPP), spray-in-place pipe (SIPP)	Sliplining, coatings and linings (CL)
Culverts and drainage structures	Cured-in-place pipe (CIPP), sliplining (SL), modified sliplining (MSL)	Coatings and linings (CL)
Replacing an Existing Pipe		
Pressure pipes (water, gas, and oil)	Pipe bursting (PB), pipe reaming (PRM)	Parallel pipeline using horizontal directional drilling (HDD)
Gravity sewer pipes (sanity and storm sewers)	Pipe bursting (PB), pipe reaming (PRM)	Parallel pipeline using microtunneling or pilot tube microtunneling (PTMT)
Service laterals	Pipe bursting (PB)	Parallel pipeline
Culverts and drainage structures	Pipe bursting (PB), pipe ramming (PR)	Horizontal auger boring (HAB), microtunneling method (MTM)

[a]Application of these methods requires special tools or equipment, specialized contractor and operator experience, improved construction practices, and/or may cost more than the main methods. In some cases, the method might be new in the area of this application, and capabilities of the method currently are not fully proven.

Trenchless technology methods are divided into three main areas: (1) construction and installation of new pipelines and utilities; (2) renewal; and (3) replacement of existing, old, and deteriorated pipelines and utilities. Trenchless technology applications for new installations carried out at river crossings, under roads and railroads. Installation of cables and telecommunications ducts, pressure pipes, gravity pipes, culverts, and drainage structures are other applications. Table 1.2 presents primary and alternative applications for trenchless technology methods for new installations, renewals, and replacement. Figure 1.6 illustrates different trenchless new installation methods to be used based on the application.

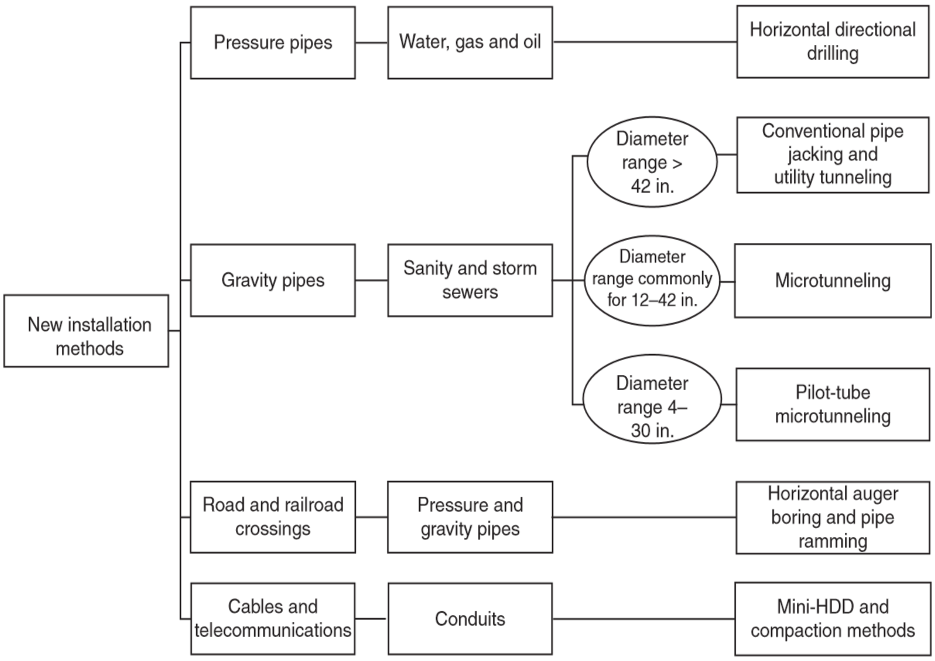


FIGURE 1.6 Applications of trenchless installation methods. (1 in. = 25.4 mm) *(Source: Najafi, 2010)*

1.5 Main Divisions of Trenchless Technology Methods

New installation or construction methods, renewal methods and replacement methods are tree major areas in TT (Figure 1.7):

New installation methods; New utility and pipeline installations (Figure 1.8).

Renewal methods; Renewing, rehabilitating, and/or renovating an existing, old, or host pipe.

Replacement methods; If required old, or host pipe is fractured/fragmented and pushed into the soil or fragmented and removed. A new product pipe is installed in the space left by old pipe. In the inline replacement method, the existing pipe acts like a pilot hole to guide the installation of the new pipe in the same space as the existing pipe occupied originally [1].

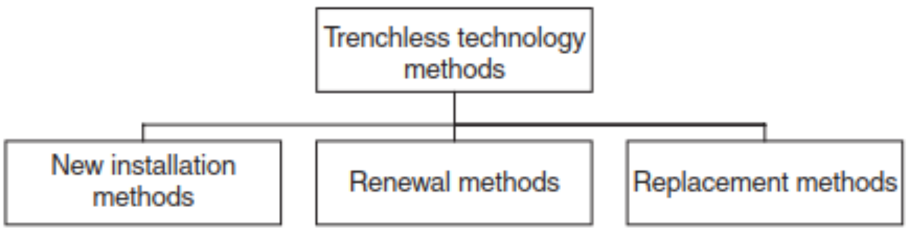


FIGURE 1.7 Main divisions of trenchless technology methods. *(Najafi, 2010)*

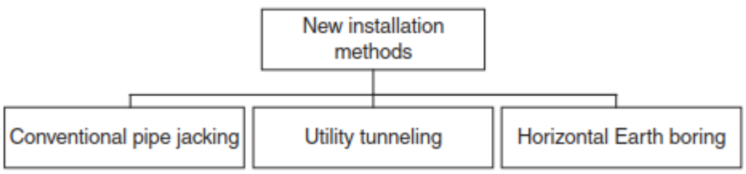


FIGURE 1.8 Trenchless installation methods. *(Source: Najafi, 2010)*

It is the fact that sometimes point repairs may be required before a renewal or replacement method can be used.

1.6 Trenchless Installation Methods

Trenchless installation methods include installing new pipelines or utility systems below ground surface without open-cut trench. Various cutting heads are in use and the selection depends on technologies and ground conditions. Schematic view of a pipe jacking system with intermediate jacking station is given in Figure 1.9. Two broad trenchless categories put forward as worker entry and nonworker entry. Najafi[1] explains the extreme cases. *"Conventional pipe jacking (CPJ) and utility-tunneling (UT) techniques require workers inside the tunnel. Horizontal earth-boring methods are accomplished through mechanical means without workers being inside. CPJ is differentiated from UT by the soil support structure. CPJ can be identified as a "one-phase", installation, where pipe sections are installed at the same time when soil excavation is made. In utility tunneling, first the tunnel is excavated and lined with a tunnel liner plate or wood lagging and steel ribs. After, the pipe sections are "transported" one by one and installed in the tunnel. After all pipe sections are installed, the annual space between the liner and the outside face of the pipe may be grouted. UT is "two-phase", installation technique."*

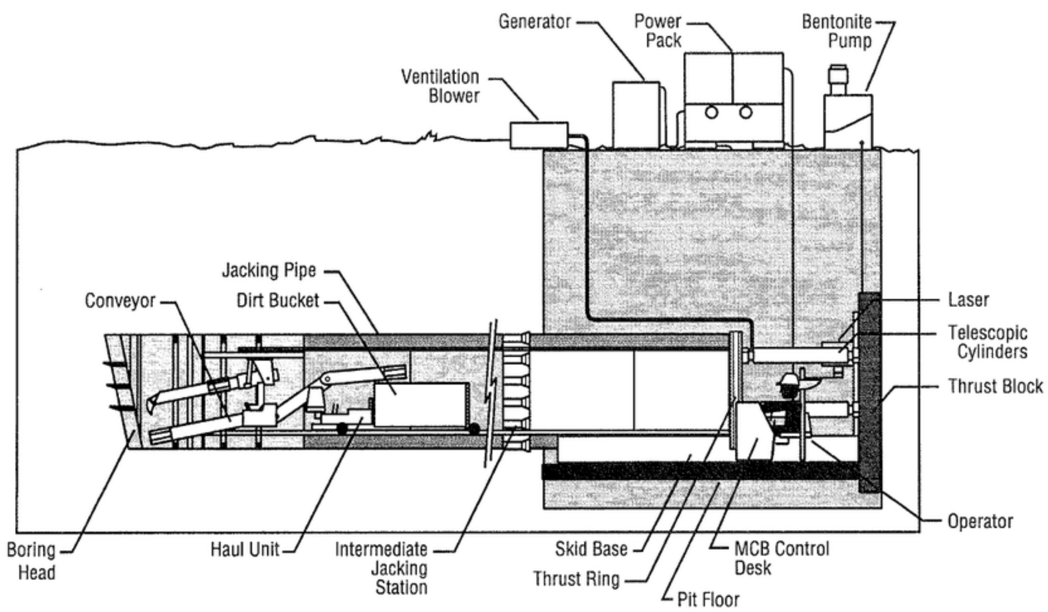


FIGURE 1.9 Schematic of a pipe Jacking Operation. *(Source: www.researchgate.net/figure//Pipe-jacking)*

1.6.1 Conventional Pipe Jacking (CPJ)

Conventional pipe jacking is far more important. Applications of it are increasing worldwide. PJ, a method of pipe installation where prefabricated pipe sections are jacked or pushed behind the tunnel boring machine or other tunnel excavation methods. Jacking is the actual pushing of pipe or casing in an excavated hole. This is usually done with hydraulic cylinders (jacks), but has been done with mechanical jacks and air jacks. The jacking frame serves to distribute the thrust load to the pipeline and the reaction load to the shaft wall or thrust wall. Pipes sections with smooth outside joints designed to be installed using pipe jacking techniques. In this method, the operator works behind the tunneling face, so the applicable diameters are for worker-entry pipes +1000mm. A hydraulic jack is used to assemble specially designed pipes and push the new pipe into place[11]. Najafi[1] in his book, describes jacking shaft. *"Jacking shaft (also launch or entry shaft) is used for excavation from which trenchless technology equipment is launched for the installation or renewal of a pipeline. Jacking shield is a steel cylinder from within which the excavation is carried out either by hand or machine. Incorporated within the shield are facilities to allow it to be adjusted to control line and grade (Figures 1.10 and 1.11). Prefabricated pipe sections are jacked behind the cutterhead (Figure 1.12). The main components of a conventional pipe jacking operation include:*

-Entry and exit shafts

-Tunnel-boring machine (TBM), earth-pressure balance machine (EPBM), open shield excavator

-Spoil removal system

-Jacking frame

-Hydraulic jacks

-Thrust block

-Intermediate jacking stations (if needed)

-Lubrication and pumping equipment

-Ventilation system (for the operator who works at the tunnel face)

-Laser guidance system

-Pipe sections

-Ancillary equipment."

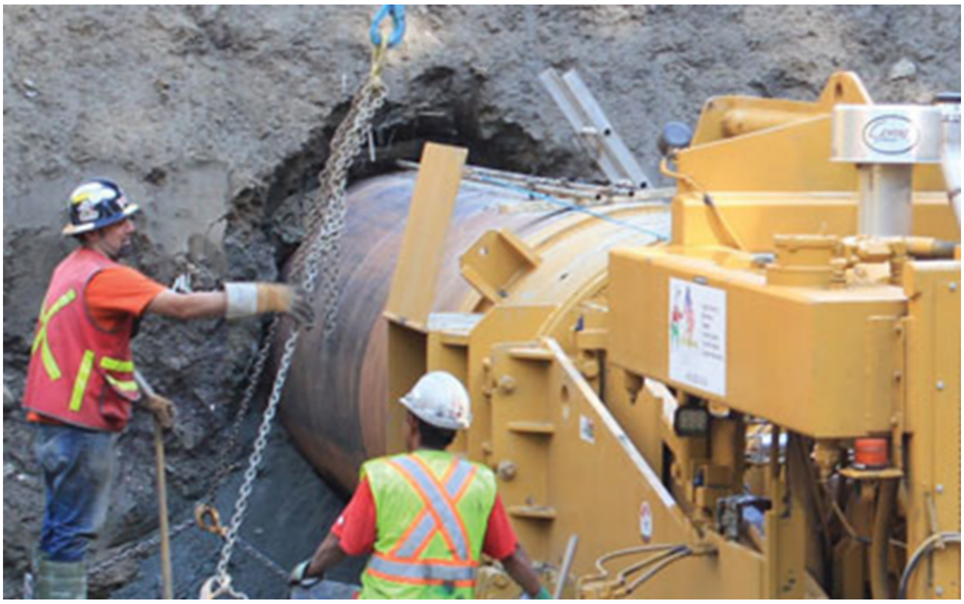


FIGURE 1.10 Pipe jacking (Side View). *(Source: ISTT.)*

FIGURE 1.11 Pipe jacking (Top View). *(Source: ISTT.)*

Pipe jacking is a non-disruptive method of installing pipes and conduits by thrusting pipes through the ground as controlled excavation is undertaken at the face. Pipes manufactured in a variety of materials to include concrete, clay, GRP, DIP and steel can be jacked. Big variety of standard pipe diameters generally range from 150mm to 2,400mm, or greater when required. Jacking lengths achievable can be considerably in excess of 1km depending on pipe diameters, ground conditions and excavation methods. Pipe sections which are jacked or pushed the tunnel comprises both microtunneling (small diameter) and conventional pipe jacking (big diameter) options. Figure 1.13 shows the lowering of the pipe jacking/microtunneling machine into the shaft.

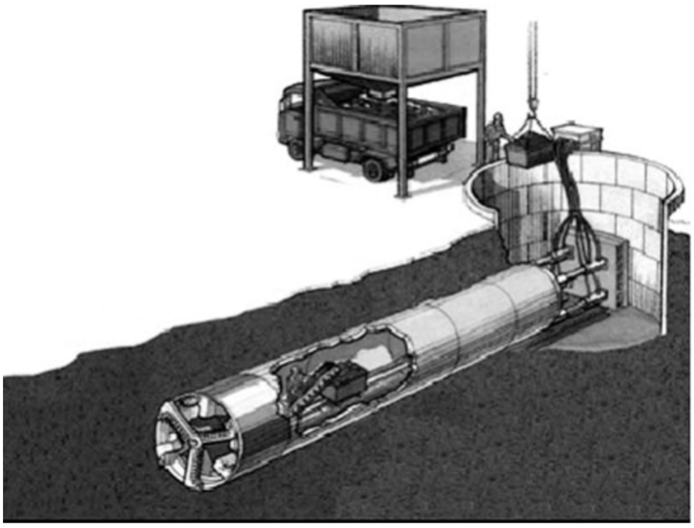


FIGURE 1.12 Conventional pipe jacking operation. *(Source: Najafi, 2010)*

FIGURE 1.13 Pipe jacking microtunneling machine is lowered into shaft. *(Source: ISTT, 2014)*

New pipe sections are jacked from a drive or entry shaft or pit. This way the complete string of pipe is installed simultaneously with the excavation of the tunnel. For this method, the pipe designed and manufactured to take both jacking and permanent loads. However, usually jacking loads control the pipe design (Figure 1.14), [1].

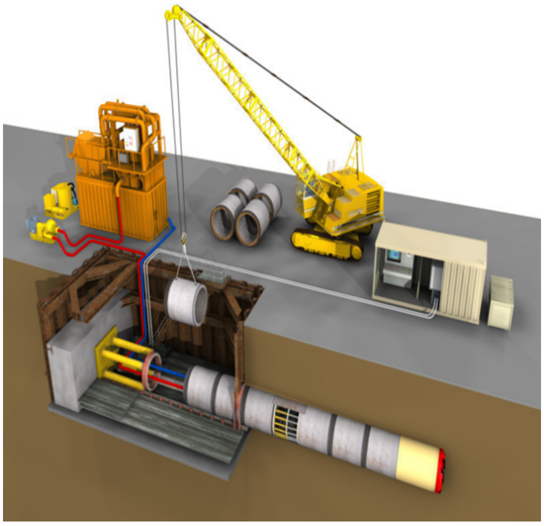


FIGURE 1.14 Pipe jacking operation system. *(Source: www.victoriatrenchlesssolutions.com.au/pipe-jacking-melbourne)*

Pipe jacking generally referred to in the smaller diameters as microtunnelling, is a technique for installing underground pipelines, ducts, and culverts. PJ is also a concept used in several trenchless technology methods (Figure 1.15). These are:

- Horizontal auger boring

- Pilot tube method

- Earth pressure balance machine (EPBM)

Figure 1.15 divides worker entry pipe jacking into open shield and closed shield.

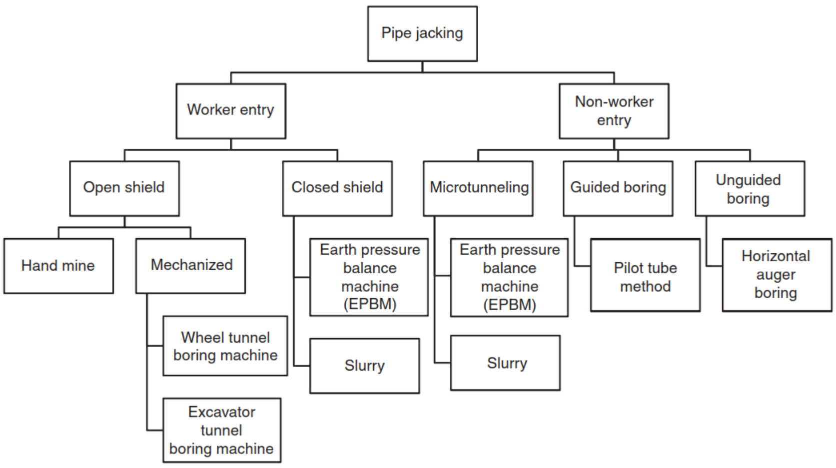


FIGURE 1.15 Types of pipe jacking. *(Source: Najafi, 2010)*

Types of Conventional Pipe Jacking

Najafi[1] in his book, describes conventional pipe jacking. *"Two main categories:*

- *Worker Entry (open shield and closed shield)*
- *Non-Worker Entry (microtunneling, guided boring and unguided boring)*

Open shield pipe jacking can be carried out manually known as open hand shield (manual excavation) or mechanically (Figure 1.16). Open shield wheel tunnel boring machine (TBM) is a shield having a rotating cutting head in which the face may be separated from the rest of the shield by a bulkhead (Figure 1.17a)."

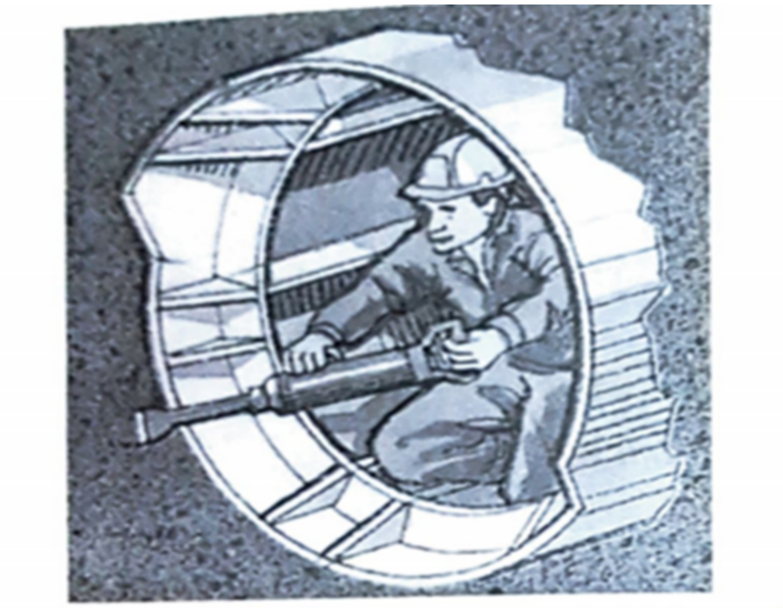


FIGURE 1.16 Open hand shield. *(Source: Pipe Jacking Association.)*

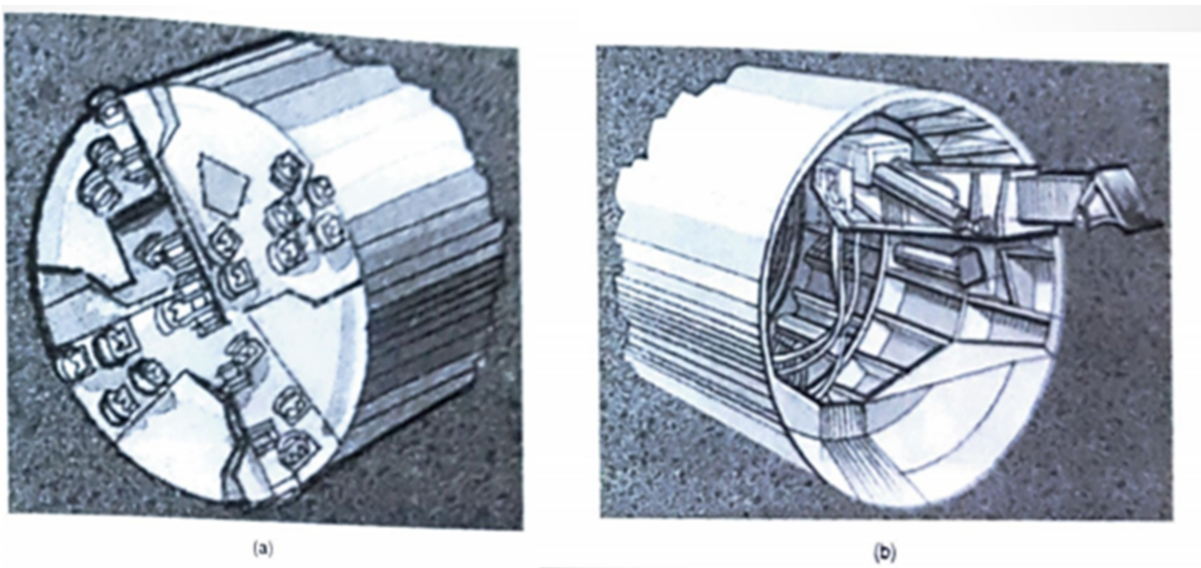


FIGURE 1.17 (a) Open shield wheel TBM. (b) Excavator TBM. (*Source: Pipe Jacking Association*.)

Open shield excavator tunnel boring machine (TBM) is an open face shield in which a mechanical excavator is mounted (Figure 1.17b). Closed shield is divided into two categories, worker entry earth pressure balance machine (EPBM) and worker entry slurry machine [1].

Earth-pressure balance machine (EPBM):

A full-face tunnel boring machine in which the excavated material is transported from the face by a balanced screw auger or screw conveyor (Figure 1.18a). The face is supported by excavated material held under pressure behind the cutter head [1].

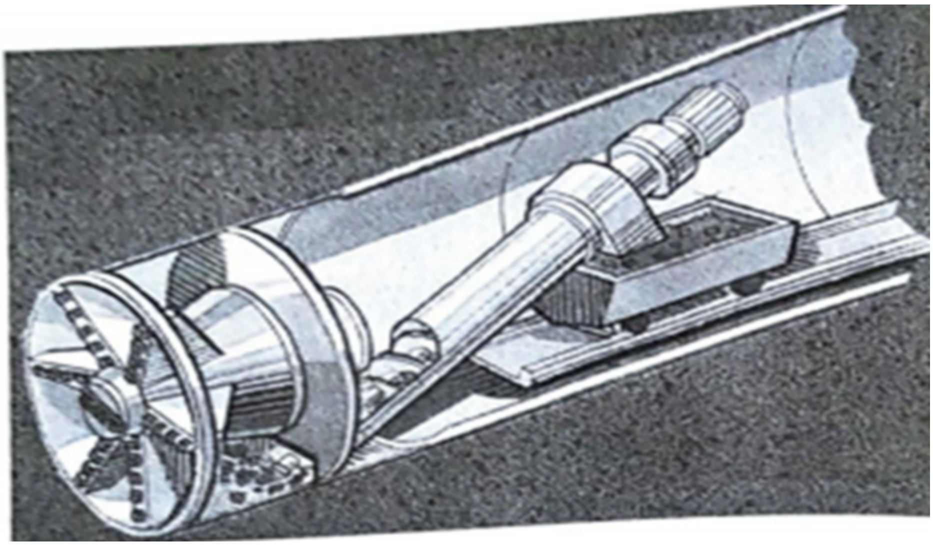


FIGURE 1.18 (a) Worker entry EPBM. (*Source: Pipe Jacking Association.*)

The special feature of Earth Pressure Balance Shields is that they use the excavated soil directly as support medium. This method is the first choice in cohesive soils with high clay and silt contents and low water permeability. A rotating cutting wheel equipped with tools is pressed onto the tunnel face and excavates the material. The soil enters the excavation chamber through openings, where it mixes with the soil paste already there. When the pressure of the soil paste in the excavation chamber equals the pressure of the surrounding soil and groundwater, the necessary balance has been achieved [1].

Slurry machine

A slurry machine as shown in Figure 1.18b is soft ground full face tunnel boring machine in which the excavated material is transported from the face in a slurry. It is also named as Slurry Balance Pipe Jacking Machine. In this machine slurry transfer system can work continuously, which enhances the average jacking speed. It has high flexibility to work in wide range of soil quality, especially for silt and sand condition. The construction excavation face is stable. The technique of using slurry pipeline can highly reduce the construction hazards. The machine is remotely controlled by the ground operating console and the response within the nose is fully automated, which can ensure the security, standardization and convenience during the operation.

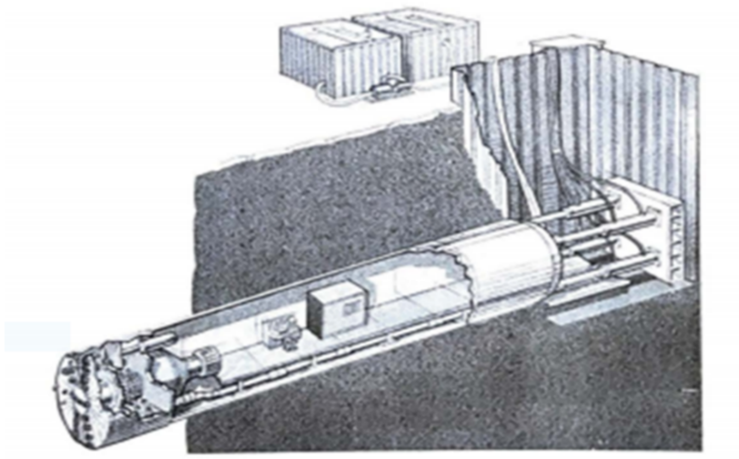


FIGURE 1.18 (b) Worker entry slurry machine. (*Source: Pipe Jacking Association*.)

1.6.2 Utility Tunneling (UT)

Najafi[1] illustrates the main feature of utility tunneling. *"Utility tunnelling is general approach of constructing underground utility line by removing the excavated soil from the front of cutting face and installing liner segments to form continuous ground support structures. The product pipe is then transported and installed inside the tunnel. The annular space between the liner and the pipe is usually filled with grout. In the utility tunneling (UT) technique, the same process as conventional pipe jacking is used, except that in utility-tunneling method, a temporary support structure (called a liner) is simultaneously constructed as the excavation of tunnel proceeds. The support structure or liner mainly forms of tunnel liner plates (TLP), steel ribs (SR) and wooden lagging (WL)."* Placement of wood or metal support beams keeps the newly made tunnel from collapsing in on workers as they continue excavating the area. The operations are two-step or two-phase fashion. The conventional pipe jacking is called a one-step or one-phase operation. In general, workers located at the face of the tunnel to perform the tunneling and remove the encountered materials. The utility tunneling methods are the same as conventional pipe jacking except in the utility tunneling, the jacking frame, intermediate jacking stations, thrust block, and lubrication and pumping equipment are not required. Since no jacking, the pipes are designed and manufactured to take only permanent loads (Figure 1.11 - 1.22), [1].

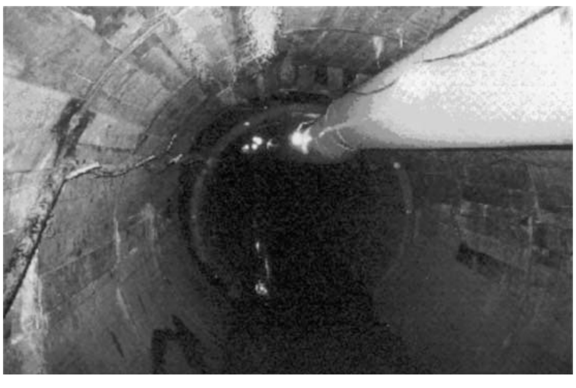


FIGURE 1.19 Inside view of a utility tunneling operations. (*Source: ISTT.*)

FIGURE 1.20 Installation of 2.250 mm diameter fiberglass pipe into an existing utility sewer. (*Source: ISTT, 2014*)

Utility tunnel is passage built underground or above ground to carry utility lines such as electricity, steam, water supply pipes and sewer pipes. The first and simplest excavation method is hand mining. Generally, workers use this excavation method for shorter tunnels as it is time-consuming. Crews work with pneumatic hand tools, picks or shovels to remove the soil. A final excavation option is the tunnelling with boring machine which uses rotary or disk cutting tool. Hand mining occurs when soil conditions vary, or large obstructions such as boulders make it challenging to use other tunneling methods. Due to the nature of this work, the minimum diameter of these lines is 1200 mm. Utility tunnels are common in very cold climates to avoid frost. They are also built-in place where the water table is to high. Tunnels are also built to avoid the danger earthquake (like in earthquake prone, İstanbul and Tokyo). UT are also built to avoid the disruption caused by recurring construction, repair and upgrading of cables and pipes [12].

FIGURE 1.21 The liner, the pipe and space to be filled (grouted). (*Source: theconstructor.org.*)

FIGURE 1.22 The utility tunneling with support structure. (*Source: ISTT.*)

1.6.3 Horizontal Earth Boring (HEB)

Najafi[1] describes horizontal earth boring processes and sub-groups. *"Horizontal earth boring machine is used to bore horizontally through the earth by means of a MTBM, cutterhead, rotating tool, or ramming tool. In the horizontal Earth-boring methods (HEBs), workers may work in the shaft or pit, but usually do not enter the borehole or enter the installed pipe (Small diameter pipe installation: 100 mm or more). The horizontal earth-boring method is further divided into a number of sub methods (Figure 1.23)."*

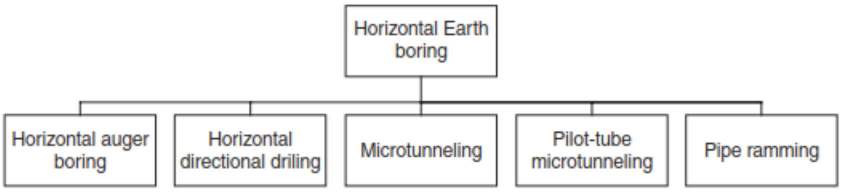


FIGURE 1.23 Horizontal Earth-boring methods. (*Najafi, 2010*)

1.6.4 Horizontal Auger Boring (HAB) Method

Horizontal auger boring technique uses of auger boring machines to prepare holes by the installation of a casing whereby the spoil is removed by the use of augers. It uses a revolving cutting head that is located at the leading end of an auger assembly to excavate the soil. Common practice is to jack the steel casing through the excavated hole as it is being bored (generally no steering capability). The spoil is then transported back to the shaft area by the rotation of the helical auger flights within the steel pipe casing. Usually, after completion of casing installation, a product pipe installed using spacers and annular gap is filled (two-step operation) with a grout (Figs 1.24 and 1.25), [1].

Horizontal auger boring machines are used to install piping underneath roadways and other infrastructure. The auger is laid into a launch pit on tracks and is slowly pushed through the ground by the machine. Casings are pushed into the bore as the auger progresses in order to keep the bore open. As each casing segment is added, a segment of helical auger is also added so that the soil is removed throughout the bore while the auger excavates the tunnel face. Once the auger reaches the receiving pit, the bore contains empty casings ready to receive the product pipe. Horizontal auger boring machines are used for the successful installation of sewage ducts and pipelines, and for crossings beneath infrastructures. It offers technical, economic and ecological advantages. Their main range of application is underground pipe jacking with comparatively small diameters, from 100 to 1400 mm with drive lengths of up to 120 meters.

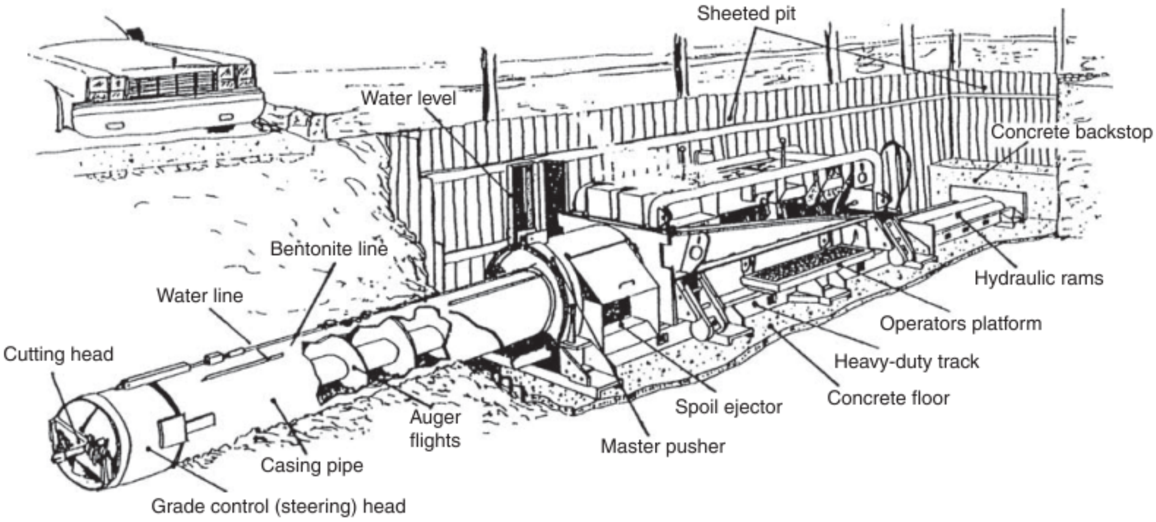


FIGURE 1.24 Track-type horizontal auger-boring operation. (*Iseley et al., 1999.*)

FIGURE 1.25 A construction work with horizontal auger boring. (*Source:* https://www.stantec.com/en/ideas/market/water/trenchless-technologies-horizontal-auger-boring)

1.6.5 Horizontal Directional Drilling (HDD) Method

Najafi[1] in his book, describes directional drilling. *"Directional drilling is a steerable system for the installation of pipes, conduits, and cables in a shallow arc using a surface launched drilling rig. Traditionally the term applies to large-scale crossings in which a fluid-filled pilot bore is drilled using a fluid-driven motor at the end of a bend-sub and is then enlarged by a wash over pipe and back reamer to the size required for the product pipe. The positioning of a bent sub provides the required deviation during pilot boring. Tracking of the drill string is achieved by the use of a downhole survey tool. This method requires the drilling of a pilot* *bore which is then enlarged with the use of reamer prior to the installation of the product pipe. Depending on the diameter of the product pipe multiple enlargements may be required. The excavation is performed by fluid-assisted mechanical action of the cutterhead (Figs 1.26 and 1.27),"*

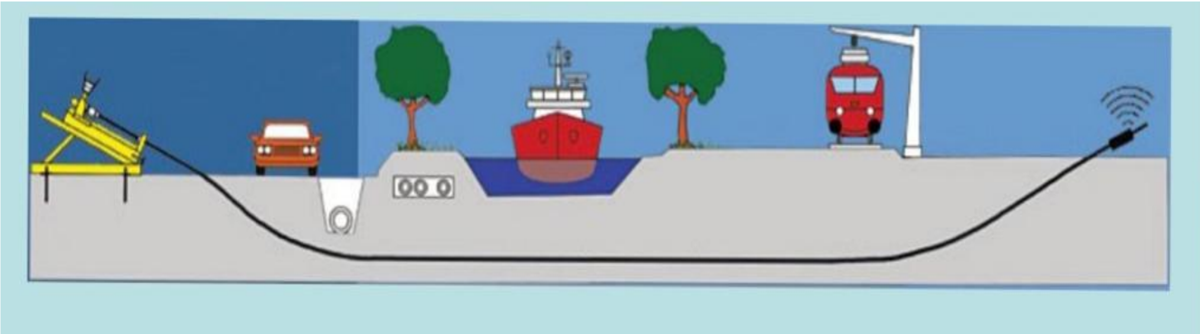


FIGURE 1.26 Benefit of HDD. (*Source: ISTT.*)

FIGURE 1.27 Birdseye view of horizontal directional drilling layout. (*Source: ISTT.*)

"The first stage of installation consists of drilling a small-diameter pilot hole along the desired centerline of a proposed profile. The subsequent stages of installation consist of enlarging the pilot hole to the desired diameter to accommodate the product pipe and the eventual pull of the product pipe trough the enlarged borehole. The enlargement process should be achieved by pulling only and not pushing the reamer (Figures 1.28 - 1.32). The directional drilling method can be classified into three broad categories of small (Mini-HDD), medium (Midi- HDD), and large (Maxi-HDD). Table 1.3 presents main features."

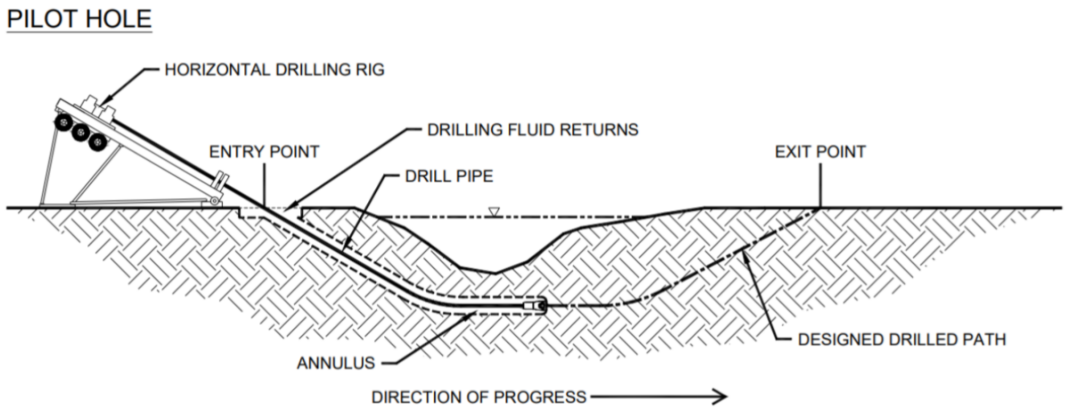


FIGURE 1.28 Pilot hole in HDD. (*Najafi, 2010*)

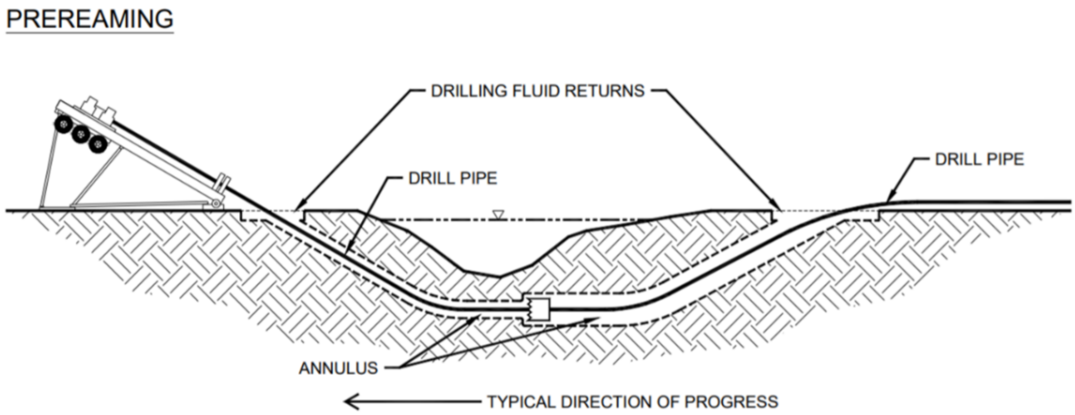


FIGURE 1.29 Prereaming in HDD. *(Source: Najafi, 2010*)

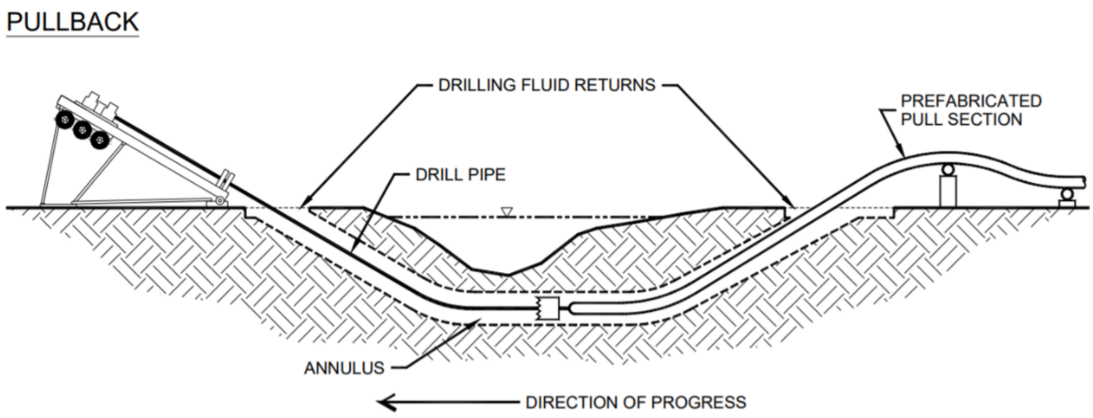


FIGURE 1.30 Pullback in HDD. *(Source: Najafi, 2010)*

FIGURE 1.31 HDD Operator pullbacks drill rods. *(Source: ISTT.)*

TABLE 1.3 Comparison of Main Features for Typical HDD Methods. *(Najafi, 2010)*

Type	Diameter (in.)	Depth (ft)	Drive Length (ft)	Torque (ft-lb)	Thrust/Pullback (lb)	Machine Weight (ton)	Typical Applications
Large (Maxi)	24–60	Less than equal to 200	Less than equal to 10,000	More than 100,000	More than 100,000	More than equal to 30	Pressure pipelines for river, shore approaches, and highway crossings
Medium (Midi)	12–24	25–75	Less than equal to 900	900–7000	20,000–100,000	Less than equal to 18	Pressure pipelines for river and highway crossings
Small (Mini)	2–12	Less than equal to 15	Less than equal to 600	Less than equal to 950	Less than equal to 20,000	Less than equal to 9	Telecom and power cables, ducts and gas lines

(1 in. = 25.4 mm,1 ft = 304.8 mm and 1 lb = 4.448 N = 0.45 kg, 1 ft-lb = 1.36 Nm)

Drilling Procedures

Drilling procedures are wisely explained by Professor Najafi [1]. *"Trailer-mounted drill rig is brought to one side of the obstacle (river, lake, road and so on) and sections of the product pipe are brought to the opposite side. Drilling and pipe installation are done in two or three steps. In the first step, a small pilot hole of 50 to 150 mm diameter is moved along the desired path of the pipeline. As drilling proceeds, segments of the drill pipe are added to form to pilot string. Through the pilot string, drilling fluids (mud, bentonite, polymer slurry) is pumped through the nozzles. The cuttings (spoils) are carried back to the rig side (Figure 1.33). In step 2, called prereaming, the drill bit is removed from the product pipe side. Segments of the drill pipe are added on the pipe side to the pilot string as they are being pulled back. This step is specifically required to prevent the contractor from pushing the reamer through the borehole, which may cause heaving of ground surface and damage to nearby utilities (Figure 1.34). In step 3, a larger reamer is used to achieve the desired size borehole (usually 1.5 times the outside diameter of the product pipe) and to pull the product pipe under the obstacle along the borehole (Table 1.4). Drilling fluids are pumped through nozzles in the reamer to lubricate the pipe being pulled and to remove spoils. Step 3 ends when the entire pipeline is pulled into the borehole beneath the obstacle (Figure 1.35)."*

Installation

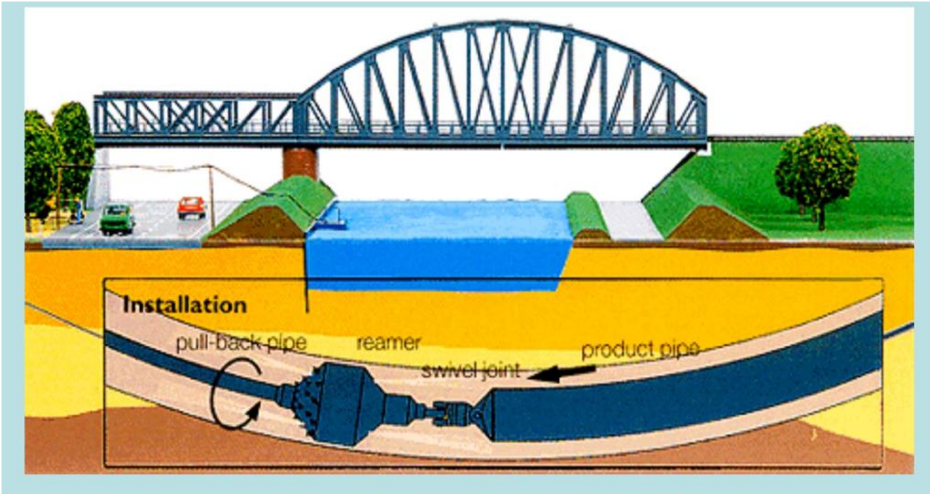


FIGURE 1.32 Pull back product pipe for installation by HDD. (*Source: ISTT.*)

TABLE 1.4 Reamer Diameters. *(Najafi, 2010)*

Product Pipe Outside Diameter	Approximate Reamer Diameter
Less than 8 in.	OD[a] + 4 in.
Between 8 and 24 in.	OD × 1.5 in.
More than 24 in.	OD + 12 in.

[a]OD—outside diameter of product pipe (1 in. = 25.4 mm).

A down hole survey system is used in large-size and some medium-size HDD operations. A pinpoint the location of the drill head from above ground is managed. A walkover survey system is used for small-size HDD systems. In Figures 1.33 through 1.35, three stages of an HDD operation can be seen with critical parts.

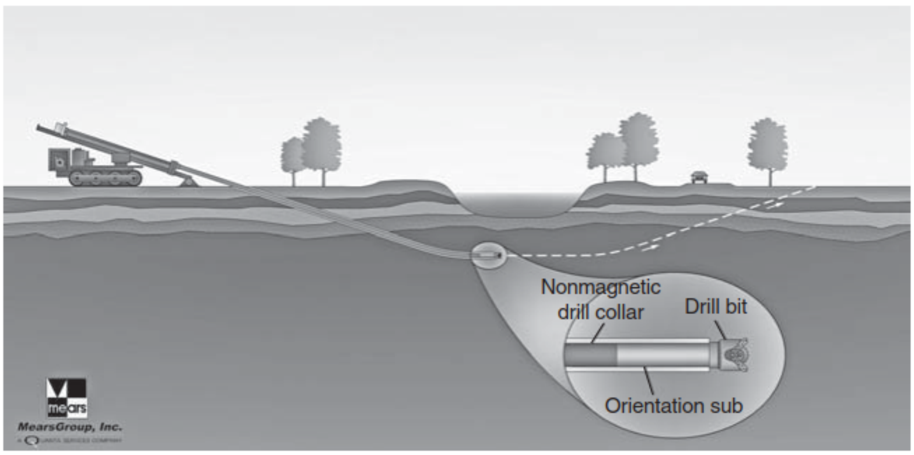


FIGURE 1.33 HDD step 1: Pilot-hole drilling. *(Source: Mears.)*

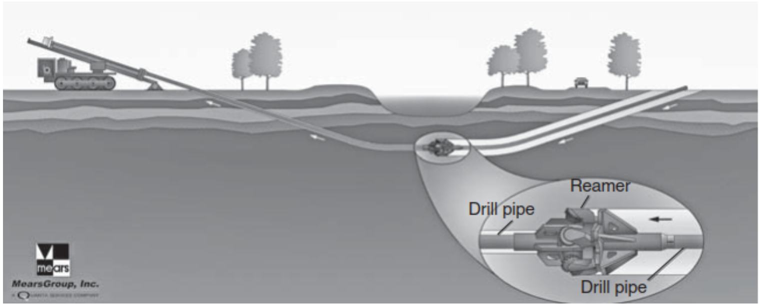


FIGURE 1.34 HDD step 2: Prereaming. *(Source: Mears.)*

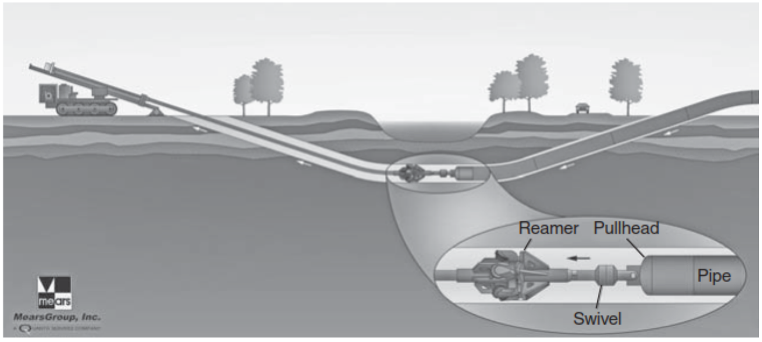


FIGURE 1.35 HDD step 3: Product-pipe pullback. *(Source: Mears.)*

1.6.6 Microtunneling (MT) Method

The microtunelling method is mainly used for installation of a gravity pipeline such as a sanitary or storm sewer. Microtunneling can install pipelines in deep levels which are difficult to reach with the normal excavators. Microtunnel boring machines (MTBM) are very similar to normal tunnel boring machines (TBMs) but are of a reduced size. Therefore, microtunneling is an important trenchless construction method for installing pipelines.

Microtunneling has a lot of advantages compared to the dig. Drive shaft for jacking and exit shaft for retrieving the MTBM are important. Main components and functions:

- Remote controlled (control panel on the surface)
- Laser guided (laser beam projected onto a target in the MTBM)
- Jacking system (consecutively pushing the MTBM)
- Face support (continuous pressure to the face of the excavation to balance groundwater and earth pressure) An accuracy of 25 mm in both horizontal and vertical alignments.
- Spoil removal by a slurry transportation.

MT is applicable to many types of soils. (1) Remote controlled- MTBM is operated from a control panel, normally located on the surface. The system simultaneously installs pipe as spoil is excavated and removed. Personnel entry is not required for routine operation. (2) Guided-The guidance system by a laser beam projected onto a target, capable of installing gravity sewers or other types of pipelines to the required tolerance, for line and grade. (3) Pipe jacked-The process of constructing a pipeline by consecutively pushing pipes and MTBM through the ground using a jacking system for thrust. (4) Continuously supported-Continuous pressure is provided to the face of the excavation to balance groundwater and earth pressures. Microtunnel boring machine (MTBM) is pushed into the earth by hydraulic jacks mounted and aligned in the jacking shaft. The jacks are then retracted, and the slurry lines and control cables are connected or disconnected. MTBM are laser guided and remotely controlled which permit accurate monitoring and adjusting of the alignment and grade as the work proceeds so that the pipe can be installed on precise line and grade. This system is primarily applied into areas where main road, railway, subway lines, airport and river passing; and areas where open excavation is risky. Initially, microtunneling methods were developed for pipes 900 mm or less. The potable water, sewage, natural gas, connection tunnels and similar projects can successfully be conducted by the microtunneling machines whose diameter vary between 800 mm to 3000 mm [1].

Figure 1.36 shows layout of microtunneling and various sections. Figure 1.37 details the machinery. Figure 1.38 presents sequence of microtunneling and pipe-jacking operation.

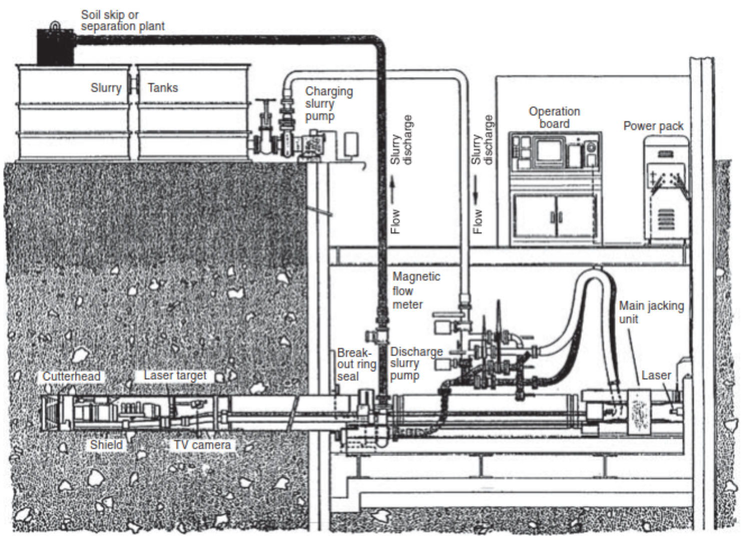


FIGURE 1.36 Schematic of a microtunneling operation. *(Source: Iseley et al., 1999)*

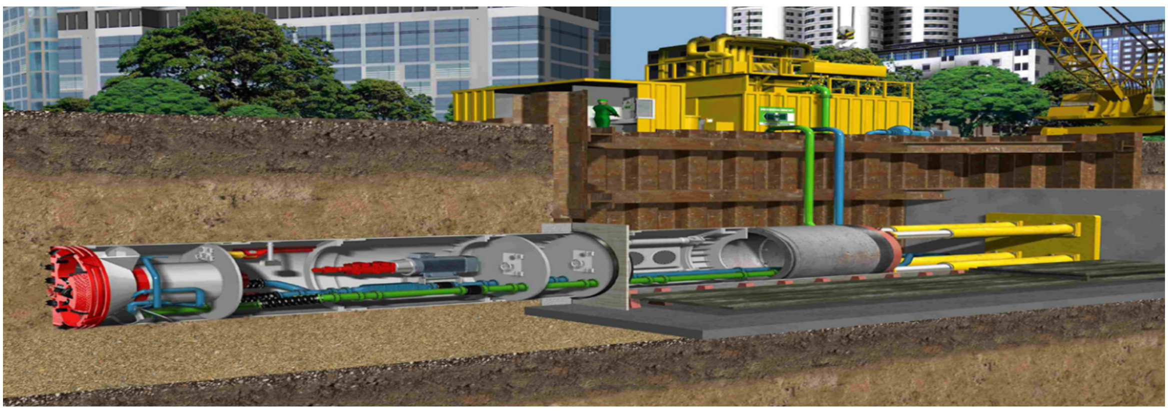


FIGURE 1.37 Machinery of microtunneling. *(Source: ISTT)*

The high accuracy of pipeline position is achieved with very tight tolerance due to usage of the modern laser guidance system and steering support. The availability of making road crossing without any stoppage of traffic flow or even crossing a water canal are main areas for MT.

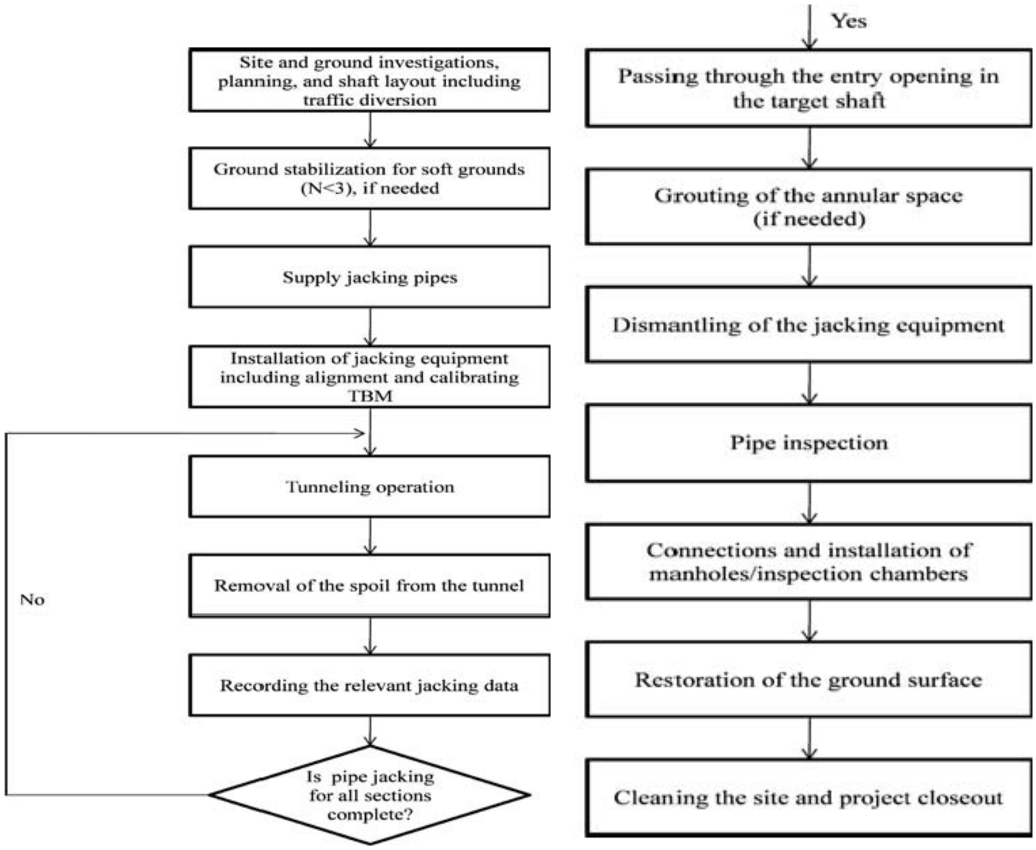


FIGURE 1.38 Microtunneling and pipe-jacking construction sequence *(Source: Najafi, 2010)*

1.6.7 Pilot-Tube Microtunneling (PTMT) Method

Pilot tube microtunneling (PTMT) has been increasing in popularity year after year since it was first introduced in the United States in 1995. This guided-boring process has grown to become a replacement for the early small diameter auger microtunnel machines. The PTMT process of installing sewer pipe is essentially a hybrid of three trenchless boring techniques:

1. A slant-faced steering head similar to that of a directional drilling,

2. The guided accuracy of a conventional microtunnel machine,

3. An auger type spoil removal system similar to a horizontal auger boring.

Pilot tube microtunneling is defined as an alternate microtunneling system for sizes 200 mm through 450 mm and larger nominal internal diameter pipe (Figure 1.39) [13].

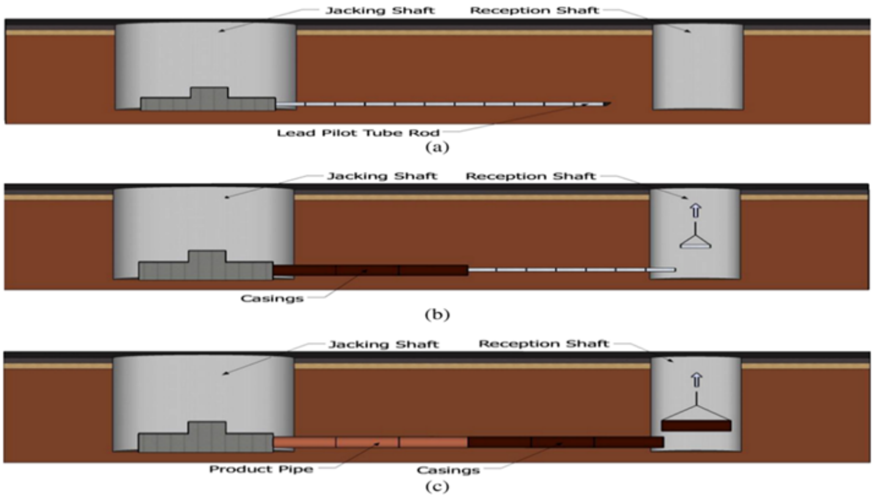


FIGURE 1.39 Pilot tube microtunneling working principle. *(Source: ISTT.)*

Najafi[1] illustrates the extreme case of PTMT. *"PTMT, also called guided auger boring, and auger drilling, used in Europe for installation of 100 to 150 mm service lateral connections. PTMT is an alternate and cost-effective method to conventional microtunneling. It combines the accuracy of microtunneling, the steering mechanism of directional drill, and the spoil-removal system of an auger-boring machine (LEDs to secure high accuracy in line and grade). Drive distances are less than 100 m, and pipe diameters are less than 700 mm."*

PTMT Operations

Najafi[1] detailes PTMT. *"PTMT operation begins with excavation of driving and receiving shafts. These shafts are usually 2 to 2.5 m in diameter. The larger shafts are generally square or rectangular. The PTMT machine is then lowered down into the drive shaft and is set to precise line, grade, and height from a control point established using surveying techniques. Pilot tube microtunneling is a multistage method. This method allows for accurately installing a product pipe to line and grade by use of a guided pilot tube, followed by upsizing to install the product pipe. PTMT consists of three stages.The first step involves the installation of a pilot tube precisely over the center line of the prospective sewer or water line as shown in Figure 1.40. The spoil is displaced by a slant-faced steering head. Pilot tube is directed at precise line and grade during advancement. The hollow stem of the pilot tube provides an optical path for the camera to view the LED target in the steering head, displaying the head position and steering orientation. This establishes the centre line for the installation of the new pipe."*

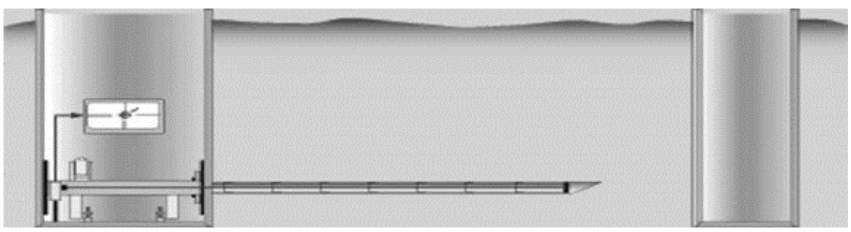


FIGURE 1.40 PTMT operation, step 1: Installation of pilot tube. *(Source: Bohrtec, 2008)*

"In step 2, the pilot tubes at the drive shaft are connected to a reamer with a diameter slightly larger than the diameter of the product pipe. Following the reamer is the auger casing, which helps in transporting the spoil back to the shaft (Figure 1.41)."

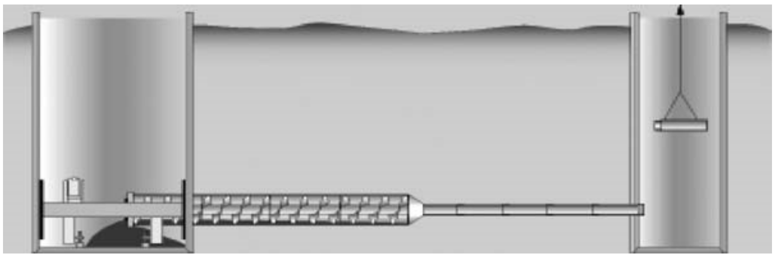


FIGURE 1.41 PTMT operation, step 2: Insert auger casing. *(Source: Bohrtec, 2008)*

"Finally, replacing the auger body with the product tube having the same diameter as the auger body. The product pipes are pushed one by one as the auger casings are removed from the opposite shaft as shown in Figure 1.42. There is no spoil removal in this step."

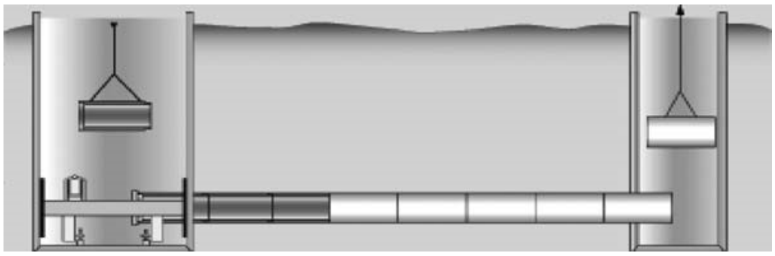


FIGURE 1.42 PTMT operation, step 3: Replace auger casing with product pipe. *(Source: Bohrtec, 2008)*

"PTMT technique can also be used for house connections, shortly lateral connections. Figure 1.43 gives laterals which connect building drain or sewer into a larger-diameter sewer (sanitary)."

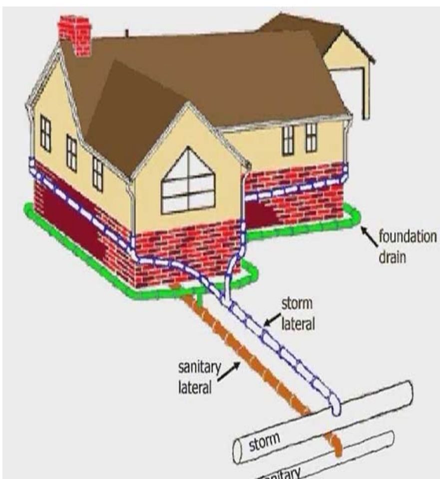


FIGURE 1.43 Laterals for sanitary and storm. *(Source: ISTT)*

1.6.8 Tunnel Boring Machine (TBM)

Since underground tunneling is very important in city life, some general information about TBM is given here. Normally, TBM is out of scope of this book,

TBM is a full-face circular mechanized shield machine, usually of worker-entry diameter, steerable, and with a rotary cutting head. For pipe jacking installation it has a string of pipes. It may be controlled from within the shield or remotely such as experienced in microtunneling. A mechanical excavator used in tunnelling to excavate the front face of the tunnel. TBM is a machine that excavates various soil or rock layers with circular cross sections as demonstrated in Figure 1.44. It is called tunneling head and also known as "mole". It can bore all kinds of matter, from hard rocks to sand. Tunnel diameter can vary from 1 meter to 19 meters. Trenchless technologies methods such as horizontal directional drilling (HDD) are used for tunnels with a lowest diameter indicated above.

Tunnel boring machines are an alternative to drilling and blasting (D&B) methods used in traditional manual construction also known as "hand mining" in rock or soil. TBM also have features such as reducing the problems that may occur on the surrounding ground and opening a smooth tunnel wall. This also significantly reduces the cost of tunnel lining and makes them use in crowded areas. The biggest drawback is its apparent cost. Although installing and transporting of TBM is rather expensive, the cost of drilling method decreases as the length of modern tunnels increases. Even if the cost of tunnel drilling machine is high, tunneling with TBM is much more effective and results can be obtained in a very short time.

FIGURE 1.44 Tunnel boring machine. *(Source:www.behance.net/gallery/20377183/ixtract-tunnel-boring-machine-TBM)*

Figure 1.45 shows the tunnel boring machine used in The Eurasia Tunnel Project. The tunnel boring machine (TBM) called "Yıldırım Bayezid" that carries out the tunnel excavation in the Eurasia Tunnel; It ranks 1st in the world with 33.3 kW/m^2 cutter head power, 2nd place with 12 bar design pressure and 6th with a cutter head area of 147.3 m^2 (D=13,7 m). The Eurasia

Tunnel Project (Istanbul Strait Road Tube Crossing Project) connects the Asian and European sides of Istanbul/Turkey via a highway tunnel crossing underneath the seafloor. The Eurasia Tunnel, between traffic-dense Kazlıçeşme and Göztepe, covers a route of 14.6 kilometers [14].

FIGURE 1.45 Tunneling machine Yıldırım Bayezid (DN:13,7 m) for The Eurasia Tunnel. *(Source: www.avrasyatuneli.com/kurumsal/galeri/fotograf/tbm-tunel-acma)*

Recent development of tunnelling machine has a lot of amazing facts: Autonomous robotic boring machines are under discussion in industrial circle. The Ecnomist Article [5], "Boring technology: Underground adventures" put forward future of TBMs. *"Advanced machines can detect and avoid obstacles such as pipes, cables, the foundations of buildings and even buried boulders. At the front, a cutting wheel with a diameter a little larger than that of the final tunnel (to allow for the thickness of the lining) is pushed forward by pistons and chews away at soil and rock as it travels. The spoil from this excavation is then taken to the surface by conveyor belts. Once enough material has been cleared, the borer is stopped, and the newly exposed section is lined with precast concrete sections. Other development is to make boring machines more powerful, so that they can cut through material faster. It also wants to automate things, to reduce labour costs, and to line the tunnel as the machines progress, instead of stopping excavation when linings are added. One idea is to compact the spoil into bricks and use those as lining material,*

Boring is being designed specifically for small-diameter tasks, such as digging conduits for cables and pipes. However, a two-lane road tunnel needs to be about 8.5 metres wide. Speeds of around two metres an hour are expected (currently average daily advance rate is 8-10 m/day for TBM and 1-2 for open trenching). It should be possible to increase both speed and scale. TBM face will combine a conventional rotary cutting head with an ultrasonic drill, which will pulverise rock with high-frequency sound waves. As with existing machines, the spoil will then be sent to the surface. Unlike existing machines, however, mole will move forward not as a rigid unit, but like a worm. The rear section will clamp itself to the wall of the newly cut tunnel and push the front section forward. The forward section will then clamp itself and pull up the rear. As it advances, a 3D printer will line the tunnel behind it. One idea is to print the wall with plastic, so that the result resembles a conventional pipe. TBM will navigate using various sensors including, crucially, ground-penetrating radar. This will enable it to operate autonomously and detect potential obstacles before it reaches them, so that it can steer around them. The great benefit of it is being able to excavate tunnels below busy cities without closing roads to dig trenches-thus avoiding making the traffic jams.

Whether the tunnels are straight or loopy, though, the future of tunnelling will be anything but boring Many of the proposed developments given above are being tested in boring companies [15]. Famous entrepreneur Elon Musk's (USA) Boring Company is one of them. Main objective is to dig tunnels faster and more cheaply than is possible at the moment. Mr Musk is surely right about one thing-that tunnelling, which is currently slow and expensive, is a technology incentive for innovation."

1.6.9 Pipe Ramming (PR) Method

Pipe ramming is a nonsteerable system of forming a bore by driving an open-ended steel casing using a percussive hammer from a drive pit. The soil may be removed from the casing by augering, jetting, or compressed air. Like horizontal auger-boring machine, pipe ramming machine is mainly used for short distance. Installation of pipelines for road and railroad crossing are main applications. The main differences between the pipe ramming method and pipe jacking method are that pipe ramming uses percussion and does not have a navigation system, while pipe jacking uses hydraulic jacks and does have an active navigation system. The pipe ramming method is preferable for shorter distances and applications that does not require very tight directional control such as cable installations. Pipe ramming method hammers a steel casing by using an air compressor. Operation initiated from a drive pit and ends generally at exit pit, sometimes at the slope. The pipe, closed end (for diameters less than 20 cm) or open end (for diameters of 20 cm or more) might be hammered. Figure 1.46 illustrates a schematic of open-faced pipe-ramming operation. In a pipe ramming operation, a ramming tool attached to the rear of a steel pipe drives the pipe into the ground with repeated percussive blows (Figure 1.47). As the pipe rammer pushes the pipe through the soil, rocks, boulders, and other obstacles are "swallowed" into it. When using large diameters, the spoil is pushed out of the steel casing using air pressure, fluid pressure and mechanical means, such as bobcat. The soil may be removed from the casing by augering, jetting, or compressed air.

The pipe ramming method can be used for longer and larger installations. This method is more useful than other trenchless methods in places that may cause collapse. It enables the laying of large diameter pipes of shallow depth. Set up time is fast. It has some disadvantages. One of them is the sound it produces is very loud. Small diameter pipes are difficult to clean.

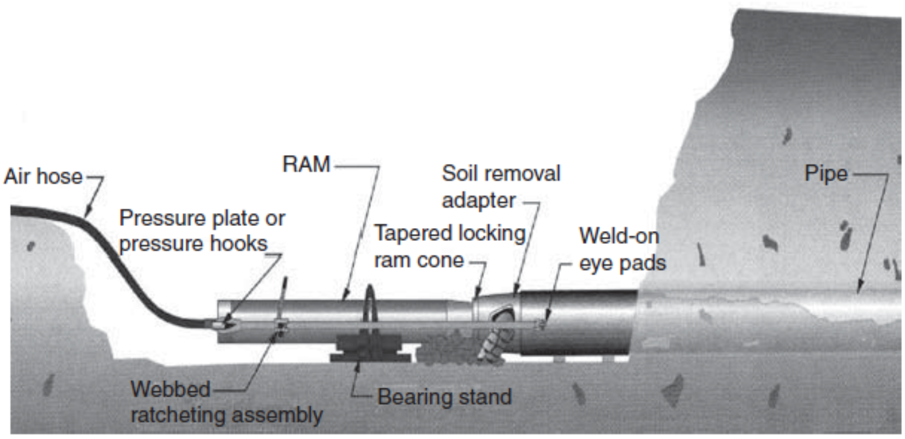


FIGURE 1.46 Pipe ramming. *(Source: TT Technologies, Inc.)*

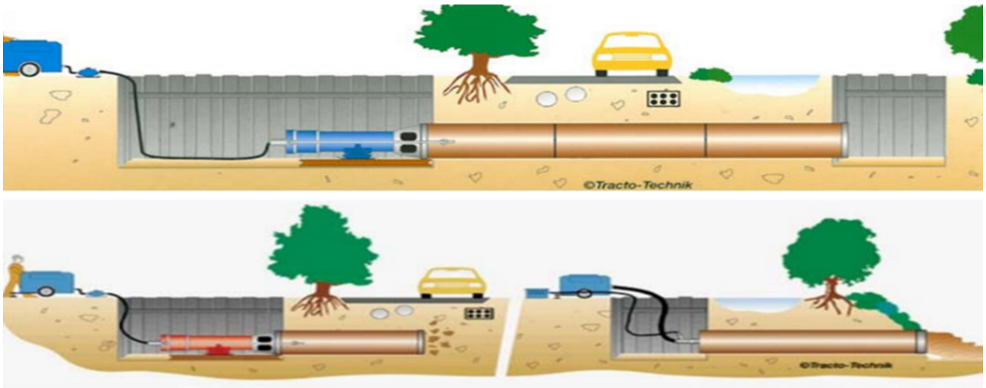


FIGURE 1.47 Pipe ramming uses. *(Source: TTUK Ltd.)*

The Pipe Ramming method is preferable for shorter distances and applications does not require very tight directional control such as cable installations.

Method Description

FIGURE 1.48 Pipe ramming and spoils. *(Source: ISTT.)*

FIGURE 1.49 Pipe ramming machine in the field. *(Source: ISTT.)*

When casings are installed, pipes of other types for distribution of sewerage, water, gas, electrical or telecommunication cables are subsequently inserted (two-phase process). This pipe ramming method provides accurate trenchless casing installation in a wide range of soil without surface slump.

The Pipe Ramming method and its description have given by Najafi [1]. *"For pipes of up to 200 mm diameter, the pipe can be driven either by having the leading end of the pipe in a wedge or cone shape. The soil is compressed around the pipe as it is being rammed and there is no spoil. For pipes larger than 200 mm the leading end is usually left open and a band is installed around the outside edge of the leading section. The band reinforces the leading edge and decreases the friction around the casing. For long length and certain soil conditions (such as stiff clays or sands) a steel pipe is installed on the top of the rammed pipe to supply water, bentonite, and/or other drilling lubricants to facilitate spoil removal and reduce friction. Special adapters can be used, and pipe segment is welded or jointed by interlocking. After the completion of ramming, cleaning out of the pipe can be done by variety of methods. The product pipe can be inserted mainly for pressure applications (water and gas). Pipe ramming method does not remove soil until casing is installed (Figs 1.48 to 1.50),"*

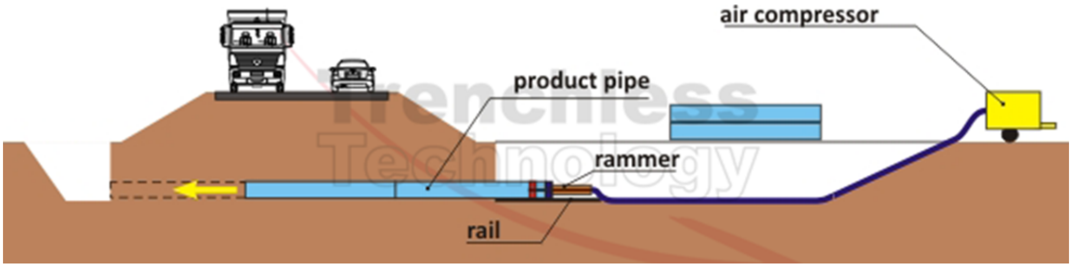


FIGURE 1.50 Pipe ramming. *(Source: www.TRENCHLESS.EU)*

A pneumatic pipe rammer may effectively be used to salvage a stuck product pipe. Using pipe ramming in HDD project is general approach and one example is sketched in Figure 1.51.

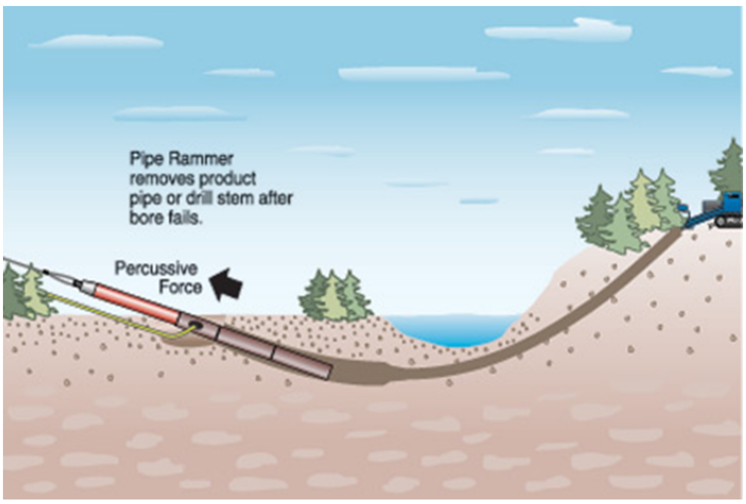


FIGURE 1.51 Pipe ramming in HDD. *(Source: ISTT)*

1.6.10 Impact Moling (IM) Method

Impact moling is a trenchless installation method for placement of small diameter pipes, ducts and cables, in which percussion or hammering action of a pneumatic piercing tool is used to create the bore by compacting and displacing the soil rather than removing it. Impact moling (also known as compaction method, earth-piercing tools, soil-displacement hammers, impact hammers, percussive moles or pneumatic moles) is used to install the things less than 10 in. (250 mm) diameter. The method typically is non-steerable, although steerable systems have reached the market in recent years (Figure 1.52).

Torpedo shape impact moling equipment creates a bore by using a pneumatic or hydraulic hammer applied on a casing. The term is usually associated with nonsteered or limited steering devices without rigid attachment to the launch pit, relying upon the resistance of the ground for forward movement. During the operation the soil is displaced, not removed. An unsupported bore may be formed in suitable ground, or a pipe drawn in, or pushed in, behind the impact moling tool.

When properly planned and executed, impact moling can be a simple and cost-effective trenchless installation method. Utility companies widely use this technique for installation of service connections to gas, water, and sewer mains, usually under sidewalks, driveways, and other short crossings under 45 m [1]. Features:

- Easy to operate
- Low cost (require small air compressor only)
- Requires little to no excavation for the connection and termination pits
- The diameter and length of the bore is limited
- It works best in compressible soils

Method Description:

Najafi [1] have given the description of impact moling. *"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 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. Figure 1.53 illustrates a schematic of impact moling operation."*

FIGURE 1.52 Impact moling. *(Source: ISTT)*

There are two main types of impact moling as nonsteerable moles and steerable moles.

i) Nonsteerable moles

Typically involve the excavation of two pits. The tools expected to advance through the ground in a straight line. A single person can operate the mole. There are two basic non-steerable systems available:

• Rigid System

• Stroke Method

• Rigid System: The piston applies impact to the casing and drives the complete displacement hammer and the attached pipe string forward with one blow.

• Stroke Method: The piston first strikes the mobile multi-cutter cone and then the casing, so that the soil displacement hammer moves forward in two steps.

ii) Steerable moles

Steerable moles may be launched from the surface or from a pit. The operations require a two-man crew. Walkover tracking system and remote steering, similar as in HDD industry is used. One operator walks the bore route with a walkover locator device and monitors the progress of the tool in the ground. The other operator implements the required course corrections using the guidance controls. A product pipe, cable, or cable duct is inserted into place after the borehole is completed [1].

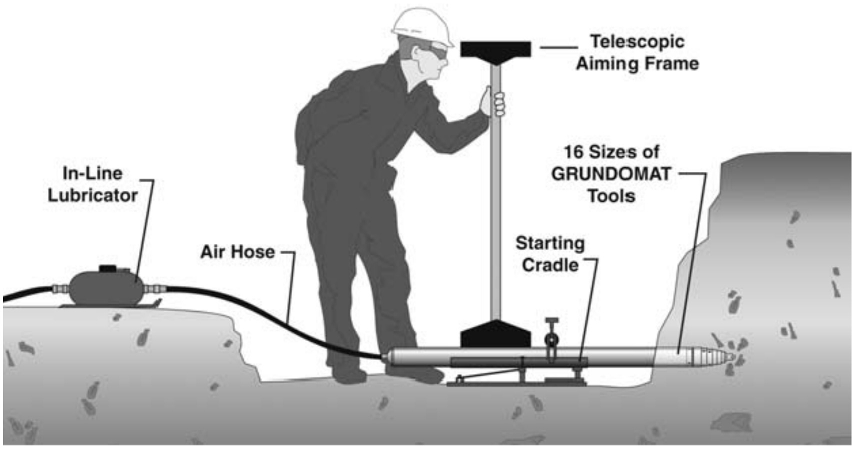


FIGURE 1.53 Impact moling. *(Source: TT Technologies)*

1.7 Characteristics and Applications of Trenchless Construction Methods

In this section Najafi [1] provides main restrictions of pipeline construction. *"This section provides information on the various trenchless methods and their applicability to the individual types of pipelines and utility installations.*

Construction method selection may include following restrictions:

- *Ground conditions*
- *Availability of experienced trenchless technology contractors and appropriate equipment*
- *Cost*

- *Safety*
- *The technical feasibility of the method desired*

The materials presented in this section should only be used as a guide. Standard pipe sizes, bore lengths, and bore depths are considerations in determining the appropriate method. Table 1.5 presents main characteristics of trenchless methods for new installations and Table 1.6 provides appropriate techniques for specific applications"

TABLE 1.5 Main Characteristics of Trenchless Installation Methods. (*Najafi, 2010*)

Trenchless Method	Diameter Range (in.)	Inst. Length (ft)	Max Depth (ft)	Pipe Material[c]	Typical Application	Accuracy
Conventional pipe jacking & utility tunneling	42 & up (144 in.)	1600–3500	N/A[a]	RCP, GRP, steel	Pressure & gravity pipes	± 1 in.
Auger boring (conventional)	4–60	600	N/A[a]	Steel	Road & railroad crossings	± 1% of the bore length
Auger boring steered on grade[a]	4–60	600	N/A[a]	Steel	Pressure & gravity pipes	± 1 in.
Auger boring steered on line + grade[a]	4–60	600	N/A[a]	Steel	Pressure & gravity pipes	± 12 in.
Mini-HDD	2–12	600	60	HDPE, steel, PVC, ductile iron	Pressure pipes/conduits/ cables	Varies
Midi-HDD	12–24	600–2000	100	HDPE, fusible PVC, steel, ductile iron	Pressure pipes	Varies
Maxi-HDD	24–60	2000–6000	200	HDPE, steel	Pressure pipes	Varies
Microtunneling	12–136	1500	N/A[b]	RCP, GRP, VCP, DIP, steel, PCP	Gravity pipes	± 1 in.
Pilot tube microtunneling	6–30	300	N/A[b]	RCP, GRP, VCP, DIP, steel, PCP	Small-diameter gravity pipes	± 1 in.
Pipe ramming	4–140	400	N/A[b]	Steel	Road & railroad crossings	Dependent on setup

(1 ft = 304.8 mm and 1 in. = 25.4 mm)

TABLE 1.6 Specific Applications. *(Najafi, 2010)*

Trenchless Method	Water	Sanitary and Storm Sewers	Gas	Electricity	Telecommunications
PJ and UT	N/A	Yes	No	No	N/A
HAB	Yes	Marginal	Yes	Yes	Yes
HDD	Yes	Marginal	Yes	Yes	Yes
MT	No	Yes	No	No	No
PTMT	Yes	Yes	No	No	No
PR	Yes	Marginal	Yes	Yes	Yes

The data given by Najafi[1] in Table 1.7 shows depth and soil condition for installation. *"Table 1.7 presents minimum safe installation depths for various trenchless installation methods categorized into different pipe diameters and soil conditions. Minimum installation depths depend heavily on subsurface conditions. Method used and pipe diameter, other factors such as type of trenchless equipment used, operators skills, project location, surface conditions, and adjacent utilities and structures are also important."*

TABLE 1.7 Minimum Depth Guideline Based on Conditions and Diameters For Trenchless Installation Methods. *(Najafi, 2010)*

Pipe Diameters (in.)	Soil Conditions	PJ/UT	HAB (ft)	HDD (ft)	MT	PTMT	PR (ft)
Small (<12)	Clayey	6 ft of cover or 3 times outside diameter whichever is more	4	4	6 ft of cover or 3 times outside diameter whichever is more	4 ft of cover or 3 times outside diameter whichever is more	2
	Silty		4				
	Sandy		6				
	Gravely		6				
Medium (12~24)	Clayey		6	8			3
	Silty		8				
	Sandy		12				
	Gravely		20				
Large (>24)	Clayey		10	25			4
	Silty		14				
	Sandy		20				
	Gravely		25				

(1 ft = 304.8 mm and 1 in. = 25.4 mm)

The detailed information shared by Najafi[1] gives general outline for implimantations. *"Among other factors, minimum depth depends primarily on the type of soil and diameter of the pipe. Unstable soil conditions (such as running sand) require deeper installations, while more stable soils such as hard clays would allow for shallower installations. Each project is unique and for a safe and successful operation, judgment of a professional engineer knowledgeable in trenchless technology methods is required. Standard pipe sizes, bore lengths and bore depths are main indicator. Table 1.8 presents selection of trenchless method based on type of pipe, pipe installation, and method of excavation and soil removal."*

TABLE 1.8 Selection of Trenchless Method Based on Type of Pipe, Pipe Installation, and Method of Excavation and Soil Removal. *(Najafi, 2010)*

Method[a]	Pipe/Casing Installation Mode	Suitable[b] Pipe/Casing	Soil Excavation Mode	Soil Removal Mode
CPJ	Jacking	Steel, RCP, GFRP, PCP	Manual or mechanical	Augers, conveyors, manual carts, power carts, or hydraulic
UT	Manual	Steel, RCP, GFRP, PCP	Manual or mechanical	Augers, conveyors, manual carts, power carts, or hydraulic
HAB	Jacking	Steel	Mechanical	Augers
HDD	Pulling	Steel, PVC, HDPE, DI	Mechanical and hydraulic	Hydraulic
MT	Jacking	Steel, RCP, GFRP, PCP, VCP, DIP	Mechanical	Hydraulic (slurry)
PTMT	Jacking	RCP, GFRP, VCP, DIP, Steel, PCP	Mechanical	Augers
PR	Hammering/driving	Steel	Mechanical	Augers, hydraulic, compressed air, mechanical skid
PB[c]	Pulling/pushing	(Steel, clay, HDPE, PVC, GFRP)[d] (Clay, concrete, cast iron, steel, DIP)[e]	Mechanical	Compaction

Abbreviations: HAB-horizontal auger boring, PR-pipe ramming, CPJ-conventional pipe jacking, HDD-horizontal directional drilling, MT-microtunneling, PB-pipe bursting. RCP–reinforced concrete pipe, GFRP–glass fiber reinforced plastic pipe, PCP–polymer concrete pipe, VCP–vitrified clay pipe, DIP–ductile iron pipe, PVC–polyvinyl chloride pipe HDPE–high density polyethylene pipe, MDPE–medium density polyethylene pipe.

1.8 Capabilities and Limitations of New Installation Methods

Trenchless technology methods have many benefits over traditional open-cut and trenching techniques. Benefits of Trenchless Technology:

Eliminating or Reducing 4D facts;

- Disruptions of Traffic.
- Damage to pavement and road structure.
- Dust and noise.
- Dirt and safety hazards.

Conditions that trenchless applications are not appropriate:

- Existence of big rocks.
- Abandoned man-made objects and structures (historical structures).
- Specific project conditions.
- Uncertain location of existing utilities.

1.8.1 Conventional Pipe Jacking and Utility Tunneling

Advantages

- Possible for almost all types of soil.
- Operator located at the excavation face (immediate corrective actions).
- Operator can see what is taking place and take immediate corrective actions for changing subsurface conditions.
- Visual or video camera inspection.
- In utility tunneling, only a small jacking force, only the shield, no jacking pipe, pipes with less wall thickness.

Limitations. Najafi[1] listed a set limitations. *“*

- *A lot of planning and coordination.*
- *All directional changes be made at the shafts.*
- *Pipe should be strong enough to resist jacking forces (in pipe-jacking method).*
- *In utility tunneling, the liner is classified as a temporary structure. A product pipe (carrier pipe) must be transported and installed inside the tunnel.*
- *In utility tunneling, annular space between the product pipe and tunnel liner be filled with grout.”*

1.8.2 Horizontal Auger Boring

Advantages. Najafi[1] listed a set advantages. *“*

- *The casing is installed as the borehole excavation takes place.*
- *There is no uncased borehole that substantially reduces the probability of cave-in.*
- *This method can be used in a wide variety of soil types.”*

Limitations

- Unsteerable
- Entry (shaft) that must accommodate pipe section lengths usually > 6m.
- Site investigation is required (for boulders, running sands, very soft ground condition).
- Accommodate rocks up to one-third of the diameter of the casing.
- Casing must be made of steel.
- With larger casing pipe installation (worker entry), it is possible to use smaller casing tubes with auger inside.
- Risk of heaving.
- Welding of two pipe sections (taking several hours).
- After casing product pipe installation (a two-phase process) [1].

1.8.3 Horizontal Directional Drilling

Advantages. Najafi[1] listed a set advantages. *"*

- *The major advantage of HDD is its steering capability.*
- *In case of hitting obstacles, the drill head can be pulled back and guided around obstacle.*
- *Small entry and reception pits (to collect drilling fluid) required.*
- *Setup time is relatively shorter than other required trenchless installation methods.*
- *The single HDD drive length that can be achieved (up to 1800 m) is longer than any other non-worker-entry trenchless method."*

Limitations

- The bore may collapse in some granular (gravelly and sandy) soils.
- In very soft soils, the steering ability may become difficult.
- Fluid recycling method is to be used. U.S. Environmental Protection Agency (EPA) does not consider bentonite and certain polymers toxic materials!
- Drilling and back reaming are time consuming and costly.
- Care should be taken on ground movement, pressurized fluids and slurry migration
- Maxi-HDD operations may require a relatively large area.

1.8.4 Microtunneling

Advantages. Najafi[1] listed a set advantages. *"*

- *The microtunneling method is capable of installing pipes to accurate line and grade tolerances*
- *It has the capability or performing in difficult ground conditions without expensive dewatering systems and/or compressed air systems to pressurize the tunnel face.*
- *Pipe can be installed at a great depth without a major cost increase.*
- *The depth factor becomes increasingly important as underground congestion is increased or high-water table and difficult ground conditions are encountered, where open cut method becomes very costly.*
- *In this method, safety is enhanced, as workers are not required to enter the tunnel*

- *Microtunneling system protects the environment.*
- *Microtunneling system does not create noise pollution.*
- *The carrier (product pipe), with sufficient axial load capacity, can be jacked directly (a one-phase process),"*

Limitations

- The capital cost of equipment is high. Distribution of costs for a 500 m of hypothetical microtunnel includes 17% for pipe, 61% for pipe jacking and 22% for shaft construction.
- However, on projects where this method has been competitively bid against other tunneling methods, the unit price costs have been competitive.
- Some MTBM system have difficulty in soils with boulders (rocks) more than one-third of the machine diameter.
- Average daily advance rate is 8-10 m/day for microtunneling and 1-2 for open trenching [1].

1.8.5 Pilot-Tube Microtunneling

Advantages. Najafi[1] listed a set advantages. *"*

- *The change-over and setup times are short.*
- *The machine technology and operation are simple.*
- *The investment costs for the equipment is reasonable.*
- *The space needed to set up the equipment is small."*

Limitations. Najafi[1] listed a set limitations. *"*

- *Steerability becomes difficult with increasing jacking distance.*
- *Because of the absence of position monitoring steering capabilities during the reaming process, obstacles or collapsing soil layer may cause directional deviations.*
- *This may lead to constraining forces (fracture the joint)."*

1.8.6 Pipe Ramming

Advantages

- Less disruption and damage to surfaces, worth conserving and minimal restoration.
- No jacking abutments or auger cutters required which could get jammed.
- Minimal depth of cover required, i.e. shallower excavations.
- Adaptable for all pipe diameters with special ram cones.
- Widely acknowledged technique.
- Short set-up and installation times.
- Wide variety of pipe lengths and sizes.
- It can be used for assisting in HDD and MTBM rescue operations.

Limitations

- The minimal amount of control over line and grade.
- The initial set up is major importance.
- Soil conditions must be known to determine the proper size of casing to be used.

- Noise level is high.
- Several hours welding.
- Casing pipe and product pipe (a two-phase process).

1.9 Planning and Safety Considerations

Any new trenchless installation or repair project needs effective analysis. Analysis indicates that the cost effectiveness of a method or technique is not highly dependent on the capital cost of the equipments. Other variants are also important. Najafi[1] developed factors and rules to be considered for a job.

"

- *Trenchless installation methods reduce the negative impacts of open-cut trenching.*
- *Many of the trenchless methods may have several potential risks.*
- *These potential risks should be considered in the planning, design, and preconstruction phase of the project.*
- *Some risk can be reduced by selection of experienced contractors and trained/certified machine operators.*
- *While generally jobsite safety is the responsibility of the contractors, project owners and consulting/design engineers also have a responsibility for ensuring proper method selection."*

A safe job starts with:

- Good organized planning and design (Figure 1.53).
- Proper geological, geotechnical, location and site investigations.
- Decisions made during the inspection of the project.
- It's important that the owner and the engineer convey all the data, including geotechnical reports and soil bore information to the contractor.
- This will help the contractor to make adjustment in machine selection and installation methods [1].
-

FIGURE 1.53 Planning and design. *(Source: ISTT.)*

Planning and design phase considerations and construction phase safety risks are given in Figure 1.54.

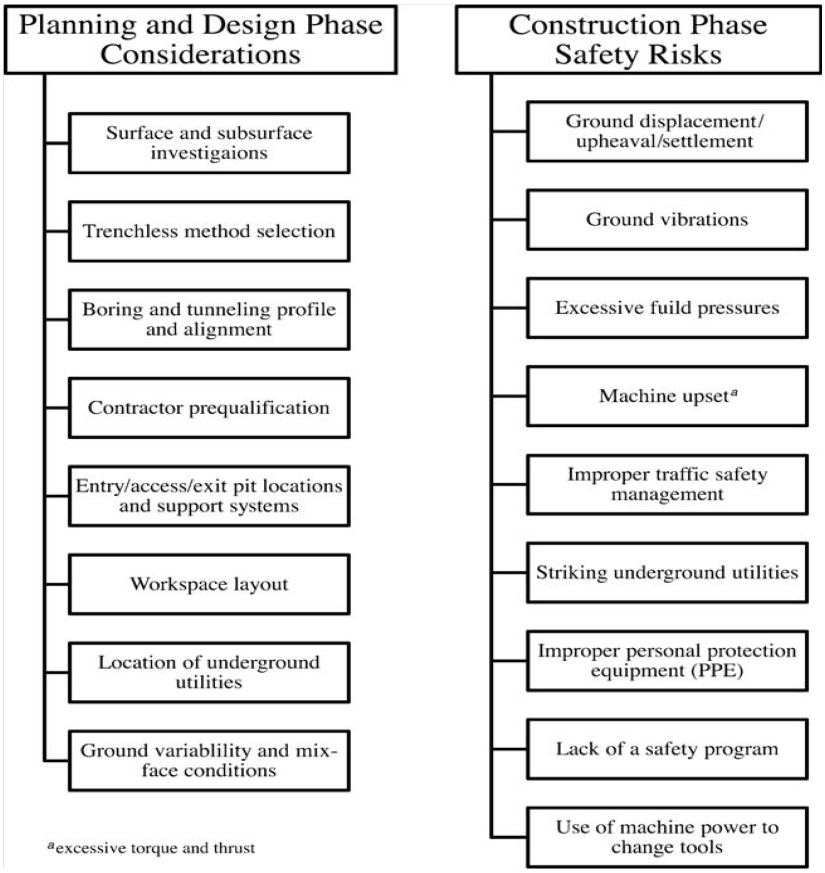


FIGURE 1.54 Sample planning and safety considerations. *(Najafi, 2010)*

The following are examples of the risks:

- Collapsing of borehole
- Ground movement and displacement
- Vibrations, including ground vibrations damaging nearby utilities and structures
- Soil and ground variability and mix-face conditions
- Excessive fluid pressures (such as in HDD) damaging nearby utilities
- Lack of keeping safe distance from parallel utilities
- Exceeding jacking capacity or torque capacity of boring machines (such as machine upset horizontal auger boring)
- Confined space entries
- Work zone traffic accidents (Figure 1.55)
- Uncovered and unmarked surface potholes
- Fall into shafts and pits
- Eye injuries from high-pressure drilling or flying objects
- Caught-in/crashed-by accidents from rotating/moving components
- Fire and explosion from breached gas lines
- Caught-in accidents from moving components
- Lack of proper work gear protection equipment
- Lack of safety equipments, safety trainings or safety meetings (Figure 1.56)
- Lack of good communication (hand signals, two-way radios) among machine operators and crew members

- Lack of good planning and job site organization [1].

a) b)

FIGURE 1.55 Potential risks. a) Proper signals and barriers b) Limited barriers without signal. *(Source: ISTT.)*

FIGURE 1.56 Safety. *(Source: IST.T)*

A safe and productive construction projects starts with a good plan and follows with implementing that plan (''plan the work work the plan''). Underground construction specifically are risky operations, therefore, for a safe and successful project, cooperation of all parties in the construction process (owner, engineer, contractor, subcontractor, regulatory agency, and so on) is required with a well-defined plan (and organization) to complete the work. As there are many dangers on construction sites, engineers, workers and contractors must follow the law and plan the most necessary safety precautions at the planning and beginning stage (Figure 1.57), [1].

FIGURE 1.57 Plan. *(Source: ISTT.)*

1.10 Cost Estimating and Bidding

General Approaches: Municipal engineers or owner of project must select a construction or repair method based on a competitive bid process. The lowest bid is generally the winning bid, if there are extenuating circumstances. The bid includes the contractor's direct construction costs (materials, labour, energy, transportation, management etc.), contingency and profit. In North America, a bid generally does not include any component of social costs. Any decision based solely on the lowest bid, will not properly reflect the true total economics of the project and therefore can lead to an inappropriate decision about the selection of the technologies (Figure 1.58).

HDD Project Specific Approaches: The cost analysis from Najafi[1] are given in Table 1.9. *"Table presents a sample unit price bid for a HDD water pipe installation project.Unit price contracting is the most common method for bidding and cost estimating of trenchless projects. Other methods of bidding trenchless installations include lump sum and cost-plus or time and materials."*

FIGURE 1.58 Bidding. *(Source: ISTT.)*

TABLE 1.9 A Sample unit price bid for a HDD water pipe installation project. *(Najafi, 2010)*

Item No.	Item Description	Quantity	Unit	Unit Cost	Total Price
1	Mobilization, bonds, insurance	1	ls	$_____	$_____
2	Stormwater Pollution Prevention Plan	1	ls	$_____	$_____
3	Trench and Excavation Safety Plan	13,936	lf	$_____	$_____
4	12" DR-18 C900 PVC water line	5,010	lf	$_____	$_____
5	12" Gate valve and valve box	2	ea	$_____	$_____
6	Service line pressure reducing valve	19	ea	$_____	$_____
7	12" × 12" tapping saddle	1	ea	$_____	$_____
8	Cut and plug existing 6" water line	52	ea	$_____	$_____
9	Fire hydrant assembly	13	ea	$_____	$_____
10	Reconnect existing fire hydrant	11	ea	$_____	$_____
11	Remove existing fire hydrant	11	ea	$_____	$_____
12	Bore without encasement – 12" DR18 C900	861	lf	$_____	$_____
13	16" bore without encasement – 8" DR18 C900	156	lf	$_____	$_____
14	New service line and meter stop-recon to ex. meter	133	ea	$_____	$_____
15	Asphalt pavement replacement	2,855	lf	$_____	$_____
16	Gravel pavement replacement	2,360	lf	$_____	$_____
17	Traffic control plan	1	ls	$_____	$_____
18	Disinfection and testing	1	ls	$_____	$_____
		TOTAL ORIGINAL BID:			$_____

When making a bid, these items (Table 1.9a) are made only once and decided to be made at the beginning of the project between the sides.

TABLE 1.9a The items made only once.

Item No.	Item Description	Quantity	Unit	Unit Cost	Total Price
1	Mobilization, bonds, insurance	1	ls	$_____	$_____
2	Stormwater Pollution Prevention Plan	1	ls	$_____	$_____
7	12" × 12" tapping saddle	1	ea	$_____	$_____
17	Traffic control plan	1	ls	$_____	$_____
18	Disinfection and testing	1	ls	$_____	$_____
		TOTAL ORIGINAL BID:			$_____

Some of the items (Table 1.9b) should be followed both at the beginning of the project and at the end of the project.

TABLE 1.9b The items at the beginning and at the end.

5	12" Gate valve and valve box	2	ea	$_____	$_____
6	Service line pressure reducing valve	19	ea	$_____	$_____
8	Cut and plug existing 6" water line	52	ea	$_____	$_____
9	Fire hydrant assembly	13	ea	$_____	$_____
10	Reconnect existing fire hydrant	11	ea	$_____	$_____
11	Remove existing fire hydrant	11	ea	$_____	$_____

These items must be made until the end of the project and projected in accordance with the proposal.

Follow-up: Cost estimating and bidding are very important for projects capabilities and project implementation. Item description, quantity, unit cost and total price should be documented before project installation. During implementation close control, layout mapping and picturing residential neighborhood are performed. As an example in Figure 1.59 arial view of microtunneling shaft layout in Concord-CA/ USA is given.

FIGURE 1.59 Let the project begin: the project used an earth pressure balance machine to install a 2.400 mm ID RCP. (Source: *ISTT.)*

CHAPTER 2

2. Pipeline Renewal, Replacement and Repair Methods

2.1 Pipe Underperformance and Inspections

Old pipeline rehabilitation is very important and this point has been examined by Najafi [1]. *"Trenchless renewal and replacement methods can be used to renew both gravity and pressure pipelines. Range of applications include sanitary sewers, storm sewers, culverts, and drainage structures, potable water pipes, natural gas and oil pipelines, sewer manhole structures, and so on. The decision process to select a specific method should consider many factors, including nature and extent of existing pipeline deterioration and problems, type of application, pipe geometry (Figure 2.1 and 2.2), as well as plans for future pipe applications, costs and availability of contractors and technology providers. A pipe-renewal selection should also consider construction cost, potential for clogging by debris, limitations on headwater elevation, pipe depth, and hydraulic performance of the new pipe. The site (soil conditions, surface conditions, and availability of space for installation), and project-specific conditions would also influence selection of a specific method. There are a wide variety of factors that affect performance of existing pipes."* These factors:

- Structural Loads (From soil and live loads)
- Wear and Corrosion
- Scour
- High Fluid Pressure
- Flow Capacity Problem
- Erosion of Streambed and Embankments

Existing pipe performance is closely related to the rate of deterioration and the service life [1].

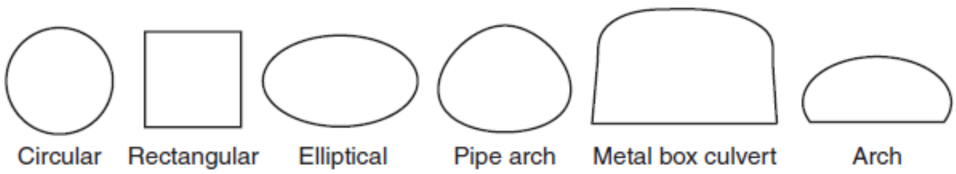


FIGURE 2.1 Common existing pipe shapes. *(Source: ISTT.)*

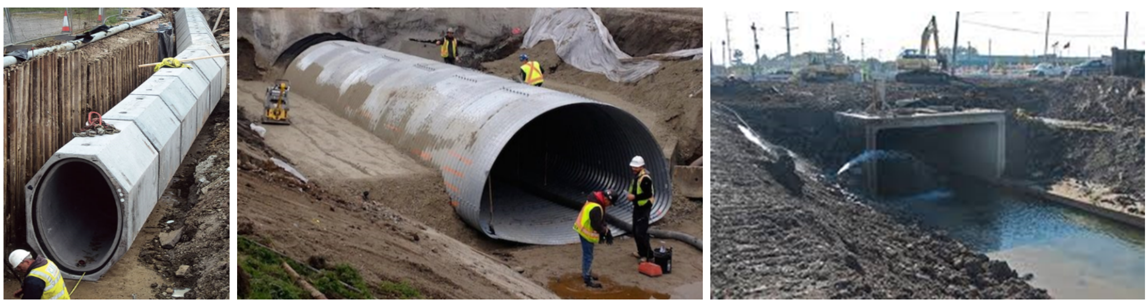


FIGURE 2.2 Pipes and pipe segments. *(Source: ISTT.)*

Pipe inspections

Noninspected and nonmaintained pipes deteriorate faster than expected length of life period. Different inspections, surveys and tests are available for old piping. External testing comprises non destructive testings (like GPR), visual inspections (like CCTV), fluid tests (like smog). Side Scanning Evaluation Technology **(**SSET**)** employs a 360-degree fisheye digital scanner, producing digital side scan images of a pipe wall instead of the forward-facing continuous video provided by typical closed-circuit television **(**CCTV**)** inspection. Non-destructive testings **(**NDT**)** are more preferable options for pipe inspections. Ground Penetrating Radar (GPR) is a ground investigation method applied to utility locating and mapping. Man-Entry Inspection are options for searching the feature of high diameter pipes. Evaluation of various tests helps to get decision of renovation and rehabilitation [16].

The planning phase for a conventional project can proceed in a more regulated and ordered fashion than that for an emergency pipe repair or replacement due to collapse in a roadway [17]. One of destruction field testing of old pipes are given in Figure 2.3. Figure 2.4 shows a non destructive underground mapping test.

Pipe Inspection Methods:

a) Man-entry inspection

Physical pipe inspection (also called worker-entry inspection) is crawling or walking through manually accessible pipelines. The logs for physical pipe inspection record information of the kind detailed under television inspection. Manual inspection is only undertaken when field conditions permit this to be done safely. Precautions are necessary. Also known as worker-entry inspection, describes any inspection, construction, renewal or repair process, which requires an operator to enter a pipe, duct or bore. The minimum size for which this is currently permissible in the United Kingdom is 900 mm (In Turkey 600 mm for manholes). The main objective of pipe inspection is to examine the condition of the existing pipe before and after liner installation. It involves physical entry and hands-on examination. During the inspection, inspectors should note incorrect things and take close-up photos or record video. Pole mounted action camera with lighting, tricycle for travel, inspection with a raft and conducting Schmidt Hammer tests are main equipments.

b) Closed-Circuit Television Video (CCTV)

CCTV inspection method is using a remote-control device (Robot) with closed-circuit television camera system with appropriate transport and lighting mechanisms to view the interior surface of pipes and structures. CCTV cameras show the root and guide the robot to clean without needing to conduct more invasive methods like digging or removing walls or flooring to gain access to plumbing. The robot, supported by high-quality softwares, are inserted through existing pipe entry points. Once the cameras are inserted, we are able to see a precise picture of our pipe's condition (generally sewer) so we can detect any damages located inside. CCTV is perhaps the best inspection device of this kind and its practice is given in Section 2.2.1.

c) Side Scanning Evaluation Technology (SSET)

While the technology of CCTV is most used one, still this technique has two basic weaknesses. It relies too heavily on the judgment of the field technicians, and it is hard to estimate the usefulness. SSET by using a fisheye camera lens to observe the pipeline in the forward direction and at near right angles to the camera's direction of travel, the information collected by SSET will provide the engineer with the ability to see the total surface of the pipe from one end to the other. SSET with three-axis mechanical or fiber optic gyroscope can travel through pipe at a uniform speed and can produce the mean daily production rates of up to 1500 m/day. The scanned image is digitized and transformed to written description, so each defect is produced at the appropriate location along the pipeline. After CCTV and/or SSET inspection and recording, if necessary another robot with various accessories (like cutter head) is sent to the pipe to clean and surface mending.

d) Non-destructive testing (NDT)

Some of the tools used in performing NDT of pipelines utilize X-rays, magnetic particles and ultrasonic sound waves (Ground Penetration Radar - GPR). While visual inspections or use of X-rays can be used to inspect pipelines above the ground, pipelines that are buried under ground or are hard to access, require the use of devices known as "pigs" to perform the inspections. Available in various sizes, pigs have about the same diameter as the inside of the pipeline and are moved by the flow of air or liquid. These devices are put into one end of the pipelines and allowed to travel towards the other end of the pipeline to record valuable data that will be transmitted for further analysis of any flaws in the pipeline. These pigs have the potential to travel several hundred kilometers in a single run.

Pigs that use the magnetic flux leakage method use a strong magnetic field that is established in pipelines by magnets, or by using an electrical current to detect damage. The array of sensors housed in the pigs detect the magnetic flux leakage at the damaged areas and provide details about the area of damage, which can then be taken care of by the Engineers. While most of the pigs use magnetic flux, some utilize ultrasound technology (like GPR) to detect damage present within the pipelines (calculate the wall thickness either). Pig like probe uses radiated electron current to locate and quantified defects.

FIGURE 2.3 Field test performance of buried flexible pipes. *(Source: Chaallal O.,et.al,)*

FIGURE 2.4 Mapping the underground by ground penetrating radar (GPR). *(Source: ISTT.)*

Defining of location of underground utilities and pipe features are important. Ground Penetrating Radar (GPR) is a tool to help. The radio waves are emitted into the ground (pulse) and facilities deflect the radio wave back up (eco) to the operator where the objects will be displayed on the equipment (Figure 2.5).

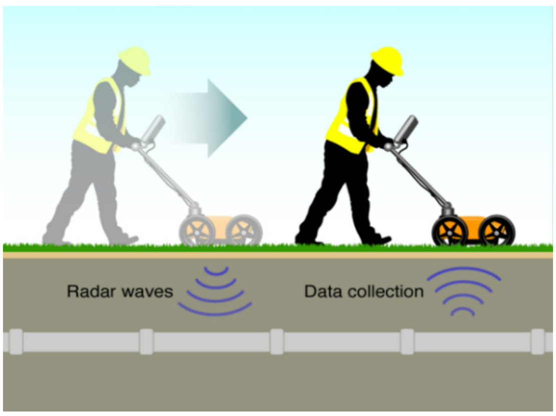


FIGURE 2.5 Working principles of GPR (pulse-eco). *(Source: ISTT)*

Rate of deterioration and the service life of pipe material and piping are closely related to the overall performance. Non-inspected and non-maintained pipes deteriorate due to various service, environmental, hydraulic, and social conditions, which often lead to emergency repairs (Figure 2.6).

a)

b)

FIGURE 2.6 Inspection and repair a) Point of water leak accurately detected *(Source: ISTT)*, b) After inspection of pipeline, localised composite repairs are performed. *(Source: www.ilsiengineering.com/project_item/southeast-louisiana)*

Table 2.1 provides group by group a summary of factors to be considered. Groups are entitled as surface conditions, subsurface conditions, existing pipeline conditions, determination of new pipe service requirements, constructability and site limitations, and strength and limitations of potential renewal/replacement methods. Further details are given by Professor Najafi[1]. *"When a project is considered for trenchless renewal or replacement, all parameters given above must be detailed. The pipeline renewal and replacement method selection process are indeed a complicated one. As already mentioned, many parameters and factors must be considered to reach an optimum solution. The decision must be made during the planning phase and re-evaluated during the design and preconstruction phase of the project. The project owner and design engineer must identify the appropriate solutions and consult with contractors and technology providers during the design and preconstruction* *phase. However, the decision-making process should not be left to contractors to be decided in the bidding phase [1].”*

TABLE 2.1 Pipeline Renewal/Replacement Parameters. *(Najafi, 2010)*

• Surface Conditions
• What is the topography? • What are the surface features? • What and where are the existing utilities located? • What and where are the sensitive areas within the project site? • What historical data is available for the project site? • Is the existing pipeline under a road, lake, or river? What are accessibility issues?
• Subsurface Conditions
• What are the general soil types, locations, and in-situ conditions? • What is the potential for the presence of rocks, cobbles, or boulders? • Is groundwater present? If yes, what is its depth? • What is the soil's corrosion potential? • What is the soil's settlement potential?
• Existing Pipeline Conditions
• What is the external condition of the existing pipe? • What is the potential for the presence of external voids around the existing pipe? • What are the internal conditions of the pipe? • What is the condition of existing manholes/on-line structures? • Where are bends, fittings, valves, service connections, concrete encasements, casing pipes, and other factors specific to the existing pipe located? Does existing pipe have repair sleeves installed?
• Determination of the New Pipe Service Requirements
• What flow capacity is required? • What length of pipe is under consideration? • What is the corrosion potential? • What are the structural requirements?
• Constructability and Site Limitations
• What safety issues need to be considered? • What type of access into the existing pipe is available? • What are the surface impacts of the construction techniques? • What are the easement needs of the construction techniques? • What impacts will groundwater have? • What are the scheduling limitations and constraints? • Will bypass pumping and flow control be required during the construction? • What is the impact of other utilities?
• Strengths and Limitations of Potential Renewal/Replacement Methods
• Are the proposed material and method a proven technology with available competent contractors? • What is the availability of the technology? • What is the anticipated service life? • What are the potential method's maintenance requirements? • What are the initial and long-term costs? • How well does the potential solution satisfy the identified service requirements? • What level of quality assurance/quality control is available?

Searching of existing pipeline conditions is very important. As an example for the question of “What is the condition of existing manholes/on-line structures?”, we can answer it by performing one of the function tests which has seen in Figure 2.7.

Pipe Underperformance and Inspections part is very important and details, especially waste water piping systems are given in recently published book of Yilmaz [18].

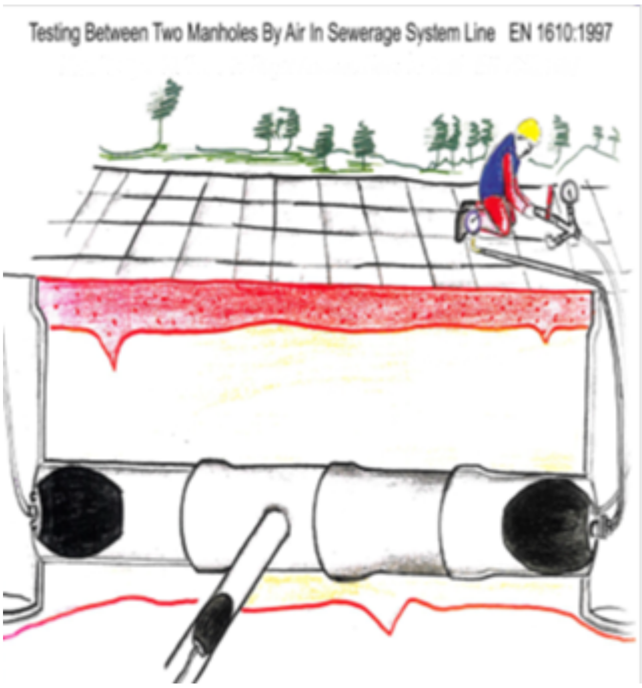


FIGURE 2.7 Non-destructive testing of sewer pipe by air (*Surce:www.fabcob.com/fotogaleri.php*).

2.2 Planning Trenchless Renewal/Replacement/Repair Project

A well organized construction project includes project definition, preliminary planning, project design, procurement of major items, project construction and project start-up.

FIGURE 2.8 High emergency cost expected for the pipe failures in urban areas. *(Source: City of Fort Lauderdale Public Works Department)*

During the project definition, preliminary planning, project design stages and major decisions are made concerning overall project size and complexity, project location, time constraints, level of quality, and costs[19].

The planning phase for a conventional project can proceed in a more regulated and ordered fashion than that emergency pipe repair and replacement due to collapse in a roadway (Figure 2.8). In an accelerated schedule such as for an emergency, the priority of speed of completion may outweigh all other priorities. As indicated in Figure 2.9 project must include novel approaches. Pro-active renewing or replacement is preferable in most cases (Figure 2.10), [1].

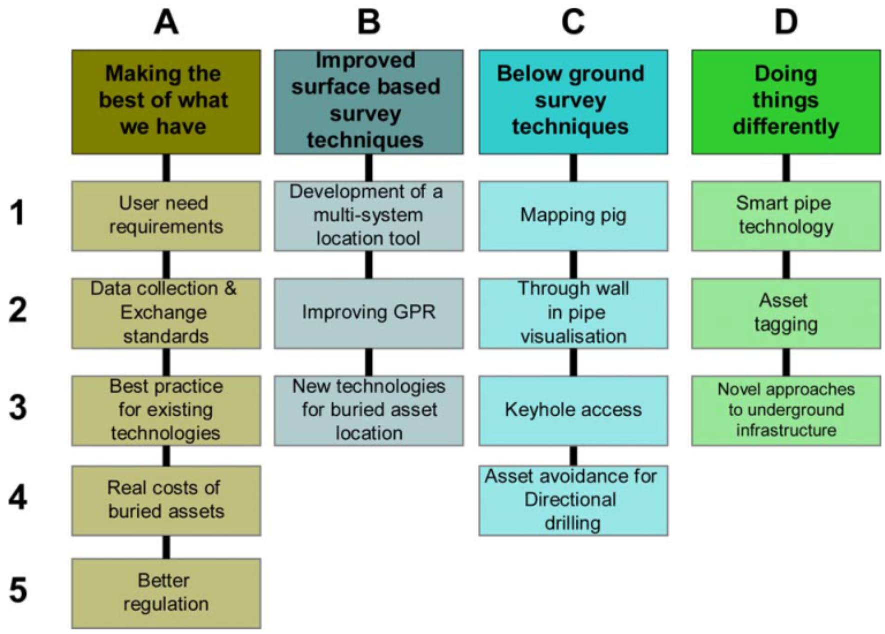


FIGURE 2.9 Research and evaluation program. *(Parker, 2007)*

FIGURE 2.10 Pre-welded polyethylene pipe sent through a former into "hearth shape" in preparation for installation into host pipe. *(Source: ISTT)*

In the planning process, it is important that the project owner must clearly identify, define and communicate the project priorities to all those working on the project. Broad views, plans and various actions should be evaluated (Figure 2.11-2.14).

FIGURE 2.11 Map of Turkey.

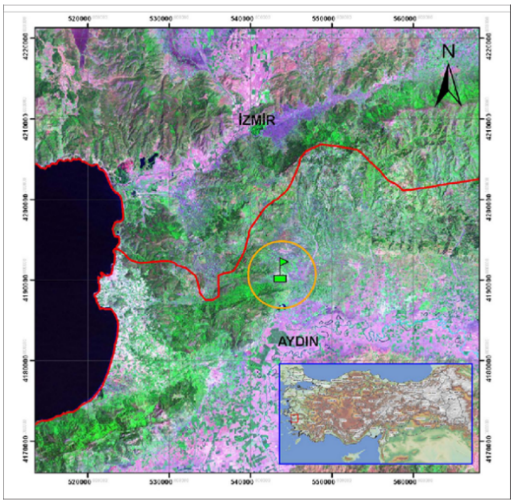


FIGURE 2.12 Project location. (Source: S. Akar, CRC Trans., Vol.15, p:669, 2011)

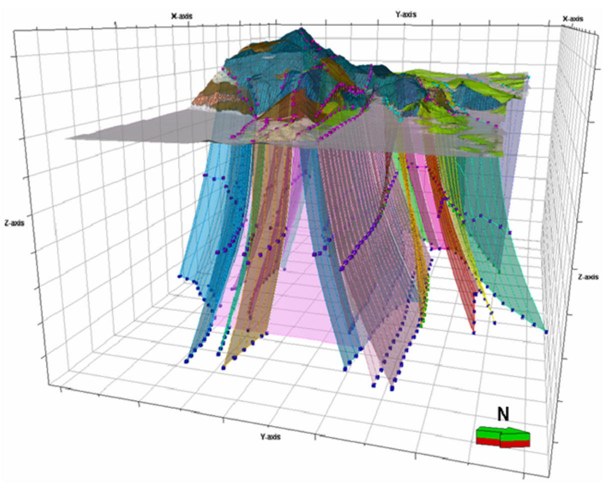


FIGURE 2.13 Modelling of surface and subsurface structure. (Source: S. Akar, CRC Trans., Vol.15, p:673, 2011)

FIGURE 2.14 Underground pipe networks. *(Source: www.plowmancraven.co.uk/services/gyroscopic-mapping-services/)*

The project owner should also perform a self-audit of their project management to help ensure that conflicting priorities are not inadvertently introduced into the project. The following sections present detailed activities on street work disruption as well as various renewal, replacement and repair methods [1].

2.2.1 Plannig and Evaluation Activities

Proper planning helps to ensure that the project will meet the needs and priorities of the owner. A specific method was followed when choosing the appropriate trenchless technology method for the installation, repair and rehabilitation of underground urban infrastructures.

Planning activities briefly covers the following steps:

- Background asssessment
- Screning of alternatives
- Data collection (Figures 2.15, 2.16)
- Evaluation and selection of alternatives

FIGURE 2.15 Model of pre-construction. *(Source: geomodel.com)*

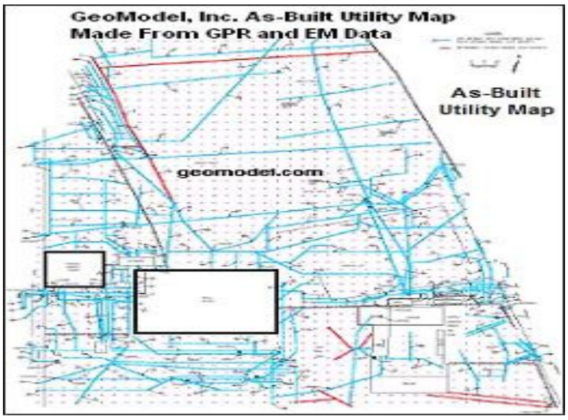


FIGURE 2.16 Data collection from GPR. *(Source: geomodel.com)*

Plannig and Evaluation activities have been explained by Najafi[1].

"Background Assessment

This activity, identifies the background and the priorities of the project and the limits of the project. Many factors may be available in existing pipe records.These are original installation data. Main factors are age of the existing pipe, type and class of existing pipe material, diameter, profile and alignment, size of trench, and backfill materials, bedding, and compaction, history of pipe problems with solutions provided such as leaks or collapse, overflow, and types of repairs and/or actions taken in the past.

Screening of Alternatives

This activity will provide a general screening of potential solutions based upon the technical conditions and needs of the project. The purpose is to further eliminate candidate solutions and identify the project to proceed.

Data Collection

This activity includes investigations that provide the information required to evaluate and screen candidate alternatives for consideration in the design phase. Data collection may provide information relating to

- *Geographic (physical) conditions*
- *Pipe flow conditions*
- *Soil (subsurface) conditions*
- *Pipe (existing, old) pipe conditions*

Surface survey, geotechnical investigations, and internal cleaning, and subsequent inspection, of existing pipe (with use of CCTV or other methods) will accomplish this goal (Figure 2.15-2.17).

FIGURE 2.17 Closed-circuit television (CCTV) inspection. *(Source: ISTT.)*

Evaluation and Selection of Alternatives

Final screening of alternatives and the selection of alternatives for proceeding into design are important step. The final screening is based upon the preliminary known data in addition to the data collected during this activity. Data collections and continuously adding new data increase project strength."

2.2.2 Design Objectives and Processes

Pipe renewal design involves a set of equations considering factors such as ground water, soil, traffic loads and other loadings condition. There are many variables and parameters used in taking decision for design. Finding proper liner wall thickness in conjunction with host pipe gets priority. For structural design the followings are important:

i) pipe wall thickness
ii) material properties
iii) pipe geometry
iv) loading conditions
v) safety factors
vi) long-term materials properties.

Design equations have been categorised into partially and fully deteriorated basis (ASTM F1216-09), [1]:

Partially Deteriorated Pipe

A partially deteriorated existing pipe (Table 2.2, Figure 2.18 and Figure 2.19) is defined as one where the pipe is corroded or cracked but has no missing pipe sections (keeps original geometry, capable of supporting all the soil and surface loads).

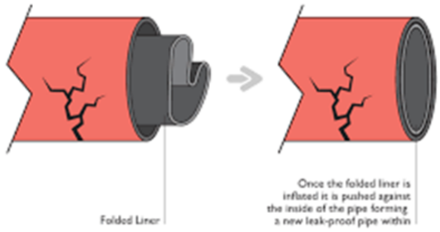


FIGURE 2.18 Fold and form pipe lining in partially deteriorated pipe. *(Source: ISTT.)*

FIGURE 2.19 Partially deteriorated pipe with liner to be thermoformed. *(Source: ISTT.)*

Fully Deteriorated Pipe

In this condition, the existing pipe is not structurally sound and cannot support soil and live loads (Table 2.2). This condition is evident when sections of the original pipe are missing, and the pipe has lost its original shape. The following considerations will also be included:

- Internal corrosion (Figure 2.20)
- Water quality associated with pipeline internal corrosion and deposits
- Flow capacity reduced from pipe internal tuberculation and deposits
- Leakage from corrosion holes and failed pipeline
- Vacuum collapse
- Ground water level is above the invert level of the existing pipe

FIGURE 2.20 Fully deteriorated pipe (internal surface corrosion). *(Source: ISTT.)*

TABLE 2.2 Current Structural Design for Pipeline Renewal Systems. *(Najafi, 2010)*

Existing Pipe Conditions	Design Objectives
Partially deteriorated	Liner design guarantees long-term hole/gap spanning capability under design operating conditions. Structural support is necessary from the existing pipe to withstand general operating pressures/external loads.
Fully deteriorated	No structural support available from existing pipe against internal/external pressures/loads.

2.3 Main Trenchless Renewal and Replacement Methods

Introductory information for main trenchless renewal and replacement methods is given by Najafi[1]. *"Trenchless renewal and replacement methods can be used to line, rehabilitate, upgrade, or renovate existing pipelines. There are also methods that can replace and enlarge existing pipelines in situ. These methods are collectively called in-line replacement methods. The term "renewal" is used when lining methods are applied to extend the design life of pipelines. When trenchless methods are used to repair pipelines without extending their design life, the term "repair" is used. The basic trenchless renewal and replacement methods are presented in Figs. 2.21 and 2.22. Categorization of them according to their application for gravity and pressure pipe is presented in Table 2.3, [1]."*

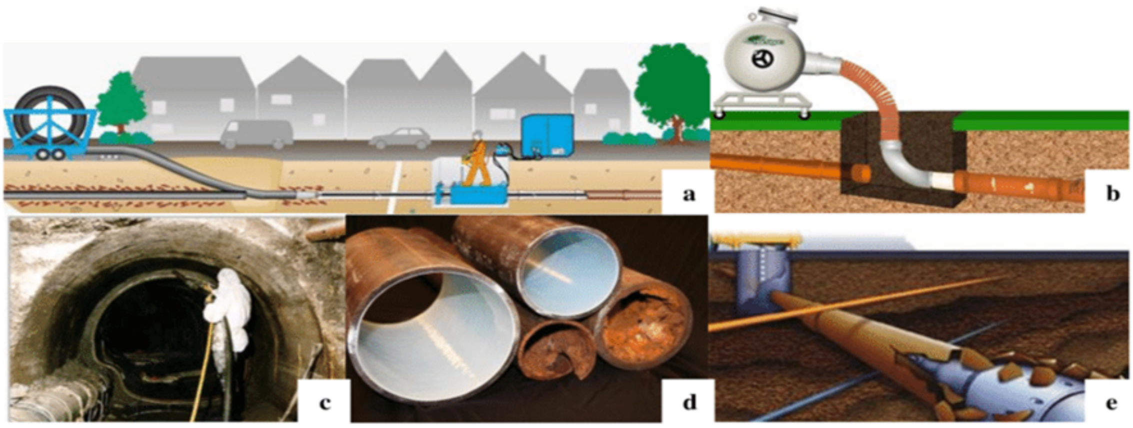


FIGURE 2.21 Old pipelines rehabilitations (a,c,e), replacements (a,e) and renewing (d) options

Factors to be considered while implementing any pipe renewal and replacement techniques and how the techniques put forward is advantageous over other competing techniques include;

- Social cost,
- Life span,
- Reliability,
- Environmental impact,
- Productivity and Schedule,
- Project cost-effectiveness,
- Applicability and constructability.

Table 2.3 present specific applications of renewal and replacement methods for common pipeline problems. Figure 2.23 illustrates a guide to select a trenchless renewal, replacement or repair method. Table 2.4 and Table 2.5 present the main characteristics of specific renewal and replacement methods. Main indicators are joint problems, corrosions, cracks/holes, inflow/infiltration, structural problems, hydraulic capacity, extension of service life (Figure 2.23), [1].

TABLE 2.3 Application of trenchless renewal and replacement methods. *(Najafi, 2010)*

Basic Method	Gravity Pipe	Pressure Pipe
Pipe-Lining Methods		
Cured-in-place pipe	Yes	Yes
Sliplining	Yes	Yes
Close-fit pipe	Yes	Yes
Coatings and linings	Yes	Yes
Modified sliplining	Yes	No
Thermoformed pipe	Yes	Yes
Trenchless Replacement Methods		
Pipe bursting	Yes	Yes[a]
Pipe removal	Yes	No
Pipe extraction	Yes	No

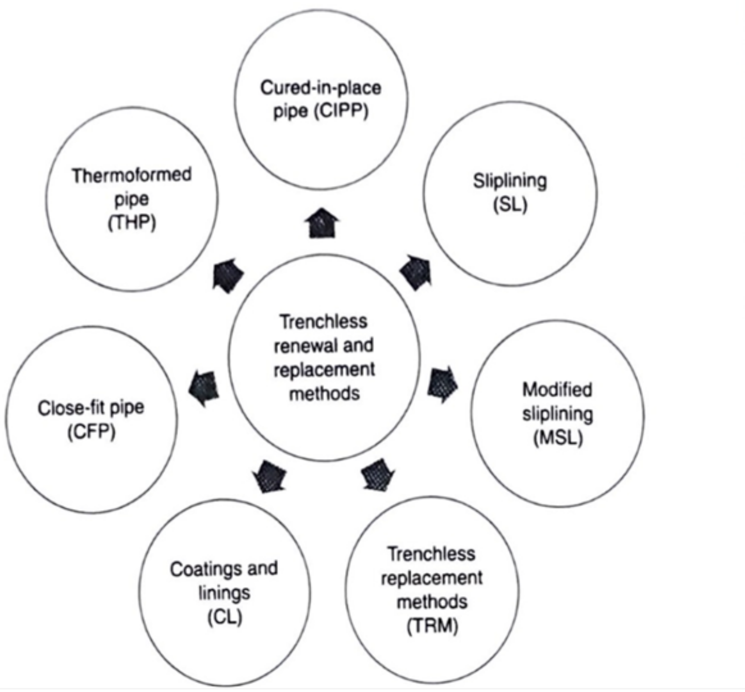


FIGURE 2.22 Basic trenchless renewal methods. *(Najafi, 2010)*

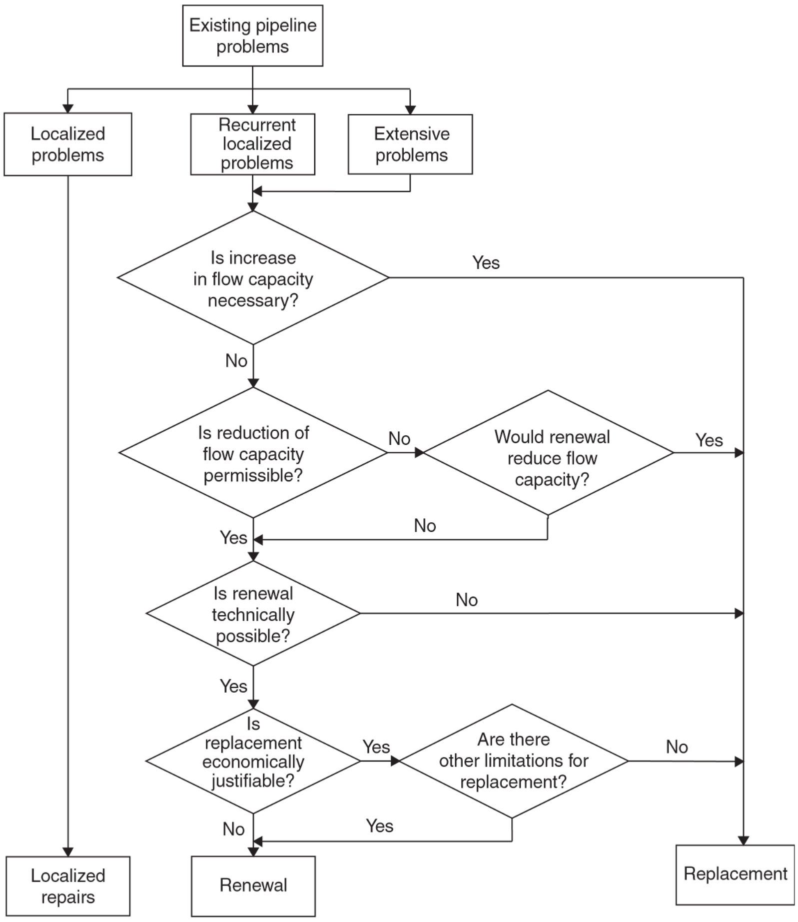


FIGURE 2.23 Decision support system for selection of a trenchless renewal, replacement or repair methods. *(Najafi, 2010)*

TABLE 2.4 Applications of renewal/replacement methods. *(Najafi, 2010)*

Renewal Method	Joint Problems	Corrosion	Cracks/ Holes	Inflow, Infiltration, & Exfiltration	Structural Problems	Inadequate Hydraulic Capacity	Extension of Service Life of Existing Pipe
Cured-in-place pipe	Marginal	Yes	Yes	Yes	Yes	Marginal	Yes
Sliplining	Marginal	Yes	Yes	Yes	Yes	No	Yes
Close-fit pipe	Marginal	Yes	Yes	Yes	No	Marginal	Yes
Thermoformed pipe	Marginal	Yes	Yes	Yes	Yes	Marginal	Yes
Coatings and linings	No	Yes	Marginal	Yes	Marginal	No	Marginal
Modified sliplining	Marginal	Yes	Yes	Yes	Yes	No	Yes
Trenchless replacement methods	Yes	Yes	Yes	Yes	Yes	Yes	Yes

TABLE 2.5 Main Characteristics of trenchless renewal and replacement methods. *(Najafi, 2010)*

Method	Diameter Range (in.)	Approx Inst. Length (ft)	Liner Material	Applications
Cured-In-Place Pipe				
Inverted in place	4–108	3000	Thermoset resin/fabric composite	Gravity and pressure pipelines
Winched in place	4–108	1000	Thermoset resin/fabric composite	Gravity and pressure pipelines
Sliplining				
Segmental	4–100	1000–2000	HDPE, PVC, GRP	Gravity and pressure pipelines
Continuous	4–63	1000	HDPE, PVC	Gravity and pressure pipelines
Modified Sliplining				
Panel lining	More than 48 in.	Varies	GRP	Gravity pipelines
Spiral wound	4–100 (Worker entry application can go larger)	1000	HDPE, PVC	Gravity pipelines
Coatings and Linings				
Coatings and linings	4–180 and larger	1500	Cement mortar/shotcrete	Gravity and pressure pipeline
	3–180 and larger	1500	Epoxy	Gravity and pressure pipeline
	4–98 and larger	500	Polyurethane	Gravity and pressure pipeline
	Dependent on the type of product and manufacturer	500	Polyurea	Gravity and pressure pipeline

Method	Diameter Range (in.)	Approx Inst. Length (ft)	Liner Material	Applications
Close-Fit Pipe				
Close-fit pipe structural	3–63	1000	HDPE, MDPE	Gravity pipelines
Close-fit pipe AWWA class III or class IV (depends on floor pressure)	3–63	1000	HDPE, MDPE	Pressure pipelines
Thermoformed Pipe				
Thermoformed pipe	4–24	500–1500	HDPE, PVC	Gravity and pressure pipelines
Lateral Renewal				
Lateral renewal	4–8	100	Any	Gravity pipelines
Point Source Repair or Localized Repair				
Robotics	8–30	N/A	Epoxy resins/cement mortar	Gravity
Grouting	N/A	N/A	Chemical gel grouts, cement-based grouts	Gravity
Internal seal	4–24	N/A	Special sleeves	Gravity
Point CIPP	4–48	50	Fiberglass, polyester, etc.	Gravity
Trenchless Replacement Methods				
Pipe bursting	4–48	1500	HDPE, PVC, DI, GRP	Gravity and pressure pipelines
Pipe removal	Up to 36	300	HDPE, PVC, DI, GRP	Gravity and pressure pipelines
Pipe extraction	Up to 24	500	Clay, Ductile Iron	Gravity and pressure pipelines

(1 in. = 25.4 mm, 1ft = 304.8 mm)

2.3.1 Cured-in-Place Pipe Process

Resin (An organic polymer) impregnation (wet-out) is main part of Cured-in-Place Pipe (CIPP) technology. In CIPP installation a plastic coated fabric tube is uniformly saturated with a liquid thermosetting resin (polyester, epoxy), while air is removed from the coated tube by means of vacuum suction. Usually the fabric is a polyester material, reinforced fiberglass, or similar. Usually water or air is used for inversion process. The pliable nature of the resin-saturated fabric prior to curing allows installation around curves, filling of cracks, bridging of gaps, and manoeuvring through pipe defects. CIPP can be applied for structural or non-structural purposes (Figs. 2.24 - 2.26). Last stage of CIPP is expanding the felt by means of fluid pressure into position on the inner wall of a defective pipeline before curing the resin to harden the material. Curing is performed by 3 different ways; Re-circulating hot water, steam or ultra-violet light.

CIPP offers lower project costs (like less road restoration), lower social costs (like less traffic disruption), lower environmental costs (like faster installation) and high quality results (like 50-70 year design life). CIPP can be used at water-sewer pipes, industrial pipelines and virtually any conduit that needs renewal [20].

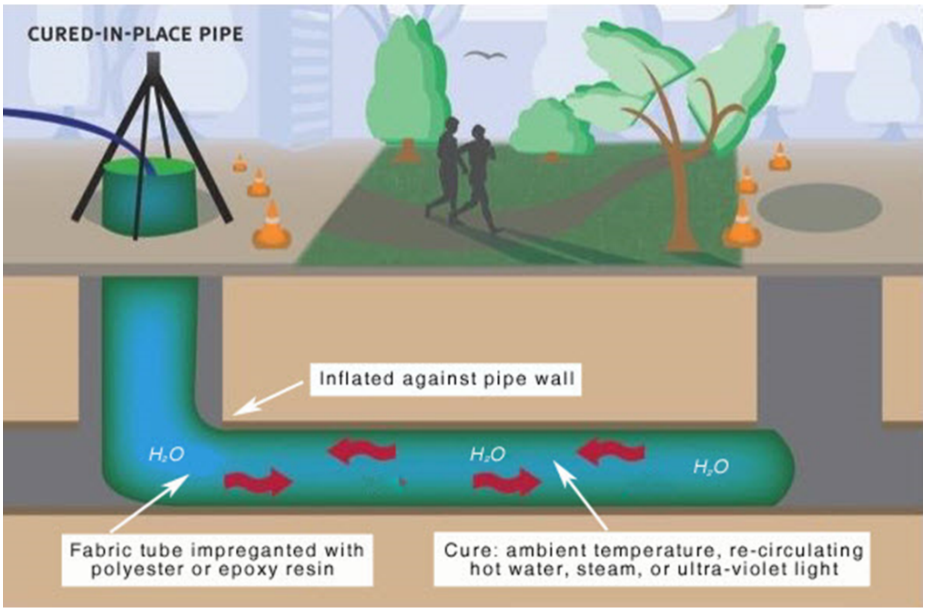


FIGURE 2.24 Cured in place pipe. *(Source: ISTT.)*

FIGURE 2.25 Surface smoothness after lining. *(Source: ISTT.)*

FIGURE 2.26 CIPP installation process. *(Source: Insituform Technologies.)*

2.3.2 Sliplining

Defination of sliplining is made by Najafi[1]. *"Sliplining method is insertion of a new pipe by pulling or pushing it into the existing pipe and grouting the annular space. The pipe used may be continuous or a string of discrete pipes. The latter is also referred to as segmental sliplining. Sliplining (SL) is mainly used for structural applications when the existing pipe does not have joint settlements or misalignments. In this method, a new pipeline of smaller diameter is inserted into the existing pipe and usually the annular space between the existing pipe and new pipe is grouted (relatively inexpensive). Sliplining can be categorized into two main groups as continues and segmental [1]."*

1. Continuous Sliplining

The continuous SL method, involves accessing the deteriorated pipe at strategic points and inserting high-density polyethylene (HDPE) or PVC pipe, joined into a continuous line, through the existing pipe. This technique has been used to renew gravity sewers, sanitary force mains, water mains, outfall lines, gas mains, highway and drainage culverts, and other pipelines. It has been used to restore pipes as small as 25 mm with the maximum pipe diameter limited by the availability of pipe material. This method can be used both for thin-walled and thick-walled liners. HDPE (or fuseable PVC) solid-wall pipe is slipped into an existing pipeline after the joints are butt-fused. The method requires a guiding trench for an insertion pit. There is typically a slight-to-moderate loss of hydraulic capacity.

2. Segmental Sliplining

This method involves the use of short sections of pipe that incorporate a flush sleeve joint commonly used in microtunneling and pipe jacking processes. A number of plastic pipe products, such as GRP, PVC, PP, and PE that include short-length sections with a variety of propriety smooth joints (both inside and outside) have been specially developed for SL sewers. This method is applicable for diameters greater than 600 mm.

Segments of the new pipe are assembled at entry points and forced into the host pipe. After the segmental pipe is installed, the annular space is grouted. The laterals are usually reconnected by excavation from outside. It is possible to use any common sewer pipe material that can be inserted into the existing pipe. To minimize the reduction in cross-sectional area of the existing pipe, the pipe must have smooth inside and outside joint.

Main stages of sliplining can be seen below:

Inspecting the existing pipe

Cleaning and clearing the host pipe from any obstruction

Joining (by butt fusion or gasketed bell and spigot) lengths of PE pipe

Providing access to the host pipe

Inserting the liner pipe and positioning it inside the existing pipe (Figure 2.27)

Stabilizing (grouting) annular space (if required)

Construction service and lateral connections

Construction of terminal connections.

FIGURE 2.27 Sliplining. *(Source: ISTT.)*

2.3.3 Modified Sliplining Process

Modified sliplining (MSL) includes methods in which pipe sections or plastic strips are installed in close-fit inside existing pipe and the annular space is grouted. There are two variations of modified sliplining method:

1. Panel Lining (PL): Panel lining renewal method is a man-entry procedure in which segments of the new lining pipe are connected inside the existing pipe and the annular space between the new pipe and the existing pipe is grouted. The shape of the culvert is covered by preparing panels and fitting them to the culvert. It can be used to structurally renew large diameter pipes. This method can accommodate different shapes. Panel linings can be used to structurally renew large-diameter (more than 1200 mm or worker-entry) pipes. This method can accommodate different shapes, such as noncircular pipelines. The main type of material

for this method is fiberglass. Figure 2.28 presents a panel lining method. Panel lining systems are one of the important solutions offered by trenchless technology. Panel lining applications are a very beneficial technology in terms of cost, time, environmental pollution and transportation delays [1].

2. Spiral Wound Process (SWP): Spiral lining or SWP is a technique in which a ribbed plastic strip is spirally wound by a winding machine to form a liner, which is inserted into a defective pipeline. The spiral wound process uses a layered composite PVC liner and cementitious grout to renew the existing pipes. Various diameter, shortly both worker or non-worker entry pipes can be renewed by SWP. The combination of the ribbed profile on the PVC liner and the highly fluid nature of the grout produce a highly integrated structure with the PVC liner "tied" to the existing pipe through the grout. The structural strength of the renewed pipe is determined by the grout characteristics. Figure 2.29 and Figure 2.30 presents a spiral wound process [1].

The work involves the following steps: Remove roots and flush debris from the pipe. Set up a sewer bypass system, if necessary, to re-route wastewater to other nearby pipes during the pipe lining process. Lower a winding machine into the manhole. Insert the liner strip into the sewer pipe through a manhole from a spool at the surface. Use the winding machine to seal the edges of the strip together and gradually build a liner inside the pipe. Push or pull the liner into place as it is formed by the winding machine. Fill any spaces in the liner with grout. Open and reinstate sewer service lateral connections that were covered by the pipe lining.

2.3.4 Coatings and Linings

Coatings and linings have been summarized by Najafi[1]. *"The spraying of a thin cement-mortar or a polymer coating on the internal surface of existing pipe is another method of pipeline renewal. For non-worker entry pipes (usually for existing pipe less than 1200 mm diameter) coatings and linings can provide improved hydraulic characteristics and corrosion protection. Additionally, specific polymer materials may enhance the structural integrity of the pipeline and seal joints or leaks. The lining materials may include cementitious materials, epoxy, polyester, silicone, vinyl ester, polyurea and polyurethane. They are sprayed directly onto pipe walls using remote controlled travelling sprayers. For worker entry pipes, sprayed cement mortars (shotcrete or gunite) are effective and widely used for renewing pressure pipes and gravity sewers and can be used for structural purposes. Figure 2.31 illustrates a coating process."* Details are given in Chapter 3.

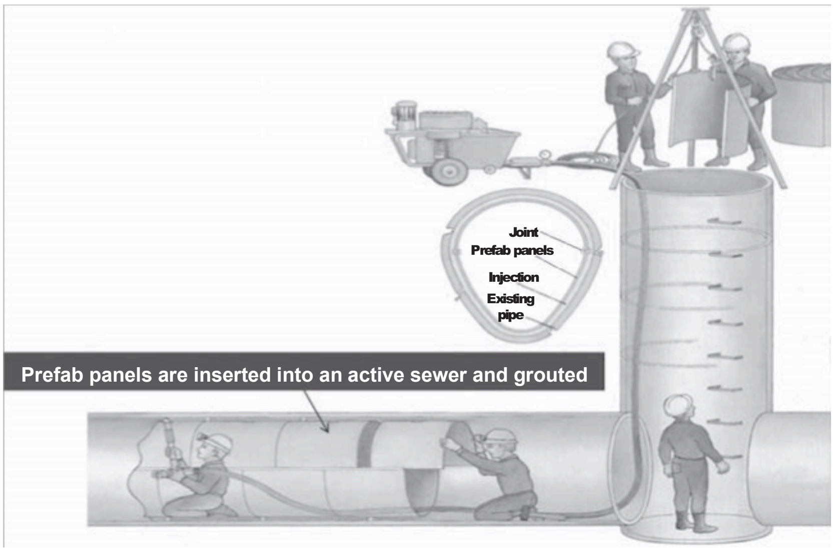


FIGURE 2.28 Panel lining method. *(Source: Channel Line.)*

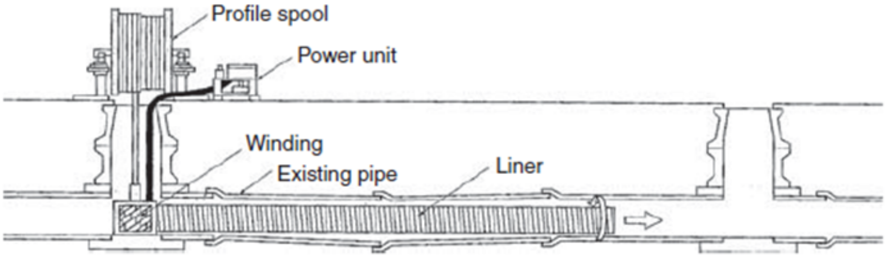


FIGURE 2.29 Schematic diagram for spiral wound process. *(Najafi, 2010)*

FIGURE 2.30 Internal feature of spiral wounding. *(Source: ISTT.)*

FIGURE 2.31 A resin lining process. *(Source: Raven Lining Systems.)*

2.3.5 Close-Fit Pipe Process

Lining with close-fit pipes is a method of pipelining where the outer diameter of the inserted pipe is a close fit with the inner diameter of the host pipe. In the beginning a folded shape product pipe is replaced in old pipe, then final shape is given by thermoforming inside the pipe being rehabilitated. Close-fit lining system is also called fold and form (F/F). An annulus may occur in sections where the diameter of the defective pipe is in excess of this. This type of trenchless pipeline renewal temporarily reduces the cross-sectional area of the new pipe. After placement, liner expands to its original size and shape at the jobsite, just to provide a close fit with the existing pipe and for pressure and gravity applications. This method can be used for both structural and non-structural purposes. Figure 2.32 and Figure 2.33 presents a semi-structural close-fit pipe (CFP) process. Lining pipe can be reduced on site and reformed by heat and pressure [1].

Main advantages of close-fit pipes:

a) Introduction can be via existing shafts or in the event of pressure pipes via relatively small trenches

b) Short construction and operation time

c) No remaining annular space; no grouting (filling) required

d) Shafts without curved channels can be passed through

e) Limited cross-section reduction (twice the wall thickness of the liner pipe)

f) Using factory-manufactured product pipes with well known material properties

g) Long unwelded length or plug connections possible

Close fit liner has very smooth internal surface. It resists against wear and aggressive waste water.

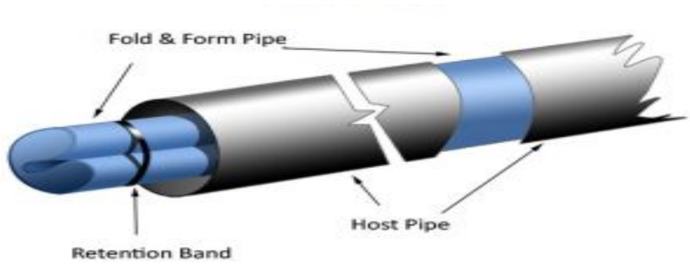
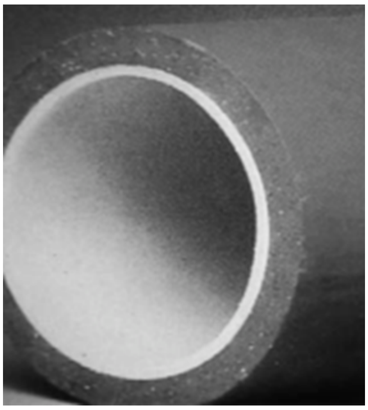


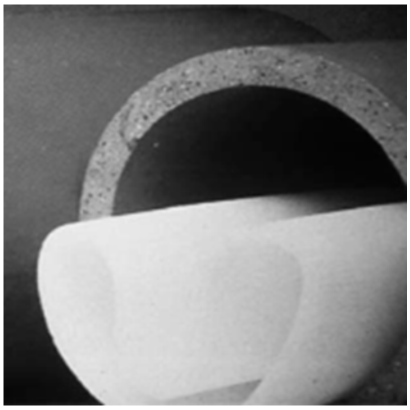
FIGURE 2.32 Close-fit pipe method. *(Source: ISTT)*

2.3.6 Thermoformed Pipe

Thermoformed is a terminology in North America for pipes that are reduced in cross section in factory by folding. After insertion, the liner is heated (thermoform) to conform to the existing pipe dimensions with a close fit. Both PVC (more common) and PE can be used for this method. A sample thermoformed pipe (THP) is illustrated in Figure. 2.34. Thermoformed pipe line system is useful in many way like transportation, installation and usage. There is no need to use more man force, machine force and cost. Thermoformed pipe, close fit pipe and F/F pipe imply more or less same thing [1].

FIGURE 2.33 A semi-structural close-fit pipe going through diameter reduction process. *(Najafi, 2010)*





a) b)

FIGURE 2.34 Thermoformed pipe. a) Final form after heating, b) C shape before heating. *(Najafi, 2010)*

2.3.7 Lateral Joints and Renewal

Service line connections, shortly lateral connections are far more important and Professor Najafi [1] describes them very good manner. *"Lateral is a service line that transports wastewater from individual buildings to a main sewer line. Lateral connection is the point at which the downstream end of a building drain or sewer connects into a larger-diameter sewer. A building sewer (sometimes referred to as a sewer lateral or house lateral) is the pipeline between the public sanitary sewer line, which is usually located in the street, and the indoor plumbing. Sewer service laterals can be renewed using any of the methods used for renewal of main pipelines such as chemical grouting, cured in place pipe, close-fit pipe, pipe bursting, and spray on coatings and linings (Figure 2.35)"*

The touching area between household pipe end and larger diameter main stream line is called lateral connection. This point is important and needs localized actions, inspections and repairs. The main characteristics and purpose of lateral renewal programs:

a) Eliminate tree rot cutting and instrusion,

b) Stop subsidence of backfilling of trench,

c) Improve and restore structural integrity of the lateral pipe,

d) Stop infiltration of ground water into the system,

e) Minimizing social cost and reduce monetary expenses for it,

f) Seal the system by grouting at the main and lateral pipe junction,

g) Eliminate and control basement back up caused by faulty lateral connections.

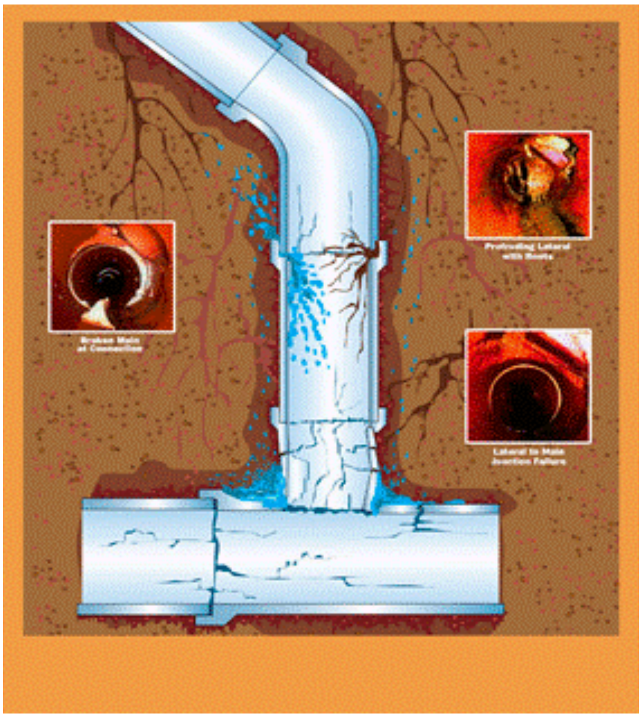


FIGURE 2.35 Lateral renewal. *(Source: ISTT.)*

2.3.8 Localized Repairs and Grouting

Point source repair or localized repairs are considered when local defects are found in a structurally sound pipeline. They are used to address point service problems or individual structural defects within a pipeline as opposed to full manhole - manhole rehabilitation. Point repair works on an existing pipe, to an extent less than the run between two access points or manholes. Remote-controlled resin injection to seal localized defect in the range of 100 to 600 mm diameter are available. Four applications can be addressed with these methods [1]:

1. To maintain the loose and separated pieces of unreinforced existing pipe in alignment to ensure load-bearing equivalent of the masonry arch.

2. To provide added localized structural support and capacity to assist the damaged pipes to sustain structural loads.

FIGURE 2.36 Internal seal point repair. *(Source: Miller Pipeline Corporation.)*

FIGURE 2.37 Localized repairs. *(Source: ISTT.)*

3. To provide a seal against infiltration and exfiltration.

4. To replace or relocate missing pipe sections.

Thanks to localized repair systems taking less time on site, require less equipment, cause minimal disruption to the locality and require less man-power.

Grouting

Grouting is very important final stage treatment of renewing and repairing applications. Najafi[1] defines groutings and aplications in 3 different ways. *"(1) Filling of the annular space between the existing, old, or host pipe and the carrier pipe. Grouting is also used to fill the space around laterals and between the new pipe and manholes. Other uses of grouting are for localized repairs of defective pipes and ground improvement prior to excavation during new installations. (2) The process of filling voids, or modifying or improving ground conditions. Grouting materials may be cementitious, chemical, or other mixtures. In trenchless technology, grouting may be used for filling voids around the pipe or shaft, or for improving ground conditions. (3) A method of filling voids with cementitous or polymer grout."* Chemistry: Suspensions - Cement or Bentonite slurry, Emulsions - Bitumen Emulsions and Solutions - Sodium Silicate or Acrylic Resin (that is pumped into voids).

Main areas:

a) Grouting is used to fill annular space between product pipe and host pipe,

b) Filling of the annular space between the existing, old, or host pipe and the carrier pipe.

c) Grouting is also used to fill the space around laterals and between the new pipe and manholes.

d) Other uses of grouting are for localized repairs of defective pipes and ground improvement prior to excavation during new installations.

Figure 2.36 and Figure 2.37 present localized repair technique by grouting. Chemical grouting can be used in cases where compression rings are used to stop the leakage when grout is "injected" or forced into the defective joint. Chemical grouting can also be done from the surface above the repair area via probe grouting. It should be noted that a new liner in a pipe cannot be considered complete if the soil surrounding the pipe still contains voids potentially creating an unstable and shifting environment.

2.3.9 Trenchless Replacement Methods

When capacity of pipelines is found to be inadequate, the pipe can be replaced with a trenchless replacement method. There are three main types of trenchless replacement methods: pipe bursting, pipe removal (also called pipe eating) and pipe extraction (see Table 2.5), [1].

Pipe Bursting

Pipe bursting, as the name implies, uses a hammer to break the existing pipe (brittle material like CI and VCP) and force broken fragments bursting head into the surrounding soil while a new pipe is pulled and/or pushed in its place simultaneously. There are different variations of pipe bursting method:

Pneumatic pipe bursting: a pneumatic hammer is used to break the existing pipe.

Static pipe bursting: the energy to break the existing pipe is in the pulling with no percussion action.

Hydraulic pipe bursting: the energy to break (without the noise) is relatively high.

Insertion method (also called pipe expansion): this method jacks a new rigid pipe (clay, cast iron, ductile iron) into the existing pipe. Figure 2.38 illustrate a schematic of pipe bursting operation. This method can be used to replace natural gas, water, and sewer pipes. This technique is useful in size-for-size replacement and up-sizing of pipeline sections. Pipes ranging from 100 to 1200 mm, max 120 m range. Limitations: hard soil conditions, expansive clays, densely compacted soil and backfills, soil below the water tables [1].

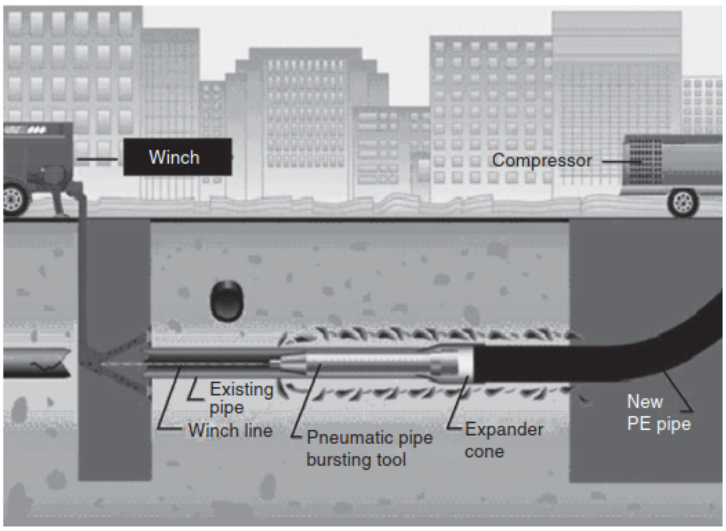


FIGURE 2.38 Pneumatic pipe bursting method. *(Source: TT Technologies.)*

Pipe Removal

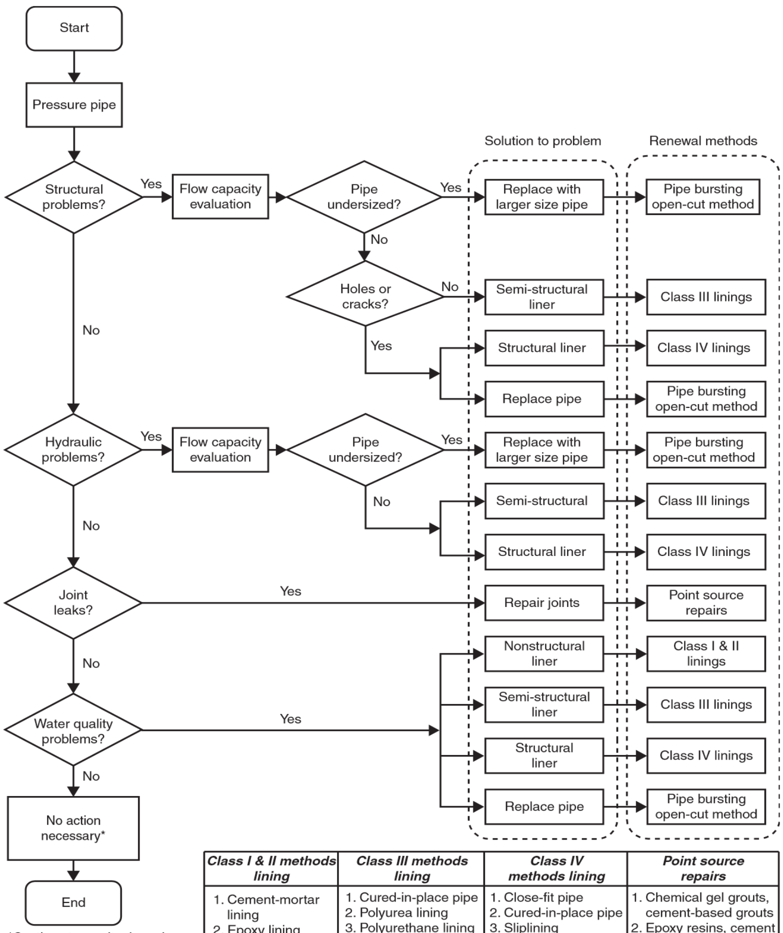
Najafi[1] explains old pipe removal and applications. *"Pipe removal, also known as pipe eating, can be performed by use of a horizontal directional drilling (HDD) rig, a horizontal auger boring (HAB) machine or a modified microtunnel boring machine (MTBM). In this method the existing pipe is broken into small pieces and taken out of ground by means of slurry (drilling fluid in HDD or MTBM method) or auger (in HAB method)."* Crushing capabilities of microtunneling machine or pulling a reamer through existing pipe is main indicator of pipe removal. The terminology pipe reaming is also used on behalf of pipe removal in industrial circle [1].

Pipe Extraction

Complete pipe extraction needs special equipments and it is rather difficult. Environmental rules obliged the authorities not to leave old and unfunctional pipes in soil. Germany is leading country in this issue.

2.4 Decision Support Systems for Gravity and Pressure Pipes

Considering the project requirements, capabilities and limitations of available trenchless renewal and replacement methods, Figures 2.39 and 2.40 illustrate sample decision support systems that can be used for pressure and gravity pipes, respectively. The reason to use a decision support system is to optimize the method-selection process based on the requirements of the project and priorities set by the project owner. No textbook or software program can make a proper recommendation for specific conditions and requirements of a project. For this reason, design engineers work with project owners to rank and weigh project priorities and then make recommendations for specific methods. The selected methods can then be advertised for bids [1].



Class I & II methods lining	*Class III methods lining*	*Class IV methods lining*	*Point source repairs*
1. Cement-mortar lining 2. Epoxy lining	1. Cured-in-place pipe 2. Polyurea lining 3. Polyurethane lining	1. Close-fit pipe 2. Cured-in-place pipe 3. Sliplining 4. Thermoformed pipe	1. Chemical gel grouts, cement-based grouts 2. Epoxy resins, cement mortar 3. Internal seal 4. Point CIPP

*Continue to monitor based on your asset management plan and pipe material and condition requirements.

FIGURE 2.39 Decision support system for pressure pipe renewal methods. *(Najafi, 2010)*

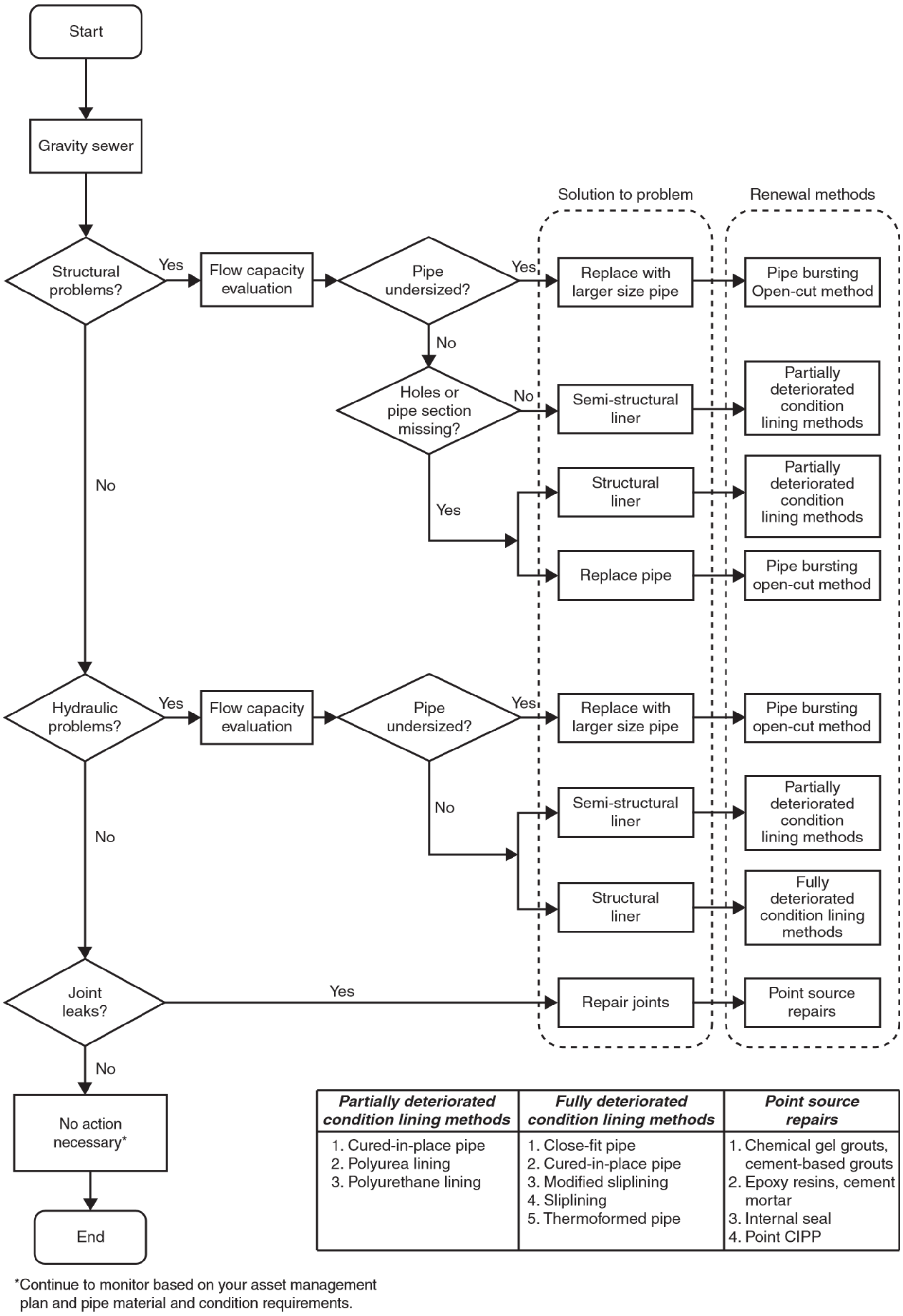


FIGURE 2.40 Decision support system for gravity pipe renewal methods. *(Najafi, 2010)*

2.5 Design Concepts for Pipeline Renewal Systems

Loading effect of pipeline renewal has been explained by Najafi [1]. *"A conventionally buried pipe is designed to "carry" or "transfer" all the loads, which includes the weight of soil backfill placed over it, hydrostatic pressures, vacuum, internal working pressures, and loads applied at the ground surface. As mentioned earlier, current methods for structural design of flexible gravity pipe liners carry two external loads. The first is sustained hydrostatic pressure due to groundwater acting in the annular space between the liner pipe and the existing pipe. The second load case assumes that overtime earth and traffic loads will be transferred from the existing pipe-soil structure to the new liner pipe."*

"Fully deteriorated pipe conditions" can be evaluated for two reasons described below:

1. The soil load reaching the liner pipe is overestimating by treating the liner as it had been directly buried in a trench.
2. The formula used to describe liner pipe response to transferred soil load, and hence calculate the required wall thickness (open-cut applications, irrational safety factors!) For the basic design concept visit web site (www.pipelinedivision.org).

TABLE 2.6 Mechanical properties of some pipes and liner materials. *(Yilmaz, 2009)*

Materials	Elastic Modulus GN m^{-2}	Tensile Strength MN m^{-2}	Elongation %	Fracture Toughness MN $m^{-3/2}$
Steel	200-215	400	4-47	50-140
Ductile Iron	170	420	>10	100
Concrete	18-30	4 (25 compression)	0	0,2-1
PVC	21-41(3, Najafi 2010)	48-62	12-80	1-5
HDPE	1	20-30	10-140	1-4
GRP	21-35	200-500	1	6-50

Long-Term Testing

The design life of pipeline systems has always been a major concern due to early deterioration of some pipe materials as well as unexpected and excessive repair and maintenance costs. Short-Term tensile strength, compressive strength, ductility (% elongation) and fracture toughness of pipe materials and liners are very important. Table 2.6 gives general values of some piping materials and liners. It is well known fact that some materials (like steel) preserve original value, while others (like PVC) loose properties by the time. Table 2.7 presents the expected useful life of various renewal methods in service life extension of the pipe based on various publications indicated. The data obtained from short-term tests cannot be used for forecasting design life of plastic liner pipes including (CIPP) method. Tensile, compressive and creep-rupture strengths of plastic pipes decrease with time (long-term stresses). Trenchless renewal and replacement methods give strength and durability to piping system. In addition they stop leaks, resist corrosion and abrasion, and install a new pipe in place of the existing and deteriorated pipe and provide a new design life [1].

TABLE 2.7 Expected Useful Life of Various Pipe Renewal Methods[a] *(Najafi, 2010)*

Method	Material Used	Expected Useful Life	Reference
Spray-in-place-pipe	Cement mortar	> 50 years	Deb et al. (AWWA, 1990)
	Epoxy resin	> 75 years	Watson, 1998
	Polyurea	> 50 years	3M water
Cured-in-place-pipe	Thermoset resin/ fabric composite	> 50 years	TTC report, 1994
Sliplining	Polyethylene	50 years	Silbert et al. (AWWA, 2002)
Thermoformed ThP	PE & PVC	100 years	Najafi & Gokhale, 2005
Close-fit pipe	PE & PVC	> 50 years	Selvakumar et al. (EPA 2002)
Modified sliplining	HDPE, PE & PVC	> 50 years	Silbert et al. (AWWA, 2002)
Pipe bursting	PE, PVC, HDPE & GRP[b]	> 50 years	Silbert et al. (AWWA, 2002)
Pipe removal	PE, PVC, HDPE & GRP[b]	> 50 years	Silbert et al. (AWWA, 2002)

[a] Expected useful life is a loose term that depends on many factors, such as quality of design and installation, liner pipe material, thickness, and its properties, pipe loadings and pipe environmental conditions, type of application, fluid properties, and existing pipe conditions and level of its deterioration.

[b] Glass reinforced pipe (GRP) has a useful life in excess of 100 Years [Silbert et al. (AWWA, 2002)].

CHAPTER 3

3. Pipe Coatings, Pipe-Soil Interaction and Pipe Selection

3.1 Coatings and Linings for Renewal of Potable Water Pipes

3.1.1 Coatings and Linings Against Corrosion

Coating and linings, especially spray-on types, are very important for pipe protection. Najafi[1] have questioned spraying and linings. *"Spray-on coatings and linings have been used to protect and renew pipelines and other infrastructure (tanks, reservoirs, primary and secondary retention and treatment basins, pump stations, diversion boxes, manholes, and other structures) for decades. Shotcrete, an air-assisted spray-on lining method for cementitious products, was developed at the beginning of the twentieth century, and became accepted as a construction method in 1910. Today, high-tech polymer coatings and composite lining methods are used to restore, protect, repair, and renew a wide range of pipelines and concrete, masonry, and steel structures. The principal objective of a coating or lining for potable water pipe application is to apply a monolithic layer that inhibits further deterioration. Corrosion is main deterioration in metallic pipes, and it can significantly reduce flow capability of the pipe and water quality (Figure. 3.1)."*

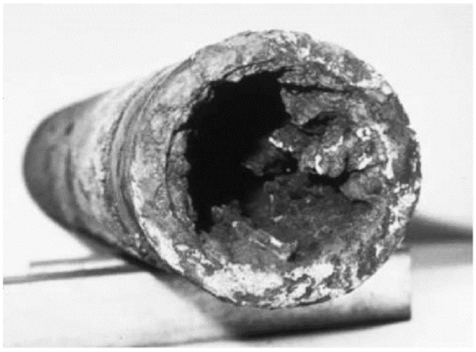


FIGURE 3.1 Excessive tuberculation in water pipes. *(Source: 3M Water Infrastructure)*

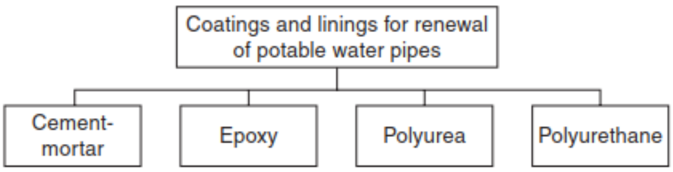


FIGURE 3.2 Basic coatings and linings materials for renewal of potable water pipes. *(Najafi, 2010)*

The primary materials used for coatings and linings fall into four broad categories of cementitious materials and polymers which include cement-mortar, epoxy, polyurea and polyurethane (Figure 3.2). Cement mortar is a workable paste which hardens to fill and seal the irregular gaps and to coat the surface, and sometimes to add decorative colours or patterns to masonry walls. An epoxy is a thermosetting polymer that possesses unique mechanical and chemical properties. The polyurea is a synthetic polymer obtained from the reaction of a diamine with a diisocyanate. Polymerization reaction is very similar to polyurethane one, but resulting link is a "urea". Polyurethane (PUR and PU) is a polymer composed of organic units joined by carbamate (urethane) links. While most polyurethanes are thermosetting polymers that do not melt when heated, thermoplastic polyurethanes are also available. Coating and lining materials indicated in Figure 3.2 are sometimes used in conjunction with one another. For chemical resistance and monolithic coverage, adhesion is generally regarded as a required attribute of coatings and linings. For structural enhancement, adhesion may or may not be a desired property. Other attributes of coatings and linings vary greatly between polymers and cementitious. Some coatings and lining materials may be excellent for bridging cracks and holes but may have low chemical resistance owing to inherently higher porosity; others may exhibit excellent long-term strength, but poor adhesion in damp environments. As for any renewal method, true project needs should be evaluated and matched with proven product attributes.

Moisture can weaken a lining's curing process as well as its ability to bond to the existing structure. Although moisture is relatively easy to mitigate in above-surface structures, it cannot be completely avoided below grade, especially in pipeline structures. Therefore, a lining with high moisture tolerance offers an adhesion advantage for pipeline projects. Epoxies and polyureas can generally be formulated to offer the best moisture tolerance, although some polyurethanes also offer moderate tolerance or require the use of an epoxy primer.

The main purpose of coating and lining is to protect the pipe walls from external effects and prevent the pipe from deforming. The structural and chemical deterioration in the pipes pollutes the clean water. Coating and lining methods make the material protected against the damage and harm from soil.

3.1.2 Water Distribution Pipe Applications

Many water utilities are faced with the problem of aging water pipe networks and the associated increasing costs. It is estimated that most water utilities have 20 to 30 percent unaccounted water problems due to aging and leaking water pipeline systems. Leakage, water quality, and structural failures are few among the various problems faced by water utilities. Majority of these problems are caused by corrosion, as well as soil movements, traffic loads, and excessive pressures. One of the causes of structural/surface damage of pipes and infiltration/exfiltration problems is dealing with pipe materials. General outline of materials properties and details are given recently published book of Yilmaz [21]. An ideal coating and lining methods discussed by Najafi [1]. *"Coating and lining material must not contain any volatile organic compounds (VOCs), must be environmentally friendly, long term durability, resistant to live (hoop, transverse and longitudinal stresses, vacuum pressure, water hammer) and dead loads (soil and hydrostatic pressure), chemical attack, and meet all applicable governmental, regulatory, and industry standards to be safe for potable water applications. Desirable properties of the coatings and linings may include rapid cure, smooth and pinhole-free coating, meeting adhesion requirements with the existing pipe, being locally available* *with certified and experienced contractors, and being cost-effective. For structural applications in worker-entry, larger-diameter pipelines, reinforced sprayed cement mortars (shotcrete and gunite) on carbon fiber can be effectively used. Non-worker-entry water pipes may require coatings and linings to be applied with a centrifugal lining machine. Centrifugally cement–mortar protective lining and coating of steel and ductile iron pipes are common practice. Water Pipe American Water Works Association (AWWA) classifies water pipe renewal methods into four categories as summarized in Table 3.1. For structural applications (category IV, in Table 3.1), the lining material must provide a new design life to the existing pipe. For semi structural applications (categories II and III), the liner may provide the following properties."*

- Sufficient toughness (fracture toughness) to survive the dynamic loadings
- Sufficient ductility (percent elongation) to accommodate any joint displacements
- Sufficient shear strength (tensile strength) to maintain longitudinal continuity in the presence of unrestrained ground movements
- Sufficient flexural strength (bending strength) to provide long-term corrosion voids spanning (cover) capability

TABLE 3.1 Structural Classification of Lining Systems (IV: lining gives extra design life to existing pipe, I: lining does not increase design life of existing pipe). *(Najafi, 2010)*

	Non-structural	Semi-structural		Structural
System Class	**Class I**	**Class II**	**Class III**	**Class IV**
Corrosion protection	Yes	Yes	Yes	Yes
Gap spanning capability	No	Yes	Yes	Yes
Inherent ring stiffness	No (Depends on bonding)	No (Depends on bonding)	Yes (Self support)	Yes (Self support)
Survives burst failure of existing pipe	No	No	No	Yes

3.1.3 Factors in Water Pipe Renewal

In almost every country in the world, underground pipes carry water to homes, schools, hospitals and workplaces. These pipes are used for a long time and as expected deteriorate over time. In pipe renewal method, design factors such as physical parameters and rate of decay and environmental factors such as groundwater, soil, traffic loads and other loading conditions are taken into account. Najafi [1] put forward the key elements for the selection of a specific method for renewal of potable water pipes.

"*Nature of problem the pipe is facing and the objectives for the renewal method*

Existing pipe material, dimensions, and features (bends, alignment, joints, history of previous repairs, depth, degree of corrosion, and so on)

Types and locations of appurtenances such as valves, fittings, and fire hydrants

Number and type of service connection

Length of time the pipe can be out of service or bypass requirements

Site- and project-specific factors (surface and subsurface conditions)

Overall cost of the renewal method (material and installation)"

3.1.4 Steps of Coatings and Linings

The successful installation of coatings and linings depends on many factors. Some of them are transportation of lining material from shop to the project site, ambient temperatures at the site, and cleanliness of the internal surface of the existing pipe as well as existing pipe conditions, geometry, alignment, and defects. Figure 3.3 illustrates the various steps [1].

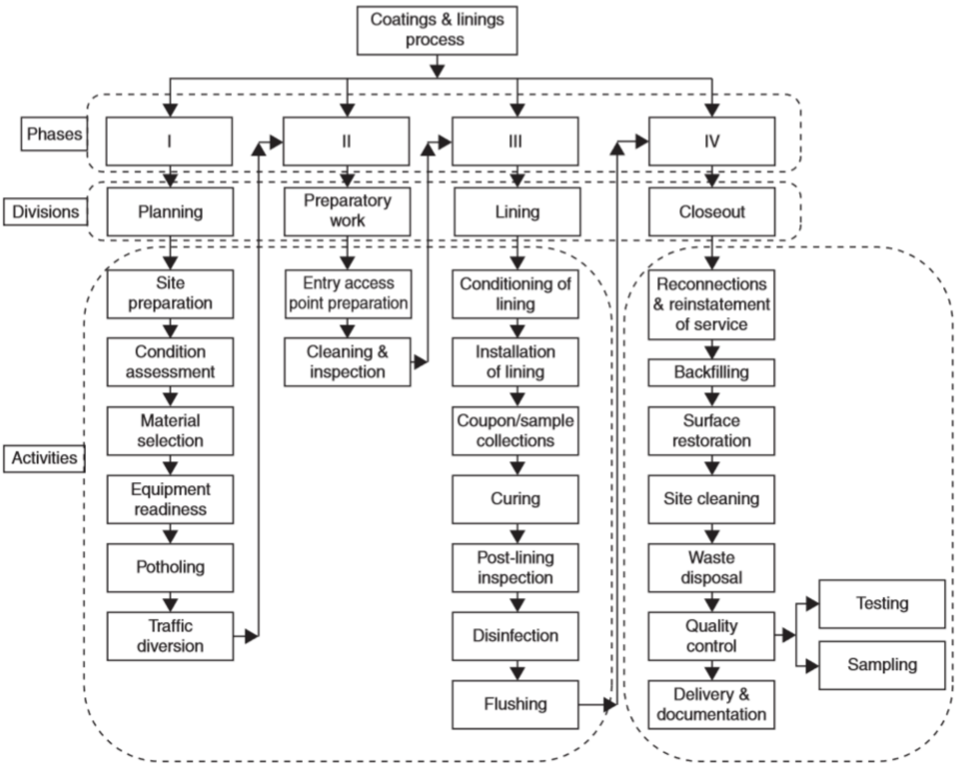


FIGURE 3.3 Steps and sequences for coatings and linings *(Source: 3M Water Infrastructure)*

3.1.5 Site Investigations and Planning

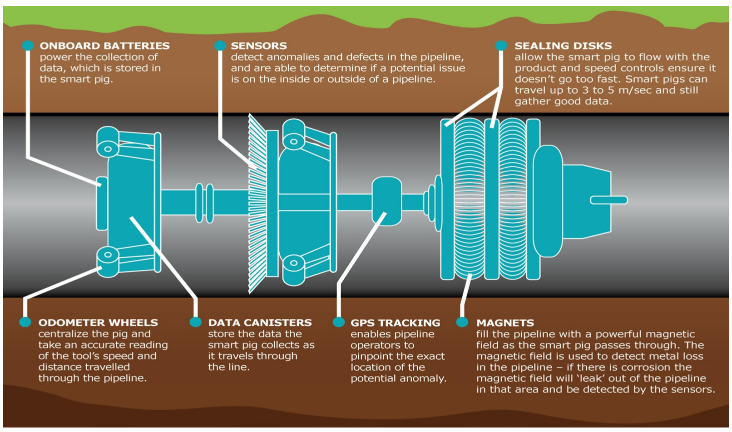
Site Investigations and Planning have been detailed by Najafi[1]. *"Every pipe renewal project is unique and requires a careful site investigation before installation can begin. In the planning phase of a project, surface and subsurface survey information provide assistance in determining the suitability of the coating and lining methods. Project owners must provide available existing pipe and site information in the bid documents, so contractors can submit realistic bids. Additionally, contractors must conduct their own surface and subsurface investigations, as bid data might be outdated at the time of bid submission and installation phase. Accurate information would lead to reduction of installation problems, quality issues, reworks and change orders, and associated social costs."* A surface and subsurface survey may include the following steps:

- Working place requirement
- All existing utilities location
- Proposed pit locations nearby features (adjacent utilities and structures)
- Surface conditions, descriptions and layouts of roadways, sidewalks, pavements and so on
- On ground or subsurface utility things such as valves, fire hydrants, and so on

It is essential to determine all valve and fire hydrant locations along the full length of the existing pipe. It is recommended that contractor or installer physically check all the dimensions supplied by the project owner in the form of drawings, videos and DVD's, and reports to ensure accuracy. Once surface and subsurface surveys are completed, pit locations and thickness and section lengths of the lining installations can be determined [1,22].

3.1.6 Water Pipe Inspection

The main objective of water pipe inspection is to examine the condition of the existing pipe before and after liner installation. CCTV is usually the method of choice to inspect the interior of water pipes and also to evaluate quality of installed pipe. Valves, water hydrants or other appropriate locations may be used as inspection insertion points. Water pipelines are searched by using various techniques. Man-entry big water pipes (main transmission lines) are examined by physical pipe inspection methods as given in Chapter 2. Small and medium diameter water pipes condition are searched by various non-destructive techniques. Two testings are given in Figure 3.4. Magnetic Flux leakage method and using of pig is given in Figure 3.4a, while in Figure 3.4b shows finding of defects by radiated electron current probe [1].



a)

b)

FIGURE 3.4 Water pipe inspection. a) Pigs that use the magnetic flux leakage method in pipelines by magnets *(Source: www.azom.com/article.aspx)* b) Probe that uses radiated electron current to find defects *(Source: ISTT, 2014)*

The nature of prelining inspection is summarized by Najafi[1]. *"The purpose of a prelining inspection is to ensure a successful liner installation in water pipes. This inspection provides a good idea of the degree of cleaning required to prepare the existing pipe before the start of a lining operation. A prelining inspection may also reveal the need for other forms of preparations required before lining, such as removal of protruding lateral service connections."* The state or presence of the following issues may be revealed during the prelining inspections:

- Structural problems (voids, cracks, holes, and so on)
- Leaking stop taps
- Leaking valves and ferrules (ringers)
- Dropped joints
- Cleaning and re-cleaning requirements
- Pipe bends that can affect cleaning and lining processes [1]

3.1.7 Pipe Cleaning Methods

All pipelines needs cleaning at some point in their service life. Pipeline cleaning is an important method to improve the efficiency of the pipeline. Before cleaning pipe initial data should be collected and analysed. With this data, the problem can be diagnosed and the need for the cleaning can be established. In addition, customer complaints are also important for utilities to select the appropriate pipe cleaning method. Three principal methods of cleaning pipelines are mechanical (rodding, balling, power bucket), hydraulic (flushing, jetting, scooter, kites, bags, tires, poly pigs) and chemical (treatment with enzymes, hydroxides, caustics, biocides, neutralizers) [18].

Cleaning must be performed on the section of the existing pipe to be lined. Before isolating and cleaning the section, water flow must be stopped or bypassed. The section of pipe will then be emptied and cleaned. The cleaning technique chosen depends on the pipe material, previous lining, and entry point locations. It must be noted that, if the structural condition of the existing pipe is poor and the pipe wall is thin, then some cleaning methods may result in damage to the pipe section being cleaned. For most problems, flushing is usually the first choice of action. This is an inexpensive and easily implemented method which requires less equipment. Figure 3.5 illustrates a conventional cleaning method using a steel rod [1].

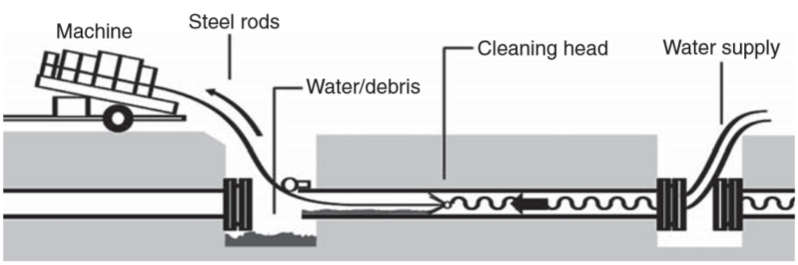


FIGURE 3.5 Rack (hanger)-feed boring machine using steel rods. *(Source: Water UK)*

3.1.8 Coating and Lining Methods Comparison

Cement-mortar (cementitious material), epoxy (polyphenolic compounds), polyurea (izosianite-amin), and polyurethane (poly-ester urethanes), are the major materials available today for potable water pipe coating and lining applications. They provide added benefits of corrosion protection and, dependent on the product and manufacturer, may provide some structural enhancements. Certain differences exist between products due to specific material properties and type and quality of applications of these products. To protect internal and external surface of the pipe means that to protect whole the material and to prevent any corrosions happens. So the pipe won't lose all of the feature. Table 3.2 present a summary of major differences for coating/lining materials [1].

TABLE 3.2 Mortar, Epoxy, Polyurea and Polyurethane Comparison. *(Najafi, 2010)*

Parameter	Cement-Mortar	Epoxy	Polyurea	Polyurethane
Corrosion protection	Passive permeable barrier	Dielectric impermeable barrier	Effective and corrosion-resistant barrier	Effective and corrosion-resistant barrier
History	AWWA Standard since 1955 ANSI/AWWA C602-06	Introduced in U.K. water industry in the late 1970s; Standard ANSI/AWWA C-620-07	Has been in use for 10 years	Has been in use for 65 years; Standard ANSI/AWWA C222-08
Pipe preparation/ cleaning	Scraper method	Rack-feed boring	Drag scraper, power boring, jetting	Drag scraper, power boring, jetting
Lining environment	Wet or damp pipe: no standing water	Dry pipe required	Dry pipe required	Dry pipe required
Typical lining thickness	4–8 mm for 4–12-in. pipe and 8–12 mm for more than 12-in. pipe	Minimum 1 mm typical 2–4 mm	Minimum 1 mm typical 2–5 mm	Minimum 1 mm typical 2–5 mm
Curing time before disinfection	Minimum 24 h	Minimum 16 h (can be less for some products)	Minimum 1 h	Minimum 2 h
VOC (lb/gal)	0.00	0.30	0.00	0.00
Application method	Centrifugal, mechanical, pneumatic, hand application	Plural component spray	Plural component spray	Plural component spray
Curing procedure	Moist curing or accelerated curing	Maintain temperature	Not required	Not required
Structural enhancement	No	No	Yes	Yes
Odor generation	No odor	Strong odor during curing	No odor	Strong odor during curing
Bonding to concrete	Good	Strong	Extremely strong	Weak

(1 in. = 25.4 mm)

3.2 Behaviour of Pipes and Pipe-Soil System

3.2.1 The Composite Nature of Pipe-Soil System

Pipe-soil interaction gives composite nature to the system and this fact has been reviewed by Najafi[1]. *"Pelines, specifically those using flexible pipe, are designed as composite structures with pipe and soil forming an integral system to resist the applied loads. The pipe-soil structure generally comprises the pipe, the in situ soil in the foundation and the trench walls, and placed soils (for bedding and backfilling) at locations below and around the pipe. Ideally, installation of placed soils should achieve a state as close to the in situ state of soils as possible. However, this is practically impossible to achieve and appropriate compaction methods are needed. A typical layout of a trenched pipe installation and the associated terminology are illustrated in Figs. 3.6 and 3.7 and described in Table 3.3."*

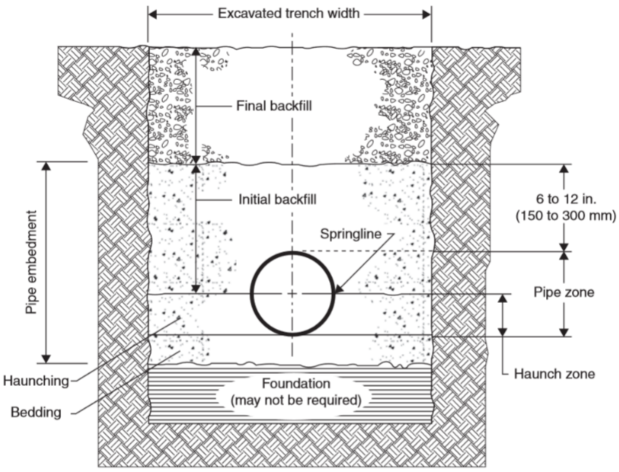


FIGURE 3.6 Typical cross-section of an underground pipeline installation for flexible pipe (Open-Cut). (*Source: ASTM D2321, 1989.*)

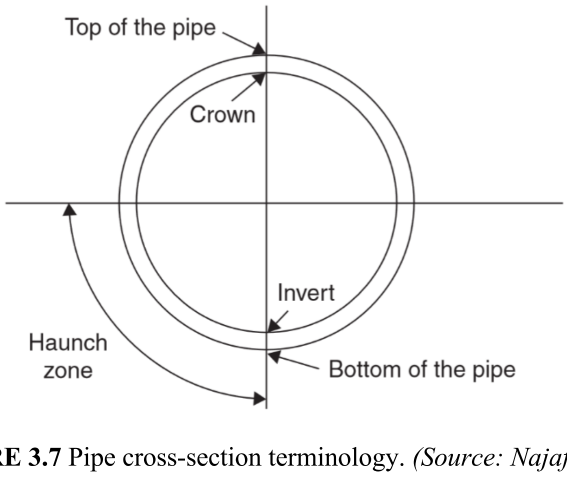


FIGURE 3.7 Pipe cross-section terminology. *(Source: Najafi, 2010)*

TABLE 3.3 Explanation of Pipeline Installation Terminology. (*Howard, 1996*)

Term	Description
Trench walls	The trench walls are comprised of undisturbed in situ soils through which a trench is excavated. Depending upon the type of soil they may be vertical or require sloping.
Bedding	Bedding is the soil placed on top of foundation and provides uniform support and grade for the pipe, except at pipe bells or large couplings where overexcavation is usually specified.
Foundation	The foundation may comprise of undisturbed in situ soil or have imported soils to replace any unsuitable material at the bottom of the trench.
Embedment	Embedment is comprised of material placed around the pipe providing a supporting structure. It consists of the bedding, haunching, and the initial backfill.
Haunch zone	Haunch zone is the area between the bottom of the pipe and the spring line. Backfill material in the haunch zone is critical in transferring forces in the lateral direction.
Springline	Springline is the horizontal centerline of the pipe.
Initial backfill	The initial backfill protects the pipe from final backfill placement. It typically begins at the springline of the pipe and continues about 6 to 12 in. on top of the pipe.
Final backfill	Material placed over the embedment up to the ground level.
Pipe zone	Depth of trench wall occupied by the pipe equal to the outside diameter (OD) of the pipe.
Trench width	Often specified in pipe design, this dimension must allow realistic side clearances to the outside diameter of the pipe, including belled ends and trench support systems. Excessive widths caused by careless excavation increase paving, loads on the pipe, quantities of earthwork and possibly the top width of the trench, affecting right-of-way, surface finishing, and so on.

(1 in. = 25.4 mm)

3.2.1.1 Rigid and Flexible Pipes

Rigid and flexible pipes have been examined by Najafi[1]. *"Broadly speaking, pipe materials fall into two categories: rigid and flexible. Rigid pipes sustain applied loads by means of resistance against longitudinal and circumferential (ring) bending. Under maximum loading conditions, rigid pipes do not deform sufficiently enough to produce horizontal passive resistance from the soil surrounding the pipe. Typical examples of rigid pipes are old cast iron pipes, clay pipes and concrete pipes. On the other hand, flexible pipes are capable of deforming (without damage to the pipe) to the extent that the passive resistance of soils on the sides is mobilized providing additional support. ASTM standards define flexible pipes as pipes that deflect more than 2 percent of their diameter without any sign of structural failure. Typical examples include ductile iron, high density polyethylene pipe (HDPE), steel pipe (SP), and polyvinyl chloride (PVC) pipes. Common terminology used to characterize properties of rigid and flexible pipes is strength and stiffness. While strength refers to the ability of rigid pipes in resisting loads and resulting stress in the pipe materials, stiffness* *refers to the ability of flexible pipes in resisting deflection. Pipes that overlap these two categories are sometimes referred to as semirigid, semiflexible. or intermediate pipes. However, such distinction is seldom made in current design standards. Examples of different types of rigid and flexible pipes are given in Table 3.4. Rigid and flexible pipes differ in the way they transfer the applied loads to the surrounding soil structure. Figure 3.8 gives a simplified illustration of the load transfer mechanism for both types of pipes due to the vertical soil pressures. As can be seen from Fig. 3.8, rigid pipes sustain vertical loads by virtue of the material strength alone and with very little deflection. On the other hand, flexible pipes tend to deflect and use the horizontal passive resistance of the soil on the sides."*

TABLE 3.4 Examples of Rigid and Flexible Pipes. *(Najafi, 2010)*

Rigid	Flexible
Concrete pipe	Steel pipe
Vitrified clay pipe	Ductile iron pipe
Prestressed concrete cylinder pipe	Polyvinyl chloride pipe
Reinforced concrete pipe	Polyethylene pipe
Bar-wrapped concrete cylinder pipe	Fiberglass reinforced plastic pipe
Asbestos-cement pipe	Acrylonitrile-butadiene styrene pipe
Fiber-cement pipe	

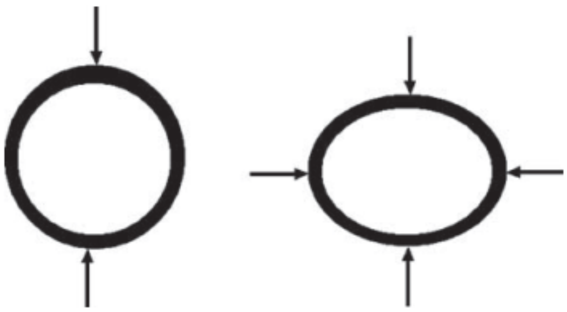


FIGURE 3.8 Load transfer mechanisms for rigid and flexible pipes. *(Source: Najafi, 2010)*

3.2.1.2 Pipe-Soil Interaction

Whether a pipe is rigid or flexible has profound effect on the way in which it interacts with the surrounding soil. The interaction between pipe and soil influences the magnitude of loads exerted on the pipe and the manner in which the pipe transfers these loads to the surrounding soils. Loads exerted on underground pipelines can be traced back to the studies conducted by M. Najafi. Figure 3.9 provides an illustration of the soil load distribution on rigid and flexible pipes. In the case of rigid pipes, the theory proposes that the soil in the side prism tends to settle relative to the central prism. This causes the pipe to assume full load of the central prism and a portion of the load from the side prisms. In contrast, a flexible pipe tends to deflect, which result in a lowering of the pressure from the central prism (Figure 3.10), [1].

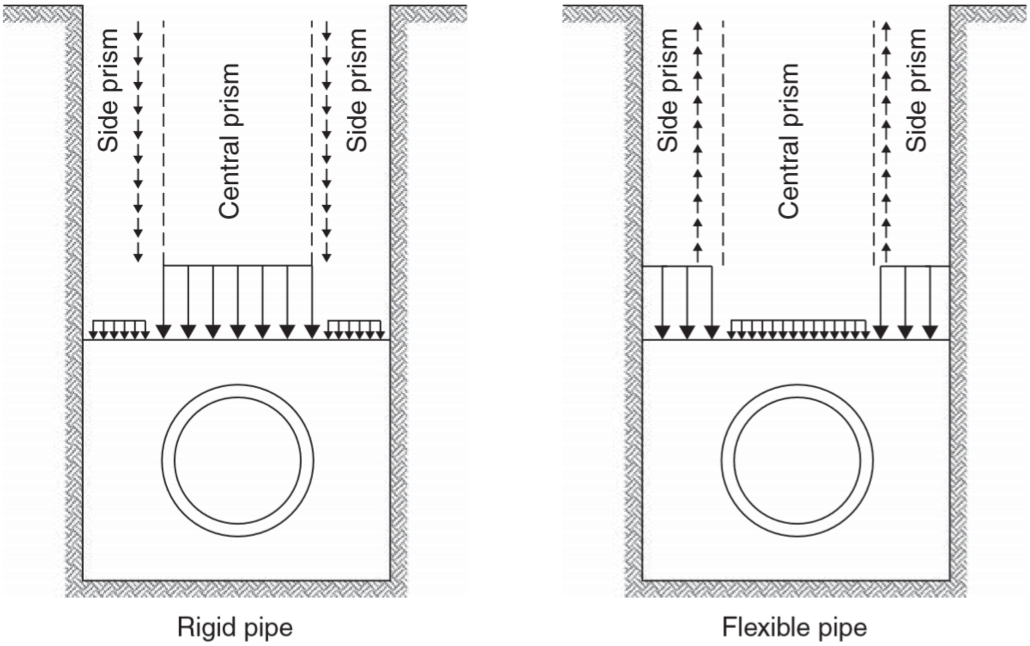


FIGURE 3.9 Trench load comparisons for rigid and flexible pipe. *(Najafi, 2005)*

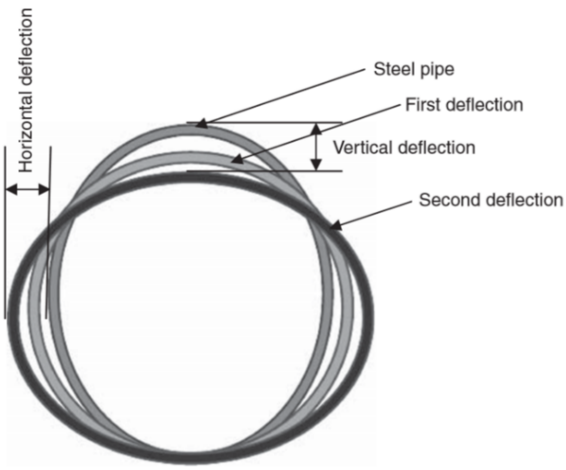


FIGURE 3.10 Load distribution on flexible pipes. *(Najafi, 2010)*

3.2.2 Modes of Pipeline Failures

Underground pipeline failures can occur in several different modes and owing to different types of causes. Three principal aspects of the physical failure mechanisms in pipelines proposed by Najafi [1]:

1. Pipe properties, material type, pipe-soil interaction, and quality of installation.

2. Operational pressure dependant internal loads and external loads due to soil, traffic loads, frost loads.

3. Third-party interference and possible occurances.

4. Material deformation/degradation/deterioration due to internal and external chemical, biochemical and electrochemical environment.

While the third aspect is usually relevant only in service conditions, the first two are very much applicable during and immediately after pipeline installation. Table 3.5 presents some of the factors that affect failure mechanisms in pipelines.

TABLE 3.5 Factors Affecting Pipeline Failures. (*Najafi, 2010*)

Pipe Factors	Environmental Factors
Type of pipe and pipe material	Defects during manufacturing
Location of the pipe	Damage during transportation, handling and installation
Diameter	Soil loads (which depend on the type of soil, density, level of compaction, etc.)
Length	Point loads from projecting rocks, etc.
Type of soil and embedment	Internal pressure loads
Joining method	Axial loads due to temperature, water hammer, etc.
Internal/external corrosion Protection	Frost loads in soils
Wall thickness	Freezing and expansion of water
Depth of installation	Loads due to expansive soils
Bedding conditions	Third-party damage
Foundation conditions	Traffic loads

Failure mechanisms for rigid pipes and flexible pipes differ in several respects. In general, rigid pipes fail in tension and crack rather than deform, if the imposed loads exceed the pipe's inherent strength. Major causes of failures in rigid pipelines:

- Insufficient load-carrying capacity of pipes
- Wrong bedding (nonuniformity)
- Inadequate construction methods (e.g., excessive trench widths and depths)
- Use of very hard and rigid jointing material resulting in a lack of axial flexibility and extensibility in pipeline
- Thermal deformation variations or moisture movements
- Different and differential settlement

Failure mechanisms and causes of them have been given by Najafi[1]. *Flexible pipes, in general, do not crack but fail by excessive deformation, buckling, or pipe flattening. Also, flexible pipes are more accommodating of faulty installation of embedment, bedding, or foundation because of their ability to deform. However, improperly placed embedment material could lead to loss of side support, which is vital for flexible pipes and could result in over deflection or flattening. Major causes of failure in flexible pipeline:*

- *Buckling*
- *Fracture*
- *Wearing, weathering, distortion and dimensional changes*

- *Voids, blisters, and delaminations*
- *Fatigue and corrosion*
- *Blocking (clogging) of the pipe system*

Specific mechanisms for failure of a pipeline also depend upon the type of material of the pipe. Structurally, a pipeline is said to have failed when the performance limits of its material have been reached. Although underground pipelines and the soil embedment around them are designed as an integral system, structural failure of the embedment soil leads to eventual failure of the pipe material." Figure 3.11 illustrates longitudinal tensile failure in pipes (in rigid pipes generally). Figure 3.12a illustrates the effect on pipe due to load and Figure 3.12b shows circular breaks of flexible ductile iron pipe[1].

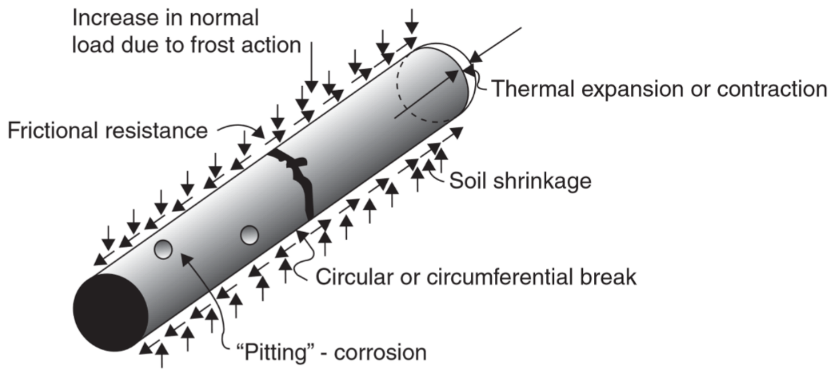
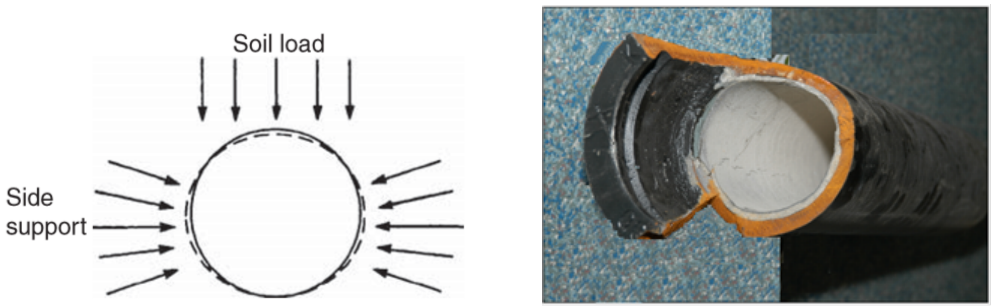


FIGURE 3.11 Longitudinal tensile failure in pipes. *(Najafi, 2010)*



a b

FIGURE 3.12 a) Side support for flexible pipes. (*NCSPA, 2000.*) b) Ductile Iron Pipe broken from socked end (*Yilmaz, 2009*)

3.3 Selection of Pipes

To provide an aid in pipe selection, this section provided detailed description of different types of pipes such as cement based (CP, RCP, PCCP, RCCP, PCP, ACP), vitrified clay (VCP), plastic (PVC, PE, GRP), and metallic pipes (DIP, CIP, SP). It should be noted that some of the cement based and plastic based pipes have been regarded as composite pipes in materials science terminology. Manufacturing process, applicable standards, joint types, advantages, and limitations of each type of pipes are important. More convincing classification of pipes is based on physical properties such as rigid and flexible pipes.

In this section an overview of rigid and flexible pipe behaviour are described. Pipe segments to pipe segments interactions, jointing and joint types are very important in rigid pipes. Interlocking jointing and push-on-gasket jointing, and some new approaches are necessary to prevent failure and leakages in pipelines.

Economics is one of the engineering considerations during the design and selection of pipe material. There are several other factors that influence pipe selection. There are several considerations for proper pipe selection.

- Type of fluid to be transported (potable water, wastewater, storm, sewer, water, oil, gas, and so on.).
- Construction and installation conditions and methods used.
- Flow characteristics, such as corrosiveness and abrasion of wastewater.
- Life expectancy and related life-cycle cost analysis.
- Pipe mechanical, physical and chemical properties.
- Ease of handling and installation of pipe.
- Availability of diameter sizes, pipe section lengths, and joints (specifically for trenchless technology).
- Construction and operational stresses in the pipe. In many cases for trenchless technology projects, the construction stresses in the pipe exceeds the operational stresses.
- Environment and location of pipe (inland, offshore, in-plant, corrosiveness of soil, and so on).
- Type of burial or support (underground, aboveground or elevated, underwater, and so on).
- Hydraulic properties of the pipe (surface roughness).

3.3.1 Rigid Pipes

3.3.1.1 Cement-Based Pipes

As it is well known, cement is main ingredient of concrete pipes. Najafi[1], in his book, describes concrete pipes, *"Pipes in this category include concrete pipe as well as asbestos-cement pipe. Both types incorporate portland cement as the base material. Concrete pipes are designed with or without reinforcements and are used for both pressure and gravity applications. Asbestos-cement pipe is composed of a mixture of Portland cement, silica, and asbestos fiber. Asbestos-cement pipes have not been manufactured or installed in EU and USA since the late 1980s, but large quantities of the pipe continue to be in service in water systems at various locations.*

Concrete Pipes

Trenchless construction with concrete pipe was first performed by the Northern Pacific Railroad/USA between 1896 and 1900, when the pipe was installed by jacking. The jacking of concrete pipe is performed both for pressure and gravity applications. Concrete pressure *pipes are also installed by tunneling methods. For small-diameter pipe in short tunnels, such as those under a highway or a railroad, it is a common practice to slide the pipe through a liner followed by grouting the interspace."* Structural integrity is very important in concrete and concrete pipes are most used ones. Searching and inspections of new and old concrete pipes as well as concrete structures are generally carried out by using GPR with advanced softwares. 2D map (tomography) of internal structure layers, along with 3D views of volume is used to locate anomalies in concrete structures [24].

Types of Concrete Pipes

There are many different types of concrete pipes for pressure and nonpressure applications. Some of them are given below:

1. concrete pipe-nonreinforced (CP): Used for nonpressure applications only, this pipe is manufactured in diameters of 100 to 900 mm, in lengths up to 2.5 m (Figure 3.13a).

2. Reinforced concrete pipe (RCP): hot-rolled rod, welded wire and cold-drawn steel wire reinforcing (Figure 3.13b).

3. Prestressed concrete cylinder pipe (PCCP): Often used in high pressure applications, PCCP is a composite pipe of concrete and steel (Photo 3.1c). There are two types of PCCP (lined cylinder pipe and embedded cylinder pipe).

4. Reinforced concrete cylinder pipe (RCCP): This is similar to PCCP but uses reinforcing cages (lattices) in place of the hard-drawn wire (Figure 3.13d). Pressure applications are its main use.

5. Bar-wrapped steel-cylinder concrete pipe: Also known as pretensioned concrete cylinder pipe, the steel cylinder is internally lined with a cement mortar lining. Once cured, a steel rod, under tension, is wrapped around the cylinder. Another cement mortar lining is then placed on the wrapped cylinder. Smaller-diameter pipes are considered rigid, whereas larger diameters behave as flexible conduits. Like the previous two types, bar-wrapped concrete pipe is also used in pressure applications (Figure 3.13e).

6. Polymer concrete pipe (PCP): Polymer concrete originated more than 20 years ago in Germany. These pipes are made by mixing a high-strength thermosetting resin plus oven-dried aggregate and cement. This type of pipe provides high corrosion resistance which facilitates to use in corrosive environment (Figure 3.13f).

7. Asbestos-Cement Pipe (ACP): EPA published a regulation on the commercial uses of asbestos in which a ban on the manufacture and installation of asbestos-cement (AC) pipe was proposed (1980s). Many AC manufacturing plants relocated to other countries, and production in the United States and European Union came to a complete stop. Many countries of the world, including Mexico and UAE, continue to specify and install asbestos-cement pipe for both water and sewer applications. The hazards of asbestos inhalation are increased during removal of the pipe, so utilities have chosen to keep them in the ground. These pipes are regularly tapped and maintained, so a working knowledge of the material is helpful (Figure 3.13g), [1].

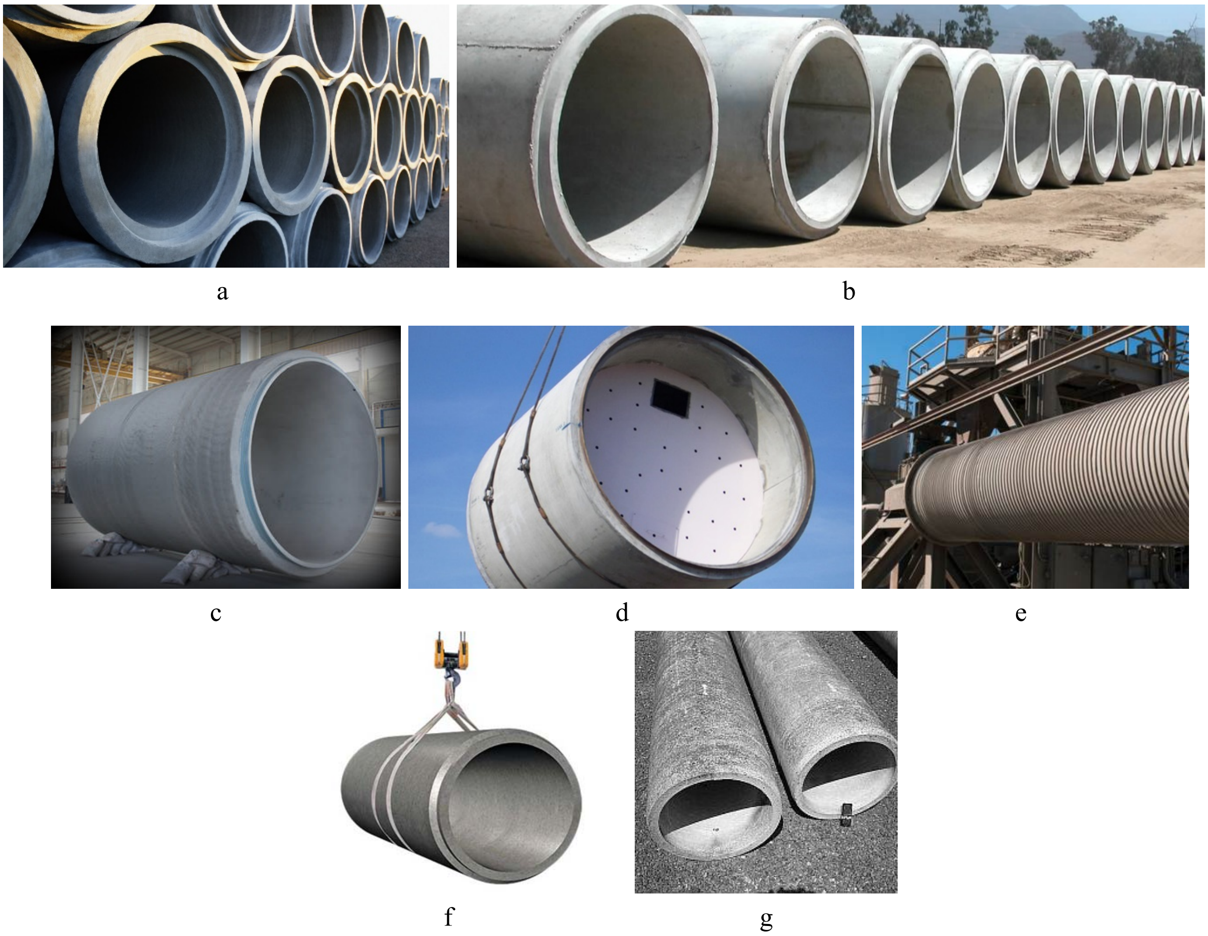


FIGURE 3.13 Concrete pipes a) Nonreinforced concrete pipes, b) Reinforced concrete pipes, c) Prestressed concrete cylinder pipe, d) Reinforced concrete cylinder pipe, e) Bar-wrapped steel-cylinder concrete pipe, f) Polymer concrete pipe, g) Asbestos-Cement Pipes. *(Source: ISTT.)*

Advantages and Limitations

Concretes are one of main materials of our industrialization era. Concrete pipes are most used and rather heavy materials. Table 3.6 presents a summary of advantages and limitations of concrete gravity and pressure pipes. The widespread use of large-diameter concrete pipe in water and wastewater applications is an indication of the material's acceptance at the municipal level [1].

TABLE 3.6 Advantages and Limitations of Concrete Pipe. *(Najafi, 2010)*

Advantages	Limitations
1. Specialized work crew not required for installation 2. Large selection of available nominal diameters 3. Wide variety of pipe lengths available 4. Large selection of both structural and pressure strengths 5. Relatively low cost of maintenance 6. Capability to withstand very high pressures 7. Ideal for pipe jacking applications owing to high compressive strengths 8. Internal corrosion can be significantly reduced by using thermoplastic lining 9. External sulfate corrosion may be reduced by an additional sacrificial wall thickness determined by the Pomeroy/ Parkhurst 'AZ' design method is more commonly added to the *inside* of the pipe wall to counter the corrosion from biogenically generated H_2SO_4. Alternatively, it is possible use Type V sulfate-resistant Portland cement.	1. In open-cut construction, pipe is sensitive to bedding conditions-shear failure and beam breakage may occur 2. Handling and installation difficulty because of heavy weight except where weight would be advantageous because of flotation concerns 3. Susceptible to external corrosion in acidic soil environments 4. Highly vulnerable to hydrogen sulfide attacks and internal microbiological-induced corrosion at crown. A concern in sanitary applications only. 5. Generally difficult to repair, particularly in cases of joint leakage or failure in pressure pipes 6. Tendency to leak because of high pipe wall porosity and shrinkage cracking 7. Without internal lining, life span is significantly reduced in the case of sanitary sewer applications and only then if there is a high potential for H_2S generation 8. Somewhat lower abrasion resistance—internal scouring can occur if solid content and flow velocities are high 9. Reinforcements in PCCP can corrode or fail without little or no external evidence

3.3.1.2 Vitrified Clay Pipe (VCP)

Vitrified clay pipes and properties of them have reviewed by Najafi[1]. *"The second group of rigid pipes among piping materials is vitrified clay pipe (Figure 3.14). For two centuries, VCP was the only commercially available material capable of withstanding the chemically aggressive environments. Clay pipes were therefore designed with a low emphasis on the effectiveness of their joints. This philosophy soon changed as engineers realized the hazards posed by wastewater leakage to soils and groundwater sources. The EPA's role in reducing infiltration or inflow (I/I) of piping were major factors in shifting to the requirement of watertight joints in sewer pipes. All factory-applied clay pipe jointing systems, whether on bell-and-spigot pipe or plain-end pipe, are designed to provide resilience and flexibility to accommodate minor pipe movement. With the proper installation, a clay pipe sewer system can meet standard infiltration or exfiltration requirements. In the arena of trenchless construction, clay pipe's ability to withstand high compressive loads and external abrasion has resulted in a significant rise in its acceptance and use in pipe-jacking and microtunneling applications."*

FIGURE 3.14 Vitrified clay pipes. *(Source: ISTT)*

Advantages and Limitations

Table 3.7 presents a summary of advantages and limitations of clay pipes. Vitrified clay pipe (VCP), or clay tile pipe, is made from a blend of clay and shale, set at a high temperature to turn the pipe into an inert ceramic. This type of pipe is regularly used in gravity sewer collection mains because it resists most sewage and has a long lifespan. Clay pipe is very heavy by nature and delivering is rather difficult [1].

TABLE 3.7 Advantages and Limitations of Clay Pipe. *(Najafi, 2010)*

Advantages	Limitations
1. Resistant to both internal and external corrosion 2. Proven history of long life of the pipe itself 3. Improved joints have been available since 1970 4. Ability to handle high compressive forces, making it ideal for jacking installations 5. Abrasion resistant	1. Available for gravity applications only because of the characteristics of the pipe 2. Sensitive to bedding conditions – may be subject to shear and beam failure 3. Poor joints in pipe installed prior to 1970 may lead to leakage and root intrusion problems 4. Short lengths, resulting in more pipe joints 5. Very brittle – frequently high breakage during shipping and handling

3.3.2 Plastic Pipes

Najafi[1] in his book, describes plastic pipes. *“Plastic pipes were introduced in the late 1950s in North America. The four important types of plastics pipes include polyvinyl chloride (PVC), high-density polyethylene (HDPE) or cross-linked polyethylene (PEX), and glass-reinforced pipe (also called fiberglass pipe). PVC and PE fall into the group of thermoplastics, while GRP and PEX is a thermoset pipe. In GRP, polyester is main constituent and combination with glass fibers gives it composite character. Thermoset plastics are processed by a combination of chemicals and heat, and once formed, cannot be reshaped. Both thermoplastic and thermoset pipes are considered to be flexible pipes and are designed accordingly. In the field of municipal trenchless construction, PE has been the dominant piping material in the past decade. By butt-fusion of successive lengths of PE pipe, or by using coiled PE, a long jointless pipe is created, which can be installed by trenchless methods* *such as horizontal directional drilling (HDD). PE is also used in open-trench construction. Traditionally, PVC has been the most dominant material for open-cut installations in the North American water and sewer markets because of its bell-and-spigot gasket-joints, its light weight in smaller diameters, and ease to work with."*

3.3.2.1 Polyvinyl Chloride Pipe

Polyvinyl chloride (PVC) was discovered almost accidentally in the nineteenth century by German scientists. Organic chemical gas, vinyl chloride (C_2H_3Cl), discovered under sunlight. Since then, scientists had observed the first polymerization and creation of a new plastic material, PVC (Figure 3.15a). In 1839, a technical paper was published detailing this new materials. In 1912, Fritz Klatte, another German, laid the groundwork for the technical production of PVC. The oldest known PVC pipe was manufactured and installed in the 1930s in World War II in Germany and continues to be in service today.

The technology was brought to the United States following World War II and by the mid-1950s ASTM groups were organized for plastic pipe standardization, The data and classifications are given by Najafi[1]

"1. PVC-U: Unplasticized PVC is widely used piping material in water and sewer systems in North America. The molecular structure of PVC pipe is a random arrangement of long chain molecules, where molecular entanglement (net) is prevalent throughout the length of the pipe. In general, the PVC molecules do not exhibit any definite directional orientation, and therefore, a generally uniform strength prevails in both the radial (circumferential) and longitudinal directions. Testing has shown that the modulus of elasticity in 15-year-old PVC is only slightly higher in the longitudinal direction than in the radial directions. For simplification, the term PVC as used in this chapter will denote PVC-U, the conventional type of PVC most used in pipe manufacture. PVC pipes are manufactured for both pressure and gravity applications. All PVC pressure pipes (ASTM and AWWA standards) must meet the tensile strength of 48 MPa, and a modulus of elasticity of 2750 MPa (long-term design stress is 14 MPa.

2. PVC-O: Molecularly oriented PVC is made in the United States by the expansion of the conventional PVC pipe; during the expansion process, the molecules become oriented in a generally radial or circumferential direction. This molecular reorientation increases the strength of the pipe in the hoop (ring) direction. Consequently, this stronger material can have a thinner wall than a conventional PVC pipe of the same pressure capacity. PVC-O pipe is not used in gravity applications.

3. PVC-M: Modified PVC is produced by incorporation of additives or impact modifiers to give the toughness (fracture resistance) of the material. Resistance to fracture by absorption of energy is an evidence of the toughness of the pipe material. PVC-M is made and used mainly in Europe and Australia. PVC-M pipe is generally used for nonburied applications."

Advantages and Limitations

Table 3.8 presents a summary of advantages and limitations of PVC pipes. They are cheap and light polymeric material with moderate strength. Small and medium diameter PVC pipes are generally in use in the field of manucipal trenchless technology.

TABLE 3.8 Advantages and Limitations of PVC Pipe. *(Najafi, 2010)*

Advantages	Limitations
1. Resistant to both internal and external corrosion 2. Gasket-joints and fusible joints have an excellent track record of leak-free performance. 3. All four restrained-joint PVC products have high tensile strengths for HDD and other trenchless processes 4. Highly abrasion resistant for sewer applications 5. Low internal frictional resistance for both pressure and nonpressure applications 6. At least 2.5 times stronger than other thermoplastic pipe (higher stiffness, higher HDB) 7. Expansion is significantly lower than in alternative thermoplastic piping material	1. Sensitive to operating temperature, must be derated in case of long-term exposure to temperatures above room temperature 2. Sensitive to ultraviolet light if exposure is greater than 2 years (unless pipe is formulated with higher ultraviolet [UV]-inhibitor level) 3. Less longitudinal flexibility than alternative thermoplastic piping material 4. Thinner-walled sewer pipe is sensitive to bedding conditions. 5. Susceptible to chemical permeation in cases of gross contamination 6. Susceptible to impact damage in cold temperatures 7. Susceptible to rapid crack propagation failure. Tapping of fused PVC pipe must be done with extreme caution.

3.3.2.2 Polyethylene Pipe

The nature and properties of PE pipes have been reviewed by Najafi[1]. *"Polyethylene (PE) belongs to a group of thermoplastics known as polyolefins, materials made by polymerization of olefin gases including ethylene, propylene, and butylene. Polyethylene (PE) was first discovered by a German scientist, Hans von Pechman in 1898, but the discovery was never commercialized. PE was rediscovered in the United Kingdom in 1933 by the Imperial Chemical Company and later commercialized in 1939 to manufacture insulation for telephone and coaxial cables. The development of low-pressure reactors in the late 1950s greatly improved the commercial manufacture of PE resins, and led to the commercial development of PE pipe in the 1960s. Today, more than 95 percent of new and replacement gas distribution pipe in the North American is PE pipe. Other applications of PE pipe gradually spread to industrial and municipal systems. Since the development of high-density polyethylene (HDPE) materials in the 1970s, a significant use for PE is sliplining renewal of nonpressure gravity sanitary sewers[23]. The development of ASTM and AWWA pressure piping standards led to the widespread use of PE pressure pipe in municipal applications in North America over the past decades. Open-cut waterworks projects are being performed with PE pipe at an increasing rate. Today, PE is the most widely used piping material for trenchless methods such as horizontal directional drilling (HDD) and pipe bursting (PB) for new installation and renewal of municipal pressure and nonpressure piping systems. Higher density of it provides greater hardness, stiffness, and tensile strength.*

ASTM classifies PE piping materials having specified density ranges as low density (LDPE), medium density (MDPE), or high density (HDPE). HDPE displays the highest stiffness whereas LDPE is the most flexible. LDPE is not used for pressure piping, but due to its *flexibility is used for pneumatic instrument controls. MDPE pressure piping is predominantly used for gas distribution. HDPE nonpressure piping materials are used for electrical and communications conduit and nonpressure corrugated and profile wall pipes. HDPE pressure piping materials are used for solid-wall pressure pipes for gas, water, force mains, nuclear and industrial process piping, and for solid-wall nonpressure applications such as sanitary sewers and culverts (Figure 3.15b). Gas pipes are generally made from MDPE. Municipal water and sewer pipes and industrial pipes are generally made from HDPE. At room temperature the pressure rating of HDPE is about 25 percent higher than MDPE pipes. Many industrial cataloques insist that HDPE materials have a design service life of 100 years in typical municipal water or sewer applications."*

Advantages and Limitations

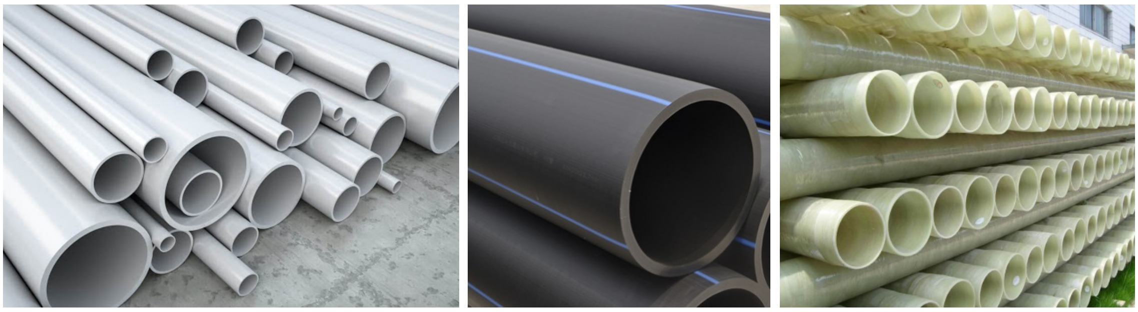
HDPE pipes are low cost polymeric materials with outstanding properties such as corrosion resistance. Table 3.9 presents a summary of advantages and limitations of HDPE pipes. Using PE, in trenchless and open trench installations are common practice made by many manucipalities.

TABLE 3.9 Advantages and Limitations of HDPE *(Najafi, 2010)*

Advantages	Limitations
1. Resistance to both internal and external corrosion. Low internal friction. Smooth interior. 2. Butt-fused joints effectively create a continuous jointless leak free joint. 3. Abrasion resistant. Use to convey sand and fly ash slurry. 4. High ductility and flexibility. Lightweight in smaller diameters. Typical minimum bend radius of 25–30 times pipe diameter. 5. Excellent resistance to fatigue and repetitive surge pressures. 6. May be repaired using mechanical couplings and saddles. 7. High resistance to failure by impact, even at very low temperatures. 8. Resists shatter-type or rapid crack-propagation failure. 9. Does not easily crack under expansive forces of freezing water. 10. PE with carbon black has a long UV resistance.	1. Older PE materials are subject to environmental stress cracking due to improper embedment or excessive local bending. Newer materials, like PE 4710 have enhanced resistance. 2. Trained labor and special equipment required for butt-fusion. However, training is available for equipment manufacturers and distributors nationwide. 3. Slightly smaller inside diameter than other pipes of the same outside diameter size. However, proper design will minimize this issue. 4. Cannot be located unless buried with metallic wire or tape. 5. Sensitive to temperature differentials, resulting in expansion and contraction unless restrained by soil embedment after burial. 6. Unprotected color products usually cannot have more than 5 years of UV resistance.

3.3.2.3 Glass-Reinforced Pipe (Fiberglass Pipe)

The third type of plastic pipe is glass-reinforced pipe (GRP), also commonly referred to as fiberglass pipe (Figure 3.15c). It has composite structure since glass and polyester is combined. Unlike PVC and HDPE, GRP is made of a thermoset material. GRP was first manufactured in the United States in the 1950s, as an alternative to corrosion-prone concrete and steel materials. GRP pipes are used in the many countries for both pressure and gravity applications, though the latter is the more prominent use. Polymer and glass mixture give strong composite character to this pipe. Flexibility is dominant character of GRP [1].



a b c

FIGURE 3.15 Plastic pipes. a) PVC, b) HDPE, c) GRP *(Source: ISTT)*

Advantages and Limitations

The widespread use of large and medium-diameter GRP pipe in water and wastewater applications is an indication of the material's acceptance at the municipal level. It is computing material of steel pipe. Table 3.10 presents a summary of advantages and limitations of GRP pipes. This composite pipe is relatively expensive and have some remarkable properties.

TABLE 3.10 Advantages and Limitations of GRP. *(Najafi, 2010)*

Advantages	Limitations
1. Good internal and external corrosion resistance in ordinary soils 2. Better abrasion resistance than cement-based pipes 3. Light weight compared to alternative materials 4. Various pressure classes available for pressure pipe 5. Excellent hydraulics due to smooth interior 6. Cast pipe has fixed OD and gasketed joints that seal on OD 7. Dimensionally stable for fluid service and weather exposure 8. Very high compressive strength (10,000 to 15,000 psi) so ideal for jacking	1. Susceptible to impact damage 2. Resin selection is important for some chemicals

3.3.3 Metallic Pipes

Metals have dominant character of high strength properties and high melting points. Najafi[1] summarized the facts of metals in TT. *"Metallic pipes in present-day use include ductile iron pipe and steel pipe. The precursor to ductile iron was cast iron pipe (CIP). Metallic pipes have traditionally been used in pressure applications, but some areas of North America use them for gravity sewer applications also. Most metallic pipes used in the past were installed* *by open-cut methods. Recent acceptance of trenchless technologies has led to the manufacture of metallic pipes with joints suited for pull-in or jacking installations. Steel pipe with welded joints is a product of choice for large diameter HDD applications (usually more than 500 mm diameters), horizontal auger boring (HAB), and pipe-ramming (PR) projects."*

Ductile Iron Pipe (DIP)

Ductile iron pipe was developed in the 1940s from grey cast iron composition by distributing the graphite into a spherical form instead of a flake form. This was achieved by the addition of spheroidazing such as magnesium to molten iron. It resulted in the ductile nature of the new pipe, in addition to higher strength, impact resistance, and other improved properties. The commercial production of ductile iron pipe began in 1955, and by the 1970s, it had almost completely replaced cast-iron pipe in municipal applications. Figure 3.16 shows structural differences of DIP and CIP. Spheroidal graphite crystals in DIP reduces notch effect experienced in CIP, and increases toughness as well as strength of it (Figure 3.16b). Ductile iron and spheroidal graphite cast iron are in use to indicate same thing in industrial circle. Since 1980, ductile cast-iron pipe for pressure pipe applications has been produced by centrifugal casting in USA and EU. Centrifugal cement mortar lining (6 mm wall thickness) is applied for the inner protection of these pipes. As a result of centrifugal lining, high quality mortar density with strong adhesion and low internal roughness are obtained. This lining ensures that the hydraulic performance is maintained over time, so debris cannot adhere to this surface. In addition to these, the lining from cement mortar protects both pipes and water [1,21].

Advantages and Limitations

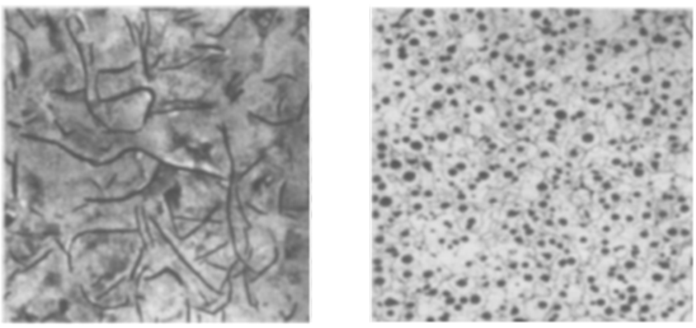
Ductile iron pipes which are advanced nature of cast iron pipe have some remarkable properties. Table 3.11 presents a summary of advantages and limitations of ductile iron pipes. The widespread use of large and medium-diameter ductile iron pipe in water applications is an indication of the material's acceptance at the municipal level.

TABLE 3.11 Advantages and Limitations of Ductile Iron Pipe. *(Najafi, 2010)*

Advantages	Limitations
1. Wide variety of internal and external corrosion protection systems available	1. Highly susceptible to corrosion, both internally and externally, unless protected
2. Internal cement mortar lining prevents tuberculation and enhances hydraulic capability	2. Not all available corrosion protection methods are effective
3. Strong material, with high load bearing strength, impact strength, and beam strength	3. Internal cement mortar lining is easily damaged if struck with a backhoe.
4. Wide variety of joints enable various applications, including trenchless	4. Cathodic protection is cost prohibitive and is rarely used in municipal systems
5. Available for both pressure and gravity applications	5. Polyethylene encasement is easily damaged and subject to improper installation
6. Wide range of diameters and pressure classes available	6. Heavy weight, resulting in high cost of labor
7. Long laying lengths reduce joints in the system	7. Lack of flexibility is an obstacle in trenchless installations
8. Pipe is highly resistant to chemical permeation in contaminated areas	8. Gaskets in the joints are highly vulnerable to chemical attack in contaminated soils

Cast Iron Pipe (CIP)

Cast iron pipe has been used for many years in potable water systems. Its first usage as pipe in Europe goes back to 15th Century (In Germany at 1455 and in France at 1664). In the United States, cast-iron pipe was introduced in the early 1800s. Becausue of sand casting technology these iron pipes were heavy and had large wall thickness. Also referred to as gray cast iron, it accounts for a very large portion of buried water-piping material throughout North America even today. Cast iron is a very strong, but brittle material. Early unlined installations of cast-iron pipe has lasted more than a century in some cases on account of thick walls of the the pipes. The thick walls played a sacrificial role as they slowly corroded over the years. Other aspect is graphite in structure increases corrosion resistance. Internal tuberculation in unlined cast-iron pipes has caused severe hindrance to flow in most cases. Figure 3.16a shows flake-like graphite crystals in cast iron pipe. These lamellar graphites behave like micro crack and leads fracture (notch effect) under load [1,21].



a) b)

FIGURE 3.16 a) Cast iron microstructure (75x), b) Ductile iron microstructure (75x). *(Source:Yilmaz, 2009)*

Steel Pipe (SP)

The nature of the steel pipe has been reviewed by Najafi[1] *"Steel pipes, made from a controlled refinement of raw iron, have seen a wide range of usage for more than a century and a half. The development of high-strength steel pipes has made it possible to transport fluids such as natural gas, crude oil, and petroleum products over long distances. The development of electric arc welding machines in 1920s made it possible to construct leak-proof, high-pressure, large-diameter pipelines. One of the earliest steel water pipe installations in the United States, still in service today, was in San Francisco in 1863. Developments in technology have given way to riveted steel pipes evolving to the automatically welded steel pipes of today. Various other developments have resulted in the creation of different types of joints as well as effective mechanisms for prevention of corrosion, making steel more versatile for trenchless and open-trench applications. In municipalities, steel pressure pipes are used today in large diameter potable water transmission applications. In municipal trenchless construction, steel pipes are used as casing pipe in processes such as microtunneling, jacking, boring, and pipe-ramming because of their high stiffness and compressive strengths."*

Corrugated Steel Pipe (CSP)

Short summary on corrugated steel pipe has been given by Najafi[1]. *"Corrugated Steel Pipe have been used for more than a century in gravity applications such as drainage and storm sewers. Though corrugated steel pipes have been used in some sanitary sewers, this is not the case today. Due to their relatively low-compressive and tensile strengths, corrugated steel pipes are not used in trenchless or pressure applications (Figure 3.17)."*

FIGURE 3.17 Corrugated steel pipe. (*Source: ISTT.*)

Advantages and Limitations

Summary of advantages and limitations of steel pipes is presented in Table 3.12. Very good mechanical properties of steel pipes are balanced with low corrosion resistance. The widespread use in water applications of large and medium-diameter steel pipe is the fact. Its municipal and private use is clear indication of acceptance.

TABLE 3.12 Advantages and Limitations of Steel Pipe. (Najafi, 2010)

Advantages	Limitations
1. Various standards and methods are available for internal and external corrosion protection 2. High tensile strength 3. High compressive strength 4. Easy to assemble, nonweld joints available 5. Adopts well to locations where soil movements occur 6. Good hydraulic properties when internally lined	1. Prone to internal tuberculation and external corrosion, subject to electrolysis 2. Use of internal and external corrosion protection raises price of the product 3. Low resistance to external pressures in large-diameter sizes 4. Air vacuum valves are necessary in large-diameter lines 5. Welding of joints require skilled labor and is time consuming 6. Special care required to ensure proper alignment at joint in welded pipe 7. Fully dependent on proper installation to limit deflection and collapse.

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Appendix A / Table: Glossary of Terms

M. Najafi, "Trenchless Technology Piping", WEF Press, Alexandria, Virginia, USA, pages:413-437, 2010

ABS: Acrylonitrile-butadiene-styrene

AC: Asbestos cement

AMP: Asset management plan; a structured approach for utilities to achieve long-term defined service standards or an external bearing used to isolate the final drive from the thrusting force of the machine.

ASTM: American Society of Testing Materials.

Auger: A flighted drive tube having hex couplings at each end to transmit torque to the cutting head and transfer the spoil back to the machine.

Auger boring: Also horizontal auger boring, a technique for forming a bore from a drive pit to a reception pit, by means of a rotating cutting head. Spoil is removed back to the drive shaft by helically wound auger flights rotating in a steel casing. The equipment may have limited steering capability. See guided auger boring.

Auger machine: A machine to drill earth horizontally by means of a cutting head and auger or other functionally similar device. The machine may be either cradle or track type.

Auger MTBM: A type of microtunnel boring machine, which uses auger flights to remove the spoil through a separate casing placed through the product pipeline.

Auger TBM: Tunnel boring machine in which the excavated soil is removed to the drive shaft by auger flights passing through the product pipeline pushed in behind the TBM.

Back reamer: A cutting head attached to the leading end of a drill string to enlarge the pilot bore during a pullback operation to enable the carrier, sleeve, or casing to be installed.

Backstop: Also thrust block, a reinforced area of the entrance pit wall directly behind the track or where the jacking loads will be resisted.

Band: A ring of steel welded at or near the front of the lead section of casing to cut relief and strengthen the casing (used in horizontal auger boring).

Bedding: A prepared layer of material below a pipeline to ensure uniform support.

Bent sub: An offset section of drill stem close behind the drill head that allows steering corrections to be made by rotation of the drill string to orientate the cutting head (used in horizontal directional drilling).

Bentonite: Colloidal clay sold under various trade names that form a slick slurry or gel when water is added; also known as driller's mud. See drilling fluids.

Bits: Replaceable cutting tools on the cutting head or drill string.

Bore: A generally horizontal hole produced underground, primarily for the purpose of installing services.

Boring: (1) The dislodging or displacement of spoil by a TBM; a rotating auger or drill string to produce a hole called a bore. (2) An earth-drilling process used for installing conduits or pipelines. (3) Obtaining soil samples for evaluation and testing.

Boring machine: An automated mechanism to drill earth.

Boring pit: Also entrance pit, launch or drive pit; an excavation in the earth of specified length, depth, and width for placing the boring machine on required line and grade.

Bottom inversion: The CIPP tube is inverted through a specially designed elbow located at the elevation of the pipe, typically in a manhole or excavated pit.

Breakout: Controls the joint make and/or break mechanism (in HDD operations).

Burst strength: The internal pressure required to cause a pipe or fitting to fail within a specified time period.

Butt-fusion: A method of joining polyethylene and PVC pipe where two pipe ends and are rapidly brought together under pressure to form a homogeneous bond.

Bypass: An arrangement of pipes and valves whereby the flow may be passed around a hydraulic structure or appurtenance. Also, a temporary setup to route flows around a part of a sewer system.

Bypass pumping: Taking all existing flow in a pipe and routing around the section of pipe to be renewed, replaced, or repaired.

Calibration hose: A flexible hose inverted into a pulled-in liner and used to hold the resin saturated fabric tube up tight against the existing, old, or host pipe until final cure has been achieved.

Can: A principal module, which is part of a shield machine as in microtunneling or tunnel boring machines (TBMs). Two or more may be used, depending on the installation dimensions required and the presence of an articulated joint to facilitate steering. May also be referred to as a trailing tube.

Carbon fiber: A reinforcing material used to strengthen cured-in-place pipe.

Carriage: The mechanical part of a nonsplit boring machine that includes the engine or drives motor, the drive train, thrust block, and hydraulic cylinders.

Carrier pipe: The tube, which carries the product being transported, and which may go through casings at highway and railroad crossings. It may be made of steel, concrete, clay, plastic, ductile iron, or other materials. On occasion it may be bored direct under the highways and railroads.

Cased bore: A bore in which a pipe, usually a steel sleeve, is inserted simultaneously with the boring operation. Usually associated with horizontal auger boring or pipe ramming.

Casing: See casing pipe.

Casing adapter: A circular mechanism to provide axial and lateral support of a smaller-diameter casing than that of the casing pusher.

Casing pipe: A steel pipe usually installed by horizontal auger boring or pipe ramming methods to support boreholes under roadways or railroad tracks through which a carrier (or product) pipes or ducts are installed.

Casing pipe method: Method in which a casing, generally steel, is pipe jacked into place, within which a product pipe is inserted later.

Casing pusher: The front section of a boring machine that distributes the thrusting force of the hydraulic cylinders to the casing and forms the outside of the spoil ejector system.

Catalyst: The component of a resin system that induces a reaction to form heat and subsequently cure the liner.

Cathodic protection: Preventing corrosion of a pipeline by using special cathodes (and anodes) to circumvent corrosive damage by electric current. Also a function of zinc coatings on iron and steel drainage products is galvanic action.

Caulking: General term which, in trenchless technology, refers to methods by which joints may be closed within a pipeline.

Cave-in: The separation of a mass of soil or rock material from the side of an excavation, or the loss of soil from under a trench shield or support system, and its sudden movement into the excavation, either by falling or sliding, in sufficient quantity so that it could entrap, bury, or otherwise injure and immobilize a person.

CCTV: See closed-circuit television inspection.

Cell classification: Method of identifying plastic materials, such as polyethylene, as specified by ASTM D3350, where the cell classification is based on these six properties: (1) density of base resin (2) melt index (3) flexural modulus (4) tensile strength at yield (5) ESCR (6) hydrostatic design basis and color.

Cellar drain: A pipe or a series of pipes that collect wastewater which leaks, seeps, or flows into subgrade parts of structures and discharges them into a building sewers; by other means, dispose of such wastewaters into sanitary, combined, or storm sewers. Also referred to as basementdrain.

Chemical grouting: Method for the treatment of the ground around a shaft or pipeline, using noncementitious compounds, to facilitate or make possible the installation of an underground structure.

Chemical stabilization: A repair method in which a length of pipeline between two access points is sealed by the introduction of one or more compounds in solution into the pipe and the surrounding ground and, where appropriate, producing a chemical reaction. Such systems may perform a variety of functions such as the sealing of cracks and cavities, the provision of a new wall surface with improved hydraulic characteristics or ground stabilization.

Chimney: The small vertical section between a manhole frame and cone, which is built from brick, masonry, or concrete adjusting rings.

Chippers: See bits.

CIPP: Cured-in-place pipe; a renewal technique whereby a flexible resin-impregnated tube is installed into an existing pipe and then cured to a hard finish, usually assuming the shape of the existing pipe.

Circumferential: The perimeter around the inner surface of a circular pipe cross section.

Circumferential coefficient of expansion and contraction: The fractional change in circumference of a material for a unit changes in temperature; expressed as inches of expansion or contraction per inch of original circumference.

Closed face: The ability of a tunnel boring machine to close or seal the facial opening of the machine to prevent, control, or slow the entering of soils into the machine. Also may be the bulk heading of a hand-dug tunnel to slow or stop the inflow of material.

Closed-circuit television inspection (CCTV): Inspection method using a closed-circuit television camera system with appropriate transport and lighting mechanisms to view the interior surface of sewer pipes and structures.

Close-fit: Description of a lining system in which the new pipe makes close contact with the existing defective pipe at normal or minimum diameter. An annulus may occur in sections where the diameter of the defective pipe is in excess of this.

Coefficient of thermal expansion and contraction: The fractional change in length of a material for a unit change in temperature.

Collapse: Critical failure of a pipeline when its structural fabric disintegrates.

Collaring: The initial entry location of casing or a cutting head into the earth.

Collection system: A network of sewers that serves one or more catchment areas.

Collector sewer: A sewer located in the public way collects the wastewaters discharged through building sewers and conducts such flows into larger interceptor sewers, pumping and treatment works (referred to also as street sewer).

Combined sewer system: A single network of sewers designed to convey stormwater as well as sanitary flows.

Competent person: One who is capable of identifying existing and predictable hazards in the surroundings, or working conditions that are unsanitary, hazardous, or dangerous to employees, and who has authorization to take prompt corrective measures to eliminate them.

Compressed air method: In trenchless technology, refers to the use of compressed air within a tunnel or shaft to balance ground water and prevent ingress into an open excavation.

Compression gasket: A device that can be made of several materials in a variety of cross sections and that serves to secure a tight seal between two pipe sections (e.g., "O" rings).

Compression ring: A ring fitted between the end bearing area of the bell and spigot to help distribute applied loads more uniformly. The compression ring is attached to the trailing end of each pipe and is compressed between the pipe sections during jacking. The compression rings compensate for slight misalignment, pipe ends that are not perfectly square, gradual steering corrections, and other pipe irregularities. Compression rings are also referred to as spacers.

Conduit: A broad term that can include pipe, casing, tunnels, ducts, or channels. The term is so broad that it should not be used as a technical term in boring or tunneling.

Cone: The section between the top of a manhole wall and chimney or the frame. The diameter of the manhole is reduced over the cone section to receive the frame. The cone section may be concentric or eccentric.

Continuous sliplining: See sliplining.

Control console: An electronic unit inside a container located on the ground surface, which controls the operation of the microtunneling machine. The machine operator drives the tunnel from the control console. Electronic information is transmitted to the control console from the heading of the machine. This information includes head position, steering angle, jacking force, progression rates, machine face torque, slurry and feed line pressures, and laser position. Some control consoles are equipped with a computer that tracks the data for a real-time analysis of the tunnel drive.

Control lever: A handle that activates or deactivates a boring machine function.

Conventional pipe jacking: Jacking pipe sections simultaneously as tunnel excavation proceeds using various forms of TBMs or hand mining (not microtunneling or pilot tube microtunneling).

Conventional trenching: See open-cut.

Corrugated pipe: Pipe with ridges (corrugations) going around it to make it stiffer and stronger. The corrugations are usually in the form of a sine wave a+B181nd are usually made of galvanized steel or aluminum.

Cradle machine: A boring machine typically carried by another machine that uses winches to advance the casing.

Creep: The dimensional change, with time, of a material, such as plastic, under continuously applied stress after the initial elastic deformation

Crossing: Pipeline installation in which the primary purpose is to provide a passage beneath a surface obstruction, such as a road, railroad track, lake or river.

Crown: (1) Top of pipe segment, or (2) The highest elevation within a pipe.

Cured-in-place pipe (CIPP): A lining system in which a thin flexible tube of polymer or glass fiber fabric is impregnated with thermoset resin and expanded by means of fluid pressure into position on the inner wall of a defective pipeline before curing the resin to harden the material. The uncured material may be installed by winch or inverted by water or air pressure, with or without the aid of a turning belt.

Cut and cover: See open-cut.

Cutterhead: Any rotating tool or system of tools on a common support that excavates at the face of a bore; usually applies to the mechanical methods of excavation.

Cutter bit (cutter head): The actual teeth and supporting structure that is attached to the front of the lead auger, drill stem, or front face of the tunnel-boring machine. It is used to reduce the material that is being drilled or bored to sand or loose dirt so that it can be conveyed out of the hole. Usually applies to mechanical methods of excavation, but may also include fluid jet cutting.

Dead man: A fixed anchor point used in advancing a saddle or cradle-type boring machine.

Deformed and reshaped: See modified sliplining.

Diameter of reamer: Largest diameter of reamer (in horizontal directional drilling).

Dimension ratio (DR): See standard dimension ratio (SDR).

Dimple: A term used in tight fitting pipeline renewal, where the new plastic pipe forms an external departure or a point of expansion slightly beyond the underlying pipe wall where unsupported at side connections. The dimples are used for location and reinstatement of laterals.

Directional drilling: A steerable system for the installation of pipes, conduits, and cables in a shallow arc using a surface launched drilling rig. Traditionally the term applies to large-scale crossings in which a fluid-filled pilot bore is drilled using a fluid-driven motor at the end of a bend-sub, and is then enlarged by a wash over pipe and back reamer to the size required for the product pipe. The positioning of a bent sub provides the required deviation during pilot boring. Tracking of the drill string is achieved by the use of a downhole survey tool.

Dog plate: See backstop.

Drill bit: A tool that cuts the ground at the head of a drill string, usually by mechanical means, but may include fluid jet cutting.

Drill string: (1) The total length of drill rods or pipe, bit, swivel joint and so on in a drill borehole. (2) System of rods used with cutting bit or compaction bit attached to the drive chuck.

Drilling fluid or mud: A mixture of water and usually bentonite and/or polymer continuously pumped to the cutting head to facilitate cutting, reduce required torque, facilitate the removal of cuttings, stabilize the borehole, cool the head, and lubricate the installation of the product pipe. In suitable soil conditions water alone may be used.

Drive or entry or launch or jacking shaft or pit: Excavation from which trenchless technology equipment is launched for the installation of a pipeline. In pipe jacking, it incorporates a thrust wall to spread reaction loads to the soil.

Dry bore: Any drilling or rod pushing system not employing drilling fluid in the process. Usually associated with guided impact moling, but also some rotary methods.

Earth piercing: (1) Term commonly used in North America as an alternative to impact moling. (2) The use of a tool, which comprises a percussive hammer within a suitable casing, generally of torpedo shape. The hammer may be pneumatic or hydraulic. The term is usually associated with nonsteered devices without rigid attachment to the launch pit, relying upon the resistance (friction) of the ground for forward movement. During operation, the soil is displaced not removed. An unsupported bore may be formed in suitable ground, or a pipe drawn in, or pushed in, behind the tool. Cables may also be drawn in.

Earth pressure balance (EPB) machine: Type of microtunneling or tunneling machine in which mechanical pressure is applied to the material at the face and controlled to provide the correct counterbalance to earth pressures to prevent heave or subsidence. The term is usually not applied to those machines where the pressure originates from the main pipe jacking rig in the drive shaft/pit or to systems in which the primary counterbalance of earth pressures is supplied by pressurized drilling fluid.

Earth pressure balance shield: Mechanical tunneling shield that uses a full face to support the ground in front of the shield and usually employs an auger flight to extract the material in a controlled manner.

Emergency repair: An unscheduled repair that must be made during a pipe failure or collapse. This type of repairs may cost many times (usually 10 times more, not including social costs) of planned repair costs and may not be as effective and/or permanent.

Emergency stop: A red, manually operated push button that, when activated, stops all functions of the machine.

Entrance pit: (1) See boring pit or drive shaft.

Entry/exit angle: Angle to horizontal (the ground surface) at which the drill string enters or exits in forming the pilot bore in a horizontal directional drilling operation.

EPDM (ethylene-propylene-diene monomer): Type of rubber that has excellent resistance to ozone, sunlight, and oxygen. It also has excellent resistance to acids, alkalis, and ketones. Plus, it has excellent heat resistance and aging. However it has poor resistance to fuels and oils.

Epoxy: Resin formed by the reaction of bisphenol and epichlorohydrin.

Epoxy lining: A curable resin system based on epoxy resins.

Exfiltration: The leakage or discharge of flows being carried by pipes or sewers out into the ground through leaks in pipes, joints, manholes, or other sewer system structures; the reverse of infiltrations.

Exit pit: See reception shaft.

Exit shaft: See reception shaft.

Expander: A tool, which enlarges a bore during a pullback operation by compression of the surrounding ground rather than by excavation. Sometimes used during a pipe bursting process as well as during horizontal directional drilling

Face stability: Stability of the excavated face of a tunnel or pipe jack operation.

Felt: A material specially designed to soak up, hold, and transport resins in place to produce a hard cured-in-place pipe.

Fiberglass: A high strength material that is commonly layered with a felt material to add reinforcement for the resin cured-in-place pipe.

Fillers: Materials used to enhance the capabilities of a resin system.

Film: Either an outer or inner material to protect the resin impregnated tube from contaminants.

Flexural modulus: The slope of the curve defined by flexural load versus resultant strain. A high flexural modulus indicates a stiffer material.

Flexural strength: The strength of a material in bending expressed as the tensile stress of the outermost fibers at the instant of failure.

Flight: The spiral plates surrounding the tube of an auger.

Fluid cutting: (1) An old trenchless method where pressurized fluid jets are mainly used to provide the soil cutting action. (2) A process using high-pressure fluid to wash out the face of a utility crossing without any mechanical or hand excavation of the soils in the face. This method is no longer allowed.

Fluid-assisted boring or drilling: A type of horizontal directional drilling technique using a combination of mechanical drilling and pressurized fluid jets to provide the soil cutting action.

Fold and form lining: Method of pipeline renewal in which a liner is folded to reduce its size before insertion and reversion to its original shape by the application of pressure, or heat, or both.

Fold and form pipe: A pipe renewal method where a plastic pipe manufactured in a folded shape of reduced cross-sectional area is pulled into an existing conduit and subsequently expanded with pressure and heat. The reformed plastic pipe fits snugly and takes the shape of the ID of the existing, old, or host pipe.

Force-main: A pipeline that conveys sanitary, combined, or stormwater flow under pressure from a pumping (or lift) station to a discharge point (treatment plant).

Forward rotation: The clockwise rotation of the auger as viewed from the machine end.

Gel Time: The time, at which a catalyzed resin system will begin to cure, creating internal heat and thus beginning to harden.

Geographical information system (GIS): A computer software system designed to store, manipulate, analyze, and print geographically referenced information.

Gravity sewer: A sewer that is designed to operate under open channel conditions (below pipe full capacity) up to a maximum design flow at which point it will become surcharged.

Ground mat: Usually used in horizontal directional drilling, metal mats rolled out on either side of drill rack for operators and crew to stand on during operation to give grounding protection in case of electrical strike.

Ground rod: This is a copper or brass rod that is hand driven into the ground and is connected to the drill rack and mats to provide adequate grounding of an HDD rig.

Groundwater table (or level): Upper surface of the zone of saturation in permeable rock or soil (when the upper surface is confined by impermeable rock, the water table is absent).

Grout: (1) Material used to seal pipeline and manhole cracks; also used to seal connections within pipe or sewer structures. (2) A material, usually cement or polymer based, used to fill the annulus between the existing pipe and the lining; and also to fill voids outside the existing pipeline. (3) A material such as cement slurry, sand, or pea gravel that is pumped into voids.

Grouting: (1) Filling of the annular space between the existing, old, or host pipe and the carrier pipe. Grouting is also used to fill the space around laterals and between the new pipe and manholes. Other uses of grouting are for localized repairs of defective pipes and ground improvement prior to excavation during new installations. (2) The process of filling voids, or modifying or improving ground conditions. Grouting materials may be cementitious, chemical, or other mixtures. In trenchless technology, grouting may be used for filling voids around the pipe or shaft, or for improving ground conditions. (3) A method of filling voids with cementitous or polymer grout.

GRP: Glass reinforced plastic, a family of renewal linings. Often generically known as reinforced plastic mortar (RPM) and reinforced thermosetting resin (RTR).

Guidance system: The guidance system continuously confirms the position of the TBM.

Guide rail: Device used to support or guide, first the shield and then the pipe within the drive shaft during a pipe jacking or utility tunneling operation.

Guided auger boring: Pilot tube microtunneling. A modified version of horizontal auger boring method.

Guided boring: This term is used in Europe for small diameter horizontal directional drilling method.

Guided drilling: See guided boring.

Gunite: A renewal technique that employs steel reinforcement fixed to the inside surface of an existing sewer line, which is sprayed with dry concrete.

HDPE: High density polyethylene, see polyethylene.

Head (static): The height of water above any plane or point of references. (The energy possessed by each unit of weight of a liquid, expressed as the vertical height through which a unit of weight would have to fall to release the average energy posed.) Standard unit of measure shall be the foot. Head in feet for water is 1 psi = 2.310 ft = 6894.757 Pa.

Heat cure: The application of either steam or hot water to cure a resin saturated tube.

Heaving: A process in which the ground in front of a tunneling or pipe jacking operation may be displaced forward and upward, causing an uplifting of the ground surface.

Height of cover (HC): Distance from crown of a pipe or conduit to the finished road surface, or ground surface, or the base of the railway.

High density polyethylene: A plastic resin made by the copolymerization of ethylene and a small amount of another hydrocarbon. The resulting base resin density, before additives or pigments, is greater than 0.941 g/cc.

Hoop stress: The circumferential force per unit areas, psi, in the pipe wall owing to internal pressure.

Horizontal directional drilling (HDD): See directional drilling.

Horizontal earth boring machine: A machine used to bore horizontally through the earth by means of a MTBM, cutterhead, rotating tool, or ramming tool.

Horizontal auger boring: The use of auger boring machines to prepare holes by the installation of a casing whereby the spoil is removed by the use of augers.

Host pipe: In trenchless renewal and replacement methods. Existing, old, or deteriorated pipe.

Hydraulic gradient line (HGL): An imaginary line through the points to which water would rise in a series of vertical tubes connected to the pipe. In an open channel, the water surface itself is the hydraulic grade line.

Hydrogen sulfide: An odorous gas found in sewer systems with chemical formula of H_2S.

I/I: Infiltration/inflow; infiltration stands for ground water seepage and inflow stands for surface water flow into the gravity collection system. Since surrounding soil is badly affected, preventing infiltration is far more important,

Impact moling: Method of creating a bore using a pneumatic or hydraulic hammer within a casing, generally of torpedo shape. The term is usually associated with nonsteered or limited steering devices without rigid attachment to the launch pit, relying upon the resistance of the ground for forward movement. During the operation the soil is displaced, not removed. An unsupported bore may be formed in suitable ground, or a pipe drawn in, or pushed in, behind the impact moling tool.

Impact ramming: See pipe ramming.

Impervious coating: The outer layer of a CIPP tube that will prevent the installation water or steam from mixing with the resin system in the tube.

Impregnated tube: A felt tube fully saturated with a catalyzed resin system.

In-line replacement: The process of breaking out of an existing, old, or host pipeline and the installation of a new pipeline at the same location. With this method, the existing pipeline will serve as a “pilot bore” for the new pipe installation, which might be a different pipe material with the same or larger diameter, and will be installed with the same alignment of the existing pipe.

Infiltration: Penetration of groundwater into the sewer system through cracks and defective joints in the pipeline, or through lateral connections, or manholes.

Infiltration or inflow (I/I): The total quantity of water from both infiltration and inflow without distinguishing the source.

Inflow: Storm water discharged into a sewer system and service connections from sources on the surface.

Interjack pipes: Pipes specially designed for use with an intermediate jacking station used in pipe jacking and microtunneling operations.

Interjack station: See intermediate jacking stations.

Intermediate jacking method: Pipe jacking or microtunneling method to redistribute the jacking force by the use of intermediate jacking stations.

Intermediate jacking stations: A fabricated steel cylinder fitted with hydraulic jacks that are incorporated into jacking pipes strung between two pipe segments. Its function is to distribute the jacking load over the pipe string on long drives thereby decreasing the total jacking forces exerted on the thrust block and pipe sections near the shaft.

Internal seal: Internal seals are used for structural repair pipe joints and missing pipe sections. It can be used in both worker entry and non worker entry pipes.

Inversion: The process of turning a fabric tube inside out with water or air pressure as is done at installation of a cured-in-place pipe (CIPP).

Invert: (1) The lowest point on the pipe circumference; also the defined channel in the manhole platform that directs flow from inlet pipe to outlet pipe. (2) The inside bottom, lowest elevation, of a pipe.

Jacking: The actual pushing of pipe or casing in an excavated hole. This is usually done with hydraulic cylinders (jacks), but has been done with mechanical jacks and air jacks.

Jacking force: Force applied to pipes in a pipe jacking operation.

Jacking frame: A structural component that houses the hydraulic cylinders used to propel the microtunneling machine and pipeline. The jacking frame serves to distribute the thrust load to the pipeline and the reaction load to the shaft wall or thrust wall.

Jacking pipes: Pipes sections with smooth outside joints designed to be installed using pipe jacking techniques.

Jacking pit: See jacking shaft.

Jacking shaft (also launch or entry shaft): Excavation from which trenchless technology equipment is launched for the installation or renewal of a pipeline.

Jacking shield: A steel cylinder from within which the excavation is carried out either by hand or machine. Incorporated within the shield are facilities to allow it to be adjusted to control line and grade.

Joint sealing: Method in which an inflatable packer is inserted into a pipeline to span a leaking joint, resin, or grout being injected until the joint is sealed and the packer then removed.

Lateral: A service line that transports wastewater from individual buildings to a main sewer line. Lateral connection: The point at which the downstream end of a building drain or sewer connects into a larger-diameter sewer.

Lateral connection: The point at which the downstream end of a building drain or sewer connects into a larger-diameter sewer.

Launch pit: See drive shaft or pit.

Lead pipe: The leading pipe designed to fit the rear of a jacking shield and over which the trailing end of the shield is fitted.

Light cure: The curing of a CIPP liner using UV light energy instead of either water or steam.

Liner: A fabric tube that has been saturated with a liquid resin.

Liner plate: A proprietary product, used to line tunnels instead of casing, and comes in formed steel segments. When these segments are bolted together they form a structural tube to protect the tunnel from collapsing. The segments are made so that they may be bolted together from inside the tunnel.

Lining: A renewal process where a new pipe or coating material is inserted or cured in place to give an existing pipe a new design life.

Localized (spot) repair: Repair work on an existing pipe, to an extent less than the run between two access points or manholes.

Locator: An electronic instrument used to determine the position and strength of electro-magnetic signals emitted from a transmitter (sonde) in a directional drilling operation, or from existing underground services, which have been energized, thereby identifying its location. In horizontal directional drilling it is referred to as a walkover system.

Machine upset: The inadvertent action of a horizontal auger boring machine that rotates the machine and track from its normal and upright position to another position.

Man-entry: Also worker-entry, describes any inspection, construction, renewal or repair process, which requires an operator to enter a pipe, duct, or bore. OSHA currently has no minimum size limit for workerentry operations; however, they address a much broader concept of confined space in Title 29 Code of Federal Regulations Part 1910.146. The minimum size for which this is currently permissible in the United Kingdom is 900 mm (approximately, 36 in.). Many trenchless technologies do not require worker-entry inside the pipe.

Manhole: A structure that allows access to the sewer system.

Manual inspection: Method of sewer inspection that usually involves physical entry and hands-on examination.

Microtunneling: A trenchless construction method for installing pipelines. Microtunneling uses all of the following features during construction: (1) Remote controlled-The microtunneling-boring machine (MTBM) is operated from a control panel, normally located on the surface. The system simultaneously installs pipe as spoil is excavated and removed. Personnel entry is not required for routine operation. (2) Guided-The guidance system usually references a laser beam projected onto a target in the MTBM, capable of installing gravity sewers or other types of pipelines to the required tolerance, for line and grade. (3) Pipe jacked-The process of constructing a pipeline by consecutively pushing pipes and MTBM through the ground using a jacking system for thrust. (4) Continuously supported-Continuous pressure is provided to the face of the excavation to balance groundwater and earth pressures.

Microtunnel boring machine (MTBM): See microtunneling.

Midi-HDD: Steerable surface-launched horizontal directional drilling equipment for installation of pipes, conduits, and cables. Applied to intermediate sized drilling rigs used as either a small directional drilling machine or a large guided boring machine. Tracking of the drill string may be achieved by either a downhole survey tool or a walk-over locator.

Mini-horizontal directional drilling (Mini-HDD): Small diameter horizontal directional drilling. In Europe it is called guided boring.

Mixed face: A soil condition that presents two or more different types of

material in the path of the bore.

Modified sliplining: A range of techniques in which the liner is reduced in cross-sectional diameter before insertion into the carrier pipe. It is subsequently restored close to its original diameter, generally forming a close-fit with the original pipe. There are different methods of cross sectional area reduction.

Needled felt: A highly absorbent felt material specially designed for the CIPP tube fabrication.

Non-worker entry: Size of pipe, duct, or bore, less than that for worker-entry.Occupational illness: Any abnormal condition or disorder caused by exposure to environmental factors associated with employment. For excavations this might include illnesses caused by the inhilation of toxic vapors.

Open-cut: The method by which access is gained to the required level underground for the installation, repair, or replacement of a pipe, conduit, or cable. The excavation is then backfilled and the surface restored.

Open face shield: Shield in which manual excavation is carried out from within a steel tube at the front of a pipe jacking operation.

On-site wet-out: A non-factory tube wet-out that is performed over the hole in the field.

Ovality: There are two definitions: (1) the difference between the maximum and mean diameter divided by the mean diameter, and (2) the difference of the mean and minimum divided by the mean, at any one cross section of a pipe, generally expressed as a percentage.

Overcut: The annular space between the excavated borehole and the outside diameter of the pipe.

PACP: Pipeline Assessment Certification Program by NASSCO.

Panel lining: Panel lining is a modified sliplining method. The shape of the culvert is covered by preparing panels and fitting them to the culvert. It can be used to structurally renew large diameter pipes. This method can accommodate different shapes.

PE: Polyethylene; a form of thermoplastic pipe.

pH: A measure of the acidity or alkalinity of a solution. A value of seven is neutral; lower numbers indicate more acidity.

Physical pipe inspection: The crawling or walking through manually accessible pipe lines. The logs for physical pipe inspection record information of the kind detailed under television inspection. Manual inspection is only undertaken when field conditions permit this to be done safely. Precautions are necessary.

Piercing tool: Similar to closed-face pipe ramming, but for small diameter (2 to 6 in. = 50.8-152.4 mm) boring; used for cable installations under roadways.

Pilot bore: The action of creating the first (usually steerable) pass of any boring process, which later requires back-reaming or similar enlarging process to install the product pipe. Most commonly applied to horizontal directional drilling but also used in pilot tube microtunneling and guided auger boring systems.

Pilot tube method: See pilot tube microtunneling.

Pinch rollers: Used to control the thickness of the resin impregnated tube during wet-out.

Pipe bursting: A pipe replacement method for breaking the existing pipe by brittle fracture, using force from within, applied mechanically, the remains being forced into the surrounding ground. At the same time a new pipe, of the same or larger diameter, is drawn in behind the bursting tool. The pipe-bursting device may be based on an impact moling tool to exert diverted forward thrust to the radial bursting effect required, or by a hydraulic device inserted into the pipe and expanded to exert direct radial force or a static hammer. For new pipe, generally a HDPE pipe is used, but currently PVC, ductile iron, clay and GRP is also used. Also known as pipe cracking and pipe splitting.

Pipe displacement: See pipe bursting.

Pipe eating: A pipe replacement technique, usually conducted by use of a horizontal directional drilling rig, in which a defective pipe is pulverized during the backreaming operation. Also microtunneling machines can be used where the existing pipe is excavated together with the surrounding soil as for a new installation. The microtunneling shield machine will usually need some crushing capability to perform effectively. The defective pipe may be filled with grout to improve steering performance.

Pipe jacking: A system of directly installing pipes behind a shield machine by hydraulic jacking from a drive shaft, such that the pipes form a continuous string in the ground.

Pipe ramming: A nonsteerable system of forming a bore by driving an open-ended steel casing using a percussive hammer from a drive pit. The soil may be removed from the casing by augering, jetting, or compressed air.

Pipe reaming: A variation of directional boring, pipe reaming can be used to replace existing clay, asbestos cement, non-reinforced concrete and PVC pipe. A reamer is pulled through the existing pipe, which cuts the pipe into small pieces. The pipe pieces are flushed out the borehole with the drilling fluid.

Pipe segment: A specific portion of the sewer or pipeline system; which usually runs between two structures (e.g., manhole, trap tanks, sumps); identified with unique sewer or pipe structure ID number.

Pipe splitting: Replacement method for breaking an existing pipe by longitudinal slitting. At the same time a new pipe of the same or larger diameter may be drawn in behind the splitting tool. See also pipe bursting.

Pipeline rehabilitation: See pipeline renewal.

Pipeline renewal: The in-situ renewal of an existing pipeline, which has become deteriorated. The selection of appropriate renewal method is dependent on type of application and characteristics and types of defectsof the existing pipe. See Chap. 2 for method selection criteria.

Plastic: Any of a variety of thermoplastic and thermoset material used in pipeline construction and renewal (e.g., polypropylene, PVC, fiberglass reinforced plastics, polyester felt reinforced pipe, epoxy and polyester mortars, and so on).

Point CIPP: CIPP techniques entail impregnating fabric with a suitable resin, pulling this into place within the sewer around an inflatable packer or mandrel, and then filling the packer with water, steam, or air under pressure to press the patch against the existing sewer wall while the resin cures.

Point repairs: Repair works on an existing pipe, to an extent less than the run between two access points or manholes.

Point source repair: See localized repair.

Polyester: Resin formed by condensation of polybasic and monobasic acids with polyhydric alcohols.

Polyethylene: A ductile, durable, virtually inert thermoplastic composed by polymers of ethylene. It is normally a translucent, tough solid. In pipe grade resins, ethylene-hexene copolymers are usually specified with carbon black pigment for weatherability.

Polymer coating: It is a thermoset coating made up of inert plastic-like epoxies, urethanes and ureas, polyesters, which have a high resistance to corrosion; they are applied by trained professionals using special spraying equipments and as per the manufacturers specifications.

Polyolefin: A family of plastic material used to make pipes.

Polypropylene (PP): A type of plastic pipe from the polyolefin family.

Potholing: Digging a vertical hole to visually locate a utility.

Preparatory cleaning: Internal cleaning of pipelines, particularly sewers, prior to inspection, usually with water jetting and removal of material where appropriate.

Preventative maintenance: Routine maintenance designed to prevent pipeline system failures and resulting emergency repairs.

Product pipe: Permanent pipeline for operational use. Pipe for conveyance for water, gas, sewage, and other products.

Protruding: To be projecting outward.

Pull-back force: The tensile load applied to a drill string during the pull back process. Horizontal directional drilling rigs are generally rated by their maximum pull-back force.

PVC: Polyvinyl chloride; a form of thermoplastic pipe.

Quality assurance: includes developing inspection and testing methods to ensure products or services are designed and produced to meet or exceed owner requirements.

Quality control: includes providing evidence needed (test results) to establish confidence among all concerned, that quality-related activities are performed.

Radian: An arc of a circle equal in length to its radius; or the angle at the center measured by the arc.

Ramming: A percussive hammer is attached to an open-end casing, which is driven through the ground. See pipe ramming.

Receiving pit: (1) See exit pit. (2) An opening in the earth located at the expected exit of the cutting head or tunneling machine (TBM). (3) The pit that is dug at the end of the bore, opposite the jacking pit. Also target pit.

Receiving shaft: See reception shaft.

Reception or exit shaft or pit: Excavation into which trenchless technology equipment is driven and recovered following the installation of the product pipe, conduit, or cable. See receiving pit.

Registered professional engineer: means a person who is registered as a professional engineer in the state where the work is to be performed. However, a professional engineer, registered in any state is deemed to be a “registered professional engineer” when approving designs for “manufactured protective systems” or “tabulated data” to be used in interstate commerce.

Rehabilitation: See renewal.

Reinstatement: Method of backfilling, compaction, and resurfacing of any excavation to restore the original surface and underlying structures to enable it to perform its original function.

Remote-control system (microtunneling): The remote-control system monitors and controls the MBTM, the automated transport system, and the guidance system from a location not in the MTBM.

Renewal: All aspects of rehabilitating, reconstructing, renovating, or upgrading with a new design life for the performance of existing pipeline systems.

Renovation: See renewal.

Repair: Reconstruction of short pipe lengths, but not the reconstruction of a whole pipeline. Therefore, a new design life is not provided. In contrast, in pipeline renewal, a new design life is provided to existing pipeline system.

Replacement: Replacing an old, existing, or deteriorated pipe with a new pipe by use of open-cut, inline replacement (pipe bursting), and/or other new installation methods (HDD, microtunneling, etc.). The new pipe may have a larger diameter and different pipe material from the existing or old pipe.

Resin impregnation (wet-out): A process used in cured-in-place pipe installation where a plastic coated fabric tube is uniformly saturated with a liquid thermosetting resin, while air is removed from the coated tube by means of vacuum suction.

Resins: An organic polymer, solid or liquid; usually thermoplastic or thermosetting.

Reverse: In horizontal auger boring, the counterclockwise rotation of the auger as viewed from the machine end.

Ring compression: The principal stress in a confined thin circular ring subjected to external pressure.

Robot: Remote-control device with closed-circuit television (CCTV) monitoring, used mainly in localized repair work, such as cutting away obstructions, reopening lateral connections, grinding and refilling defective areas, and injecting resin into cracks and cavities.

Robotic cutter: A device used to re-open house connections after the installation of a liner without excavation.

Rod pushing: Method of forming a pilot bore by driving a closed pipe head with rigid attachment from a launch pit into the soil, which is displaced. See thrust boring.

Roller cone bit or reamer: A bit or reamer in which the teeth rotate on separate, internal shafts that are usually aligned perpendicular to line. Used for boring rock.

Rollers: The rollers that control the exact amount of resin material that is required to properly saturate a felt tube.

Rotary rod machine: A machine used to drill earth horizontally by means of a cutting head attached to a rotating rod (not an auger). Such drilling may include fluid injected to the cutting head through a hollow rod.

Saddle: In horizontal auger boring, a vertical support mechanism to hold the casing in position while starting (collaring) the bore.

Saturated tube: See impregnated tube.

SBR (styrene butadiene): Type of rubber that has good abrasion resistance and excellent impact and cut-and-gouge resistance. Used as gasket material.

SDR: See standard dimension ratio

Segmental lining: See sliplining.

Segmental sliplining: See sliplining.

Self-cleansing: A consequence of good hydraulic design when the pipe invert is kept relatively free of sediments by ensuring adequate flow velocities.

Semi-structural liner: A liner that in its own entity does not have the required strength to withstand internal, external, or both types of loading from soil column, traffic, and groundwater pressure for the design life of the product, but will offer some level of structural support against internal pressure.

Separate system: A system that uses sanitary sewers to convey the wastewater and stormwater sewers to carry the stormwater.

Sewer: An underground pipe or conduit for transporting stormwater, or wastewater, or both.

Sewer cleaning: The use of mechanical or hydraulic equipment to dislodge, transport, and remove debris from sewer lines.

Sewer lateral: A building sewer (sometimes referred to as a sewer lateral or house lateral) is the pipeline between the public sanitary sewer line, which is usually located in the street, and the indoor plumbing.

Sewer pipe: A length of conduit, manufactured from various materials and in various lengths, that when joined together can be used to transport wastewaters from the points of origin to a treatment facility. Types of pipe are: acrylonitrile-butadiene-styrene (ABS); asbestos-cement (AC); brick pipe (BP); concrete pipe (CP); cast iron pipe (CIP); polyethylene (PE); polyvinyl chloride (PVC); and vitrified clay (VC).

Shield (shield system): means a structure that is able to withstand the forces imposed on it by a cave-in and thereby protect employees within the structure. Shields can be permanent structures or can be designed to be portable and moved along as work progresses. Additionally, shields can be either pre-manufactured or job-built in accordance with 1926.652(c)(3) or (c)(4). Shields used in trenches are usually referred to as "trench boxes" or "trench shields."

Shoring (shoring system): A structure such as a metal hydraulic, mechanical or timber shoring system that supports the sides of an excavation and is designed to prevent cave-ins.

Shotcrete: Spraying wet concrete (see also gunite).

Skin friction: Resistance to advancement caused by soil pressure around the pipe or casing.

Slipline: A renewal technique covering the insertion of one pipe inside an existing pipe.

Sliplining: (1) General term used to describe methods of lining with continuous pipes and lining with discrete pipes. (2) Insertion of a new pipe by pulling or pushing it into the existing pipe and grouting the annular space. The pipe used may be continuous or a string of discrete pipes. The latter is also referred to as segmental sliplining.

Slurry: A fluid, mainly water mixed with bentonite and sometimes polymers, used in a closed loop system for the removal of spoil and for the balance of groundwater pressure during tunneling and microtunneling operations.

Slurry chamber: Located behind the cutting head of a slurry micro-tunneling machine. Excavated material is mixed with slurry in the chamber for transport to the surface.

Slurry line: A series of hoses or pipes that transport tunnel muck and slurry from the face of a slurry microtunneling machine to the ground surface for separation.

Slurry separation: A process where excavated material is separated from the circulation slurry.

Slurry shield method: Method using a mechanical tunneling shield with closed face, which employs hydraulic means for removing the excavated material and balances the ground water pressure. See also earth pressure balance machine.

Social costs: Costs incurred by society as a result of underground pipeline construction and renewal. These include but not limited to traffic disruptions, environmental damages, safety hazards, inconvenience to general public, and business losses owing to road closures.

Soft lining: See cured-in-place pipe (CIPP).

Spiral lining: A technique in which a ribbed plastic strip is spirally wound by a winding machine to form a liner, which is inserted into a defective pipeline. The annular space may be grouted or the spiral liner expanded to reduce the annulus and form a close-fit liner. In larger diameters, the strips are sometimes formed into panels and installed by hand. Grouting the annular space after installation is recommended.

Spiral weld pipe (casing): Pipe made from coils of steel plate by wrapping around a mandrail in such a manner that the welds are a spiral helix.

Spiral wound: In this process a new pipe is installed inside the existing pipe from the continuous strip of polyvinyl chloride (PVC). The strip has tongue and groove casting on its edges. It is fed to a special winding machine placed in a manhole, which creates a continuous helically wound liner that proceeds through the existing pipe. The continuous spiral joint is watertight. Upon completions of the annulus space between the lining and the existing pipe wall is usually required.

Spoil (muck): Earth, rock, and other materials displaced by a tunnel, pipe or casing, and removed as the tunnel, pipe or casing is installed. In some cases, it is used to mean only the material that has no further use.

Spot repair: See localized repair.

Spray lining: A technique for applying a lining of cement mortar or resin by rotating a spray head, which is winched through the existing pipeline.

Springline: (1) An imaginary horizontal line across the pipe that passes between the points where the pipe has its greatest cross-sectional width. (2) Midpoint of a pipe cross section (equal vertical distance between the crown and the invert of the pipe).

Standard dimension ratio (SDR): Standard dimension ratio is defined as the ratio of the outside pipe diameter to wall thickness. Same as DR.

Static mixer: A computerized device that provides fast, uniform resin and catalyst mixing.

Steering head: In horizontal auger boring, a moveable lead section of casing that can be adjusted to steer the bore.

Styrene: A component of polyester and many vinyl ester resin systems.

Subsidence: The settlement of the ground, pipeline, or other structure. The effects may not be evenly distributed and/or immediately noticeable. Differential settlement may occur.

Sump: A depression usually in the drive pit to allow the collection of water and the installation of a sump pump for water removal.

Swivel: In horizontal directional drilling, it is used to attach product pipe (to be pulled into drilled hole) to drill pipe to prevent it from rotating.

Target shaft or pit: See reception or exit shaft or pit.

TBM: See tunnel boring machine.

Teeth: See bits.

Televise: Process by which a sewer, pipeline or lateral is inspected with a closed-circuit television camera.

Thermocouple: A device used to measure the internal temperature of a resin-saturated felt tube during the installation process.

Thermoformed pipe: A type of renewal method that uses polyvinyl chloride (PVC) or polyethylene (PE) pipe that is expanded by thermo-forming to fit tightly to fit inside the existing, old, or host pipe.

Thermoplastic (TP): A polymer material, such as polyethylene, that will repeatedly soften when heated and harden and reformed when cooled. TPs are generally much easier to recycle than their thermoset (see below) counterparts.

Thermoset (TS): A polymer material, such as rubber, that does not melt when reheated. TS polymers can be formed initially into almost any desired shape, but they cannot be reformed at a later time.

Thermoset resin: A material, such as epoxies, that will undergo or has undergone a chemical reaction by the action of heat, chemical catalyst, ultraviolet light, etc., leading to an infusible state.

Thrust: Force applied to a pipeline or drill string to propel it through the ground.

Thrust block: See backstop.

Thrust boring: A method of forming a pilot bore by driving a closed pipe or head from a thrust pit into the soil which is displaced. Some small-diameter models have steering capability achieved by a slanted pilot-head face and electronic monitoring. Back reaming may be used to enlarge the pilot bore. Also loosely applied to various trenchless installations methods. See rod pushing.

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

Thrust pit: See drive pit.

Thrust ring: A fabricated ring that is mounted on the face of the jacking frame. It is intended to transfer the jacking load from the jacking frame to the thrust bearing area of the pipe section being jacked.

Top Inversion: The CIPP tube is inverted from an inversion ring located at the top of the inversion platform.

Torque: The rotary force available at the drive chuck.

Track: A set of longitudinal rails mounted on cross members that support and guide a horizontal auger boring machine.

Trench (trench excavation): A narrow excavation (in relation to its length) made below the surface of the ground. In general, the depth is greater than the width, but the width of a trench (measured at the bottom) is not greater than 15 feet (4.6 m). If forms or other structures are installed or constructed in an excavation, so as to reduce the dimension measured from the forms or structure to the side of the excavation to 15 feet (4.6 m) or less (measured at the bottom of the excavation), the excavation is also considered to be a trench.

Trenching: See open-cut or conventional trenching.

Trenchless: A technology that is used for renewal of existing pipelines, typically without any excavation.

Trenchless methods: See trenchless technology.

Trenchless rehabilitation: See renewal.

Trenchless technology: Also NO-DIG, techniques for underground pipeline and utility construction and replacement, rehabilitation, renovation (collectively called renewal), repair, inspection, and leak detection, etc., with minimum or no excavation from the ground surface.

Tube: The fabric material tube used to carry and hold the thermoset resin materials in place against the existing pipe prior to curing.

Tuberculation: Localized corrosion at scattered locations resulting in knob like mounds.

Tunnel: An underground conduit, often deep and expensive to construct, which provides conveyance and/or storage volumes for wastewater, often involving minimal surface disruption.

Tunnel boring machine (TBM): (1) A full-face circular mechanized shield machine, usually of worker-entry diameter, steerable, and with a rotary cutting head. For pipe jacking installation it leads a string of pipes. It may be controlled from within the shield or remotely such as in microtunneling. (2) A mechanical excavator used in a tunnel to excavate the front face of the tunnel (mole, tunneling head).

Ultra violet light cure: See light cure.

Uncased bore: Any bore without a lining or pipe inserted, that is, self-supporting, whether temporary or permanent. Not recommended except in special conditions.

Underground utility: Active or inactive services or utilities below ground level.

Upset: See machine upset.

Upsizing: Any method such as pipe replacement or pipe bursting that increases the cross-sectional area of an existing pipeline by replacing with a larger-diameter pipe.

Utility tunneling: It is general approach of constructing underground utility line by removing the excavated soil from the front of cutting face and installing liner segments to form continuous ground support structures. The product pipe is then transported and installed inside the tunnel. The annular space between the liner and the pipe is usually filled with grout.

VCP: Vitrified clay pipe.

VCT: Vitrified clay tile or vitrified clay tile pipe.

Velocity head: For water moving at a given velocity, the equivalent head through which it would have to fall by gravity to acquire the same velocity.

Vinyl-ester: Resin systems used for many industrial applications requiring a higher level of corrosion resistance.

Viscosity: That property of a fluid which determines the amount of its resistance to a shearing stress.

Voids: (1) Holes on the outside of the pipe in the surrounding soil or material. (2) A term generally applied to paints to describe holidays, holes, and skips in the film. Also used to describe shrinkage in castings or welds.

Walkover system: See locator.

Washover pipe: In horizontal directional drilling, sometimes (for drilling in rock) a rotating drill pipe of larger diameter than the pilot drill pipe is used and placed around it with its leading edge less far advanced. Its purpose is to provide stiffness to the drilling pipe to maintain steering control over long bores, to reduce friction between the drill string and the soil and to facilitate mud circulation.

Water jetting: (1) Method for the internal cleansing of pipelines using high-pressure water jets. (2) An obsolete and unauthorized method for cutting earth with water jetting.

Water table: (1) The depth of the ground water. (2) The upper limit of the portion of ground wholly saturated with water.

Weatherability: The properties of a plastic material that allows it to withstand natural weathering; hot and cold temperatures, wind, rain, and ultraviolet rays.

Wetout: The process of injecting resin into, and distributing it throughout, a hose or tube, which will then be installed into the pipeline and cured in place.

Winch: Mechanical device used to pull the CCTV cameras or cleaning tools through a pipe.

Appendix B / Summary In Turkish: Kazısız Teknolojiler ile Boru Döşemeye Giriş

1. Giriş

"Gözden ırak, gönülden ırak" atasözümüz her ülkede yansımasını bulmaktadır. Örneğin İngilizler yakın manadaki "Out of sight, out of mind – Gözden ırak, düşünceden ırak" sözcüğünü çok kullanırlar. Bu sözler adeta yeraltındaki yatırımlar ve servisler için söylenmiş gibidir. Yeraltı sistemlerinde aktif olarak çalışmayan insanların çok azı, ayaklarının altında yatan karmaşık boru ve kablo ağını ve önemini anlar. Unutulmamalıdır ki, şehirlerde gömülü olan yeraltı borulu sistemlerin toplam uzunluğu o şehirdeki yol ve cadde uzunluğunun 5 katı kadardır. Gömülü sistemler ister yerel otorite, ister hükümet olsun karar vericiler tarafından da zaman zaman az önemli görülür ve ihmal edilir.

Su, atık su, yağmur suyu, gaz, petrol, elektrik, telekomünikasyon ve diğer endüstrilerin borulu sistemlerinde, zayıf teknik donanım, zayıf güvenlik gerekleri, kullanımın değişimi ve akışkan parametrelerin artması veya azalması nedeniyle rehabilitasyon gerekmektedir. Ayrıca hızlı ekonomik büyüme ve şehirleşme yeni hat döşeme ve yatırım yapmayı da gerektirmektedir.

Günümüzde altyapı hizmetlerinin inşası ve rehabilitasyonu iki şekilde yapılabilmektedir. Bunlar; klasik açık kazı teknolojisi ve kazısız teknolojilerdir (KT). Açık kazıda ihtiyaç duyulan hat yüzeyden iş makinelerinden de yararlanılarak kazı ile inşa edilir veya eski hatta problemin oluştuğu hat boyunca kazı yapılarak borulu sistemin yenilenmesi sağlanır. İster yeni hat inşası ister eski hat yenileme olsun, KT'de çok az kazı yapılarak veya kazısız (NO-DIG) olarak ihtiyaç karşılanır. Kuzey Amerika Kazısız Teknoloji Cemiyetinin (NASTT) tarifine göre, "Kazısız teknoloji, yeraltı hatlarının döşenmesi, değiştirilmesi, incelenmesi, yerlerinin tespit edilmesi ve kaçakların belirlenmesi eylemlerinin toprak yüzeyinden en az kazı yapılarak gerçekleştirilmesidir". Kazısız teknolojide borulu sistem uzunluğu ne olursa olsun, hat için yüzeyden giriş ve çıkış noktaları açılır (veya varsa bacalar-manholler kullanılır) ve teknoloji desteği ile borulu hat kısa sürede döşenir veya yenilenir.

Yeraltı yapılarında kazısız sistemler büyük önem kazanmıştır. KT uygulamalarını veren faaliyetler ve avantajları çok önemsenmeli, idareler yanında cemiyetler/dernekler ve üniversiteler de sorumluluk almalıdır.

2. Sınıflandırmalar

KT için farklı sınıflandırmalar vardır. Ek Şekil 1'de KT ana uğraş alanları sınıflandırılmıştır.

EK ŞEKİL 1. Kazısız rehabilitasyon teknikleri ile yapılan uygulamalar. (Yılmaz, 2009)

3. Gelişmeler

KT alanındaki gelişmeler ve yenilikler:

i.Yüksek güç, hız ve esneklikte çalışan yatay yönlenmiş delgi metodları,

ii. Akışkan püskürterek delme sistemleri,

iii. Toprak ve kayaları yüksek frekanslı ultra ses kırıcılarla pulvarize eden sistemler,

iv. Hat önündeki öğütülen toprağı tuğlaya dönüştürme veya hattın iç yüzeyine anında sıvama,

v.Kazı makinesinin sert ünite olmak yerine kurtçuk gibi esneyebilme kabiliyeti kazanması,

vi. Melez sistemler (kesici baş ilerlemesi ile senkronize çalışan 3D baskı teknolojisi ile plastik borunun/astarın eklemeli olarak yerinde üretilmesi gibi),

vii. KT Sistemlerine ileri tanı ve yönlendirme kabiliyeti ve yapay zeka ile otonom özellik kazandırma.

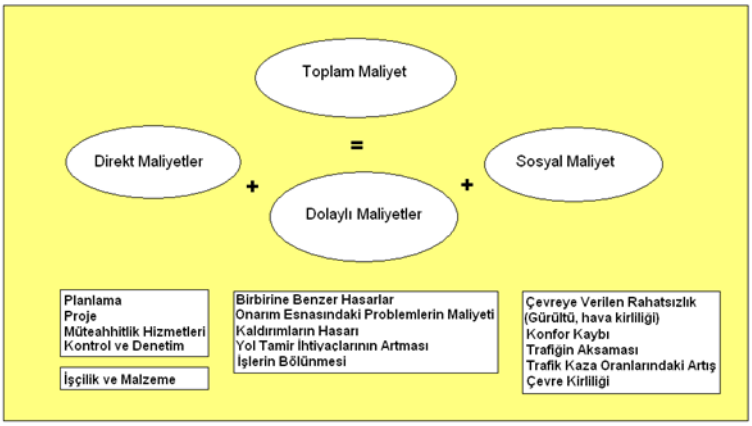
Kazısız yöntem yeni eğilimlerden biri olup eski veya yeni hat inşası, trafik ve çevre rahatsız edilmeden açık kazıya (trenching) göre daha kısa süre ve maliyetle gerçekleştirilir. Yatay yönlenmiş delgi (Horizontal Directional Drilling) ile boru döşeme en önemli kazısız teknoloji yöntemlerinden biridir. Buradaki süreç yönetimi, hidrolik esaslar ve yenilikler çok etkileyicidir. Bu sistemde önce kırıcı kafa yeni hat açar veya eski hat içini genişletir. Aynı veya daha büyük çaplı kafa açılan oyuğa kilometrelerce uzunlukta olabilen yeni boruyu çeker. Bu ve benzeri yöntemler, kazılı teknolojilerin topluma verdiği toplam göreceli rahatsızlık derecelerini büyük ölçüde azaltmış veya önlemiş olur.

4. Maliyetler

Kazılı teknolojilerde proje maliyet hesaplamalarında metreküplük toprak hafriyatı önemli parametre iken, kazısız teknolojilerde borulu sistem uzunluğu, kısaca metre başı maliyet önemli bir ölçektir. KT'de malzeme ve işçilik projenin nerede ise ¾'ünü kapsarken, açık kazı'da bu iki kalem %40'larda olup, sosyal maliyetler (% 40) ve diğer/dolaylı maliyetler (% 20) önemli olmaktadır. KT'de sosyal maliyetler çok düşüktür (% 5), diğer/dolaylı maliyetler ise kazılı ile aynı mertebededir (% 20). Örneğin kazılı veya kazısız yüksek yoğunluklu polietilen (HDPE) boru hattı döşeme maliyetleri artan çap ile doğrusal olarak artar. Göreceli maliyet yöntem ne olursa olsun 50 mm çap için bir birim ise, 300 mm çap için iki birimdir. 300 mm çap için HDPE boru özelinde döşeme maliyet sıralaması: i) Açık kazı için 4 birim, ii)KT-Deforme baskı boru ile astarlama için 2 birim, iii) KT-Yatay yönlenmiş delgi için 2 birim altı, iv) KT-Boru patlatma için 1,5 birim ve v) KT-Kaymalı astarlama için ise 1 birim üstüdür (En ucuz KT yöntemi). Bu mukayeseli değerler görecelidir, hat uzunluğu ve toprak yapısı gibi birçok faktöre bağlı olarak revizyona muhtaçtır.

5. Sosyal Maliyetler

Uygulanacak bir projenin topluma olan maliyeti göz önünde bulundurulmalı ve asgari düzeyde toplumun etkilenmesi sağlanmalıdır. Toplumsal maliyeti oluşturan sosyal gruplar beş bölüme ayrılmıştır. Bunlar trafik, çevre, ticaret, endüstri, kentsel ve toplumsaldır. Sosyal maliyet, bir projenin yürütülmesi için yapılan bütün eylemlerin ve çevreye etkilerin maliyeti şeklinde tanımlanabilir. Bu eylemlerdeki birçok kalem proje maliyeti olarak hesaplanmasına karşın, genellikle toplam maliyet içinde verilmez, bazı kalemlerin ise parasal karşılığı hesaplanamaz. Toplumsal maliyetin hesaplanması kolay değildir. Bu maliyetlerin tümü topluma yansımaktadır. Örneğin sosyal maliyetin bir bölümünü projede kullanılacak malzeme ve ekipmanların taşınması oluşturmaktadır. Boru hatlarının maliyeti ve oranlar yeni hat döşeme durumunda ve rehabilitasyon projesinde de farklılaşmaktadır. Ek Şekil 2'de maliyet kalemleri verilmiştir.



EK ŞEKİL 2. Su ve atık su hatlarının rehabilitasyonlarında meydana gelen toplam maliyetler. (Ohiowater; Yılmaz, 2009)

6. Boru Hattı İncelemeleri

KT'de boru döşenecek güzergah veya rehabilite edilecek (yenilenecek) boru hattı genellikle tahribatsız olarak incelenir. Boruları incelemede; i) iç, ii) cidar ve iii) dış inceleme olmak üzere 3 farklı kategori vardır. Başlıca tahribatsız inceleme teknikleri:

- Kapalı Devre Televizyon Vidio (Closed-Circuit Television Video-CCTV),
- Kenar Taramalı Değerlendirme Teknolojisi (Side Scanning Evaluation Technology-SSET)
- Radyografi,
- Termografi,

- Magnetik Teknik,
- Yer Geçirgen Radar (Ground Penetration Radar - GPR),
- Titreşim,
- Kızılötesi,
- Mikrodalga,
- Elektron Akım Testi (Electron Current Test)
- Hava Testi, Duman Testi (Air Test, Smog Test)
- Lazer Tarama sistemleridir.

Eski boru hattını incelemeden sonra rehabilitasyan yöntemi, gerekçeleri ve gerekleri tartışılır.

7. Yeni Hat Döşeme

Geleneksel Boru İtme - Conventional Pipe Jacking (CPJ): Muhtelif başlıklı makineler ile veya el kontrollü olarak delik açma ve sıralamalı boru itme.

Toprak-Basınç Dengeli Makine - Earth-Pressure Balance Machine (EPBM): Yüzeydeki malzemelere mekanik basınç uygulayarak mikrotünel veya tünel açma.

Çamur Makinası - Slurry Machine (SM): Kapalı ön yüzeyli mekanik başlık ile kırpılmış toprak malzemeleri hidrolik olarak çamurla alan ve yeraltı suyunu dengeleyen makine.

Hizmet Tüneli - Utility Tunneling (UT): Yeraltı hizmet hattını kesici yüz önünden toprakları alarak oluşturma, kenarları astarladıktan sonra ürün boru/boruları yerleştirme eylemi.

Yatay Toprak Borulama - Horizontal Earth Boring (HEB): Yatay olarak delgi yapan kesici başlı, döner takım ve itme sistemli borulama.

Yatay Burgulu Delme - Horizontal Auger Boring (HAB): Boru açma makinesi ile ön yüzü sertleştirilmiş çelik boruyu itme, içte kalan toprağı burgu ile boşaltma ve ürün boruyu yerleştirme eylemi.

Yatay Yönlenmiş Delgi - Horizontal Directional Drilling (HDD): Boru, kanal ve kabloların yönlendirilmeli olarak giriş haznesinden diğer uca doğru birkaç kademeli işlemle döşenmesi.

Mikrotünel Açma – Microtunneling: Yüzeydeki kontrol odasından yönetilen, derinden kazı toprağını çekerken boru parçaları döşenmesini gerçekleştiren, itmeli ve döner kesicili sistem.

Pilot Boru Destekli Mikrotünel Açma - Pilot-Tube Microtunneling (PTMT): Güdümlü-burgulu boru açma olarak ta anılan, yüzeye yakın, düşük çaplı servis bağlantı gibi işlere dönük eylem.

Tünel Açma Makinası - Tunnel Boring Machine (TBM): İnsan girebilir çapta dönen kırıcı başlı-köstebek olarak adlandırılan- makine uzaktan yönlendirilir, kesici yüzdeki toprak arkaya iletilir, boru grupları arka arkaya birleştirilir (veya büyük çaplarda parçalar montajlanır).

Boru Çakma - Pipe Ramming (PR): Sert çelik borulu çerçeve kesikli/darbeli şekilde açılan giriş alanından itilir, çerçeve kılıf içi toprak burgu ile veya basınçlı hava ile çıkarılır.

Darbeli Yatay Kazı – Impact Moling (IM): Torpida şeklinde kolay yönetilebilir sistem havalı/hidrolik çekiçleme ile genellikle düşük çaplı delik açar.

Konu edilen KT metotlarının ortak yönleri yanında büyük farklılıkları da vardır. İki aşamalı borulama dış koruyucu çerçeveli sistem ile içeriye yerleştirilmiş ürün boru birlikteliğini verir. Buna 2 fazlı (kademeli) borulama da denir. Burada iç içe 2 boru veya 2 oluşum döşenmiş olup, Hizmet Tüneli, Yatay Burgulu Delme, Boru Çakma teknikleri örnek olarak verilebilir. Tek fazlı (kademeli) borulamaya örnek olarak Geleneksel Boru İtme, Mikrotünel Açma, Pilot Boru Destekli Mikrotünel Açma, Yatay Yönlenmiş Delgi ve Darbeli Yatay Kazı verilebilir. Burada sadece hat boyunca tek boru sistemi döşenir.

Diğer unsurlar, teknoloji yoğun olup olmama, boru çap aralıkları, hat uzunlukları ve derinlikleri ile ilgilidir. Bir kısım yeni hat döşeme tekniklerinin, hat yenileme ve eskiyen hattın değiştirmesi işlevine de sahip oldukları unutulmamalıdır.

Yatay Yönlenmiş Delgi Metodu, boru, kanal ve kablo altyapı hizmetlerinin yeraltına yerleştirilmesinde uygulanan bir kazısız inşaat tekniğidir. Özellikle otoyol, demiryolu, nehir, doğal koruma alanları, tarihi alanlar veya altyapı hizmetlerinin altından hat geçirileceği durumlarda uygulanır. HDD esnekliğine ve minimum kazı gereksinimine bağlı olarak en çok tercih edilen kazısız yöntemdir. Bu metot çapta 50 mm' den 1200 mm'ye, uzunlukta 3000 metreye kadar uygulanabilmektedir.

Mikrotünel Açma nüfus yoğun bölgelerde boru itme ile yapılır. Değerlerin korunması, düşük sosyal maliyet ve çevre dostu döşeme özelliği bu kazısız teknolojiyi tümleşik açık kazıya (ve döşeme ve kapamaya) göre avantajlı kılar. Uzaktan kontrol ve yönetime sahip bu sistem, derin alanlarda bile yeraltı su ve toprak basıncını dengeleme kabiliyetine sahiptir.

Tünel açma makinaları, benzeri olduğu mikrotünel açma sistemlerinin çok büyük halidir ve çaplar 1 metre ile 19 metre arasında yığılma gösterir. TBM dönen silindirik başlık ile sert taş ve topraklı zeminler delinebilir ve sistem oldukça pahalıdır, çoğu zaman tek kullanımlıktır. Burada tünel açma hızı 8-10 m/gündür, açık kazı tünelde (delme ve patlatmalı) ise hız 1-2 m/gündür.

8. Boru Hattı Yenileme

Kaymalı astarlama - Continuous Sliplining: Eski hattaki boru çapından daha küçük çapa sahip esnek bir astar borunun yerleştirilmesi ve sonra bu yeni astarla tekrar servis hattına bağlanması yoluyla sistemin rehabilite edilmesi yöntemi (Gerektiğinde eski-yeni boru arası boşluk doldurulur. Çok hızlıdır ve 80–3500 mm arası çaplara uygundur). Kesit kaybından dolayı hidrolik kapasite düşüşü yaşanır.

Deforme Baskı Boru İle Astarlama , Katla/Şekil Ver – Swage lining, Fold/Form: PE veya PVC boru çap küçültücü kalıp veya merdanelerden geçirilerek eski hata rahatça sokulur. Bu yolla giriş rahat olur. Son aşamada yerleştirilen astar boru çapı büyütülür ve eski – yeni boru sıkı geçmesi (teması) sağlanır. İşlem adımları: Termoplastik malzemeler ısıtılır ve fabrikada deforme edilir, soğuk ortamda bekletilir, yuvarlak ve U şeklindeki deforme boru rehabilite edilecek eski boruya yerleştirilir, sıcak su veya buhar ile ısıtılır ve eski hat içinde düzgün boru formu geri kazanılır. Türevleri: **Parça astarlama - Segmental Sliplining, Panel Astarlama - Panel Lining, Sarmal Sargı Boru - Spiral Wound Pipe, Sıkı Geçme Boru - Close-Fit Pipe, Isıyla Şekil almış Boru - Thermoformed Pipe.**

Boru İçinde Kürleyerek Astarlama - Cured-in-Place Pipe (CIPP): Yeni açılan veya mevcut iki şaft (baca) arasına bir astar (reçine emdirilmiş özel kumaş) malzemesinin yerleştirilmesi, basınç altında eski boru yüzeyine sıkı temasının sağlanması ve takiben kürlenmesi eylemlerini kapsar. Reçineli kumaş, sıcak su-buhar (polyester astar kumaşlar için) veya UV (cam elyaf kumaşlar için) ile kürlenmeyi (sertleşme) takiben eski boru içine tam olarak oturmuş (sıkı geçmiş) yeni boru gibi nitelikli bir astar elde edilir, ana ve yanal bağlantılar yapılır ve sıvı akışına açılır. Akışkanlık ve akış kapasitesi düşmez. Kumaş yerleştirme ve sertleştirme sırasında akış tamamen kesilmelidir.

9. Boru Hattı Değiştirme

Boru Patlatma - Pipe Bursting: Patlatma yöntemi, yeraltındaki mevcut hattaki eski boruların kırılarak (parçalanarak) ve toprağa doğru itilerek genişletilen hat içine yeni boru döşeme tekniğidir. Kırıcı kafanın arkasından çekilen yeni borular eski hatta döşenir. Kırma eylemi, statik, hidrolik ve mekanik tahrikli olan darbeli kırıcılarla sağlanır. Kırık parçalar iç bölgelere itilir, yeni boru hat çapı ve hidrolik kapasite arttırılabilir.

Boru Çıkarma - Pipe Removal, Pipe Eating : Eskimiş boru hattı, çekmeli çalışan kırıcı (Genişletici-Reamer) etkisiyle küçük parçacıklara ayrılır (ufalanır), suya katılır, oluşan çamurla geri çekilir (HDD, HAB ve MTBM sistemleriyle). Eski boru parçaları çevre direktiflerine uygun olarak toprakta bırakılmaz.

Boru Çekme – Pipe Extraction: Eski borunun çekilerek ve sürüklenerek hattan çıkarılması. Yüzey sürtünmesinin düşürülmesi için malzemeye ve çekme tarzına dönük yenilikçi adımlar atılmalıdır (Çevre direktiflerine uygun).

10. Kazısız Teknoloji Boru (ve Astar) Malzemeleri

Borular, farklı ve yeni türleriyle basınçsız ve basınçlı hatların vaz geçilmez malzemeleridir. KT'de üç grup boru malzemesi kullanımdadır:

Rijit Borular: Beton ve türevleri (Ön Gerilmeli Beton gibi), Asbest Çimento, Emaye Kil, Dökme Demir

Esnek Borular: Plastik (Poli Vinil Klorür, Yüksek Yoğunluklu Polietilen gibi), Çelik, Cam Fiber Takviyeli Plastik (Kompozit)

Yarı – Rijit Borular: Düktil Demir

11. Sonuç

Bugün dünya çapında, başta su ve kanalizasyon olmak üzere, birçok yeraltı hizmet sistemlerinde acil tamir, değiştirme ve yenilemeye ihtiyaç duyulmaktadır. Bu sistemlerin çoğu tasarım ömürleri aşıldığı halde hizmet vermektedir. Bu eski hatlarda mevcut olan çatlaklardan ve bağlantılardan sıvı sızdırır bir şekilde hizmet alınmakta ve ani hasar tehlikesi yaşanmaktadır. Diğer yandan, bu sistemlerin beslediği yerlerdeki talep tasarımda planlananı çok aşmıştır. Şehirlerin gelişmeleri ve yeni hat ihtiyaçları, özellikle telekomünikasyon, yeraltı yapılarının önemini daha da arttırmıştır. Çözüm, yeni hat inşası yanında eski hatların tamiri, yenilenmesi ve değiştirilmesindedir. Bunların ekonomik, sosyal ve çevresel etkilerinin en aza indirilerek yapılması önem arz etmektedir. Bu gereklere büyük ölçüde kazısız teknolojilerle ulaşılır. Kazısız teknoloji özdeyişleri, “Minium kazı, minimum risk”, “Kazı yok, risk yok”, hep hatırlanmalı ve karar süreçlerinin çok boyutlu olduğu bilinmelidir.

Bugün ülkemizde ve dünyada KT konularında farkındalık çok artmıştır. Tanıtım ve bilgi paylaşımı amaçlı uluslararası ve ulusal toplantılar da sık aralıklarla yapılmaktadır. 1986 Eylül’ünde hayata geçirilen ISTT (Uluslararası Kazısız Teknolojiler Cemiyeti) ve ona bağlı olarak örgütlenen ulusal kazısız teknoloji cemiyetleri bu alanda önemli işleve sahiptir. Bunlardan biri de 2010’da ülkemizde kurulan Altyapı ve Kazısız Teknolojiler Derneğidir (AKATED-TSITT). Bu derneğin genç yöneticileri geçen 10 yılı aşkın süre içinde çok sayı ve çeşitte faaliyet yürütmüşler, ISTT içinde de öne çıkarak önemli sorumluluklar yüklenmişlerdir.

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