

**TRENCHLESS TECHNOLOGY VS OPEN TRENCH METHODOLOGY:
IMPLEMENTATION IN SOUTH AFRICA'S CONSTRUCTION INDUSTRY**

by

MARIQUE GROBBELAAR

20647876

Submitted to comply with the conditions for the degree.

Ph.D. Quantity Surveying (12262017)

Department of Construction Economics

Faculty of Engineering, Built Environment & Information Technology

Study Leader: Prof J.H. Cruywagen

Co-Study Leader: Prof. B.G. Zulch

UNIVERSITY OF PRETORIA

2024

DECLARATION

I, the undersigned, hereby declare that the work contained in this dissertation is my own original work and that any sources are adequately acknowledged in the text and listed in the bibliography.

I accept the rules of the University of Pretoria and the consequences of transgressing them.

This dissertation is submitted in fulfilment of the requirements for the degree of **Ph.D. Quantity Surveying** at the University of Pretoria and that I have not previously submitted it in its entirety or in part, to any other University for a degree.



Signature of acceptance and confirmation

Student Name: Marique Grobbelaar

Date: August 2024

TABLE OF CONTENTS

TITLE PAGE	i
DECLARATION	ii
TABLE OF CONTENTS	iii
LIST OF FIGURES	ix
LIST OF TABLES	xi
ABBREVIATIONS AND ACRONYMS	xiii
ACKNOWLEDGEMENTS	xiv
ABSTRACT	xv

PART 1: FRAMEWORK 1

CHAPTER 1: FRAMEWORK OF RESEARCH STUDY 1

1.1	TITLE	1
1.2	INTRODUCTION AND BACKGROUND OF STUDY	1
1.3	PROBLEM FORMULATION	6
1.4	STATEMENT OF THE PROBLEM	7
1.5	RESEARCH QUESTION	7
1.6	HYPOTHESIS	7
1.7	PURPOSE OF THE STUDY	7
1.8	STUDY OBJECTIVE	8
1.9	IMPORTANCE OF THE STUDY	8
1.10	ASSUMPTIONS, SCOPE AND LIMITATIONS	10
1.11	PRELIMINARY LITERATURE REVIEW AND CONCEPT CLARIFICATION	11
1.12	PROPOSED METHODOLOGY	12
1.12.1	LITERATURE STUDY	12
1.12.2	EMPIRICAL STUDY	12
1.13	ETHICAL CONSIDERATIONS	13
1.14	OUTLINE AND TIME FRAME	13
1.15	SUMMARY	14

<u>PART 2: METHODOLOGY</u>	15
CHAPTER 2: RESEARCH STUDY METHODOLOGY	15
2.1 INTRODUCTION	15
2.2 RESEARCH OBJECTIVE	15
2.3 RESEARCH METHOD	16
2.4 RESEARCH DESIGN	18
2.5 ETHICAL APPROVAL	23
2.6 SAMPLING DESIGN	24
2.7 SAMPLING SIZE	24
2.8 RESEARCH STRATEGY: STRUCTURED QUESTIONNAIRE	25
2.9 DATA ANALYSIS AND REPRESENTATION	28
2.10 RESEARCH QUALITY	28
2.11 SUMMARY	29
<u>PART 3: LITERATURE REVIEW</u>	30
CHAPTER 3: BASICS OF TRENCHLESS TECHNOLOGY	30
3.1 INTRODUCTION	30
3.2 HISTORY OF TRENCHLESS TECHNOLOGY	30
3.2.1 FIRST UNDERGROUND WORK	31
3.2.2 EARLY TRENCHLESS METHODS (1890-1970)	34
3.2.3 TRENCHLESS METHODS – (1970 -1990)	37
3.3 THE COMPARISON BETWEEN THE OPEN TRENCH METHOD AND THE TRENCHLESS METHOD	41
3.3.1 OPEN TRENCH/ OPEN-CUT EXCAVATION	43
3.3.2 TRENCHLESS METHOD	44
3.3.3 COMPARISON OF CONSTRUCTION PROCEDURES FOR THE TRADITIONAL METHOD AND TRENCHLESS TECHNOLOGY	46
3.4 FURTHER CONTRIBUTIONS TO KNOWLEDGE	53
3.5 THE ECONOMIC STATUS OF WATER AND SANITATION	56
3.6 THE MEASUREMENT OF TRENCHLESS TECHNOLOGY	57

3.7 SUMMARY	63
CHAPTER 4: INSTALLATION OF NEW SERVICE PIPELINES	64
4.1 INTRODUCTION	64
4.2 WORKER ENTRY METHODS	65
4.2.1 TRADITIONAL PIPE JACKING	65
4.2.2 UTILITY TUNNELLING	71
4.3 NON-WORKER ENTRY METHODS	71
4.3.1 HORIZONTAL AUGER EARTH BORING	71
4.3.2 HORIZONTAL DIRECTIONAL EARTH DRILLING	72
4.3.3 MICROTUNNELING	81
4.3.4 PILOT TUBE MICROTUNNELING	81
4.3.5 PIPE RAMMING	83
4.4 PLANNING A TRENCHLESS PROJECT	84
4.4.1 PLANNING PHASE	84
4.4.2 DESIGN PHASE	86
4.2.3 UTILITY SURVEY PHASE	87
4.2.4 CONSTRUCTION PHASE	87
4.2.5 CLOSE-OUT PHASE	88
4.5 CHARACTERISTICS AND APPLICATION OF THESE METHODS	89
4.5.1 PIPE JACKING AND SERVICE UTILITY TUNNELLING	91
4.5.2 HORIZONTAL AUGER EARTH BORING	91
4.5.3 HORIZONTAL DIRECTIONAL EARTH DRILLING	92
4.5.4 MICROTUNNELING	93
4.5.5 PILOT TUBE MICROTUNNELING	94
4.5.6 PIPE RAMMING	95
4.6 DRAWBACKS OF THESE METHODS	95
4.7 SUMMARY	102
CHAPTER 5: REPLACEMENT OF SERVICE PIPELINES	104
5.1 INTRODUCTION	104
5.2 PIPE RENEWAL AND PIPE REPLACEMENT METHODS	104
5.2.1 PIPE CRACKING/PIPE BURSTING	106
5.2.2 SLIP LINING	109
5.2.3 CURED-IN-PLACE PIPES (CIPP)	112

5.3 PLANNING A TRENCHLESS RENEWAL/REPLACEMENT PROJECT	114
5.3.1 PLANNING PHASE	114
5.3.2 DESIGN PHASE	115
5.3.3 UTILITY SURVEY PHASE	116
5.3.4 CONSTRUCTION PHASE	117
5.3.5 CLOSE-OUT PHASE	118
5.4 CHARACTERISTICS AND APPLICATION OF THESE METHODS	118
5.4.1 PIPE CRACKING/PIPE BURSTING	120
5.4.2 SLIP LINING	120
5.4.3 CURED-IN-PLACE PIPES (CIPP)	121
5.5 DRAWBACKS OF THESE METHODS	121
5.6 SUMMARY	125
<u>PART 4: DATA COLLECTION</u>	126
CHAPTER 6: THE FINANCIAL AND ECONOMIC IMPACT OF TRENCHLESS TECHNOLOGY	126
6.1 INTRODUCTION	126
6.2 DATA COLLECTION	126
6.3 DATA ANALYSIS	126
6.4 PART 1: GENERAL INFORMATION	128
6.4.1 Q1 – PROFESSION	128
6.4.2 Q2 – YEARS OF EXPERIENCE	129
6.4.3 Q3 – SECTOR OF CONSTRUCTION	130
6.4.4 Q4 – GEOGRAPHICAL LOCATION	131
6.4.5 Q5 – TYPE OF SERVICES PROVIDED	132
6.4.6 Q6 – TYPE OF PIPING MATERIAL	133
6.5 PART 2: NEW PIPELINE INSTALLATIONS	134
6.5.1 Q7 – NEW PIPELINE INSTALLATIONS	134
6.6 PART 3: RENEWAL AND REPLACEMENT METHODS	139
6.6.1 Q8 – RENEWAL AND REPLACEMENT METHODS	139
6.7 PART 4: IMPORTANCE OF PROJECT SPECIFICATIONS	142
6.7.1 Q9 – PROJECT SPECIFICATIONS FOR NEW PIPELINE INSTALLATIONS	142
6.7.2 Q10 – PROJECT SPECIFICATIONS FOR RENEWAL & REPLACEMENT METHODS	144

6.8 PART 5: THE FINANCIAL ASPECT OF THE TRADITIONAL MEHTOD	146
6.8.1 Q11 - LOWEST CONTRACT VALUE	146
6.8.2 Q12 – HIGHEST CONTRACT VALUE	147
6.8.3 Q13 – AVERAGE CONTRACT VALUE	148
6.8.4 Q14 – AVERAGE COST PER METRE	149
6.8.5 Q15 – COST ON THREE MAIN PROJECT DETERMINANTS	150
6.9 PART 6: THE FINANCIAL ASPECT OF TRENCHLESS TECHNOLOGY	151
6.9.1 Q16 – LOWEST CONTRACT VALUE	151
6.9.2 Q17 – METHOD USED IN LOWEST CONTRACT VALUE	152
6.9.3 Q18 – AVERAGE CONTRACT VALUE	153
6.9.4 Q19 – METHOD USED IN AVERAGE CONTRACT VALUE	154
6.9.5 Q20 – HIGHEST CONTRACT VALUE	155
6.9.6 Q21 - METHOD USED IN HIGHEST CONTRACT VALUE	156
6.9.7 Q22 – AVERAGE COST PER METRE ON LAST PROJECT	157
6.9.8 Q23 – COST ON THREE MAIN PROJECT DETERMINANTS	160
6.9.9 Q24 – OPTION BETWEEN RENEWAL OR REPLACEMENT METHODS	161
6.10 PART 7: TRENCHLESS TECHNOLOGY AGAINST THE TRADITIONAL METHOD	162
6.10.1 Q25 – TRENCHLESS AGAINST THE TRADITIONAL METHOD	162
6.11 SUMMARY	165
<u>PART 5: DISCUSSION OF RESULTS/ EMPIRICAL STUDY</u>	166
CHAPTER 7: RESULTS SUMMARY AND DISCUSSION	166
7.1 INTRODUCTION	166
7.2 PART 1 – GENERAL INFORMATION	166
7.3 PART 1 – RESULTS SUMMARY	167
7.4 PART 2 – NEW PIPELINE INSTALLATIONS	168
7.5 PART 2 – RESULT SUMMARY	169
7.6 PART 3 - RENEWAL AND REPLACEMENT METHODS	169
7.7 PART 3 – RESULT SUMMARY	170
7.8 PART 4 – IMPORTANCE OF PROJECT SPECIFICATIONS	170
7.9 PART 4 – RESULTS SUMMARY	170
7.10 PART 5 - THE FINANCIAL ASPECT OF THE TRADITIONAL METHOD	171

7.11 PART 5 – RESULTS SUMMARY	178
7.12 PART 6 - THE FINANCIAL ASPECT OF TRENCHLESS TECHNOLOGY	179
7.13 PART 6 – RESULT SUMMARY	182
7.14 PART 7 - TRENCHLESS TECHNOLOGY VS THE TRADITIONAL METHOD	183
7.15 PART 7 – RESULT SUMMARY	192
7.16 SUMMARY	193
<u>PART 6: CONCLUSION</u>	194
CHAPTER 8: CONCLUSION AND RECOMMENDATIONS	194
8.1 INTRODUCTION	194
8.2 RESEARCH QUESTION	194
8.3 HYPOTHESIS	196
8.4 KEY RESEARCH FINDINGS	198
8.5 PURPOSE AND OBJECTIVE OF THE STUDY	204
8.6 FURTHER RESEARCH	205
8.7 SUMMARY	206
8.8 CONCLUSION	209
REFERENCES	210
APPENDIX A	223
APPENDIX B	224
APPENDIX C	225
APPENDIX D	227
APPENDIX E	244
APPENDIX F	245

LIST OF FIGURES

Figure 1: Early Cast-Iron Pipes.....	31
Figure 2: Brunel Shield Patent Drawing.....	33
Figure 3: Couch's Rock- Drilling Machine.....	34
Figure 4: Pipe Jacking of Reinforced Concrete Pipes.....	35
Figure 5: Comparison of pipeline tension in Trenchless Installations and The Traditional Method.....	42
Figure 6: Horizontal Directional Earth Drilling Machine.....	53
Figure 7: Drilling Heads.....	54
Figure 8: Drilling Fluid Mixing System for HDD.....	54
Figure 9: Pipe Jacking of the 900mm pipe.....	55
Figure 10 : Final Day of Pipe Jacking for 900mm pipe.....	55
Figure 11: 1200mm diameter pipe being jacked.....	56
Figure 12: Worker inside 1200mm diameter pipe.....	56
Figure 13: Three Primary Components of Trenchless Technology Methods.....	64
Figure 14: New Installation Methods for Trenchless Technology.....	64
Figure 15: Standard Pipe Jacking System.....	66
Figure 16: Pipe Jacking Shield.....	67
Figure 17: Conventional Pipe Jacking.....	99
Figure 18: Utility Tunnelling.....	99
Figure 19: Horizontal Directional Earth Drilling.....	100
Figure 20: Horizontal Auger Earth Boring Machine.....	100
Figure 21: Microtunneling.....	101
Figure 22: Pilot Tube Microtunneling.....	101
Figure 23: Pipe Ramming.....	101
Figure 24: Summary of the Methods for New Installation of Pipelines.....	102
Figure 25: Slip Lining Process.....	123
Figure 26: Cured-In-Place Process.....	123
Figure 27: Pipe Bursting.....	124
Figure 28: Summary of the Methods for Replacement of existing pipelines.....	125
Figure 29: Answer for Voluntary Participation.....	127
Figure 30: Q3 - Results of Respondents - Sector of Construction.....	130
Figure 31: Q4 - Results of Respondents - Geographical Locations.....	131
Figure 32: Q5 - Results of Respondents - Type of Services.....	132
Figure 33: Q6 - Results of Respondents - Type of Piping Material.....	133

Figure 34: Q7.1 - Results of Respondents - New Installations - Type of Services	134
Figure 35: Q7.2 - Results of Respondents - Type of Piping Material.....	137
Figure 36: Q8.1 - Results of Respondents - Type of Service	139
Figure 37: Q8.2 - Results of Respondents - Type of Piping Material.....	140
Figure 38: Q9 - Results of Respondents - Project Specifications for New Pipeline Installations.....	143
Figure 39: Q10 - Results of Respondents - Project Specifications for Renewal and Replacement Methods.....	145
Figure 40: Q11 - Results of Respondents - Lowest Contract Value	146
Figure 41: Q12 - Results of Respondents - Highest Contract Value.....	147
Figure 42: Q13 - Results of Respondents - Average Contract Value	148
Figure 43: Q14 - Results of Respondents - Average Cost per Metre	149
Figure 44: Q15 - Results of Respondents - Cost on Three Main Project Determinants ...	150
Figure 45: Q16 - Results of Respondents - Lowest Contract Value	151
Figure 46: Q17 - Results of Respondents - Method for Lowest Contract Value.....	152
Figure 47: Q18 - Results of Respondents - Average Contract Value	153
Figure 48: Q18 - Results of Respondents - Method for Average Contract Value.....	154
Figure 49: Q20 - Results of Respondents - Highest Contract Value.....	155
Figure 50: Q21 - Results of Respondents - Method for Highest Contract Value.....	156
Figure 51: Q22 - Results of Respondents - Average Cost per Metre	158
Figure 52: Q23 - Results of Respondents - Cost on Three Main Project Determinants ...	160
Figure 53: Q24 - Results of Respondents - Option Between Renewal or Replacement Methods.....	161
Figure 54: Q25 - Results of Respondents - Trenchless Technology or Traditional Method	164
Figure 55: Results from Empirical Study.....	201
Figure 56: The Sanddrift Project done by AECOM in Cape Town using CIPP	207
Figure 57: Total Amount of Projects executed by the Top 50 Trenchless Technology firms in America & Canada.....	207
Figure 58: Total Revenue for the Top 50 Trenchless Technology Firms in America & Canada.....	208

LIST OF TABLES

Table 1: The basic procedure for pipeline installation between Open-Cut and Trenchless.	46
Table 2: Total Capital Replacement Costs for Water and Sanitation in South Africa	56
Table 3: A template for the Cost Comparison between the Traditional and Trenchless Method	59
Table 4: Elemental Estimate for Trenchless Technology.....	61
Table 5: Standard System for Trenchless Technology.....	62
Table 6: Main Characteristics of New Trenchless Methods with Typical Application Thereof.	90
Table 7: Comparison of Slip Lining Methods.....	111
Table 8: Specific Applications for Renewal and Replacement Methods	119
Table 9: Main Characteristics of Renewal and Replacement Methods with Typical Application thereof	119
Table 10: Voluntary Permission of Each Respondent	127
Table 11: Q1 - Results of Respondents - Profession	128
Table 12: Q2 - Results of Respondents - Years of Experience	129
Table 13: Q3 - Results of Respondents - Sector of Construction	130
Table 14: Q4 - Results of Respondents - Geographical Location.....	131
Table 15: Q5 - Results of Respondents - Type of Services.....	132
Table 16: Q6 - Results of Respondents - Type of Piping Material.....	133
Table 17: Q9 - Results of Respondents - Project Specifications for New Pipeline Installations.....	142
Table 18: Q10 - Results of Respondents - Project Specifications for Renewal and Replacement Methods.....	144
Table 19: Q11 - Results of Respondents - Lowest Contract Value.....	146
Table 20: Q12 - Results of Respondents - Highest Contract Value.....	147
Table 21: Q13 - Results of Respondents - Average Contract Value.....	148
Table 22: Q14 - Results of Respondents - Average Cost per Metre.....	149
Table 23: Q15 - Results of Respondents - Cost on Three Main Project Determinants	150
Table 24: Q16 - Results of Respondents - Lowest Contract Value.....	151
Table 25: Q17 - Results of Respondents - Method for Lowest Contract Value.....	152
Table 26: Q18 - Results of Respondents - Average Contract Value.....	153
Table 27: Q19 - Results of Respondents - Method for Average Contract Value.....	154
Table 28: Q20 - Results of Respondents - Highest Contract Value.....	155

Table 29: Q21 - Results of Respondents - Method for Highest Contract Value	156
Table 30: Q22 - Results of Respondents - Average Cost per Metre.....	157
Table 31: Q23 - Results of Respondents - Cost on Three Main Project Determinants	160
Table 32: Q24 - Results of Respondents - Option Between Renewal or Replacement Methods.....	161
Table 33: Q25 - Results of Respondents - Trenchless Technology or Traditional Method	163
Table 34: Cost Comparison between the Traditional and Trenchless Methods	202

ABBREVIATIONS AND ACRONYMS

Closed Circuit Television	CCTV
Close Fit Pipe	CFP
Conventional Pipe Jacking	CPJ
Cured-In-Place Pipes	CIPP
Ductile Iron Pipes	DIP
Earth Pressure Balance Machine	EPB
Full Tunnel Boring Machine	FTBM
Glass Reinforced Plastic Pipes	GRPP
Horizontal Auger Earth Boring	HAB
Horizontal Directional Earth Drilling	HDD
High Density Polyethylene	HDPE
Horizontal Earth Boring	HEB
Intermediate Jacking Station	ISJ
International Society for Trenchless Technology	ISTT
Microtunnel Boring Machine	MTBM
Polyvinyl Chloride	PVC
Polymer Concrete Pipes	PCP
Reinforced Concrete Pipes	RCP
Southern African Society for Trenchless Technology	SASTT
Tunnel Boring Machine	TBM
Vitrified Clay Pipes	VCP

ACKNOWLEDGEMENTS

I would like to thank the following people/organisations for their support and effort:

- God, for his grace and blessing me with all the opportunities in my life.
- My study leader, Prof. J.H. Cruywagen for his support and guidance. He provided me with assistance and went the extra distance.
- Mrs Leonie Jacobs for all her assistance with the Ethics Committee and being my fellow PhD student.
- All the staff at the Department of Construction Economics that assist students every day.
- My husband for being my biggest fan, best friend and for encouraging me to keep going. Love you more than you will ever understand.
- My parents and in-laws for their love and understanding.
- The rest of my close family members and friends that have been there since the beginning.
- To anyone who understood when I needed to cancel plans, work over weekends or miss social events.

ABSTRACT

TRENCHLESS TECHNOLOGY VS OPEN TRENCH METHODOLOGY: IMPLEMENTATION IN SOUTH AFRICA'S CONSTRUCTION INDUSTRY

By

MARIQUE GROBBELAAR

STUDY LEADER: Prof. J.H. Cruywagen
CO-STUDY LEADER: Prof. B.G. Zulch
DEPARTMENT: Construction Economics
FACULTY: Engineering, Built Environment and Information Technology
UNIVERSITY: University of Pretoria
DEGREE: Ph.D. Quantity Surveying

Trenchless Technology is the term for the implementation of methods for the installation of new pipeline services or the rehabilitation of existing networks without the use of open trench pipeline excavation or limited disturbance within the surface of the earth. Trenchless Technology is a guided drilling process that forms an arc in a straight profile underneath the ground surface. The guided drilling is performed with a variety of machines and equipment. The drilling process can replace or install service lines under existing structures, urbanised areas, roadways and natural water sources. The term mostly refers to these methods being implemented in a horizontal direction.

Trenchless Technology is known for reaching great lengths and allows for the installation of a variety of different pipeline material. The advancement of this field has led to the installation of bigger diameter service lines and increasing the overall completion programme of construction and civil engineering projects.

The purpose of the study is to analyse the comparison between Trenchless Technology and the Traditional Open Trench Method within the construction industry of South Africa. The study further examines the financial viability of implementing Trenchless Technology as an

alternative to the traditional method for the installation of new service lines or the rehabilitation or repair thereof. The literature review is based on the limited amount of information available for the Trenchless Technology field within South Africa. It examines the advantages and disadvantages between the two methods and attempts to clarify the unfamiliarity and develop a broader availability of information for these methods. It aims to inform the potential of Trenchless Technology and the implementation of this method within our country, especially within the public sector. The empirical study examines the financial viability of the method.

Keywords: Traditional Open Trench Method, Trenchless Technology, Alternative Method, Financially Viable, South Africa

PART 1: FRAMEWORK

CHAPTER 1: FRAMEWORK OF RESEARCH STUDY

1.1 TITLE

Trenchless Technology vs Open Trench Methodology: Implementation in South Africa's Construction Industry.

1.2 INTRODUCTION AND BACKGROUND OF STUDY

The term Trenchless Technology refers to a type of subsurface technology that uses a few excavations or no trenching within the earth. It is rapidly being implemented within the construction and civil engineering sector. The method is used for the installation of new underground infrastructure or the replacement of existing underground infrastructure that is located deep within the subsurface of the earth. The technique allows for minimal disruptions above the earth's surface (Najafi, 2013: 1; Sullivan, 2018b: online).

Trenchless Technology uses guided drilling to form an arc or straight profile under the ground. This technique can install or replace pipelines under highways, railway lines and road networks. The drilling process can also cover longer distances underneath rivers, lagoons and highly urbanised areas (Najafi, 2010: 5; Sullivan, 2018b: online).

In 1970, Eric Wood was the first person to introduce pipe rehabilitation. He used a felt pipe filled with a resin. The tube was pulled through the existing pipe and air was used to expand the inside of the tube. The tube filled the inside surface of the existing pipeline and created a new pipeline within the existing system (Sullivan, 2018b: online).

By 1974, an Engineering Company, DJ Ryan and British Gas developed the first pipe rehabilitation method. The method used displacement hammers and horizontal ramming machines to break open the existing pipe (Sullivan, 2018b: online).

During the 1970s, Japan invented a technique for Trenchless Technology, known as microtunneling. By 1984, the United States of America had also implemented this technique. This method was used for the first time in Florida. The technique was used to install a 180m long pipeline with a diameter of 1800mm under the I-95 freeway (Sullivan, 2018b: online). Even though it has taken a long time for Trenchless Technology to become a potential technique, more companies are starting to realise the impact of using these techniques to repair and upgrade the existing infrastructures of cities (Sullivan, 2018b: online).

Municipalities have realised that they no longer have to excavate sites to repair damaged pipes. The technique allows for less physical digging and fewer repairs to roads, walkways and highways. Cured-In-Place pipes also offer a solution against the corrosion of pipes and reduce the maintenance of the new pipeline by 30 years. Since the implementation of CIPP, other forms of Trenchless Technology have been invented (Sullivan, 2018b: online).

Trenchless Technology was originally developed to answer the need within the public service providing sector. The underground service network for many countries has been around for centuries. Due to the expansion and population growth of the world, cities have become more populated and space limitations are increasing. It is difficult, if not impossible, for municipalities to repair or replace all the service networks while accommodating the daily population growth (Sullivan, 2018b: online).

According to Trenchless Technologies C.C. (2005f: online), the following piping material is installed with Trenchless Technology:

- Gas
- Water
- Sewage
- Telecommunication
- Electrical

Trenchless Technology has the two following primary categories (Najafi, 2013: 3):

- New Pipeline Installation
- Pipeline Rehabilitation

1.2.1 New Pipeline Installations

New pipeline installations involve placing new pipelines or service utilities underground without the need for an open-cut trench. This technique can be categorised into three primary components, namely:

1.2.1.1 Directional Drilling / Horizontal Drilling

Horizontal Directional Earth Drilling is known as the process of installing new pipelines or services underground. The main concept of the process involves a machine that drills in a horizontal direction into the earth's subsurface, thus eliminating Open-Face trenches. A drill head is at the start of the drilling process and is connected to drilling rods. The drill head rotates at a high speed to drill into the earth's surface. The drilling rods are used to push the drill head forward into the underground surface. Each drill rod is linked to the end of the previous rod, thus creating a chain or a link of rods. The rods determine the length of the excavation line (Najafi, 2010: 16).

When the drill head reaches the end of the pipeline, a reamer and pipe-puller are connected to the drilling rods in the place of the drill head. The new pipeline is connected to the pipe-puller and is then installed by pulling the drilling rods back to the starting position of the drilling process. The new pipeline follows the newly drilled path. The reamer is used to cut or enlarge the diameter of the hole. A fluid of bentonite clay is injected into the hole during the reaming process, which stabilises the inside of the hole in order to pull through the new pipeline (Trenchless Technologies C.C, 2005b: online).

1.2.1.2 Pipe Ramming/ Pipe Jacking

Pipe Ramming or Pipe Jacking uses a pipe that is rammed through the soil using a device that is added to the end of the pipe. This technique does not create a borehole, but rather drives the hammer through the soil. The hammer is rammed through the soil by making use of an air compressor that is used as the power source. This technique is limited to the use of steel pipes due to the impact of the force on the pipeline (Najafi, 2010: 38).

Two pits are excavated within the ground, one at the beginning of the pipeline and the other at the end. A pneumatic hammer is used to drive steel casings through the ground surface, connecting the two excavated pits. A correctly sized rammer is placed at the launching pit. The first casing is connected to the front of the rammer, directly or via ramming cones. The air-supply is partly opened to start the ramming process. The air-supply is then slowly increased as the first casing starts to enter the subsurface (Trenchless Technologies C.C, 2005d: online).

As each casing length enters the subsurface, the rammer is removed, and the next casing is welded to the back of the current casing within the pilot hole. The rammer is then reinstalled to continue the ramming process. The soil inside the steel casing is removed via pressurisation (Najafi, 2010: 38).

1.2.1.3 Microtunneling

Microtunneling uses a remotely controlled microtunnel boring machine, also known as a Microtunnel Boring Machine (MTBM). The same method, done on a larger scale, is known as Tunnelling and uses a Tunnelling Boring Machine (TBM). The machine is remotely controlled for the installation of mechanical tunnelling systems. The machine is moved forward by making use of pipe jacking. The cutter head needs to be selected for each project to cut through the ground conditions. This technique also requires the excavation of a load pit and a receiving pit (Najafi, 2013: 4).

Both techniques use the pipe jack-and-bore method to directly install new pipelines. These methods use mechanical or fluid pressure to balance the earth's pressure. A launch pit is excavated within the earth. The TBM/MTBM is lowered into the launch pit. The machine is a cylindrical shaped machine with a rotating cutter head. The machine is pushed forward via jacks to create a pilot hole (Najafi, 2010: 10).

The machine has a closed slurry system. This system allows a slurry to pass through the drilling head of the machine. The slurry prevents friction and offers protection for the drilling head. The slurry also mixes with the loose soil and is pumped back up towards the earth's surface. The solids contained within the slurry are separated and the extra soil is disposed of (Najafi, 2010: 20).

1.2.2 Pipeline Rehabilitation:

Pipeline rehabilitation is the process of rehabilitating an existing service line or utility where it can be fully utilised without the need to replace it. This technique can be categorised as follows:

1.2.2.1 Pipe Cracking/ Pipe Bursting

Pipe Cracking is a method of Trenchless Technology that replaces existing pipelines. It is a technique used to fracture an existing pipeline from the inside. A machine is placed within an excavated pit at the end of an existing pipeline. A second pit is excavated at the beginning of the existing pipeline. Rods are pushed through the centre of the existing line by the machine until it reaches the beginning of the pipeline inside the pit (Najafi, 2010: 348).

A pipe cracking head is attached to the tip of the rods. The new pipeline for the service is attached to the end of the pipe cracking head. The machine pulls the rods back towards the end pit. The pipe cracking head at the tip of the drilling rods expands and breaks the existing pipeline from the inside. The broken pieces of the pipeline are pushed to the outside surrounding area under the earth's core. A new pipeline is then pulled through, in the place of the old service line (Najafi, 2010: 348).

1.2.2.2 Slip Lining

Slip lining is a technique used that replaces an existing pipeline by leaving it in place. A smaller diameter High-Density Polyethylene pipe is pulled through the existing pipeline. This technique is used when the existing pipeline cannot be removed or bursts from the inside. This technique is not widely used, since the old service line is left within the earth's surface and not removed, which is an environmental issue for companies and municipalities (Najafi, 2013: 20).

Another altered form of the technique is known as Modified Slip Lining. This process also involves a smaller diameter pipe being inserted into the old service line. The new pipes are specifically rolled or designed to form a tight fit within the old defective pipe. The pipes are inserted within the existing service line and are expanded using steam or a re-rounding

device. The ends are grouted together to form a continuous airtight service line (Trenchless Technologies C.C., 2005e: online).

1.2.2.3 Cured-In-Place Pipes (CIPP)

This technique uses a type of resin that moulds to the host pipe. The seamless pipe restores the structural capability of the pipe, prevents penetration by the elements, and eliminates joints in pipelines. This technique has also been proven to reduce the effects of corrosion on service pipelines. A resin-saturated felt tube that is made of polyester or fibreglass cloth is inserted or pulled through the existing pipeline. The liner is fed through the pipe using water or air-pressure, as the resin cures it forms a tight-fitting pipe. This pipe is joint-less and corrosion-resistant (Najafi, 2013: 17; Trenchless Technologies C.C., 2005a: online).

1.3 PROBLEM FORMULATION

Trenchless Technology is the technique of installing, repairing and renewing underground services, ducts and cable lines by reducing or eliminating the need for excavations. It might be able to reduce the environmental impact and operational costs and produce an alternative to the Open Trench Method. It develops mapping techniques, and evolves tunnelling devices and specialist equipment (Najafi, 2013: 2; Patel, Pitroda. & Bhavsar, 2014: online).

The first appearance of Trenchless Technology has made its introduction into the construction industry. Horizontal Directional Earth Drilling is being used for the installation of fibre lines for wireless technology, sewer pipelines, and waterlines, to name a few. Pipe cracking is a newer method that is used for pipeline rehabilitation where CCTV cameras are used to inspect pipeline conditions. The uses and implementation of Trenchless Technology is continuously developing, and the public is finding and inventing more ways to attempt the successful utilisation of this technique (Allouche, Murray, Vos & Dalgleish, 2019: online).

Trenchless Technology is, therefore, a method that could prove beneficial in the installation of new pipe services or replacing and upgrading the existing service network.

1.4 STATEMENT OF THE PROBLEM

The financial viability of implementing Trenchless Technology within the construction industry in South Africa compared to the traditional Open Trench Method.

1.5 RESEARCH QUESTION

What are the advantages and disadvantages of Trenchless Technology compared with the Open Trench method?

Is it financially viable to implement Trenchless Technology within the construction and civil industry of South Africa?

1.6 HYPOTHESIS

Trenchless Technology might be a new method that contributes to the construction industry by implementing technology for pipeline installations.

Trenchless Technology might provide more advantages and fewer disadvantages compared to the Traditional Method.

Trenchless Technology might be a financially viable solution for installing new pipe services or replacing existing underground services or pipe networks.

1.7 PURPOSE OF THE STUDY

The purpose of the study is to understand the basic principles of Trenchless Technology in order to implement and manage this system within the construction industry. The purpose is, furthermore, to determine the advantages and disadvantages of using new Trenchless Technology and if the method is financially viable. Finally, it is to determine if South Africa can execute this process in a more economical manner than the traditional Open Trench Method.

1.8 STUDY OBJECTIVE

Developing an estimation framework for determining the pricing of Trenchless Technology compared to the traditional method. This will assist to critically analyse the financial viability of both methods and to determine the best method to implement within certain conditions.

1.9 IMPORTANCE OF THE STUDY

Technology greatly influences many industries, including the construction and civil industry. New methods and the creation of new machinery have made the lives of construction individuals easier over the years. The public is forced to develop a coping mechanism and adaptive behaviour to deal with the change that technology causes within the business sector. New technology that is being used within the construction industry needs to be studied in order to understand the implications or movement it causes within an industry.

A faster method usually means that there are fewer costs for a company in the long run. The biggest advantage of Trenchless Technology is that it is a faster method of installing new pipelines by eliminating trench pipeline excavation, but the physical labour workers for trench pipeline excavation are also eliminated from the process. This can cause a huge unemployment field within the construction industry (Najafi, 2013: 2). Such an unemployment field may cause an economic struggle within the construction industry for any country. This affects the company and the public in return. The biggest disadvantage of Trenchless Technology is the pricing. The machines and equipment are expensive and require maintenance, like any other piece of civil or earthworks equipment. The operator needs to be a skilled professional, who falls in a higher salary bracket than an apprentice.

The disadvantages of the Open Trench Method:

The study of the disadvantages of the traditional method will provide an indication if the trenchless method could be considered as an alternative to pipeline installation. If the disadvantages of the traditional method can be exchanged for the benefits of the other method, it could be considered the better option to implement. The following are a few disadvantages of the Open Trench method (Patel, Pitroda & Bhavsar, 2014: online):

- The open trench causes obstructions in roads, highways and railways. A diversion or solution needs to be implemented to divert traffic.
- The obstruction causes a new traffic route to be implemented. This causes a traffic impact in the bigger surrounding area.
- This method causes the public and companies to spend more money on travel costs. The diversion causes the fuel costs of the public to rise, especially in very crowded communities.
- Digging deep trenches can cause the ground to destabilise. This can cause cracks to form in the buildings surrounding the area.
- The Open Trench Method can cause damage to existing structures and services. The forces that act on the surrounding area during demolition can develop structural faults within the surface and cause structures and surfaces to crack.
- The Open Trench Method causes damage to existing service lines or cables already installed underground. The replacement of these lines and cables or providing temporary support for the service lines can be costly.
- The trenches need to be barricaded or fenced. This will prevent public injuries near the construction site.
- The Open Trench Method cuts deep into the earth's surface. This means that trees, roots, branches and shrubs will be encountered during the process.
- The trench will need to be refilled and the footprint it has left will need to be rehabilitated.

(Patel, Pitroda & Bhavsar, 2014: online).

The advantages of Trenchless Technology:

The study of the advantages of Trenchless Technology will determine if it provides the necessary benefits to substitute for the downfalls of the traditional method. The following are a few advantages of Trenchless Technology:

- It reduces damages to the earth's surface. The method drills underneath the earth's surface and creates a pilot hole only in the diameter of the pipeline. The other methods displace the soil to the sides of the pilot hole.

- It reduces the damage caused to buildings, roads, highways and other service lines. The method has no need for any demolition work. The forces that act on the surrounding area during demolition are, therefore, eliminated.
- It reduces the implication of poorly compacted trench pipeline excavation. Open trenches need to be compacted properly. This prevents soil erosion or sink holes within the earth.
- It reduces the number of resources and machinery needed. There is far less equipment and resources needed than when making use of the Open Trench Method.
- It avoids an impact on traffic. The public traffic is not influenced, as this method does not require roads or highways to be closed off. The traffic can move freely over the pilot hole under the surface.
- It can save underground space by replacing the existing service lines. Replacing the existing service lines instead of installing a new pipeline can be beneficial. In many towns or cities, the space for service lines underneath walkways is limited.
- It reduces the environmental impact. The pipeline rehabilitation process allows old service lines to be fully removed and replaced with new service lines. Old cast iron and steel pipes can be replaced with new eco-friendly pipes. It reduces the chemical reaction caused by old service lines.
- It is faster and can cover longer distances. This technique can cover a longer distance at a reduced speed, as it uses mechanical power rather than physical power.

(Patel, Pitroda & Bhavsar, 2014: online).

Therefore, all the financial aspects of this new method need to be studied in order to determine if it is a financially viable solution for the installation of new pipelines or the replacement and upgrading of existing service networks.

1.10 ASSUMPTIONS, SCOPE AND LIMITATIONS

The study will focus on the implications of Trenchless Technology within the construction industry as well as the financial and economic influence of this new technological method. The study will mainly focus on the implication and effect within the construction industry in South Africa. The study is limited to South Africa to manage the amount of data on an international level.

1.11 PRELIMINARY LITERATURE REVIEW AND CONCEPT CLARIFICATION

The literature review discusses the principles of Trenchless Technology and the financial viability of implementing the process within the construction industry of South Africa. The study will commence with an introduction to Trenchless Technology. It will cover the basic principles and the initiation of the technique. It will outline the basic procedure and give an in-depth explanation of the basic way the technique is executed. It will highlight the basic usage and initial purpose of the technique.

The study will analyse the techniques for the installation of new pipeline services and current pipeline rehabilitation. The study will contain the type of techniques used for each of the two categories. It will also analyse the possible evolution and adaptiveness of each technique. These techniques have been altered and changed by companies to be implemented within specific situations. Studying these altered techniques could prove beneficial to the financial impact caused by Trenchless Technology.

The study will deal with the financial impact of Trenchless Technology. The shortcomings and rewards of Trenchless Technology will be analysed. A financial study including rates, calculations and equations will be compiled in order to compare the finances of Trenchless Technology to the conventional Open Trench Method. The different types of machines, equipment and materials used, will be taken into consideration.

The economic impact of Trenchless Technology will be analysed. Many public entities are showing a growing interest in the techniques to upgrade and replace existing service pipelines. The current underground service networks of most countries are old and outdated. Maintenance to underground service lines have proven to be costly and almost impossible in most cases. The extent and size of current service pipelines within cities exceeds the ability of the Open Trench Method to be implemented efficiently. The networks are too immense to implement the old method, by the time a partial section of services is repaired or replaced, they need to be serviced again.

The need for the technique within the public and private sector can influence the economy of any country. The repair and upgrade of existing service lines can increase the efficiency of service supplies to the public and the private sector. The efficiency of service supply can lead to reduced costs within the public sector. Reduced costs for the public means that the

buying power of the community increases. The extent and potential of this technique on the economy needs to be critically analysed.

This study will also enable contractors to budget for the installation and replacement of service pipelines. The budget for any construction project can determine the financial viability of the technique. The successful implementation of this technique has already caused a shift in time, cost and planning within construction projects. The correct usage of the methods can vastly increase the productivity of contracting firms and reduce the overall time needed for the complete rehabilitation of a city.

1.12 PROPOSED METHODOLOGY

The research methodology used in the research study includes the following methods:

1.12.1 LITERATURE STUDY

A literature study will be undertaken, which includes books and academic articles in order to address the problem statement. The resources will be used to compile basic information and an introductory overview regarding Trenchless Technology. It will outline the techniques used within the industry and the ability of those techniques to be enhanced or revolutionised. The study will determine the financial and economic impact of the technique within the construction industry.

1.12.2 EMPIRICAL STUDY

An empirical study will be concluded involving questionnaires in order to address the problem statement. The questionnaire will be sent to professionals within the construction industry. The data gathered will be analysed to determine how the construction industry perceives this method and the adaptiveness of the industry to implement this method.

The questions will focus on the implementation of Trenchless Technology and determine the overall knowledge of the group. The questionnaire will also assist in determining the current status of the technique within the construction industry. The status will aid the study to determine the financial viability of the technique. The greater the existing interest in the technique, the greater the probability of the technique being financially viable.

1.13 ETHICAL CONSIDERATIONS

The research will be done ethically by representing the results or any data obtained in the manner for which it was intended. The research will be honest, just, fair and a true representation of the actual reflection of the outcome. No information of the respondents completing the questionnaire will be given for any other use, other than that for which it is intended.

No information gathered from the professionals will in any way be altered or changed. The information within this research project will be used for the sole purpose of distributing information and clarification of the problem statement. Additional or personal information will not be shared without the consent of those involved. The results of this research will be made available to all respondents. Approval from the Ethical Committee of the Faculty will be obtained to ensure the correct procedure was followed and the results are presented in a principled manner.

1.14 OUTLINE AND TIME FRAME

The proposed structure is as follows:

Part 1: Framework

Chapter 1: Framework of Research Study

Part 2: Methodology

Chapter 2: Research Study Methodology

Part 3: Literature Review

Chapter 3: Basics of Trenchless Technology

Chapter 4: Installation of New Service Pipelines

Chapter 5: Replacement of Service Pipelines

Part 4: Data Collection

Chapter 6: The Financial and Economic Impact of Trenchless Technology

Part 5: Discussion of Results / Empirical Study

Chapter 7: Results Summary and Discussion

Part 6: Conclusion

Chapter 8: Conclusion and Recommendations

References

Appendices

1.15 SUMMARY

Technology is constantly evolving and influencing the construction industry. This chapter identifies the problem statement and possible hypothesis that can determine the implication of Trenchless Technology within the construction industry. The technique can be beneficial by providing a financially viable solution for upgrading the service networks of countries. This method might reduce the cost associated with many civil and building projects and might eliminate the Traditional Open Trench Method. This can ensure projects are completed within an accurate and better pre-determined budget.

PART 2: METHODOLOGY

CHAPTER 2: RESEARCH STUDY METHODOLOGY

2.1 INTRODUCTION

This chapter outlines how the research methodology was designed, and the method used for obtaining the data and information to formulate the results for the research. Information or data collected for the purpose of the critical assessment of the financial viability of implementing Trenchless Technology within the construction industry in South Africa compared to the Traditional Open Trench Method, was obtained by means of a survey.

According to Mishra and Alok (2017: online), *“Research methods include all the techniques and methods which have been taken for conducting research whereas research methodology is the approach in which research troubles are solved thoroughly. It is the science of how research is conducted systematically.”* Therefore, research would be the technique used to gather information and the research methodology would be the framework of the process for obtaining that data.

The research methodology should achieve the research objective through a research method, research design and structured research strategy. The design and method of the strategy determine the success of the research. This chapter covers the research method used, ethical clearance, the research participants, informed consent, sampling sizes, sampling techniques, data collection and data analysis of the research study.

2.2 RESEARCH OBJECTIVE

The main research objective was to determine the financial viability of Trenchless Technology within the construction industry of South Africa when compared to the Traditional Open Trench Method.

The objectives of the research study can be divided as follows:

- An introduction of Trenchless Technology.
 - It determines the field of professionals involved, the types of services Trenchless Technology is mainly used for, the types of piping material mainly used, and the geographical location Trenchless Technology has been implemented.
- New pipeline installations.
 - It determines the most utilised new method for the installation of services and the corresponding piping material and services provided.
- Renewal and replacement methods.
 - It determines the most utilised renewal method for the installation of services and the corresponding piping material and services provided.
- Importance of project specifications.
 - It determines the project specifications that determine the financial viability of Trenchless Technology projects.
- The financial aspect of the Traditional Method.
 - It determines the average contract value and cost per metre of the Traditional Method and the aspect on which the most money is spent.
- The financial aspect of the Trenchless Technology.
 - It determines the average contract value and cost per metre of the Trenchless Technology and the aspect on which most money is spent.
- Trenchless Technology against the Traditional Method.
 - This determines the preferences between using Trenchless Technology and the Traditional Method for the installation and renewal of services.

2.3 RESEARCH METHOD

Research can be conducted by using a combination of qualitative and quantitative data. Quantitative data is information that can be quantified, counted or measured. This type of

data can be given a numeric value. Qualitative research is descriptive and relies on personal accounts that illustrate how people think or act within society. The quantitative method will be used to give logic, reasonable and verifiable results based on scientific interpretation of the questions (Mishra & Alok, 2017:3).

The research method involved compiling a structured questionnaire. Structured interviews were considered as a research method. The interviews would have only provided the insight and feedback of a few respondents. The amount of data gathered would have been insufficient to provide results for the determination of the financial viability of the methods. The data could not be compared to the other responses of the interview participants, as the data would have been the personal interpretation and experience of that respondent. The number of respondents needed for the interview would have been a vast sample size. The respondents of the sample population would have been incredibly difficult to determine, as the field of Trenchless Technology is limited and there is not a group of respondents that could be isolated for a research study based on their unique knowledge of the field for determining the problem statement. Trenchless Technology has only recently gained interest in South Africa and, therefore, the structured interviews were discarded (University Libraries, 2018: online).

There were challenges when compiling the survey. The survey needed to gather all the financial determinations of all the methods of Trenchless Technology while comparing it to the Traditional Open Trench Method. The other challenge was the limited number of professionals within this field. Two main methods were used to collect information for the compilation of the survey. These methods were internet research on the financial determination of open trench pipeline excavation and Trenchless Technology. The other method was the analysis of the literature review (University Libraries, 2018: online).

The Southern African Society for Trenchless Technology (SASTT) was contacted for the possibility of assisting with data collection for the research study. The SASTT consists of a group of professionals that are contractors within the field of Trenchless Technology within South Africa. This group of professional contractors have also executed and implemented projects beyond South African borders (SASTT, 2020d: online).

2.4 RESEARCH DESIGN

The following factors were considered for the research design:

- Importance of the problem statement

The problem being solved is the starting point of developing a questionnaire. If the problem is considered highly important, the responses will be high. The problem statement should be relevant to the respondents. The problem statement is aimed at the field of Trenchless Technology and the group of respondents represent the SASTT. The researcher referred back to the problem statement established at the beginning of the research study (Choudhury, A. 2020: online).

- The type of information required.

The researcher did extensive research on the data already available or published. The researcher then determined which data was still required through the formal questionnaire. The researcher determined which data could be obtained through the questionnaire to address the problem statement (Choudhury, A. 2020: online).

- Reference previous questionnaires

The researcher studied other questionnaires of a similar format. The questionnaire was submitted to the SASTT for critical analysis and was discussed within a meeting. The members presented their experience and assisted with constructing the questionnaire. The questionnaire was changed and altered according to the feedback and insight received from the council at the SASTT (Choudhury, A. 2020: online).

- Thorough knowledge of hypothesis

The researcher referred to the hypothesis and literature review to frame the questionnaire. This assisted with determining the crucial issues of the research problem. The researcher referred to the hypothesis that was determined at the beginning of the research study and determined if it would be proven based on the questions within the questionnaire (Choudhury, A. 2020: online).

- Clear understanding of the research objective

The researcher acquired the knowledge of the field and an understanding of the primary research objective. The nature of the data that would be gathered was analysed and the graphical representation was determined (Choudhury, A. 2020: online).

- Numerous revisions of the questionnaire

The researcher had numerous revisions. The discussion with the SASTT determined that the same question asked in a different way, could provide different results. The members of the SASTT did a trial run of the different questionnaires until the most adequate one was chosen (Choudhury, A. 2020: online).

- Willingness of the respondents

The accuracy of the questionnaire depends on the willingness of the respondents. Therefore, the respondents were chosen very carefully. The group of respondents had the desired knowledge and were likely to respond to the questionnaire. All the respondents were involved in the field of Trenchless Technology. This meant that all of them had an interest in the research topic. The interest increased the willingness of the respondents to complete the questionnaire (Choudhury, A. 2020: online).

- Precision of hypothesis

The questions were narrowed by means of analysis work in order for the respondents to provide an answer. The focused hypothesis creates an effective questionnaire. The success of the questionnaire was dependent on the precision of the hypothesis (Choudhury, A. 2020: online).

- Size of questionnaire

The researcher ensured that the questionnaire was not too long. The longer the questionnaire that the respondents have to answer, the less essential data is collected. The questionnaire was divided into seven parts to group the results obtained from the respondents. The questionnaire was the appropriate length, to ensure that the respondents did not get annoyed by the length or time taken to complete the survey (Choudhury, A. 2020: online).

- Cover letter

The researcher included a cover letter with the questionnaire. A formal questionnaire requires a cover letter that explains the research problem and objective to the respondents. This ensure that the respondents are aware of the aim and can provide accurate and informative data. The cover letter represented the research organisation as a University. The impression of scientific competence showed that nothing was hidden or ambiguous (Choudhury, A. 2020: online).

- Prestige of the research institute

The research institute was presented as the University of Pretoria. This university is known for its reputation and the responses would be high. The respondents generally show more interest if the research institute is known (Choudhury, A. 2020: online).

- Purpose of the study

The researcher included the purpose of the study in the cover letter. It is important that the respondents knew why data and information was needed from the group (Choudhury, A. 2020: online).

- Appearance and general layout of questionnaire

The general layout and appearance were considered when compiling the questionnaire. The professional appearance removed any doubt experienced by the respondents regarding the ethical intent of the researcher (Choudhury, A. 2020: online).

- Type of questions

The researcher determined the type of questions that would be included in the questionnaire. The type of questions determined the type of responses received from the respondents. The researcher ensured that all the questions were relevant and relatable to the respondents (Choudhury, A. 2020: online).

- Sequence of questions

The order of the questions was determined by the researcher. The questions followed a logical order and determined the direction of the results. The general questions were first

followed by the more complex questions. The questions were closely related and consistent. This determined the reliability of the answers given by the respondents (Choudhury, A. 2020: online).

- Sending reminders

The researcher had a follow-up procedure. The researcher sent an email to the respondents to remind them about the questionnaire. The reminder increased the number of respondents received (Choudhury, A. 2020: online).

- Proper time of sending the questionnaire

The researcher sent the questionnaire at a proper time. The questionnaire was sent to the respondents after the December break. This meant that the respondents were free and available to answer the questionnaire. The timing ensured a high response rate of the questionnaires (Choudhury, A. 2020: online).

- Correct contact information

The researcher ensured that all contact information of the respondents were correct. This ensured that respondents received the questionnaire and that the responses and results could be received. The correct contact information is essential. The researcher consulted with the SASTT about the contact information of each respondent. If the contact information was incorrect, the researcher followed up with the SASTT (Choudhury, A. 2020: online; SASTT, 2020d: online).

The questionnaire was compiled over a period of two months. The questionnaire was divided into seven parts and consisted of twenty-three questions in total. The seven parts ensured that the data was collected within a structured method and that the data could be analysed effectively. The seven parts also ensured that the trenchless methods were compared to the Traditional method in terms of each financial factor that determines the financial viability. The questionnaire was structured so that the participants in the research study could provide answers based on their knowledge, previous experience and personal judgement.

The questionnaire was structured to prevent the frustration with filling out a form by reducing the time frame spent on the questionnaire and the respondents mostly providing data by a

selection process or providing short answers. The questions within the questionnaire were kept informative and tried to relate to the interest of the participants in order to keep them motivated and providing answers that could be analysed. Most of the participants had a keen interest in expanding the field of Trenchless Technology as it is such a small community. Focussing the questions on their interests provided data based on their knowledge and experience. This generated data that determined the financial factors of the methods for renewal and installing pipeline services.

After the completion of the questionnaire, a formal letter was sent to the SASTT. The SASTT was contacted before the ethical application was submitted, to ensure the possibility of the society assisting with the distribution of the survey to their members. The letter requested the participation and permission for the society's involvement in the research study. The letter further requested the utilisation of the mailing list and personal contact details of their members (SASTT, 2020d: online).

Please refer to Appendix A.

The letter was attached to an email that was sent to the SASTT. The letter informed the SASTT that participation in the research study was voluntary and the letter further explained the purpose of the study. The letter also provided an introduction of the researcher and how the results of the study would be published. The SASTT provided consent for the results to be published within the research study and the information of all respondents would remain anonymous (SASTT, 2020d: online).

The SASTT responded by sending a formal return letter. The letter gave permission for the participation of the society within the research study. The society also confirmed sharing the contact details of their members and assisting with the distribution of the questionnaires (SASTT, 2020d: online).

Please refer to Appendix B.

2.5 ETHICAL APPROVAL

After the approval was received from the SASTT to participate in the research study, ethical approval needed to be obtained. The application for ethical clearance was submitted in the month of September. The approval process happened over a two-month period. Therefore, ethical clearance was only received at the end of the year. The ethical application was done online and reviewed by the Faculty Committee for Research Ethics and Integrity (SASTT, 2020d: online).

The online application involved providing information on the aims and objective of the research study. The sample size and duration of the research study had to be determined. The application further requested that the research team elaborate on the research method and materials to be used during the research study. The application needed to outline how the confidential information would be analysed, handled and stored. The committee needed to identify the risks and ensure that participation in the research study remained voluntary. The online application required a consent form to be attached to the questionnaire. The template provided by the ethics committee was used. The consent form was issued with the distribution of each questionnaire. Each participant returned the signed consent form upon completion of the questionnaire. The questionnaire had to include a cover letter. The cover letter was intended to inform the participant of the objective of the research study and provide an introduction on the necessity for gathering data (SASTT, 2020d: online).

The approval letter from the ethics committee was received by the end of October. The letter provided the commencement date for the research period. The research study commenced after the letter of approval was received and the questionnaires was forwarded to the SASTT. The society assisted with distributing the questionnaire electronically to the members of the SASTT. The aim of the ethics committee is to ensure that the research study is conducted in an ethical manner and adheres to the ethical standards of the University (SASTT, 2020d: online).

Please refer to Appendix C.

2.6 SAMPLING DESIGN

The sampling group was based on the members registered at the SASTT. The SASTT was chosen as the society represents the professionals involved within the field of Trenchless Technology within South Africa. The society was founded as a non-profit organisation to inform the public and other parties on the work and benefits of Trenchless Technology in South Africa. It further represents the role Trenchless Technology plays within the development of our country. The main mission of the society is to promote and support Trenchless Technology within South Africa (SASTT, 2020d: online).

The SASTT is the main governing body of Trenchless Technology in South Africa. The SASTT is affiliated with the International Society for Trenchless Technology (ISTT).

The members registered with the SASTT need to meet certain criteria for acceptance as members. All members need to have participated or executed projects within South Africa using Trenchless Technology. Most members have obtained degrees and diplomas within the field of Civil Engineering and have registered companies that are involved in Trenchless Technology (McCombes, 2022: online).

The members can register their businesses or companies with the Society and automatically become a part of the ISTT. The International Society represents Trenchless Technology on a global scale. The ISTT was established in 1986 within the United Kingdom. The objective of this society is to advance the science and practice of Trenchless Technology for the benefit of the public. They further promote the education and training involved with Trenchless Technology. The ISTT has twenty-eight affiliated societies and represents them on a global scale (ISTT, 2022: online).

2.7 SAMPLING SIZE

The sample size was not pre-determined and was dependent on the number of members registered with the SASTT. The sample size could not be pre-determined by means of a formula or selection process. There are a limited number of professionals involved within the Trenchless Technology field in South Africa. The questionnaire was distributed to 50 participants that were all involved in the field of Trenchless Technology. The SASTT consists

mostly of professionals involved within the field of Civil Engineering that moved over to Trenchless Technology. The respondents had registered companies that participated in Trenchless Technology projects. The qualification criteria used by the SASTT for membership clearance ensured the sample size consisted of professionals (McCombes, 2022: online).

2.8 RESEARCH STRATEGY: STRUCTURED QUESTIONNAIRE

The purpose of a questionnaire is to extract a large amount of data from a large group of respondents. Due to the immense field and several methods used within Trenchless Technology, a research method was used to gather a large amount of data for the validation of the problem statement (Ponto, 2015: online).

The main research method used for the research study was a structured questionnaire. The questionnaire was prepared by the researcher to gather data and information to determine if Trenchless Technology is a financially viable option to implement over the Traditional Open excavation method. The questionnaire was compiled based on the review of the literature and data gathered from electronic sources on the financial factors influencing Trenchless Technology and the Traditional Open Trench Method (Ponto, 2015: online).

The questionnaire had a cover letter. The letter provided the aim and objective of the research study. The letter did not only provide an introduction to the respondents about the research study but mentioned that participation within the study was voluntary. The questionnaire was accompanied by a separate consent form. The questionnaire was distributed via electronic mail. The questionnaire could be completed electronically using a common software program link (Ponto, 2015: online).

The questionnaire consisted of the following sections:

- **Part 1 – General Information**

This part consists of questions for gathering general information on the participants. The two questions in the beginning of this section focus on determining the industry and geographical location of the participants. The other two questions determine the type of services they have installed and the type of piping material they have worked with. These four general questions

determine if the participants have been involved with Trenchless Technology and the Open Trench Excavation Method in South Africa. It also provides clarity on the type of piping material the participants have installed.

- **Part 2 - New Pipeline Installations**

This section focuses on the installation of new pipelines using all Trenchless Technology methods and the traditional method. It compares the seven main methods of Trenchless Technology with the traditional method by determining the type of service and the piping material used for that service. This gives a clear indication of which piping material is used with which method. It determines the method and material used within the industry of South Africa.

- **Part 3 – Renewal and Replacement Methods**

This part compares the three renewal methods of Trenchless Technology and the traditional method. It determines the type of services and piping material used for the renewal and replacement of existing services. This section will determine which piping material could be used with which method. The participants will also give an indication of which methods have been utilised within South Africa.

- **Part 4 – Importance of Project Specifications**

This part determines the importance of project specifications by the participants. The value of each project specification can determine which aspect of a project is the most vital. This can determine which part of a project has major cost implications or financial probability. The part consists of two questions. The one question is related to new installation methods and the other, replacement methods for Trenchless Technology.

- **Part 5 – The Financial Estimate of the Traditional Method**

There are five questions within this section of the questionnaire. All five questions focus on the financial aspect and considerations of the Traditional Method. The first three questions determine the contract values of a project which the participant has executed using the Traditional Method in South Africa. The fourth question enquires about the average cost per

metre for the Traditional Method that participants disbursed on a project. The last question determines which element the participants spent the most money on between labour, site establishment and machinery/equipment in terms of the Traditional Method. This part will determine the financial viability of the Traditional Method within the industry.

- **Part 6 – The Financial Estimate of Trenchless Technology**

This section has nine questions compiled to determine the financial viability of all the Trenchless Technology methods. The first six questions determine the contract values of projects that used any of the Trenchless Technology methods. The participants were asked the contract value of projects they have executed, and the method used for the specific project. The seventh question determines the average cost per metre for the different types of Trenchless Technology methods. The second last question determines which element the participants spent the most money on between labour, site establishment and machinery/equipment in terms of Trenchless Technology. The last question is based on the opinions and knowledge of the participants. It gives participants the opportunity to state which renewal or replacement method is the most cost-effective for service lines. This part will determine the financial viability of Trenchless Technology within the industry.

- **Part 7- Trenchless Technology Compared to the Traditional Method**

The last part of the questionnaire gathers the personal insight and experiences of the participants. These standard questions give participants the opportunity to choose between the Traditional Method or Trenchless Technology based on their personal experience and knowledge. This part will determine the preferred method of the participants. The preferred method could possibly provide an indication of which method is the most financially viable as most participants have a registered company within the industry and their goal is to make a profit.

Please refer to Appendix D for the questionnaire handed to the SASTT for data collection.

2.9 DATA ANALYSIS AND REPRESENTATION

The completed questionnaires were returned electronically by the participants. The data of each question from each respondent was analysed by viewing the data digitally. The data analysis was done by computer-based software. The electronic method was chosen for its high storage capacity, graphical representation and data combination methods (The National Academics of Science, 2022: online).

The data was grouped according to the question number while keeping the structure of each part of the questionnaire. The accumulated data for each question was given a numeric value and the results were represented using a graph. The data was analysed as a whole group in order to assure the anonymity of the participants. The graphs were analysed to determine the results and findings of each question. The results and findings were used to determine the summary and to verify the problem statement (The National Academics of Science, 2022: online). Each question was represented by a graph and some of the data collected was presented as a table. All the parts of the questionnaire were kept separate but analysed as a whole (The National Academics of Science, 2022: online).

Chapter 6 covers the data analysis and interpretation of the research study. The findings and recommendations are discussed in Chapter 7.

2.10 RESEARCH QUALITY

The questionnaire was distributed to respondents within the field of Trenchless Technology. The members of the SASTT are considered to be professionals within the field and have international accreditation. This ensured that the research gathered is of the best quality. The questionnaire was examined by the Board Members of the SASTT before being distributed to the participants. The representatives of the society were included in the search study. Another factor that determined the research quality was the structure and content of the questions within the questionnaire. Each question was formulated keeping in mind the professionals within the field and attempts to keep the respondents interested within the topic. The questionnaire makes provision for data to be interrupted as facts and statements but provides a few questions for personal interpretation (INNSPub, 2022: online).

2.11 SUMMARY

This chapter gave an outline of the research methodology used for this research study. It includes the detailing of the research method, research design and research strategy used to achieve the research objective. It further describes the process of data collection and analysis to determine the research results and findings. The structured research strategy will ensure that the research study is valid, and the environment follows the right process. It further ensures that the strategy is ethical and produces good quality data that can be analysed and interpreted. The research methodology determines the achievement of the research objective and determines the conclusion of the problem statement.

PART 3: LITERATURE REVIEW

CHAPTER 3: BASICS OF TRENCHLESS TECHNOLOGY

3.1 INTRODUCTION

Trenchless Technology is the broad term for the installation of pipe networks or service lines without any surface disruptions. It is a hydro-mechanical method that is steerable, easy and environmentally friendly. It uses a wide range of technology, processes and techniques to place new pipes, cables, or conduits in the ground between two predetermined locations without the use of continuous, open-cut excavations between those two points. The method is also used for renovating, replacing and rehabilitating existing service lines. Trenchless Technology almost always refers to the installation of these services in a horizontal direction (Bayer, 2005: 10).

3.2 HISTORY OF TRENCHLESS TECHNOLOGY

Since the beginning, mankind has needed shelter. As time progressed, the building of shelters changed from primary resource structures to permanent buildings. It was realised that any permanent building had to provide more services than just shelter. Since developments became permanent, society needed a way to get services from a main permanent service supply source to another permanent structure. Since the surface was covered with primary infrastructure, the most efficient way was to create an underground network that connected all the buildings within the area. Manual labour was used to dig trenches within the surface of the earth. The pipelines were laid within the trench and the trench was covered. The connection of all the buildings within an area soon created a linked network of underground services (Farr, 2012: online).

As the population grew, so did the demand for more permanent structures. The increase in the number of structures led to more connections to the existing underground services. Villages became towns and towns expanded into cities. The infrastructure above the surface of the earth was maintained and constantly upgraded as expansion took place, but the underground network remained constant for many years during the fast development of cities (Farr, 2012: online).

It became apparent that the old network lines had to be upgraded in order to keep up with the demand for more permanent structures. This created a need for replacing or rehabilitating existing pipelines without demolishing a whole section of buildings and finding faster alternatives for the installation of new service networks (Farr, 2012: online).

The rising demand for both the quantity and quality of these services has put significant pressure on their planning, engineering, installation, and maintenance. Additionally, the increased value of surface structures has led to higher costs for maintaining these underground services and fulfilling consumer needs. Upgrading the underground network, for most cities, proved to be difficult as the pipelines were located underneath a vast collection of permanently built structures. Improvements such as highways, streets, buildings and railroads have made it difficult or more expensive to implement the Open Trench Method. Securing the necessary permission to disrupt the natural flow of a settlement or development has become more difficult. Trenchless Technology offers an alternative solution to the problem (Kramer, McDonald & Thomson, 1992: 17).

3.2.1 FIRST UNDERGROUND WORK

The first underground tunnelling was recorded in 3000 B.C. This was done for the exploration and obtainment of ore through the process of mining. During the Bronze Age (2000 B.C.) the construction of the Palace of Minos at Knossos, Crete, revealed the first evidence of pipes for utilities. The earthenware pipes conveyed water and acted as drains for the building. During 1200 B.C. tunnelling was used to construct utility lines to tap water supplies for very old cities from the interception of the underground water table (Kramer, McDonald & Thomson, 1992: 17).

During the Industrial Revolution, cities grew fast as people migrated from rural settlements to find employment in urban areas. This was due to the discovery of steam power and smelting processes for minerals and ores. This created advanced developments in the transport and utility infrastructures



*Figure 1: Early Cast-Iron Pipes.
(Kramer, McDonald & Thomson, 1992: 20).*

that are still used today. In the 1800s in Europe, people started using cast iron pipes (See Figure 1) to regulate the water needed within different areas of the city. The introduction of these horizontal pipes allowed for the first delivery of water under pressure. These pipe networks are still being used in the United States and United Kingdom (Kramer, McDonald & Thomson, 1992: 18-20).

In 1792, the discovery of gas led to the establishment of an underground pipe network by the London Gas Light and Coke Company in 1812. Numerous companies in Britain began manufacturing and selling gas using these underground pipes. In 1821, natural gas lines were introduced in the United States. The 19th century saw the development of electric power generation, thanks to a filament that enabled the production of electric lamps for domestic and street lighting. Towards the end of the century, the telephone was introduced as a means of communication. While many wires were installed above ground, some ducts were placed beneath roadways. (Kramer, McDonald & Thomson, 1992: 21).

In 1818, Isambard Kingdom Brunel, invented the circular iron tunnelling shield (See Figure 2), which is the basis of some of the processes used in Trenchless Technology. The circular shield was made from cast iron pieces that were attached to one another. The idea was to connect the pieces within the circular excavated hole and proceed to re-assemble the pieces as manual labour dug forward and the walls were reinforced. From 1820 to 1840, Brunel successfully created an underground tunnel beneath the Thames River to carry people across the river. The tunnel is still used today (Kramer, McDonald & Thomson, 1992: 21).

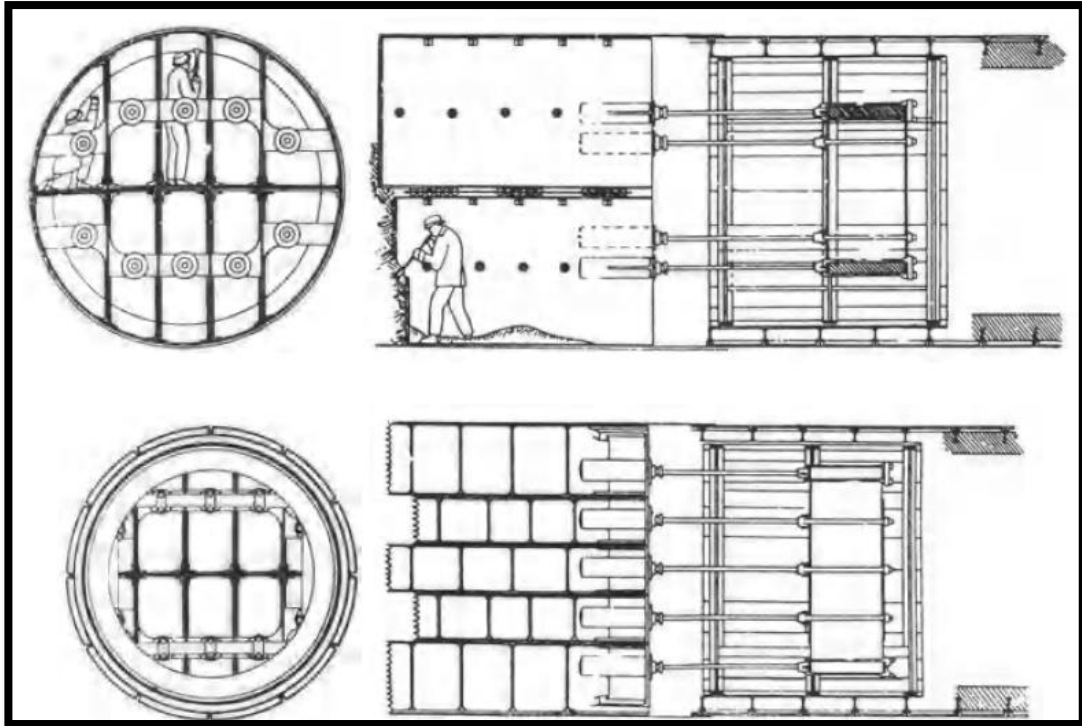


Figure 2: Brunel Shield Patent Drawing.
(Kramer, McDonald & Thomson, 1992: 21).

In 1849, Samuel Dunn created a tunnel shield that could move forward in one piece using pressure. By 1868, Alfred Beach used a tubular shield that was pushed forward by hydraulic jacks. The shield was used to drive a 2.4m diameter brick-lined tunnel that stretched from Liberty Street to the Harlem River in New York. The tunnel was completed in 1870 (Kramer, McDonald & Thomson, 1992: 22).

The idea of a drill hammer mechanical driven by compressed air by J.D. Brunton in 1844, inspired J.J. Couch to make the first percussion rock drill powered by steam in 1849 (See Figure 3). This machine inspired the design of the hydraulic jacks used for the tunnel shield. J.W. Fowle was later given the credit for inventing a direct-action drilling machine during 1874. This was followed by an intense period of new inventions and modifications to existing machines and methods (Kramer, McDonald & Thomson, 1992: 23).

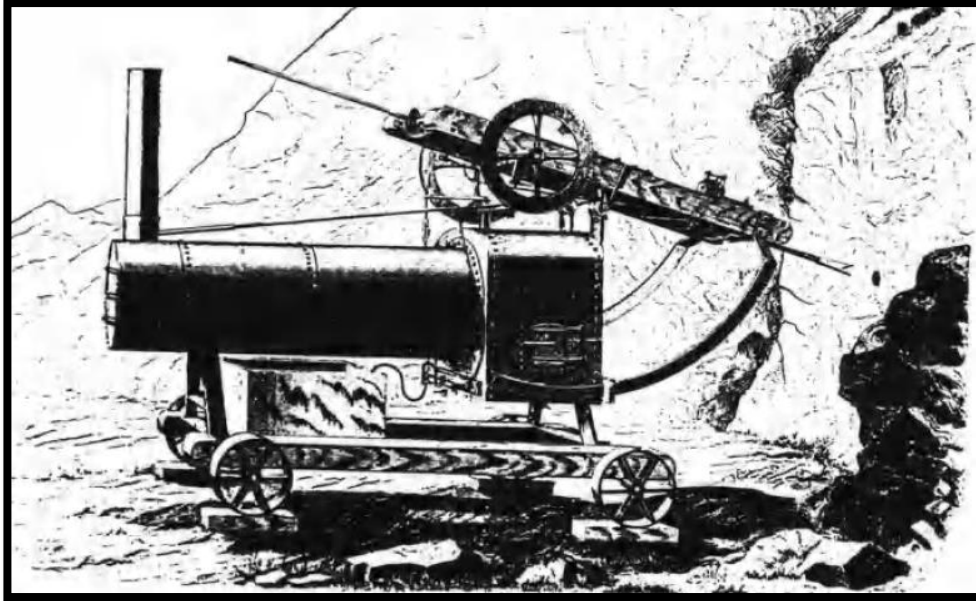


Figure 3: Couch's Rock- Drilling Machine.
(Kramer, McDonald & Thomson, 1992: 23).

The revolution of construction in Europe and the United States, inspired inventors, engineers and businesses to develop installation methods for utilities. This created the foundation of Trenchless Technology (Kramer, McDonald & Thomson, 1992: 23).

3.2.2 EARLY TRENCHLESS METHODS (1890-1970)

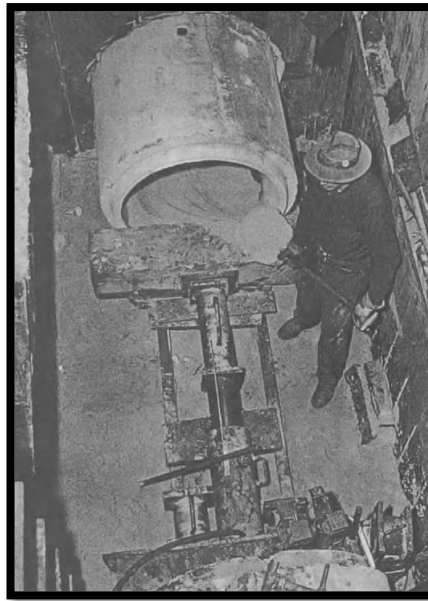
The earliest implementation of the trenchless method dates back to the start of the 1890s. Many different countries around the world started using the early design of pipe jacking or pipe ramming. The two main countries were the United States and the United Kingdom. Only after the 1940s did countries use the basic method of installing pipelines with drill rigs, which is known as Directional Drilling. The United States of America was the first country to successfully develop a drill rig with a rotating bore head (Kramer, McDonald & Thomson, 1992: 24).

3.2.2.1 Pipe Jacking/ Pipe Ramming

During this time period, pipes were installed using compressed air from the first hydraulic jacks based on the concept of Couch's Rock-Drilling Machine. The following is a list of countries that implemented this method from the early 1880s to end of 1970:

- United States of America

During 1896 to 1900, the United States of America were already using pipe jacking, also known as pipe ramming, to install cast-iron pipes. By the end of the 19th century, Europe had started using the earliest forms of Trenchless Technology. World War I (1914-1918) contributed to the development of pipe ramming. Both the Allied and German forces used a hand auger to drill a hole in the side of a trench. A pipe with a length of between 75 to 100mm, with explosives at the tip, was inserted into this hole. Extra lengths of pipes were attached to the end and pushed forward by pressure; allowing the explosive charge to get closer to enemy lines before detonating. By 1930, the United States of America were making use of reinforced concrete pipes through ramming (Kramer, McDonald & Thomson, 1992: 24).



*Figure 4: Pipe Jacking of Reinforced Concrete Pipes.
 (Kramer, McDonald & Thomson, 1992: 25).*

Significant development occurred between the 1940s and 1950s. The need to rebuild Europe after World War II and the demand from American civilians for a higher standard of living necessitated improvements in utility infrastructure. Rotating drilling machines and thrust drilling equipment, connected with screws and hydraulic jacks, were used to create holes beneath roads and railways, allowing pipes or services to be pulled through (Kramer, McDonald & Thomson, 1992: 24).

- United Kingdom

In 1958, James Thomson had to install sewer lines under a main railway. The restrictions on space did not allow him to consider an Open Trench Method. After reading about pipe jacking

being implemented in the United States, he chose to develop a system for the project. Despite various drawbacks, the necessity for pipe jacking under railways and main roads became evident (See Figure 4). Consequently, several businesses and entrepreneurs in Britain, France, Germany, and Switzerland established pipe-jacking companies. This spurred the development of high-quality, more flexible jointed concrete pipes and other piping materials, with greater lengths and larger diameters. Additionally, the enhanced power and compaction capabilities of hydraulic rams minimized the size of work shafts and the space required for these machines (Kramer, McDonald & Thomson, 1992:30).

The development of pipe jacking created more sophisticated shields and contributed to the start of the tunnel boring machine (TBM) industry. Compressed airlocks were introduced with ramming to stabilise the hole for working underneath the water table. Another important aspect was the research being done on the load and frictional forces of the pipes (Kramer, McDonald & Thomson, 1992: 31).

3.2.2.2 Horizontal Drilling / Directional Drilling

Horizontal Drilling is the process of installing a pipe underground using a ground launched drilling rig. The basic form of this method was only used by countries during the late 1940s. The first implementation of early Directional Drilling was done in 1946 in the United States.

- United States of America

In 1946, Fred Melsheimer recognized the need for horizontal or directional drilling for installing electrical cables. He developed a wet-boring machine equipped with a drill rig that rotated hollow drill rods with a cutter head at the front. A bentonite slurry mixed with water was used to feed the machine's head under pressure. This technology was adapted from the oil industry. Although this was the first documented use of Trenchless Technology to install a new pipeline, the machine could only cover relatively short pipeline lengths (Kramer, McDonald & Thomson, 1992: 26).

Martin Cherrington first developed the idea of installing a new pipeline, without digging a trench, when he witnessed a gas company use an air drill to install service lines. By 1964, he had successfully built a horizontal drill rig. The new machine completed several contracts for gas companies within Los Angeles. The new machine had one problematic drawback, namely, guiding the drill head and keeping to the path of the new pipeline. Several pilot holes

needed to be dug in order to determine the whereabouts of the drill head underground. Even though the pilot holes created a time delay on each project, they were all successfully completed. By 1971, a gas company had contracted the new horizontal drilling contractor to complete the installation of a new gas line underneath a river crossing. PG&E installed a gas line underneath the Pajaro River, near Westville in California (Bayer, 2005: 14; Kramer, McDonald & Thomson, 1992: 5).

3.2.3 TRENCHLESS METHODS – (1970 -1990)

After the 1970s conventional pipe jacking and directional drilling evolved. From the 1970s countries were spending more money on the development of trenchless methods and improving technology. During this period, microtunneling was added to the list of trenchless methods. The United States of America, the United Kingdom, Europe and Japan largely contributed to the field of Trenchless Technology that is used today.

- United States of America

During the 1970s, Martin Cherrington managed to successfully complete over 36 crossings underneath roads and rivers. The first flat-slanted horizontal bore rig was designed and developed in 1979. During 1982 to 1985, the United States Electric Power Research Institute (EPRI) assisted in the creation of the first bore head attached to the front of the horizontal drilling machine. This allowed for the installation of a 1kV power cable. Aviation Engineers assisted with attaching an altered transmission-receiver from old aircrafts to the front of the bore head. This allowed for the detection and more controllable guidance of the bore head underground. By the end of 1985, the United States Gas Research Institute of Chicago and Charles Machine Works (Ditch Witch), developed the first small scale dry horizontal bore unit with a position detector. By 2001, mud motors were developed to attach to the machines. These motors supplied extra power to drive the drilling rods through hard rock. Diamond bits were used to construct a hard rock drill head (Bayer, 2005: 14; Kramer, McDonald & Thomson, 1992: 32-33).

- United Kingdom

In 1970, Eric Wood developed the first cured-in-place piping. He needed to repair an air duct pipe above a mushroom bed but was unable to remove and replace the existing pipeline. He used a felt tube filled with a type of resin. The tube was wrapped in plastic and pulled through the 70m existing pipeline. He then used air to expand the new pipe and harden it naturally in place. This resulted in a new encased pipe within the original plumbing system (Kramer, McDonald & Thomson, 1992: 34; Sullivan, 2018b: online).

Despite the success of the technique, the implementation of the process was not immediately accepted. A decade later, companies started to implement CIPP (Cured-In-Place Pipes) for replacing pipeline networks. In 1977, the United Kingdom needed to replace thousands of old cast-iron service pipes. The British Gas Company along with the Engineering Company, DJ Ryan, developed the method of bursting a pipe from the inside. By 1980, the company was successful in using displacement hammers and a horizontal ramming machine to break-open existing service lines. The company pulled in new lines behind the old service lines (Sullivan, 2018b: online).

The two companies were granted the patent in 1981. Other manufacturers and suppliers were unwilling to commit to the same licensing agreement, due to high transfer fees and royalties needed for the installation of each metre of service lines (Sullivan, 2018b: online).

- Japan

During the 1960s, Japan had virtually no public sewer system for their towns or cities. Less than 8% of the population had access to a wastewater system. A major sewer project was implemented during the 1960s. This project posed a number of social and technical problems. The cities and towns within Japan are mainly located in coastal areas. The streets are narrow, and the areas are densely populated. The ground consists of sand, silts and gravel. The underground water table is also very deep. The traditional method would have been slow, costly and disruptive, as the services had to be laid at deeper depths (FSTT, 2004: 27).

Japan had a technological advantage in electronics. In 1973, Komatsu developed the first microtunneling machine. The machine was a pilot-bore controlled and operated remotely. By 1980, several hundred of these machines were used throughout Japan. The experience gained from the earlier development of these machines, allowed Iseki Inc. to reduce the size of the machine, allowing for the installation of service lines as small as 300mm in diameter. Microtunneling spread to the rest of the world. German engineers and Japanese contractors were used for the sewer programme in Hamburg. This area experienced difficult ground conditions and was a big, populated city by the 1980s. The rapid growth and success in microtunneling together with pipe jacking in Japan, led to the government implementing restrictions on the traditional method (FSTT, 2004: 27; Kramer, McDonald & Thomson, 1992: 31).

By the end of 1985, microtunneling and pipe jacking allowed contractors to install permanent, high-quality pipes using the trenchless method. This method often proved that the trenchless method could provide equal or better workmanship than the traditional method (FSTT, 2004: 27; Kramer, McDonald, & Thomson, 1992: 32).

- United States of America

During 1979 to 1987, Dr Tom Iseley managed and owned a utility company in the water and sewer pipeline business. He started promoting Trenchless Technology in 1988, when he started teaching at the Louisiana Tech University. In 1989, he founded the Trenchless Technology Centre (TTC). A centre that serves as a research facility for the improvement and implementation of trenchless equipment and procedures. In 1993, Dr Tom Iseley, received a grant of 1.2 million dollars for a research project. He along with the United States Army Corps of Engineers had to evaluate and develop technologies for microtunneling, Horizontal Directional Earth Drilling and Cured-In-Place Pipes. He has numerous achievements in the field of Trenchless Technology. After the development of the centre, Trenchless Technology was implemented by oil companies and coal mining companies within Europe and the United States of America. The companies investigated the feasibility of reaching the core of mineral lines from the side of hills and mountains. In 1990, the North American Society for Trenchless Technology was established (Najafi, 2012: 34).

- Europe

By 1986, Trenchless Technology was introduced throughout Europe. The term “controlled flush horizontal drilling” was adopted in Europe. By 1987, Trenchless Technology had been implemented within the United Kingdom (Bayer, 2005: 15).

During 1987, the German Company, Tracto-Technik, developed the first steerable dry bore unit and in 1989, the first fluid bore unit. These units were used for the installation of extraction conduits below the runway at the Frankfurt Airport. The first horizontal well sinking project for the control of contaminated wastewater was completed in 1990 in Günzburg, Bavaria (Bayer, 2005: 15).

From 1989 to 1991, several Trenchless Technology companies were established in Germany. In 1992, while using several horizontal drilling rigs simultaneously, Germany upgraded the local supply of drinking water and natural gas within the new states within a couple of months. In 1993, the first pulling of a new pipe inside an old pipe using a horizontal drill rig, while sealing it from the inside was completed successfully. This introduced the implementation process of Pipe Cracking and Cured-In-Place Pipes (Bayer, 2005: 15).

The installation of firmly connected grey cast iron pipes using Trenchless Technology, was done by 1995. The installation of clay ware pipes followed by the year 1998. Mud motors for horizontal drilling machines were introduced in 1995. The final development of mud motors specifically for horizontal drilling machines was only finalised and used successfully by 2001. The mud motor provided additional power to the machine and also displaced the drilling fluid to the front of the drill bit. The more powerful motor caused the development of hammering bore heads for drilling into hard rock by 2003 (Bayer, 2005: 16).

After Trenchless Technology became a standard within civil construction, the process was implemented within the commercial and residential community. Today, the term Trenchless Technology refers to the near-subsurface installation of cables, pipes and networks. Due to many major accomplishments throughout the world, there has been a rapid development in trenchless equipment and methods. The machines are equipped with more powerful motors, can reach longer drilling lengths, include 3-D detection and control remotes, flush drilling mechanisms and can drill pilot holes in reverse (Bayer, 2005: 19).

3.3 THE COMPARISON BETWEEN THE OPEN TRENCH METHOD AND THE TRENCHLESS METHOD

Both methods are used for the installation of services within the ground, but both are executed in different ways.

There are three common techniques for surface hole creation, namely (Kramer, McDonald, & Thomson, 1992: 1; Oosthuizen, & Van Rooy, 2015: 70):

3.3.1 Compression displacement of the soil (Pressing or Punching)

This technique compresses the soil into the surrounding earth without cutting. This method can only be used in porous, moist and compactable soil at a shallow depth (less than 1.8m deep). This method usually requires a high-trust load as the soil is being displaced. This displacement can cause damage to nearby structures and facilities.

3.3.2 Percussive displacement of the soil (Striking or pounding)

This technique uses an impact or percussion hammer to crush the earth using pressure. This method is used on very hard rock.

3.3.3 Cutting of the soil

This technique uses cutting to remove soil with a drill bit. The soil is then removed by circulating a fluid or a mechanical conveyor.

The Open Trench Method of pipe installation refers to the process of digging open the top part of the earth to form a trench. While the process of trenchless refers to the direct drilling, underneath the surface, in the same direction as you would do a trench. The Open Trench Method for installation is the most common and primitive way of installing a pipeline or rehabilitating existing services. It involves the basic use of labour and hand tools or can be done by mechanical power (Eco Builder, 2011: 18-19).

The trenchless method can be defined as the method for installing new pipelines or the replacement/ renewal of existing services below the ground, without disturbing the surface of the earth (Bayer, 2005: 13; Najafi, 2010: 3).

Therefore, the term Trenchless Technology can be defined as the technology for the placing of new pipes, cables or conduits in the ground between two predetermined points. It is the accumulative engineering, equipment and experience that allows the installation or rehabilitation of services using the trenchless method. (Bayer, 2005: 13).

Trenchless Technology constitutes an alternative to the Open Trench Method due to its usability and efficiency within all ground conditions. The most prominent feature of the Open Trench Method is the utilisation of equipment and the amount of transport required. A large excavator, a small-sized excavator, a compressor and a jackhammer are the minimum equipment required for trench pipeline excavation. The trenchless method only requires the bore rig and a lorry with a built-in drilling fluid mixer (Bayer, 2005: 34-35).

The traditional method has the soil infill and traffic tension acting directly on top of the pipeline causing deflections and more strain on the pipeline. Due to the arching effect created by the trenchless method, the pressure on the pipes are more uniformly distributed (See Figure 5). This means that the trenchless method reduces future maintenance and replacement of services (Najafi, 2010: 3).

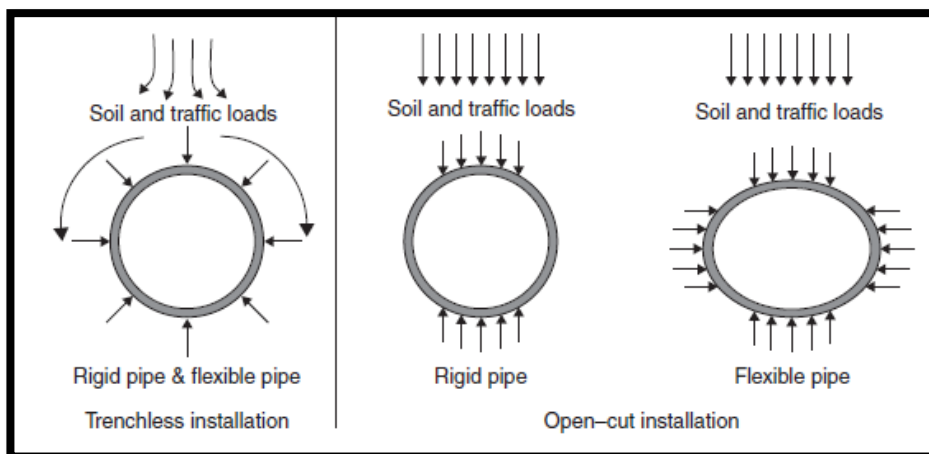


Figure 5: Comparison of pipeline tension in Trenchless Installations and The Traditional Method. (Najafi, 2010: 4-5)

3.3.1 OPEN TRENCH/ OPEN-CUT EXCAVATION

The Open-Cut or traditional method is defined as an *indirect method of pipeline installation*. The conventional approach entails excavating a trench along the route of the planned pipeline, installing support for the trench walls, constructing a foundation or sub-soil bedding, placing the pipe in segments within the trench, embedding the pipe with filling, infilling of the trench and compaction of the top surface. Most effort and planning associated with this method is managing traffic, sloping of soil, dewatering, levelling and reinstating the surface area. The smallest part of the attention is given to the actual installation of the service or utility. The repeated movement of the soil in trenching, hoarding, hauling, infilling, compaction and reinstatement contributes to almost 70% of the cost of the entire project (Najafi, 2010: 3).

The following are methods for trench pipeline excavation:

Hand Tools for Soil Excavation:

Spade/Shovel

The spade or shovel is a tool that consists of a metal plate that has sharp edges. The plate is attached to the end of a long handle, usually made of wood. The shape and design help with the excavation and lifting of soil (Anupoju, 2020: online).

Hoe

A hoe is an excavation tool that consists of a square metal plate attached to a long handle. The sharp edge, at the tip of square, allows the worker to dig into soft to medium soil. It is used to loosen the soil in order to remove the excavated soil from the trench (Anupoju, 2020: online).

Pick Axe/ Mattock

The pick axe is a metal spike attached perpendicular to a handle. The one side has a pointed metal spike and the other side has a wide blade. The pick axe is used to cut through hard soil (Anupoju, 2020: online).

Mattock

The mattock looks very similar to a pick axe. The mattock is a metal plate attached perpendicular to the handle. The one side has a rectangular flat piece of metal and the other

side a small square blade. This tool is mainly used to lift small to medium rocks located in the trench (Anupoju, 2020: online).

Mechanical Tools for Excavations:

Tracked Excavator

An excavator is a machine that consists of two parts. It consists of a cabin and a long arm. A digging bucket is added to the front of the arm. The entire upper part of the machine can rotate 360 degrees and the vehicle moves by traction. The excavation of the trench is done by the bucket with hydraulic movement. The bucket can also be used for loading (Anupoju, 2020: online).

Back Hoe Excavator

The machine consists of two parts. The smaller bucket is located at the back side, while the bigger loading bucket is located at the front. The smaller bucket is used for excavating the soil, while the bigger bucket is used for loading or pushing the soil (Anupoju, 2020: online).

Trencher

The trencher is construction equipment used to dig trenches. This machine was specifically designed to dig trenches for pipes or cables. It uses a big chain for cutting through the soil. There are two types of trenchers, namely: Chained or Wheeled (Anupoju, 2020: online).

3.3.2 TRENCHLESS METHOD

Classification of the Trenchless Method into Three Categories:
(Najafi, 2010: 8; Oosthuizen & Richardson, 2011:20):

1. New Installation Method – The new installation method will be discussed in Chapter 4.
2. Renewal Method – The methods for the renewal and replacement of pipelines will be discussed in Chapter 5.
3. Replacement Method

The trenchless method works on the combined principle of hydro and mechanical. The drilling is not performed using only a conventional mechanical technique, but also using concentrated ground loosening water jets or bore suspension jets. It penetrates from the nozzles at the tip of the bore head and causes a hydro-mechanical penetration of the soil. The loosened soil becomes discharged due to the suspension in the backflow along the bore rod and the other soil particles are partially relocated into the vicinity of the borehole (compacted). This causes a new and more compact bedding within the borehole by saving void space. The void volume is stabilised at the same time by the suspension that is added to the high-pressure water jets (Bayer, 2005: 19; Oosthuizen & Richardson, 2011:20).

All trenchless drilling techniques require the use of machinery. The process usually starts with the main drilling machine, referred to as the bore unit. The small and medium-class drilling units are mobile, self-propelled or self-anchoring. They require less installation than bigger bore units. Big bore units often require assembly or are built-into-place on site. The small to medium machines are already assembled and can start the process once dropped into position. Other methods like Open-Shield require a small hand-held drilling machine (Bayer, 2005: 18).

Peripheral devices are also required for any trenchless drilling process. A mobile power supply unit and an integrated fluid mixing system needs to be connected to the main bore unit. Other methods require frames, shields, hydraulic jacks, spoil removal systems, ventilation systems and limited ancillary equipment. A transportation vehicle for the bore unit or components of the bore unit needs to be arranged and available (Bayer, 2005: 18).

Most horizontal drilling machines have a form of a bore head, drill head or cutter head. The head is used to cut through soil and break down rock formations. It creates the borehole by displacing soil in an outward direction. In most cases, the bore head has a cylindrical body with an asymmetrical construction, a bevelled screw-down face and a lateral bevelled supporting face. The head is usually located at the front of the drilling process. The head can be attached to either a machine or drilling rods that pushes the head forward (Bayer, 2005: 18).

The borehole refers to the narrow shaft in the ground created by the bore head. It is the path or tunnel in which the utility or service lines are installed. It is usually located close to the surface and exposed to vibrating loads. The ground requires constant stabilisation against the latent risk of collapse. Drilling fluid pumped through the drilling system, helps to stabilise

the borehole by closing the pore volume. It reduces the friction experienced by the bore head, carries the soil structure and embeds the product piping. Reaming is the term used to upsize the diameter of the borehole. Special attachments can be equipped to the head of the drilling machine to enlarge the diameter of the borehole (Bayer, 2005: 18).

3.3.3 COMPARISON OF CONSTRUCTION PROCEDURES FOR THE TRADITIONAL METHOD AND TRENCHLESS TECHNOLOGY

Table 1 below shows a comparison between the Traditional Method and trenchless method for the general construction process of a new service line.

Table 1: The basic procedure for pipeline installation between Open-Cut and Trenchless. (Najafi, 2010:6)

<i>Construction Process</i>	<i>Open-Cut</i>	<i>Trenchless</i>
<i>Surveying of Services</i>	✓	✓
<i>Establishment</i>	✓	✓
<i>Cleaning & Grubbing</i>	✓	✓
<i>Transporting & Sorting of Piping Material</i>	✓	✓
<i>Top Soil Removal</i>	✓	x
<i>Transporting & Laying of Pipes</i>	✓	Limited
<i>Welding of Joints</i>	✓	✓
<i>Protective Lining or Sealant at Joints</i>	✓	✓
<i>Test of Pipelines</i>	✓	✓
<i>Trenching for Pipes</i>	✓	x
<i>Dewatering of Trenches</i>	✓	✓
<i>Lowering of Pipe into Trench/ Pit</i>	✓	Limited
<i>Moving Excavated Soil</i>	✓	x
<i>Infilling of Hole</i>	✓	x
<i>Compaction of Excavated Soil</i>	✓	x
<i>Carting Away of Excavated Soil</i>	✓	x
<i>Leak or Pressure Testing</i>	✓	✓
<i>Making Good the Surface</i>	✓	Limited
<i>Final Inspection of Pipeline</i>	✓	✓
<i>De-establishment of Equipment & Labour</i>	✓	✓
<i>Preparation of As-built</i>	✓	✓

Surveying of Services

Both methods require the surveying of services beforehand. The Traditional Method and trenchless method will both have an underground network of services. The layout of this network will still need to be designed and pre-determined by a group of professionals. The method chosen will have an effect on the length and route of the network. The trenchless method can be used to install services underneath rivers, roads, water tables, structures etc. It is believed that the trenchless method will allow for the execution of works within the

shortest possible path, rather than the Traditional Method that needs to follow a longer route around obstacles or structures. It is believed that the trenchless method can also reach longer lengths and deeper depths, in a shorter time, compared to the traditional method. (Najafi, 2010: 5; Bloc Contractors, 2020: online).

A comprehensive soil study has to be done for both methods. The trenchless method requires a more comprehensive study of the soil. The traditional method is an open trench on the surface. If hard rock is encountered, it can be removed by chemical or mechanical power, whereas the trenchless method is covered by the surface. If the drill head cannot break the hard rock, the line will need to be re-tracked and an alternative path will need to be determined. (Najafi, 2010: 5; Bloc Contractors. 2020: online).

Establishment

Any form of establishment still needs to be done for both methods. Health and safety procedures for both methods will need to be implemented. (Najafi, 2010: 5).

The traditional method will require the procurement of labour and mechanical digging machines. The trenchless method will require an operator and the preferred drilling machine. (Najafi, 2010: 5; Bloc Contractors. 2020: online).

Cleaning and Grubbing

The surface will need to be cleaned and cleared for both methods. As site clearance is usually done for the entire terrain on new developments, either method benefits. On a site where there is usually just a need for the installation of single services or an existing site, the trenchless method has less cleaning and grubbing. (Bloc Contractors. 2020: online).

The Traditional Method will need to be cleaned and cleared along the route of the services. The trenchless method will only need to be cleaned and cleared at the starting pit and end pit. The trenchless method requires less working space than the traditional method. (Najafi, 2010: 5).

Transportation and Sorting of Piping Material

Both methods require the transportation and sorting of piping material. These two methods use the same piping material to install services. The advancement in the trenchless method has allowed for the installation of bigger diameter service piping. While the traditional method is restricted to the depth that can be excavated in the subsurface, considering the geographics of the earth. (Najafi, 2010: 5; Mishra, 2020: online).

The piping material needs to be transported to site and off loaded upon arrival. The piping material then needs to be sorted according to the type of service it will provide. Both methods require the piping material to be available in order for the work to be done (Bloc Contractors, 2020: online).

Top Soil Removal

The Traditional Method needs to remove the top soil of the earth's surface. This is done by excavating from the surface of the land into the sub-surface of the earth. The Trenchless method involves the removal of soil at the starting and end pit. Since the Trenchless method enters from the side at the starting pit and ends at the end pit, no top soil needs to be removed for the service line itself. (Najafi, 2010: 5; Mishra, 2020: online).

Transporting and Laying of Pipes

The trenchless method does not require any physical laying of the pipes, as the pipe follows the drilling path of the machine. The traditional method requires physical labour to lay the piping material within the excavated trench. Both methods require the transportation of the piping material from the stockpile to the required location and the movement of the equipment, machinery and workers/operator. (Najafi, 2010: 5).

Welding of Joints

Welding joints are needed if the service line needs to connect to other service lines or when the current service line needs to change direction. All service lines are usually planned for installation in the longest possible lengths, with the fewest possible connections and turning points, regardless of the method chosen. (Najafi, 2010: 5).

With the Traditional Method, the joint is welded or connected within the open trench. The trenchless method only allows for joints to be welded or installed at the start or end pit. It is therefore necessary to ensure that no joints will be needed within the underground drilling route of the trenchless method. If joints are needed within a long continuous service line, there will need to be another pit between the two main pits. There are polyurethane coating solutions for the trenchless method that can be applied at joints that offer a sealed anti-erosion application. (Najafi, 2010: 5; Mishra, 2020: online).

Protective Coating or Sealant at Joints

There is a need for a sealant or protective coating at the joints within the service line. All service lines need to be enclosed and protected from outside materials or liquids. The sealant or protective coating serves as protection from the elements at a weak point within the main service line. The sealing of the joint can be done with the installation of the joint, for both methods. (Najafi, 2010: 5).

Testing of Pipes

Testing of service lines is mandatory for both methods. The trenchless and Traditional Method can cause unseen damage to the service line. These service lines also need to be able to withstand pressure from within. Both methods use the same testing methods of the service lines. (Najafi, 2010: 5).

Trenching of Pipes

The term “trenchless” is derived from the fact that this method does not require any trenching. The Traditional Method requires and is executed using only trenching. (Najafi, 2010: 5).

Dewatering

Dewatering is needed for both methods. The excavated trench, a result of the Traditional Method, is exposed to the weather and possible rainfall. The trenchless method, although covered, can be filled with water at the start and end pit, should the pits get flooded and water enters into the service line. (Najafi, 2010: 5).

Lowering of Pipe into Trench/Pit

The lowering of the pipe into the trench is a physical task performed by workers in the Traditional Method. The trenchless method does not require a smaller amount of physical labour. The piping material needs to be lowered into the starting pit and sometimes needs to be attached to the drilling machine. (Najafi, 2010: 5).

Moving of Excavated Soil

The traditional method, in most instances, requires the movement of excavated soil. The volume of excavated soil from the traditional method increases as the length of the service line increases. Due to the network of service lines needed and the depth of the excavations, the volume of the excavated surfaces can quickly cause a decline in the available work space on the surface. The excavated soil then needs to be moved by means of physical labour or mechanical power (Najafi, 2010: 5).

The trenchless method does not require any moving of excavated soil. Due to the method of implementation, the soil is displaced underneath the ground due to pressure. The soil from the excavated start and end pit is moved to a location close-by. The soil is later used to cover the start and end pit after the Trenchless method is no longer needed (Najafi, 2010: 5; Wesser, 2020: online).

Infilling

The excavated trenches created by the traditional method, need to be infilled with soil after the service line has been laid. Only a small portion of the excavated soil will be used for infilling. The remainder of the volume of the infilling, will be from imported soil that has been collected by additional transportation trucks from a different supplier. (Najafi, 2010: 5; Apeldoorn, 2013: 57 ; Wesser, 2020: online).

The trenchless method does not require any infilling except at the start or end pit. The service lines installed with this method are already surrounded by the existing soil layers. Since there is less disturbance in the earth surrounding the service line, there will be no need to use additional soil to stabilise the surrounding area. The natural structure of the soil underground is preserved. (Najafi, 2010: 5; Apeldoorn, 2013: 57).

Compacting of Excavated Soil

The traditional method requires compaction of the infilled soil. The imported soil used for the infilling of the traditional method needs to be compacted to minimise compressive strain and tensile stress experienced by the service line (Najafi, 2010: 5; Wesser, 2020: online).

Due to the cylindrical geometry of the borehole, the tensions of the soil will be ideally diverted away from the service line in an arch form. The solid filling being dispersed to the sides by means of pressure from the drill rod, creates a suitable natural ground cover for acting forces (Najafi, 2010: 5; Wesser, 2020: online).

Carting Away of Excavated Soil

After infilling and compaction, the surplus of the excavated soil needs to be carted away from the site. The amount of excavated material created by the traditional method, that needs to be carted away, depends on the ground conditions. The more stable the current ground conditions, the less excavated material will need to be removed from the site. (Najafi, 2010: 5; Apeldoorn, 2013: 56).

The trenchless method does not require any hauling of the excavated pipeline material. Almost all of the ground fill will be used to infill the start and end pits. (Najafi, 2010: 5; Apeldoorn, 2013: 57).

Leak/ Pressure Testing

Both methods require testing to be done. After the installation of service pipes, testing is required. The most common tests would be pressurisation and leak tests. The service lines need to be protected from pressure and elements such as water, air and soil. This will preserve the life span or facility of the service line. This also reduces the amount of maintenance that needs to be done in the future. The testing for both methods will usually be done in the same manner and using the same machines. (Najafi, 2010: 5).

Making Good the Surface

The traditional method requires the restoration of the surface after the completion of the service line. After compaction of the ground surfaces, the surface needs to be cleaned and levelled. If the trenching occurred through a road, railway or structure, the existing service needs to be repaired and restored to its previous state. (Najafi, 2010: 5; Apeldoorn, 2013: 57).

The trenchless method does require limited making good of surfaces. The method installs service lines underneath the natural ground surface. The method is also used to install service lines underneath roads, railways and structures. The restoration of the natural ground surface at the start and end pit needs to be rectified and returned to its previous state. (Apeldoorn, 2013: 57)

Final Inspection

Both methods require a final inspection. The final inspection will usually be done by a qualified Civil Engineer or appointed specialist. The traditional method will be inspected in the same manner as the trenchless method. Both need to comply with all standards and regulations (Najafi, 2010: 6; Apeldoorn, 2013: 57).

De-establishment of Equipment & Personnel

Both methods require the de-establishment of equipment and personnel. The trenchless method has less de-establishment than the traditional method. Since the traditional method requires more equipment and staff, there will be more time spent on the de-establishment of the site. (Najafi, 2010: 6; Apeldoorn, 2013: 57).

Preparation of As-built

Both methods require the creation and submission of as-built drawings. Revised drawings will need to be submitted by the contractor, showing the changes made from the initial drawings to the exact layout of the services upon completion (Najafi, 2010: 6; Apeldoorn, 2013: 57).

3.4 FURTHER CONTRIBUTIONS TO KNOWLEDGE

During the research study, two site visits were organised. The site visits were for the two most common trenchless methods used in South Africa. The first site visit was for the installation of a HDPE pipe near a school. The pipeline installation made use of Horizontal Directional Earth Drilling.



*Figure 6: Horizontal Directional Earth Drilling Machine
(Author's Own Source).*

This was a small project, but bigger projects have been documented in South Africa. This pipeline covered a distance of 1 500m and had a diameter of 110mm. The pipeline is used for the supply of water for the rural school from the main municipal feed. This project was chosen as the pipeline was installed under a two-lane roadway.

Different boring heads were used to break down the hard soil within the earth's surface. Drilling rods were used within the drilling magazine to reach the great length of the pipeline. The contractor made use of a back-reamer to increase the diameter of the pilot-hole until the new pipeline diameter was reached. The Horizontal Directional Earth Drilling machine was connected to a drilling fluid mixing unit located on the back of a truck. The drilling fluid was pumped from the container on the truck to the Horizontal Directional Earth Drilling machine via a hose. The drilling fluid is essential for cooling down the drilling head and breaking down soil in the ground. The fluid is necessary for drilling methods that occur underneath roadways.

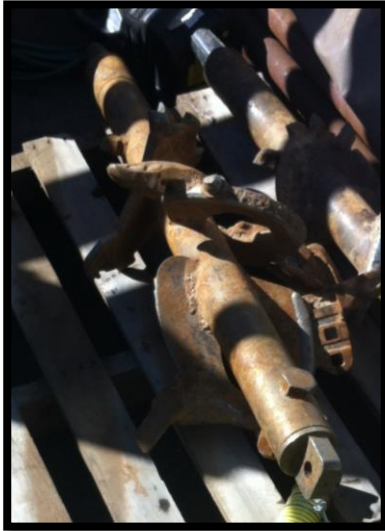


Figure 7: Drilling Heads
(Author's Own Source).



Figure 8: Drilling Fluid Mixing System for HDD
(Author's Own Source).

The second site visit was for a Pipe Jacking Project. The project was done in the province of Gauteng, close to Vereeniging. This was for the installation of a reinforced concrete pipe needed for stormwater. There were two pipelines installed with different diameters. The smaller pipeline had a diameter of 900mm. The pipeline needed to cover a distance of 45m and reached a depth of 3.5m. The first pipeline started with the contractor digging the entry and exit shaft with the excavator. The entry shaft needed to be bigger as the Pipe Jacking machine needed a bigger space. The project made use of hydraulic jacks to push the concrete pipes forward.

The small cutter head was jacked forward to create the pilot hole. As the cutter head was jacked forward, it cut into the soil to create the tunnel for the pipeline. The reinforced

concrete pipes were jacked behind the cutter head. The reinforced concrete pipes were inserted and jacked forward in sections. Figure 9 clearly shows a backing support, made of wood, to offer resistance in the opposite direction for the jacking pressure. The small hydraulic jack system can be seen on the floor of Figure 9. Figure 10 shows the last day for the Pipe Jacking of the smaller pipe. The small pipe was completed within two days.



Figure 9: Pipe Jacking of the 900mm pipe
(Author's Own Source).



Figure 10 : Final Day of Pipe Jacking for
900mm pipe
(Author's Own Source).

The second pipeline had a diameter of 1200mm. It needed to cover a distance of 50m at the same depth of 3.5m. The entry and exit shafts were excavated by machine. The entry shaft required a larger launching pit than the other pipeline. This pipeline made use of worker-entry to cut through the soil. No cutter head was jacked forward with this pipeline. The beginning of the pilot hole was drilled by hand with a jackhammer in the entry shaft. The first section of the reinforced concrete pipe was jacked forward. The workers entered the pipeline and began the excavation within the pipe. The soil was removed from inside the pipeline to the outside. The hard rock was broken down by a jackhammer and drilling fluid. As the workers progressed within the pipeline, the next section of the reinforced concrete pipe was jacked into place.



Figure 12: Worker inside 1200mm diameter pipe
(Author's Own Source)



Figure 11: 1200mm diameter pipe being jacked
(Author's Own Source).

3.5 THE ECONOMIC STATUS OF WATER AND SANITATION

In 2017, the Department of Water and Sanitation of South Africa released a framework for the national water investment in the country. The publication indicates the replacement costs of all water, sewerage and stormwater pipelines and infrastructure in South Africa. The projection includes all nine provinces and are presented in the table below: (Department of Water and Sanitation, 2018: 10-12; Water Technology, 2013: online).

Table 2: Total Capital Replacement Costs for Water and Sanitation in South Africa
(Department of Water and Sanitation, 2017: 9).

	TOTAL CAPITAL REPLACEMENT COSTS
Dams	R 502 031 067 244.00
Boreholes	R 45 862 044 415.00
Pipelines	R 131 633 460 511.00
Canals	R 59 768 314 839.00
Water Treatment Works	R 66 244 812 301.00
Bulk Pump Stations	R 43 713 011 456.00
Reservoirs	R 39 783 801 189.00
Reticulation	R 117 020 069 057.00
TOTAL REPLACEMENT COSTS OF ALL WATER AND SANITATION	<u>R 1 006 056 581 012.00</u>

Water is a critical resource that is required by both the public and private sectors. South Africa is classified as a water scarce country, but all water sources have been developed

and built to provide for the country. Table 2 shows that over R 248 billion of the budget is allocated to underground pipelines and networks. This amount represents replacing the current infrastructure only. The cost for upgrading and maintaining the current water and sanitation in our country needs to be added to Table 2 (Department of Water and Sanitation, 2018: 10-12; Water Technology, 2013:online).

The future expansion will be more costly and will need to include technical, social and economic solutions to meet the growing water demands of our country. It was estimated that over R 89.9 billion per annum needs to be spent over the next 10 years. This amount includes upgrades to serve service level increase, sustain effective service delivery and develop new infrastructure for the growing water demand (Department of Water and Sanitation, 2017: 10; Roosenburg, 2004: 1).

3.6 THE MEASUREMENT OF TRENCHLESS TECHNOLOGY

The study aimed to compile an Elemental Estimate and Standard System of Measure for Trenchless Technology. This could assist with determining the financial viability of Trenchless Technology within the construction industry. The proposed methods for measurements and calculations could be utilised to determine the financial viability between the traditional and trenchless method. It could assist with determining the possibility of implementing a Trenchless Technology Method within certain projects. It will further assist professionals within the field to determine the cost and provide accurate pricing.

Table 3 represents a cost comparison between the traditional and trenchless methods. Project specifications can influence the costing of Trenchless Technology, therefore the cost needs to be determined for each project before the method can be considered. This template could be used to determine an estimate or pricing for the two methods. The total cost of each method is compared directly next to one another and the most viable method can be implemented.

Table 4 represents an example if Trenchless Technology would be included within the Guide to Elemental Cost Estimating as prepared and printed by the Association of South African Quantity Surveyors. Below is the proposed location of the primary element within the document.

SECTION	ELEMENTS	COMPONENTS
External works and services	Trenchless Technology	New pipeline installations Rehabilitation of existing pipelines Profit and attendance

Table 5 represents an example if Trenchless Technology would be included in the Standard System of Measurement. The measurement group would be located under the External Works trade in the document.

Table 3: A template for the Cost Comparison between the Traditional and Trenchless Method

COST COMPARISON FOR THE TRADITIONAL VS TRENCHLESS METHOD						
			TRADITIONAL		TRENCHLESS	
			Rate	Total	Rate	Total
1. Preliminaries & General				xxx		xxx
Site Establishment	Item	xxx	xxx	xxx	xxx	xxx
Insurance and Guarantees	Item	xxx	xxx	xxx	xxx	xxx
Site Facilities	Item	xxx	xxx	xxx	xxx	xxx
Health & Safety	Item	xxx	xxx	xxx	xxx	xxx
Surveying of Services	Item	xxx	xxx	xxx	xxx	xxx
Soil Investigation	Item	xxx	xxx	xxx	xxx	xxx
Preparation of As-built Drawings	Item	xxx	xxx	xxx	xxx	xxx
De-establishment	Item	xxx	xxx	xxx	xxx	xxx
2. Earthworks				xxx		xxx
Site Clearance	m2	xxx	xxx	xxx	xxx	xxx
Trenches for Pipes	m3	xxx	xxx	xxx	xxx	xxx
Dewatering of Trenches	Item	xxx	xxx	xxx	xxx	xxx
Infilling of Trenches	m3	xxx	xxx	xxx	xxx	xxx
Compaction of Excavated Soil	m2	xxx	xxx	xxx	xxx	xxx
Carting away Excavated Soil	m3	xxx	xxx	xxx	xxx	xxx
3. Services				xxx		xxx
Sewerage	m	xxx	xxx	xxx	xxx	xxx
Electrical	m	xxx	xxx	xxx	xxx	xxx
Water	m	xxx	xxx	xxx	xxx	xxx
Stormwater	m	xxx	xxx	xxx	xxx	xxx
Gas	m	xxx	xxx	xxx	xxx	xxx
4. Labour				xxx		xxx
General Labour	Item	xxx	xxx	xxx	xxx	xxx
Specialised Labour	Item	xxx	xxx	xxx	xxx	xxx
5. Equipment				xxx		xxx
Manual Tools	Item	xxx	xxx	xxx	xxx	xxx
Machinery	Item	xxx	xxx	xxx	xxx	xxx
6. Other Services				xxx		xxx
Transport	Item	xxx	xxx	xxx	xxx	xxx
Welding of Joints	Item	xxx	xxx	xxx	xxx	xxx
Protective Coating or Sealant	Item	xxx	xxx	xxx	xxx	xxx
Encasing	Item	xxx	xxx	xxx	xxx	xxx
7. Testing				xxx		xxx
Testing Water Pipes	Item	xxx	xxx	xxx	xxx	xxx
Pressure Testing	Item	xxx	xxx	xxx	xxx	xxx

**ESTIMATED TOTAL COSTRUCTION COST
(CARRIED TO SUMMARY)**

SUMMARY

Length of Pipeline
 Construction Start Date
 Construction End Date

m
 Date
 Date

xxx
 xxx
 xxx

SUMMARY OF CONSTRUCTION COSTS

1. Preliminaries & General
2. Earthworks
3. Services
4. Labour
5. Equipment
6. Other Services
7. Testing

	TRADITIONAL		TRENCHLESS		
	Cost (R)	Rate per m (R)	Cost (R)	Rate per m (R)	Cost Difference %
1. Preliminaries & General	xxx	xxx	xxx	xxx	xxx
2. Earthworks	xxx	xxx	xxx	xxx	xxx
3. Services	xxx	xxx	xxx	xxx	xxx
4. Labour	xxx	xxx	xxx	xxx	xxx
5. Equipment	xxx	xxx	xxx	xxx	xxx
6. Other Services	xxx	xxx	xxx	xxx	xxx
7. Testing	xxx	xxx	xxx	xxx	xxx

**ESTIMATE OF CONSTRUCTION COSTS
(EXCLUDING CONTINGENCY)**

Contingency

xxx	xxx	xxx	xxx	xxx
xxx	xxx	xxx	xxx	xxx

**ESTIMATE OF CONSTRUCTION COSTS
(EXCLUDING ESCALATION)**

Escalation

xxx	xxx	xxx	xxx	xxx
xxx	xxx	xxx	xxx	xxx

**ESTIMATE OF CONSTRUCTION COSTS
(EXCLUDING VAT)**

Vat @ 15%

xxx	xxx	xxx	xxx	xxx
xxx	xxx	xxx	xxx	xxx

**ESTIMATE OF CONSTRUCTION COSTS
(INCLUDING VAT)**

xxx	xxx	xxx	xxx	xxx
------------	------------	------------	------------	------------

Table 4: Elemental Estimate for Trenchless Technology

CODE	SECTION AND ELEMENT	CODE	COMPONENTS	MEASUREMENT REQUIRED FOR ELEMENTAL OR COMPONENT	UNIT	COMPOSITION OF ELEMENT OR COMPONENT	TAKING OFF / PRICING NOTES
6	EXTERNAL WORKS AND SERVICES						
	...						
620	Trenchless Technology			Length of pipeline and services	m	All the work in connection with the Trenchless Technology installation and sundry builder's work	
		620.10	New pipeline installations	Length	m	Drilling, piping material, valves, fittings, access points, sleeves, sundry builder's work, etc.	Measure different methods, piping material and diameters separate.
		620.15	Rehabilitation of existing pipelines	Length	m	Coating material, epoxy, drilling, cracking, sundry builder's work, etc.	Measure different methods, piping material and diameters separate.
<i>Manholes, inspection chambers, pumps, stations, treatment plants, septic tanks, catch pits, sumps, retention ponds, ditches, culverts, etc. measured under the corresponding service under the applicable element such as soil drainage, sub-surface water drainage etc.</i>							
		620.20	Profit and attendance	Number	No	Profit and attendance for the principal contractor in connection with 620.10 and 620.15 above	

Table 5: Standard System for Trenchless Technology

continued

Item or work to be measured	Unit	Measurement rules	Description shall be deemed to include	Explanatory notes
TRENCHLESS TECHNOLOGY				
33	Earthworks			
40 Earthworks		35 All earthworks associated with Trenchless Technology shall be given in accordance with the principles laid down in the "Earthworks" trade.		
34	Classification etc.			
		36 The nature of the soil should be known 37 Soil investigation and report needs to be done by professional 38 Site establishment should be established and included 38 Allowance shall be made for hard and soft rock		
35	New service pipeline installations			
41 New service pipeline installations using any Trenchless Technology method	m	39 Different piping material, diameters and methods shall be measured separately. 40 The type of method used shall be included in the description. 41 The depth of the pipeline should be separated in stages of 1.5m deep	Drilling, piping material, valves, fittings, access points, sleeves, sundry builder's work, etc.	
36	Replacement of existing service pipelines			
42 Replacement of existing service pipelines using any Trenchless Technology method	m	42 Different piping material, diameters and methods shall be measured separately. 43 The type of method used shall be included in the description.	Coating material, epoxy, drilling, cracking, sundry builder's work, etc.	

3.7 SUMMARY

This chapter outlines the preliminary definition of the term Trenchless Technology. It further explains the start of trenchless methods and the development of the process through time. It gives a clear introduction into the history of Trenchless Technology and the general method.

The introduction between the execution of the Traditional Method compared to the trenchless method will provide the basis for a financial analysis, to determine which process is more financially viable.

CHAPTER 4: INSTALLATION OF NEW SERVICE PIPELINES

4.1 INTRODUCTION

This chapter outlines the methods for the installation of new pipelines or utility service lines using trenchless methods. As previously noted, Trenchless Technology can be categorized into three primary area, namely:

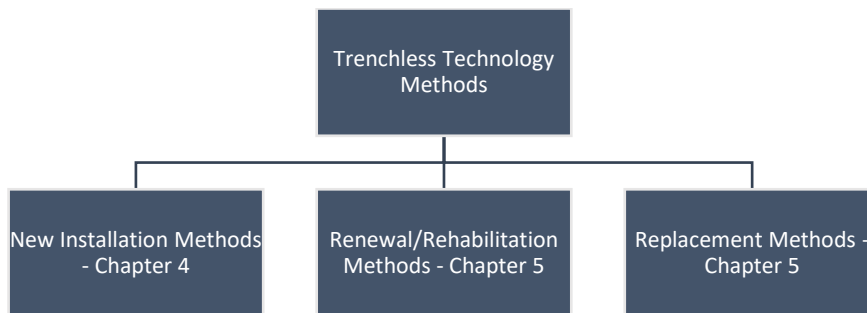


Figure 13: Three Primary Components of Trenchless Technology Methods

New installation methods refer to the installation of new pipelines or utilities below the ground without direct installation into an open-cut trench. New Trenchless Installation Methods can be subdivided into the following three categories, namely:

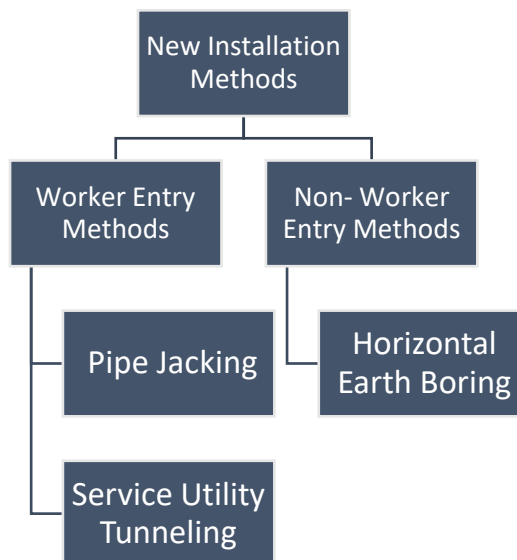


Figure 14: New Installation Methods for Trenchless Technology

4.2 WORKER ENTRY METHODS

Worker entry methods require the workforce inside the tunnel for excavation and pipeline installation. This method is for the installation of big diameter service lines, usually bigger than 1 000 mm in diameter. This method is divided into two techniques, Conventional Pipe Jacking (CPJ) and Utility Tunnelling (UT) (Mishra, 2019: online; Castro Facilitator, 2020: online).

4.2.1 TRADITIONAL PIPE JACKING

Traditional Pipe Jacking (CPJ) is a pipeline installation method where prefabricated pipe sections are pushed forward behind a tunnel boring machine (TBM) or another excavation technique. According to Mohammad Najafi (2010: 9), this process is defined as a “*one-phase*” installation, where the pipe segments are installed simultaneously while excavating. Pipe jacking is also known as a worker-entry installation. This means that workers are required or can enter the inside of the tunnel or borehole during pipe installation and excavation (Pipe Jacking Association, 2017: online).

It is important to understand the difference between the theory and the method of pipe jacking. The theory of pipe jacking is the use of hydraulic rams to jack prefabricated segments to line the tunnel formed by a cutter head or shield. The method of pipe jacking is used with auger boring and microtunnelling, to form part of the technique. The diameter of the borehole ranges from 300-900mm for microtunneling and exceeds 900mm for pipe jacking (Pipe Jacking Association, 2017: online).

Three key areas of pipe jacking are the front face, the main line and the jacking pit.

1. The Front Face

This is known as the front end of the borehole. It is the area between the soil and the front part of the machine. A shield or cutting edge is fitted to the front end of the pipe jack. The shield performs the following functions:

- Temporary support of the soil
- Safe working space
- Attachment for cutting equipment or cutter heads
- Attachment for face-stabilisation attachments

- Tracking or location equipment
- Adjusting the directional altitude

(Kramer, McDonald & Thomson, 1992: 88; Castro Facilitator. 2020: online).

The shield can be a steel can or motorised tunnelling machine. The shield is important in adjusting the directional path to get the right line and level.

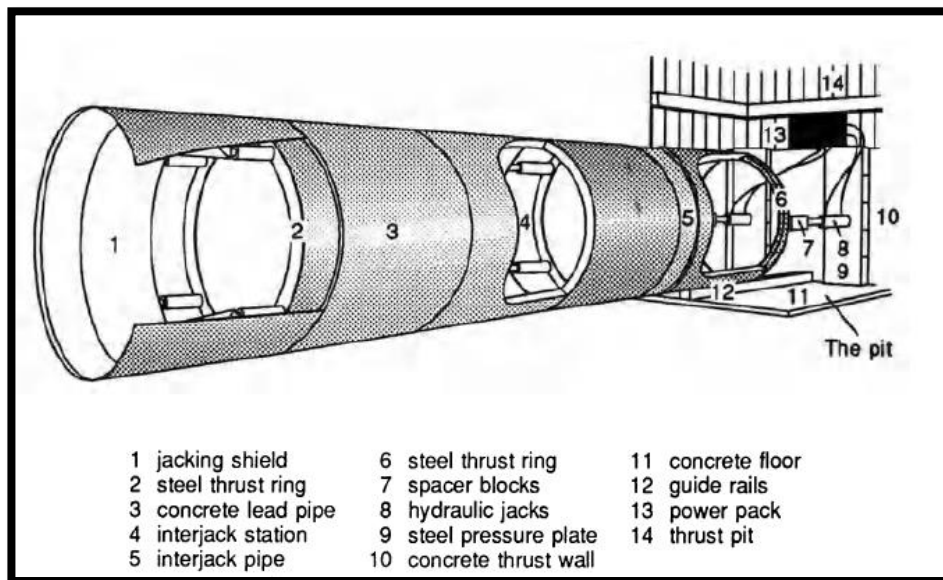


Figure 15: Standard Pipe Jacking System
(Kramer, McDonald & Thomson, 1992. 89)

There are four main types of shields:

- Conventional Shields – (Open Front Face Shield)

Allows direct access to the face. They are inexpensive, simple and flexible. These shields are used for short drilling paths and in durable ground conditions. The conventional shield can be classified as manual or mechanical. Rotary cutter heads can be added to this shield. (Kramer, McDonald & Thomson, 1992: 90).

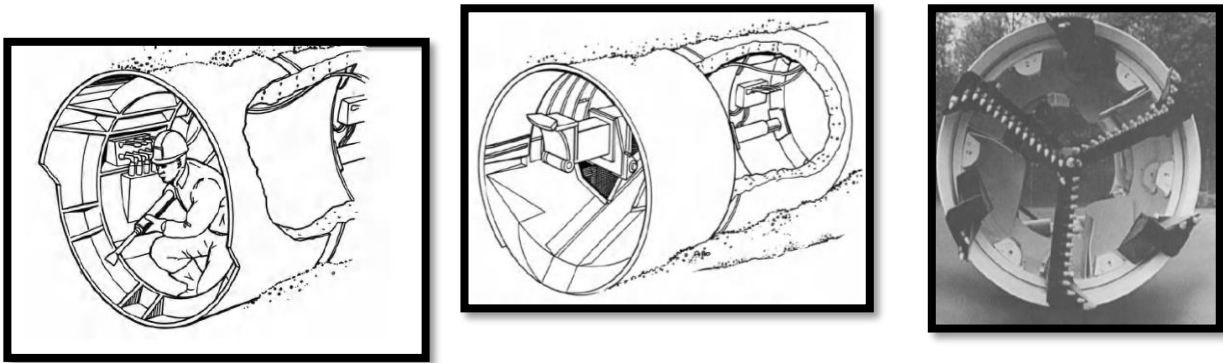


Figure 16: Pipe Jacking Shield
 (Kramer, McDonald & Thomson, 1992: 91-92)

- Compressed-Air Shields – (Closed Front Face Shields)

This shield uses compressed air to counterbalance the pressure of the soil and groundwater, to stabilise the borehole. It is the most common method, as only the face, shield and first two pipes experience pressure. The line and the shaft are free of loads. This shield is used in unstable conditions where water might be present. The air-lock moves forward as the pipes are jacked. Compressed air work should only be done by skilled and experienced operators (Kramer, McDonald & Thomson, 1992: 90).

- Auger-Type Shields, also known as an Earth-Pressure Balance Machine (EPBM) – (Closed Front Face Shield)

These shields are fully mechanical. They are operated remotely and excavate with a full-face cutter head that rotates. The excavated material is conveyed away from the face using auger flights. The face is held by the pressure of the excavated material behind the cutter head. There are various cutter heads available to be installed to the shield and for different ground conditions. Auger-shields are mainly applied to small diameters, for example microtunneling (Kramer, McDonald & Thomson, 1992: 92).

- Pressure-Chamber Shields, also known as a Slurry Machine – (Closed Front Face Shield)

A complete tunnel boring machine (TBM) features a pressure chamber situated behind the cutter head or disc, filled with water, slurry, or soil. This chamber is pressurized to counteract the soil and water pressure within the borehole. These machines are remotely controlled and

are utilized for safer pipe installation, especially in challenging ground conditions (Kramer, McDonald & Thomson, 1992: 93).

Spoil Disposal

The excavated soil from the face excavation must be transported along the line to the drive pit and then carried to the surface. The removal process depends on the length of the line, the type of soil, the type of shield and the space available in the borehole. The spoil can be removed in the following ways (Kramer, McDonald & Thomson, 1992: 93; Castro Facilitator, 2020):

- Skips on a rail system or with wheels
- Conveyors
- Auger flights in tubes
- Slurry pumping

2. The Line

The line is the actual pipeline or casings. These are pressed into the borehole to form the lining of the pipe. There are three methods for lining the borehole, namely (Kramer, McDonald & Thomson, 1992: 94):

- Single Pass – The primary driven pipe, becomes the permanent line. This is the most common method, as the method allows for the immediate installation of the end product.
- Double Pass – A temporary casing is first installed and later jacked out by the permanent pipe. This method is rarely used and is only needed when the pipe is used as a telecommunication multi-duct conduit.
- Casing System – A casing is jacked into the borehole and the circular space between the outer duct and casing is filled in. This method is used for crossing work for example, under railways.

The pipes are manufactured out of concrete, clay, plastic, steel or cast-iron. If these pipes are to be utilised as the main line, they need to provide the required force, watertightness and stability. These pipes also need to be designed to withstand the high-end load when

being jacked into position. Jacking loads are uniformly transferred from one pipe to another by load-distribution rings known as joints. The extra thickness of the pipe joint needs to be incorporated into the wall thickness. Pipe jacking is the most common method for installing gravity flow pipes for sewer lines. The sewer lines need to be installed at deep depths and a level that provides gravity flow. Gravity sewers are the biggest market for jacking, but pressure lines are installed using concrete or iron pipes. Welded-steel pipes are only selected for the casing, as they do not provide the external protection needed to prevent damage during driving (Kramer, McDonald & Thomson, 1992: 95).

The length of the line depends on the jacking power of the rams or the weight being applied to the pipes. The load applied to the pipe is determined by the weight of the pipe and the surface friction between the pipe and the soil. A suitable lubricant can be injected between the pipe and soil to maximise the length of the line. Another alternative for extending the line, is installing Intermediate Jacking Stations (IJS) along the line of the pipe. The total length of the line can be split between the number of IJSs. This reduces the load to maximum stages at each point. A single pass of 914m has been achieved with this method (Kramer, McDonald & Thomson, 1992: 96).

3. Jacking Pit/ Thrust Pit/ Jacking Shaft/ Launch Shaft/ Entry Shaft

The jacking pit is usually an excavated pit in the ground from which Trenchless Technology equipment is launched. It serves as a space for the machinery to fit into. The pit is usually encased with concrete walls and a floor. It serves as a working space for work entry and non-work entry methods. The other purpose of the pit is to line up the equipment at the correct level and gradient (Kramer, McDonald & Thomson, 1992: 97).

Pipe Jacking Method

This method starts with the excavation of the jacking pit (See Figure 15 No.14) and a reception shaft. The pits are usually located at manhole level. The pit is usually excavated with a mechanical machine. The jacking pit is lined with concrete thrust walls (See Figure 15 No. 10) and a concrete floor (See Figure 15 No. 11). This provides a stable surface for the placement of the pipe jacking machine and provides a solid surface from which the pipes can be jacked or rammed. Sealing and stabilising techniques are used to prevent ground failure. An entrance hole can also be constructed from concrete (Najafi, 2010: 9).

The jacking framework is lowered into the pit and placed into position. The shield (See Figure 15 No.1) is then lowered into the pit and set on the launch cradle or guide rails of the jacking frame (See Figure 15 No. 12). The hydraulic jacks (See Figure 15 No. 8) drive the shield through the face of the jacking pit wall. The hydraulic jacks are powered by an electrical source (See Figure 15 No. 13). There are spacer blocks (See Figure 15 No. 7) between the section being jacked and the rams. A steel pressure plate (See Figure 15 No. 9) is installed against the concrete thrust wall to absorb the reaction force of the hydraulic jacks (Kramer, McDonald & Thomson, 1992: 98).

Once the shield has entered the ground, a load-distribution ring (See Figure 15 No. 2) is installed behind the shield. The lead pipe (See Figure 15 No. 3) of the line is set behind the first load-distribution ring. As the lead section of the pipe is jacked through, behind the first ring and shield, successive sections of the pipe follow (See Figure 15 No. 5). These are also known as interjack pipes. The line is jointed between sections with load-distribution rings (See Figure 15 No. 6). An IJS (See Figure 15 No. 4) can be installed along the line at any required position, between the interjack pipes, where the load of jacking needs to be reduced (Najafi, 2010: 10).

The shield cuts the soil during excavation into smaller particles. In the Open Face shield the excavated soil is removed from the tunnel by workers making use of conveyors or skips. The soil is transported from the shield (end) to the jacking pit (start), to remove the excavated material from the tunnel. Closed Face shields make use of auger flights or slurry tubes. An auger flight is a tube with a screw rotating metal shaft on the inside. The auger is connected behind the TBM and breaks the soil into even smaller particles. The smaller particles are transported to the jacking pit by conveyors (Kramer, McDonald & Thomson, 1992: 98).

The slurry system is a closed loop system. The slurry is a mixture of water and bentonite or polymers. The slurry is mixed on the ground surface within containers and is pumped by discharge pumps, through pipes to the slurry chamber located behind the shield. The shield moves the excavated material to the slurry chamber. The slurry mixes with the excavated material in the chamber. The slurry is then pumped through pipes back to the top of the earth to the separation system. This container separates the slurry from the excavated material. The slurry is re-introduced into the closed system and used again. All excavated material from these soil disposal processes is carted away from site in dump trucks (Kramer, McDonald & Thomson, 1992: 98).

4.2.2 UTILITY TUNNELLING

According to Najafi (2010:14) utility tunnelling (UT) can be referred to as *two-phase* trenchless installation. The same process is used in utility tunnelling as in conventional pipe jacking. The shield is pushed forward by hydraulic jacks. As excavation of the borehole takes place temporary supports, known as liners, are manually installed within the shield. The liner is usually made from steel ribs with wooden lagging. The liners support the excavation until the tunnel is complete. After the completion of the tunnel, the product pipe is pushed into the tunnel by hydraulic jacks. The circular space between the liner and product pipe needs to be grouted. The pipes or utility lines are installed within this tunnel by workers. This method is rarely used and has been replaced by other trenchless methods. In pipe jacking the casing pipe acts as the liner and the pipes follow the shield (Sullivan, 2018a: online).

4.3 NON-WORKER ENTRY METHODS

Non-worker entry is the method where workers enter the shaft or pit, but do not enter the borehole or the utility line itself. This method is used for the installation of smaller diameter service lines (Usually 100mm and more). This method is referred to as Horizontal Earth Boring (HEB). HEB is the collective name given to non-worker entry methods and can further be sub-divided into the following techniques (Najafi, 2010: 15; Castro Facilitator, 2020):

- Horizontal Auger Earth Boring
- Microtunneling
- Pilot Tube Microtunneling
- Pipe Ramming
- Horizontal Directional Earth Drilling

4.3.1 HORIZONTAL AUGER EARTH BORING

Horizontal Auger Earth Boring (HAB) is a more cost-effective and smaller scale pipe jacking method. This process involves jacking a steel casing from the driving pit or shaft, while removing the soil within the casing by means of a rotating auger flight. The rotating auger provides torque to the cutter head by the auger motor located in the pit. The cutter head is mounted to the front face of the boring machine and consists of multiple cutter blades. The earth is cut by using the rotation of the cutting blades provided by the rotating auger flight.

The front part of the auger flight is connected to the cutter head while the end is connected to the mover (Najafi, 2010: 16; Trenchless Technologies C.C., 2005b: online).

As the cutter head cuts into the earth, the soil is transported from the head through the rotating auger, within the steel casing, to the pit. The prime mover is located at the edge of the pit and provides thrust to move the steel casing, cutter head and auger flight forward. A bentonite line is installed around the steel casing to reduce friction around the casing and earth. The steel casing supports the soil within the tunnel. The final service pipeline is installed within this casing and the circular space is filled with grout. This method is often not steerable, but control and monitoring equipment can be added (Najafi, 2010: 16; Castro Facilitator, 2020: online).

4.3.2 HORIZONTAL DIRECTIONAL EARTH DRILLING

Horizontal Directional Earth Drilling (HDD) is a steerable method for the installation of new pipeline services. An HDD machine is a surface launched drilling rig. This process is not primarily performed by means of a conventional technique but uses high pressure or water jets that are connected to the bore head that causes a hydro-mechanical penetration into the ground (Najafi, 2010: 18).

Horizontal Directional Earth Drilling machines can be divided into these four groups, namely:

- Midi bore rigs
- Mini bore rigs
- Maxi bore rigs
- Mega bore rigs

Mini bore rigs

These machines are mostly used within the inner-city for the installation of pipes and cables. They are used within the city due to their small size and mobility. They also tend to have a lower noise output than the other machines. These size machines also require the least floor area and commonly operate on rubber caterpillar tracks, but can be manufactured without these tracks. The tracks can be omitted since this machine is easy to transport on a loading-bed truck (Willoughby, 2005: 17; Rig Worker, 2022: online).

Midi bore rigs

These machines tend to be a bit bigger. They are also used within the inner-city, but are suitable to drill underneath small rivers and environmentally friendly tasks. These machines are all manufactured with rubber caterpillar tracks, thus making them self-propelled and all-terrain (Willoughby, 2005: 20; Rig Worker, 2022: online).

Maxi bore rigs

These machines are used for greater bore lengths and for bigger diameters within the ground. These machines are more commonly used for pipeline systems that have to be drilled underneath rivers, and railway and road crossing systems (Willoughby, 2005: 19; Rig Worker, 2022: online).

Mega bore rigs

These machines are used for extremely long lengths that need to be covered and extremely big diameters that have to be drilled. They have been used by big leading companies in Eastern Europe and Asia (Rig Worker, 2022: online).

A Horizontal Direction Drilling system consists of the following components:

- The Main Drill System

The drilling system is known as the part of the machine that transmits the force and torque to the drill rods. The drilling system consists of a Bore rig, Slide drill and Supporting shields (Willoughby, 2005: 20).

The Bore rig is the under-part of the machine that consists of the engine for traveling motion (self-propelled) and an integrated hydraulic drive that is used for thrusting and pulling (radial and axial movement) of the rods (Skonberg & Muindi, 2014: 2).

The Slide drill is used to operate the drill rods. The drill rods are rotated forward and backwards parallel to the Bore rig. The Slide drill is mounted to the Bore rig and by using its rotational slide movement force, torque, pulling and pushing forces are exerted onto the drill rods, reamer or bore heads.

In the front of these machines are clamping jaws. The jaw system serves the purpose of holding the drill rods in place for screw connections and/or counter-functions. Thus meaning that the jaw system allows the operator to connect rods, if necessary, or allows him/her to loosen or fasten the drilling rods (Willoughby, 2005: 25).

Many HDD machines come equipped with supporting shields. As mentioned above, almost all of the machines are equipped with rubber caterpillar tracks that help the machine to remain in place. The Mini and Midi machines are equipped with front and rear supporting stilts, whereas the Maxi and Mega have hydraulically driven anchors (Willoughby, 2005: 25).

Since the Maxi and Mega bore rigs are not equipped with self-propelled engines, due to their size, they require a power supply unit. The supply unit is a diesel engine that is connected to the undercarriage system (lower part of the machine) that runs the entire HDD machine. This unit is usually purchased separately from the HDD machine and should be powerful enough to operate that entire machine (Willoughby, 2005: 25).

- Drilling Fluid Mixing System

This unit is normally not attached to the HDD machine itself; it is normally attached to a separate vehicle such as a truck. This is mainly done because the bigger the machine the more units it can require. There is no provision made for the enormous amount of space required by the fluid mixer on the HDD machine. The mixing fluid that is poured into the mixing unit is used for loosening the soil particles within the ground. This allows for easier drilling in harder rock/ground conditions and prevents the bore head from getting stuck. The fluid is pumped through the drill rods to the bore head or reamer, by making use of a mud pump (Willoughby, 2005: 25; Skonberg & Muindi, 2014: 5).

Pressure is used to pump the fluid through the drill rods that also causes the friction experienced by the drill rods against the borehole to be reduced and to reduce the temperature of the bore head. These systems usually consist of two tanks, but one tank system is not uncommon. Bentonite or Polymer is mixed with water within the two tanks. The mud pump only pumps one tank at a time until it is empty before moving on to the second tank. This allows the refilling of a tank without disrupting the process of drilling (Willoughby, 2005: 25).

- Drill Rod String

Drill rods are basically long hollow horizontal pipes that attach to one another by means of pressure exerted by the HDD machine. Several drill rods connected together are known as a drill string. The drill rods are used to transmit the power to the bore head or reamer, depending on which is attached. They also serve to transport the drilling fluid to the head of the drill string (Skonberg & Muindi, 2014: 7).

The drill rods that are used with the HDD machines are specially manufactured to withstand bearing loads, strain, compression, axial pushing and pulling forces. These drill rods have been specially manufactured to withstand bending forces. This is due to the drill path that has to be followed, which most of the time contains curves and bends due to unmovable objects or obstacles (Willoughby, 2005: 25).

Drill rods can either be connected using pressure or screwing one into the other. The connections of the rods are done by the turning action created by the engine. The Mini and Midi machines usually contain drilling rods of 3m long. The rods are special twin-drive percussive drilling rods that are capable of absorbing high loads. The Maxi and Mega machine has drilling rods that stretch up to 6m or even longer (Skonberg & Muindi, 2014: 8).

- Bore Head / Cutter head

The bore head is the tool, as mentioned, that is attached to the front of the drilling rods. This part of the machine serves to create the borehole and the tunnels within which the pipes or cables will be installed. The main purpose of the bore head is to concentrate the drilling fluid while cutting through the rock or soil. The drilling fluid allows the soil or rock to loosen the space between the particles by filling it with the liquid. Therefore, the whole drilling process is known as a hydro-mechanical loosening process.

There are a variety of bore heads used by Horizontal Directional Earth Drilling (HDD) machines. The type of bore head used depends on the ground conditions. Soil analysis must, therefore, be done beforehand and the ground conditions must be checked by a professional before starting to drill. The following types of bore heads are available (SASTT, 2017c: 14; Willoughby, 2005: 35):

- Bore heads that contain front nozzles
- Bore heads that contain front and rear nozzles
- Bore heads with attached welds
- Bore heads with metal plates or bits
- Bore heads with attached hard metal front drilling bits
- Bore heads with round shaft chisel bits
- Bore heads with screw-on metal plates
- Bore heads with rotating nozzles
- Bore heads with setting angles
- Bore heads with location/transmitter devices

These heads are mainly used for soil and soft ground conditions. They are used for pilot bores, backreaming and clearing and smoothing out boreholes. The following bore heads are used for drilling through rock formations.

- Three cutting blade chisels (Soft but solid rock).
- Conical toothed roller chisels (Medium rock formations).
- TCI (tungsten carbide) roller chisels
- Carbonados or PCD (diamond heads) chisels (Hard rock)

The type of rock bore head to be used depends on the type of structure, hardness, grain, nature, tectonic fault planes, inner fault planes and the compressive strength of the ground surrounding the drilling site or the ground formation trough, which the bore head must drill. These rock bore heads are also used within small stone, gravel, block debris, rubble, landfill and any other ground condition that contains hard components (SASTT, 2017c: 13).

- Drill Rod Magazine

The drill rods mentioned above have to be kept within a container for safety reasons, this container is known as the Drill Rod Magazine. The magazine box is connected to the slide drill. The slide drill grasps the drilling rods from the magazine and slides them into position. The slide drill then, either by rotation or pressure, attaches the rods to one another. Different types of drilling magazines can be found namely:

- Storage box
- Vertical boxes stacked on runners
- Wedge-shaped slide box
- Barrel magazine
- Spherical magazine
- Chain magazine

Even though the only purpose of the Drill Rod Magazine, is to stack the rods in place, the rods are kept securely in position by means of choosing the right sized magazine.

- Backreamers

Reamers or backreamers are used to increase the diameter of the borehole, after the bore head has created the borehole. The upsizing of the borehole is usually done in stages. This means using a bigger reamer than the previous one each time and doing so until the borehole is the correct diameter for the pipe or cable to be installed. Usually when the last reamer is to be attached, which is the correct diameter of the borehole to allow pipe installation, the smoothing reamer is attached. The smoothing reamer usually does not have any teeth or blades and only removes the remaining roughness and smooths out the borehole. This enables the pipes or cables to be installed easily and not to be damaged in any way. Attached to the smoothing reamer is a swivel followed by the pipe puller. The smoothing reamer indicates the end of the reaming process (Skonberg & Muindi, 2014: 9).

A wide variety of reamers exist namely:

- Stepped reamer: Pyramid shape
- Conical reamer
- Fly cutter
- Blade reamer
- Barrel reamer
- Round shaft reamer
- Removable blade reamer

All reamers, due to being exposed to such harsh ground conditions and forces, need to be equipped with protection.

- Detection and Data Collection Devices

The detection equipment is used to detect the bore head underneath the soil. This is usually done because the bore head gets stuck due to the soil consistency or the soil structure giving way. The position of the bore head is found due to a transmitter or wires within the bore head. The transmitter sends out an electrical pulse that is picked up by the detection device on the surface above the ground. The detection device then notifies or alerts the operator of the position of the bore head when directly above the head. There are two techniques used to determine the location of the bore head, namely, the Walkover techniques and Wire-cable technique.

- Walkover technique

The walkover technique allows detection and steerability of the bore head. Steel structures such as train rails, reinforcing steel bars, steel piping etc. can greatly influence the detection of the bore head and restrain the application of this procedure. A cylinder-shaped transmitter is used in this process. This device has to be calibrated with the detection device before it is supplied with power, this prevents the transmitter from detecting other steel material that might give off an electric-magnetic pulse. The transmitter has to be safeguarded against the forces and pulses experienced by the bore head. A bore head is equipped with specially made shock absorbers into which the transmitter is placed (Zhou, 2014: online).

A receiver (detection device), is used above the surface to locate the transmitter at the end of the bore head. The signal strength received by the detection device determines the depth of the bore head. The stronger the signal, the shallower the bore head is located to the surface. The detection device is equipped with a small LCD screen that determines and displays the exact depth of the transmitter. The data compiled by the receiver can then be sent to the operation panel on the HDD machine. This is done by radio signals that are sent between the two devices. The data on the operating panel can be used for referencing or analytical reports (Zhou, 2014: online).

- Wire-cable technique

The wire-cable technique entails a thin mono wire installed in the drilling rods. The wire is connected to the operating panel located on the HDD machine and runs through the drilling rods until it reaches the bore head. This technique is commonly used in extreme depths or under inaccessible obstructions. During the drilling of the pilot bore, every drill rod that is attached must first be connected to the inner cable to form a continuous connection (Zhou, 2014: online).

This method of bore head detection tends to be expensive, due to the elimination of the physical device, referred to as the receiver. The bore head with this technique has a different kind of detection transmitter attached at the end. The transmitter is a small device that determines the location, and measures the inclines and directional angles of the pilot bore (tunnel) created by the bore head. The transmitter and the bore head should be made of anti-magnetic steel. This steel tends to be very expensive and sensitive to loads (Zhou, 2014: online).

A magnetometer is used to pick up the electric-mechanical pulse created by the cables in the drilling rods. These wires send out these pulses due to the vibration forces caused by the drilling process. The cables receive the drilling pulses and convert it into stronger pulses that can be picked up by the magnetometer. This technique is also limited to the amount of steel or metal objects that are located close by, as they tend to interfere with the electro-magnetic pulses (Zhou, 2014: online).

Another way to detect the position of the bore head is by acquiring gyroscopic equipment. These machines can only be operated by specialists because they tend to be complex and expensive to operate. The wire-cable is a technique only used for difficult situations such as when is necessary to drill underneath big obstacles, like rivers, dams, houses or skyscrapers (Zhou, 2014: online).

- Transport and Power Supply Unit

The transport unit is the actual truck or low-bed that is used to transport the machine. Maxi and Mega drill rigs often require their own power supply unit. This is an operating panel connected to a power supply, similar to a battery pack. The power supply is a stand-alone unit that works as an inverter to supply power to the machines in remote areas (Rig Worker, 2022: online).

- Mud Recycling Unit

The recycling unit is a stand-alone unit separate from the Horizontal Directional Earth Drilling machine. The unit is a separate system that takes the used drilling fluid and separates the drilling fluid and solid soil particles. The used drilling fluid is pumped from the pilot hole into the recycling unit located on the surface. The recycling unit separates the fluid and soil particles. The particles are disposed of and the recycled drilling fluid is pumped back into the drill rig system for re-use. This reduces the running and operating costs for Horizontal Directional Earth Drilling projects (Rig Worker, 2022: online).

At the start of this method, a pilot bore must be drilled. The diameter of the pilot bore varies between 50 to 150mm. An HDD machine is located at the starting point of the pilot bore. The pilot bore is drilled using a bore head or cutter head attached to steel rods that rotate. The steel rods are located within a drilling magazine attached to the HDD machine. The rods connect by means of pressure. The pressure exerted on the cutter head pushes it forward and cuts the earth in a rotating motion. The drilling rods are connected, one after the other, thus increasing the length of the pilot bore. The pilot bore is drilled along a desired path and ends at the target pit. A bentonite slurry or mud mixture is pumped through the drill string to the cutter head nozzles to lubricate the drilling process (Bayer, 2005: 19; SA Drilling, 2020: online).

The bore head is removed and a reamer is attached to the end of the drill string at the target pit. The reamer is then drawn back through the pilot bore to the starting position. The pulling of the reamer to the starting point is achieved by reversing the rotating motion of the drill string. The reamer then enlarges the cross-section of the pilot bore as it reverses. The reamer then cuts and back draws all excavated soil to the starting point of the pilot bore. The reamer needs to be pulled to prevent disturbance to the soil and the collapse of the pilot bore. The reaming process can be repeated several times to get the desired diameter for the pipeline installation. When the reamer reaches the starting pit, it is removed, and the original cutter head and drill string is pushed back to the target pit. A larger diameter reamer is replaced with the cutter head and the reamer is pulled back again (Bayer, 2005: 20; SA Drilling, 2020: online; Rig Worker, 2022: online).

When the cross-section created by the reamer is the desired diameter, the pipeline can be connected to the back of the reamer. The pipe can then be pulled back to the starting point with the reamer. An internal pipe puller is connected to the reamer via a swivel. The swivel

prevents the pipeline from rotating with the reamer and drilling rods. The diameter of the pilot bore needs to be 30% larger than the diameter of the pipeline. It is only during the reaming process that the pipeline can be installed (Bayer, 2005: 21; SA Drilling, 2020: online; Water World, 2006: online).

4.3.3 MICROTUNNELING

Microtunneling (MT) is a miniaturised, remotely controlled form of pipe jacking. A MTBM is a smaller version of a TBM. The machine is a cylindrical-shaped machine with a rotating cutter head. The machine, followed by the pipeline or casing, is pushed forward via jacks to create a pilot hole. This method is used to install pipelines with a smaller diameter of 900mm or less. This method has an accuracy of 25mm in the vertical and horizontal alignment of pipes (FSTT, 2004: 32).

The microtunneling method requires the following components (Najafi, 2010: 22; Brightway, 2017:online):

- Drive Shaft – The shaft where the MTBM starts excavation and where jacking takes place.
- Exit Shaft – The shaft where the MTBM exits and is retrieved.
- Remote Controlled MTBM – Usually controlled from a control panel.
- Laser Guides – Guidance system to determine the trajectory of the pilot hole.
- Jacking System – The hydraulic jacks that push the MTBM and piping material forward.
- Slurry Pumping System and Recycling Unit
- Tanks
- Operation Boards
- Power Banks

4.3.4 PILOT TUBE MICROTUNNELING

Pilot Tube Microtunneling (PTMT) is an alternatively cost-effective method to the conventional microtunneling method. This method is also known as Guided Auger Boring or Pilot Pipe Jacking. It combines the accuracy of microtunneling, the steering of directional drilling and implements the soil removal system used by Auger drilling. The PTMT machine

has an auger and a guidance system attached to the main component of the machine. The guidance system consists of a camera attached theodolite with light emitting diodes (LEDs). This ensures accuracy of the line and levels for the pipeline installation. PTMT can be a cost-effective method for the installation of pipelines in softer ground conditions, driving distances of less than 100m and pipe diameters of less than 700mm. This method is implemented within house connections direct to sewer manholes. This method is also popular due to its success in shallow installations with smaller working space requirements and smaller jacking pits required (Najafi, 2010: 22; Water World, 2006: online).

The PTMT process starts with the excavation of the drive and receiving shaft. The shafts are usually 2m by 3m in width. The machine is lowered into the driving shaft by means of a hoist or winch. The machine is set on the exact line, gradient, angle and height from a control point within the shaft. The point is determined by using surveying equipment on the surface. The guidance system has a monitor screen and a theodolite with a camera attachment, that is independent from the jacking frame. The theodolite is set-up according to the height, grade and line of the new pipeline within the shaft. The first step involves installing a pilot tube in line with the centre of the proposed pipeline. The rotating steering head enters the wall of the driving shaft and is followed by a line of hollow sections of rods (Najafi, 2010: 22; Water World, 2006: online).

The soil is displaced to the side by a slanted face steering head. The hollow inside the stem of the pilot tube allows the camera to observe the LED target in the steering head to determine its position and orientation. This ensures the level and centre installation of the new pipeline. When the pilot head reaches the receiving shaft, a reamer with a diameter slightly bigger than the final service line is connected to the pilot tubes within the drive shaft. After the reamer, casings with an auger flight inside are installed. As the reamer rotates it cuts the soil and the soil is moved to the auger. The rotating auger transports the excavated soil from within the auger casing to the receiving shaft (Najafi, 2010: 25).

The excavated soil is removed from the driving shaft by a muck bucket or vacuum truck. As the reamer moves forward the pilot tube is lifted out of the receiving pit in sections by means of a hoist. When the head of the reamer reaches the receiving shaft, the product pipe is lowered into the driving shaft in sections. The sections of the product pipe are jacked forward in the pilot hole towards the receiving shaft. The auger casings are lifted out of the receiving pit as the product pipe pushes it forward toward the pit and takes its place within the pilot hole. This technique can also combine the product pipe and auger casing being jacked at

the same time. The auger casing is coupled inside the product pipe while reaming is taking place (Najafi, 2010: 25).

4.3.5 PIPE RAMMING

Pipe ramming is like horizontal auger earth boring. Pipe ramming is mainly used for the installation of service lines for roads or railway crossings. This method uses an air-compressor to hammer a steel casing inside the ground from a driving pit. The pipe is either hammered closed or open-ended. The energy from the percussion hammer that is attached to the end of the casing, drives the pipe through the soil. It does not create a borehole, but forces the casing through the soil (Najafi, 2010: 26; IMESA, 2017: 1; Trenchless Technologies C.C., 2005d: online).

For pipes up to 200mm in diameter, the leading section has a wedge or cone shape. This means the face is closed and the soil is compressed around the pipe as it is being rammed forward. There is no soil removal for a closed faced. This is also known as impact moling (Najafi, 2010: 26).

For pipe larger than 200mm in diameter, the face is left accessible, and a band is installed around the outer perimeter of the leading pipe. The band reduces the friction around the casing and reinforces the leading section of pipe. The guiding pipe cuts a borehole equal to the diameter of the band. The soil enters the pipe and is forced to the rear of the pipe. When longer lengths are required or more difficult ground conditions are encountered, a steel pipe is installed on top of the ramming pipe. The steel pipe supplies water, bentonite or drilling fluid to reduce friction or assist with the removal of the excavated soil. Adapters are used to connect different sizes of piping to the ramming device. After the installation of the adapters, lugs are welded to the pipe. They hold straps, chains or hoists linked to the ramming device in place (PE100, 2015; Trenchless Technologies C.C., 2005d: online).

After each section of the rammed pipe, another section is welded to form an interlocking chain. The procedure is repeated until the entire pipeline is installed. Cleaning the inside of the pipe and removing the excavated soil is done by high pressurised air or auguring. The size of the driving pit and the length of the rammed pipes are determined by the conditions of the project. If there is sufficient space available, the pipe can be rammed in longer sections. If the area is congested then smaller sections of pipe need to be rammed, which requires more time for welding the pipes together. If the line and angle of the pipe installation

are critical, the pipe can be supported using stands, launch cradles or platforms (PE100, 2015: online; Trenchless Technologies C.C., 2005d: online).

4.4 PLANNING A TRENCHLESS PROJECT

The consideration between the traditional method and using a trenchless method requires proper planning and a thorough investigation of the scope of works. The planning for utilising a trenchless method includes project clarification, project planning, project design, procurement of materials, construction and the close-out. During the planning phase it is important to determine the project size, complexity of the services, location, project duration, quality required, costs available and safety considerations (Crofts & Gyons, 2001: 10-15; IMESA, 2017: 7)

4.4.1 PLANNING PHASE

The planning phase involves determining the project objective, investigating the background of the project, identifying the risks, collecting data, evaluating the design and determining the best trenchless method to implement. Defining the scope of works is the most important part of the planning phase. The main component of a well-defined scope of works is understanding a client's requirements. Once the requirements have been established, the contractor can determine the scope of work needed to successfully meet the client's expectations (Nanan, 2020a: online; Crofts & Gyons, 2001: 10-15).

Defining the scope will determine the framework for various activities, namely:

- Schedule of Construction Activities.
- Project Programme.
- Resource Procurement.
- Budget Determination.

Determining the scope of works determines the amount of work to be done and prevents additional work outside the original project description (Najafi, 2010:242 ; Nanan, 2020a: online).

Background Assessment

This part of the planning phase involves assessing background factors that influence the project. A study of the ground conditions, access points and available space will determine the limitations of the methods to be considered for the project. The required specifications of the new pipeline will determine the proposed method to be used. The diameter, type of pipeline, services to be provided, the length of the network and the depth at which the pipeline needs to be installed should be considered and determined during the planning phase. These factors determine the type of trenchless method that can be implemented and the limitations of the method (Nanan, 2020a: online).

Screening of Alternatives

This part involves screening or analysing the proposed methods based on the background factors. During the screening process, applicable methods are analysed to determine their implementation success. A trial run of the proposed methods can be introduced to eliminate the non-potential methods and gather additional data (Nanan, 2020a: online).

Data Collection

This part involves gathering and collecting data that will assist in determining the best trenchless method for implementation. Other tests that can assist with determining the best method is surface surveying and a geotechnical investigation. A geotechnical investigation will assist in determining the soil capacity, shear strength, groundwater properties and moisture tolerance. This will assist in determining how the new pipeline will interact with the ground conditions (Crofts & Gyons, 2001: 10-15).

Data elements to consider (Nanan, 2020a: online):

- Site topography.
- Soil properties.
- Existing structures and obstacles.
- Location of existing utility lines.
- Site access and space available.
- Dewatering requirements.
- Drilling pressure.

- Subsurface forces.
- Depth of water table.
- Depth and diameter of pipe required.
- Drilling fluid needed.

Evaluation and Selection of Method

This part involves the analysing of the potential method and the introduction into the design phase. The data gathered during the planning phase is used for the design phase. The physical and structural properties required for the new pipeline should be considered during the evaluation. The clarification on the scope of works will assist the contractor in determining the appropriate method, equipment and resources to be utilised for achieving the project objective (Crofts & Gyons, 2001: 10-15).

4.4.2 DESIGN PHASE

Trenchless methods involve the study of structural and physical factors during the design phase. Design factors to consider for the new installation method include properties such as pipe thickness, material properties, structural properties and long-term performance. All methods have different design considerations and one method does not provide a solution for all drilling projects (Nanan, 2020a: online).

The design phase is dependent on the information available on the required flow rate, lateral connections, service depth and access points of the new pipeline. A utility survey can also assist with determining the location of existing services within the area. The design phase is dependent on the design done by the engineer. The detailed drawings provided by the engineer can provide the contractor with the necessary project information. The specifications and relevant information on the drawings could assist the contractor with implementing the correct method and execute a flawless network design. A layout of current service lines and nearby structures can assist with determining the design of the new pipeline (Nanan, 2020a: online).

The following activities need to be performed during design considerations (Najafi, 2010: 241):

- Utility Survey.

- Risk assessment plan
- Drawings and specifications
- Investigating of existing pipes.
- Investigating of site conditions.
- Entry and exit shaft requirements.
- Geotechnical Investigation
- Maximum allowable operating pressure
- Ground movements
- Quality control
- Cost estimation.
- Pressure, force and load calculations.

4.2.3 UTILITY SURVEY PHASE

A utility survey determines the presence of existing pipelines, utilities and structures. The engineer or contractor needs to determine the exact location of existing pipelines in order to reduce the risk of damage to a working service line or structure. The replacement or repair of the existing pipeline can increase the cost of a project or become an unforeseen risk (Najafi, 2010: 242).

Determining the location of existing service lines can (Nanan, 2020a; Crofts & Gyons, 2001: 10-15):

- Determine the location, size and depth of the entry and exit shafts.
- Reduce the damage to nearby structures or buildings.
- Enhances the safety of workers and the public.
- Determines the number and cost of service lines or structures that need to be repaired if damaged during the installation process of the new pipeline.

4.2.4 CONSTRUCTION PHASE

After the new pipeline has been designed and the specification has been agreed upon, construction can commence. The construction phase is the actual installation of the chosen

trenchless method. During the construction phase, there are factors that need to be considered by the contractor.

The following need to be considered during construction for a new pipeline installation (Najafi, 2010: 252):

- Traffic regulation plan.
- Quality control and assurance.
- Risk assessment plan.
- Health and safety
- Shoring of entry and exit shafts.
- Bypassing current or existing utility lines.
- Dewatering of the new service line.
- Manhole connections.
- As-built drawings.
- Contingency plan.
- Erosion and sediment control of the surrounding soil.
- Protection plan for existing service lines and structures.
- Construction monitoring reports.
- Field testing of all service lines during the entirety of the project.
- Site restoration and spoil material removal.
- Space allocation and machinery placement planning.
- Reinstating of services and operation inspection at close out.

During the construction phase, safety planning and disaster management needs to be implemented. The contractor needs to identify all risks and hazards associated with the project. Even though all trenchless methods reduce the exposure of workers to hazards, the entry and exit shafts need to be stable and the frames need to be able to withstand the pressure and force of the drilling rig (Nanan, 2020a: online).

4.2.5 CLOSE-OUT PHASE

The close-out phase involves the final evaluation of the new pipeline. This phase determines if the new pipeline delivers the services effectively and if the pipeline accomplished its

primary objective. This phase involves the testing of the new pipeline to ensure its structural, operational, quality and life expectancy have been achieved (Nanan, 2020a: online).

4.5 CHARACTERISTICS AND APPLICATION OF THESE METHODS

This section deals with the various new pipeline installations and their applicability to individual types of pipelines and utilities. Restrictions on the type of method to be implemented may include soil restrictions, experience of the contractors, the necessary equipment, costing, safety requirements and the feasibility of the method. Each project is different and professional knowledge in Trenchless Technology is required (Vaardini, 2015: online).

Table 6 shows the main characteristics of the new installation methods regarding different pipe diameters and specific applications for each method. The installation depths depend on the subsurface circumstances, the process used and the pipeline diameter. Other factors such as the type of trenchless machinery, operator's skills, project location, surface restrictions, adjacent structures and neighbouring utility or service lines can also influence the type of method to be implemented (Najafi, 2010: 31).

Trenchless Technology methods have several advantages over the traditional Traditional Method, including reducing traffic interferences, damage to road surfaces, noise and dust, as well as fewer safety hazards. While Trenchless Technology has many advantages, there are circumstances where the Traditional Method will need to be considered. Ground conditions where big boulders or rocks are present underground or the unknown location of existing service or utility lines can prevent the use of the trenchless method (Environmental Protection Agency, 2006: 2).

Table 6: Main Characteristics of New Trenchless Methods with Typical Application Thereof.

(Najafi, 2010: 32).

"Steel – Steel Casing Pipes; RCP – Reinforced Concrete Pipes; GRP – Glass Fibre Reinforced Plastic Pipes; PCP – Polymer Concrete Pipes; VCP – Vitrified Clay Pipes; DIP – Ductile Iron Pipe; PVC – Polyvinyl Chloride Pipes; HDPE – High Density Polyethylene Pipe".

Trenchless Method	Diameter Range (mm)	Length of Pipeline (m)	Max Depth (m)	Piping Material	Typical Application	Accuracy (mm)
Pipe Jacking & Utility Tunnelling	1000 – 3600	480 - 1060	Jacking Pit	RCP, GRP, Steel	Sanitary & Stormwater	+ -25
Horizontal Auger Earth Boring	100 – 1500	180	Pit Depth	Steel	Water, Sanitary & Stormwater, Gas, Electrical, Telecommunication	25-300
Horizontal Directional Earth Drilling	50 – 1500	180-1800	18-60	HDPE, Steel, PVC, DIP	Water, Sanitary & Stormwater, Gas, Electrical, Telecommunication	Varies
Microtunneling	300 - 3400	450	Shaft Depth	RCP, GRP, VCP, DIP, Steel, PCP	Sanitary & Stormwater	+ -25
Pilot-Tube Microtunneling	150 - 760	100	Shaft Depth	RCP, GRP, VCP, DIP, Steel, PCP	Water, Sanitary & Stormwater	+ -25
Pipe Ramming	100 - 3500	120	Pit Depth	Steel	Water, Sanitary & Stormwater, Gas, Electrical, Telecommunication	Varies

4.5.1 PIPE JACKING AND SERVICE UTILITY TUNNELLING

4.5.1.1 Advantages

Pipe jacking and service utility tunnelling can be done in all types of ground conditions with a high degree of accuracy. Since the workers are located at the front of the excavation face, they can see the type of ground conditions they are working in and can correct anything immediately. The front of the tunnel face can be inspected by a professional or visually using cameras. When unforeseen circumstances arise, they can be identified quickly and removed or rectified (Najafi, 2010: 33; Jain, 2022: online).

4.5.1.2 Limitations

Pipe Jacking and Utility Tunnelling are specialized fields of operation. This method requires a lot of planning and coordination beforehand. All directional changes are made within the shaft. With Pipe Jacking, the pipe should be able to resist the jacking force. Therefore, not all types of pipes can be used with this method. In Utility Tunnelling, the liner is a temporary structure, and the product pipe needs to be installed within this structure and the circular space filled with grout. This can be a costly and time-consuming method (Najafi, 2010: 36; Jain, 2022: online).

4.5.2 HORIZONTAL AUGER EARTH BORING

4.5.2.1 Advantages

The main advantage of this method is that the casing is installed while excavation takes place. The borehole is immediately encased and reduces the probability of a cave-in. It also reduces surface subsidence along the borehole. With the correct cutterhead and accurate implementation of this method, it can be used in a wide variety of ground conditions. This makes it a very versatile method (Najafi, 2010: 36; Midwest Mole, 2022: online; Smith, 2021: online).

4.5.2.2 Limitations

This method is usually unsteerable. Some basic steering systems can be implemented such as walk-over tools, to help achieve an accurate angle and line installation. This method can require entry points and receiving pits to recover the cutter head. To identify large rocks, very soft sand or very weak ground conditions can only be done by a thorough site investigation. The casing must be made of steel to assist the rotating auger on the inside. The steel casing can only accommodate rocks up to one third of its diameter. Large rocks can cause the casing to bend or a cave-in. The augers are used to remove excavated soil within the casing. If too much thrust force is applied at the front and not enough soil is removed, it can cause heaving. The welding of two segments of pipes may take several hours (Najafi, 2010: 36 ; Midwest Mole, 2022: online; Smith, 2021: online).

4.5.3 HORIZONTAL DIRECTIONAL EARTH DRILLING

4.5.3.1 Advantages

The biggest advantage of Horizontal Directional Earth Drilling is its steering capabilities. If the drilling head hits an obstacle in the drilling path, it can be retracted and guided on a new path around the obstacle. This system can launch from the ground, requires only a minor entry point and a small end pit. The time required for the initial set-up of this method is relatively shorter when compared to the other trenchless methods. This method can reach a single drive length of up to 1800 meters. It is the longest drive of any of the non-worker entry methods (Najafi, 2010: 37; SA Drilling, 2020: online).

4.5.3.2 Limitations

The disposal of the bentonite slurry used during the drilling process needs careful consideration and planning. A fluid recycling method can be used with this method to separate the soil cuttings from the slurry. Even though bentonite and certain polymers used with this method are not considered toxic, it is considered ethical practice to remove the drilling fluid from underneath the surface. The successful implementation of this method is determined by a thorough site and subsurface investigation. Corrective measures or backreaming, during the drilling process, can be very time consuming and lead to an increase in project costs. This method is known for causing ground movements in

geologically sensitive areas. The movement in the earth can cause the bentonite slurry to migrate away from the drilling path and into cracks in the surrounding area. Not upholding the fluid flow or pressure can cause the soil to collapse (Najafi, 2010: 37; SA Drilling, 2020: online).

A mini-Horizontal Directional Earth Drilling rig is a smaller, portable and more contained system, that can be used in smaller areas. The maxi-Horizontal Directional Earth Drilling rig is much larger and requires more working space. An investigation for workspace availability should also be conducted to determine the size of the rig that can be used (Najafi, 2010: 38; King, 2012: online).

The other limitation is the risk that the pilot bore can collapse in very granular soils such as sand. The steering abilities of this method become more difficult in loose soil particles. Horizontal Directional Earth Drilling and Horizontal Auger Drilling have the smallest pipe diameter installation range but can reach the longest installation length in a single drilling attempt (Najafi, 2010: 37; King, 2012: online).

4.5.4 MICROTUNNELING

4.5.4.1 Advantages

Microtunneling has the most accurate line and gradient tolerance for pipeline installations. This method can be implemented within very difficult ground conditions without expensive dewatering systems or pressurised air systems. Pipelines can be installed at great depths without having a significant impact on the overall project costs. The factor of depth becomes important when there is a higher water table and difficult ground conditions. The cost associated with the Traditional Method grows as the depth factor is taken into consideration. This method offers safety to the workers and operators, as they are not required to enter the tunnel, but can work at great depths. The main product pipe can be jacked without the need for a separate casing for soil stability (Najafi, 2010: 38; Brightway, 2017:online).

4.5.4.2 Limitations

This method is limited by the high capital cost of the equipment. A significant amount of money is required by companies to acquire the technology to implement this method. In order for this method to have a competitive price against other methods, the expensive

equipment should first be paid off by the bidding company. Therefore, companies have to take extra care when handling or maintaining this equipment (Najafi, 2010: 38; Brightway, 2017:online).

Even though these machines have strong cutting power, a boulder or solid piece of rock bigger than one-third of the machine's diameter will prove difficult to cut through. This increases the time frame of the project and leads to an increase in project costs. The cutter head can be damaged and will require replacement (Najafi, 2010: 38; Edge Underground, 2021: online).

4.5.5 PILOT TUBE MICROTUNNELING

4.5.5.1 Advantages

The set-up time required for this method is quicker when compared to the other methods. The technology used within this method is simple and it is quick for operators to learn the basic operations. The workspace required for this method is smaller than the conventional Microtunneling method. Since the technology is more basic compared to conventional Microtunneling, the capital cost for the equipment is more reasonable (Najafi, 2010: 38; PE100, 2015: online; Bruce, 2002: online).

4.5.5.2 Limitations

This method makes use of soil displacement rather than soil removal. Soil displacement can only be successfully implemented in ground conditions that allow for soil displacement and have voids within the soil structure. These types of soil have a higher risk of causing cave-ins with the pilot bore. The steerability of this method becomes more difficult as jacking distances increase. The decreased steerability along with the soil with bigger volume voids can cause the directional deviation of the pilot bore. This creates constraint forces on the joints of the drill rod connected to the reamer and can cause a crack in the drilling equipment (Najafi, 2010: 38; PE100, 2015: online; Bruce, 2002: online).

4.5.6 PIPE RAMMING

4.5.6.1 Advantages

Pipe ramming is the most efficient technique for installing pipelines and utilities under roads and railways. The adaptable shaft sizes, long drive lengths and the ability to implement it within a vast number of ground conditions makes this technique the most practical and economical for installing steel pipes. A single size pipe ramming machine with the air compressor can be used to install a variety of pipeline lengths and diameters. This method has also been used in the recovery of Horizontal Directional Earth Drilling and Microtunneling equipment (Najafi, 2010: 39; Nanan, 2020b: online; Meskele & Stuedlein, 2012: online).

4.5.6.2 Limitations

The biggest limitation for this method is the limited control over the line and gradient for pipeline installations. It is therefore important that the initial set-up of this method is planned beforehand and that the line and gradient is determined before ramming commences. The presence of obstacles such as hard rock, can cause the deflection of smaller pipelines. An adequate soil study needs to be conducted to determine the condition of the soil, which will assist in determining the size of the pipe casing. This method is known as a two-phase process and the welding of the two sections of steel pipes between ramming can be time consuming. Pipe ramming has a high noise level. Due to the high noise levels, this method can seldom be used in highly populated areas (Najafi, 2010: 39; Nanan, 2020b: online; Meskele & Stuedlein, 2012: online).

4.6 DRAWBACKS OF THESE METHODS

Trenchless methods reduce the negative impact of the Open Trench Method in terms of damage to surrounding infrastructure, but there are risks to consider. There are many risks associated with the trenchless methods mentioned in this chapter. These risks should be considered in the planning, design, pre-construction of the project and when deciding on the type of trenchless method to implement. Some risks can be reduced or mediated by the employment of experienced, qualified, certified and trained contractors. The general site safety is the responsibility of the contractor, but the consulting engineers also have a responsibility to assist with the proper method selection, provide accurate information and conduct proper soil investigations. The success of these methods depends on good

planning, appropriate design, thorough soil investigations, site inspections and the profile and alignment of the installation (Patel, Pitroda & Bhavsar, 2014: 3; The Pipe Shark, 2020: online).

The trenchless method uses machines to install service lines or pipelines blindly. The Open Trench Method disturbs the ground area while the trenchless method only disturbs the service zone. The structural design of pipelines or service lines requires calculations of deflection, buckling, and cracking that are based on the interaction between the soil and pipeline. The soil with the service lines forms an integral system. The project plan and specifications of the pipeline system can provide basic guidelines for the requirements of construction and installation, but the site conditions can fluctuate between different sites. These conditions need to be considered by the engineer and contractor. This can lead to alternative or additional construction considerations to be added to the original scope of works to address the unexpected conditions of the site. These additional considerations can have an initial cost implication on the budget of the project, but being aware of the consideration can reduce the risk of unexpected costs during the installation of the service lines. The trenchless method does tend to incur higher initial and professional costs than the traditional method (Patel, Pitroda & Bhavsar, 2014: 7-11; The Pipe Shark, 2020: online).

The biggest drawback of the above-mentioned Trenchless methods is the extremely high capital cost required. These methods rely on the implementation of technology, machinery and equipment. These components can be expensive. The other drawback would be the labour costs. While the traditional method can make use of more unskilled labour, this is not the case for the trenchless methods. These methods require skilled operators and engineers. The high equipment and labour costs can cause the traditional method to be considered in most cases (Patel, Pitroda & Bhavsar, 2014: 7-11; Drain, 2022: online).

The following are the basic risks associated with the installation of new service pipelines using trenchless methods for the entire project team (Najafi, 2010: 10; Vos, 2020: online):

- Pilot bore collapse.
- Ground or soil displacement.
- Creating large voids in the soil structure.
- Possible movement of sensitive buildings in the immediate area.
- Unavoidable obstacles in the pilot bore path.

- Drilling heads or equipment getting stuck below ground.
- The exact location and type of other utilities in the area.
- High maintenance and replacement costs during projects.
- Unexpected higher costs during installation.
- Higher soil studies and analysis costs.
- Increased specialist costs and machinery costs.
- Higher costs on small projects.
- Limited control over line and gradient.

The use of Trenchless Technology not only requires a good surveying plan, but also an understanding of the geological conditions and a basic understanding of the Trenchless Method to be implemented. The contractor needs a basic understanding of how the selected method excavates, removes the soil, installs the pipeline and knowledge of the required equipment. The contractor requires further skills in geotechnical engineering, material science, soil management, spatial management and programme management.

The design and installation of trenchless projects requires an understanding by the contractor of the involvement of risks. A risk can be defined as a chance or probability of an event occurring that exposes someone to a level of danger or harm.

Most risks associated with Trenchless Technology are engineering or human error. These risks can be controlled by implementing changes within the design or operation procedure. These primary risks have a cost implication for the contractor.

These costs involve providing payment for (Najafi, 2010: 41; Vos, 2020):

- Legitimate changes due to defective designs.
- Changed project conditions.
- Financial losses due to defective work caused by workers.
- Underestimating production rates
- Usage of incorrect equipment for the type of soil.
- Risk of damage to third parties.
- Injury or fatal casualties to workers or the public.

The initial calculation of capital and admin costs of the contractor might not include the full scope of the costs associated with the above-mentioned risks. These costs can affect the time programme or the finished product. They can also cause financial strain for the contracting company. The engineering skills required by the contractor are using the combined knowledge of science and technology to modify the environment for the benefit of everyone involved.

Eliminating all risks associated with the installation of new pipelines is practically impossible, but it is possible to limit the cost of the risk. This is done by lowering the probability of an event associated with these methods. Therefore, another important skill required by the contractor is Risk-Based Engineering. This involves considering the risk involved, the probability factor of that event occurring, and the cost associated with that risk. Since Trenchless Technology is an iterative process, secondary risks can stem from the mitigation methods selected to reduce the primary risk. These secondary risks have a new cost and probability factor.

Secondary risks to the contractor could possibly include (Najafi, 2010: 41; Bayat, 2020: online):

- Paving, road or rail reconstruction
- Existing utility replacement costs
- Cost of lost revenue
- Possible redirection of traffic flow

Many trenchless projects will not require Risk-Based Engineering due to the simplicity of the project. The decision to implement Risk-Based Engineering should be based on the value of the project and if the work is being conducted in an area with high value such as expensive residential areas, commercial districts or major infrastructures such as highways or railroads. Using Risk-Based Engineering does involve a detailed level of understanding of the implementation of all the trenchless methods and the limitations thereof (Doherty, 2017: 35).

As mentioned above, another drawback of new installation methods is the high maintenance costs. All these methods require constant repair and maintenance on the equipment and machinery. These methods are exposed and implemented within hard ground conditions and use centralised forces to move through the earth. The constant exposure causes general

deterioration of the cutter heads, frames and jacking equipment. The required repair and maintenance can influence the cost associated with the project or scope of works. These costs could determine if the traditional method would have been a more suitable alternative than trenchless methods (Doherty, 2017: 35).

Unavoidable obstacles within the drilling path is another drawback to consider or evaluate. These obstacles can cause equipment parts or machinery to get stuck underneath the earth's surface. Retrieving the equipment under the surface can create another risk for the contractor. The recovery can create unnecessary additional project costs. If the equipment or machinery cannot be repaired, replaced or retrieved; it increases the capital costs for the contractor on that project (Doherty, 2017: 35; Bayat, 2020: online).

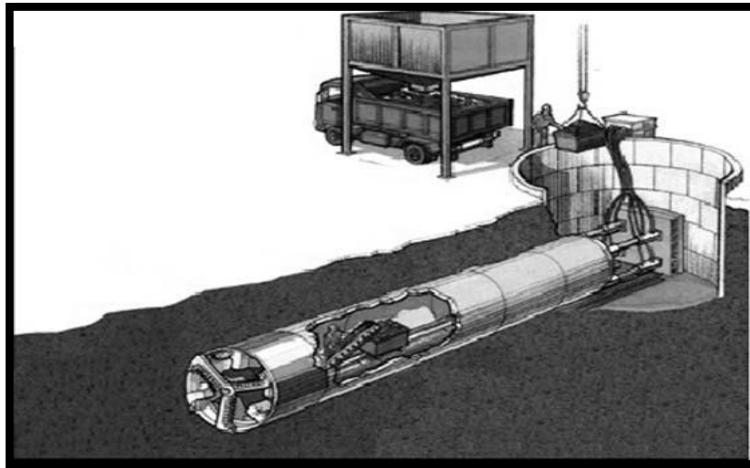


Figure 17: Conventional Pipe Jacking
(Najafi, 2010: 10).



Figure 18: Utility Tunnelling
(Water World, 2006: online).

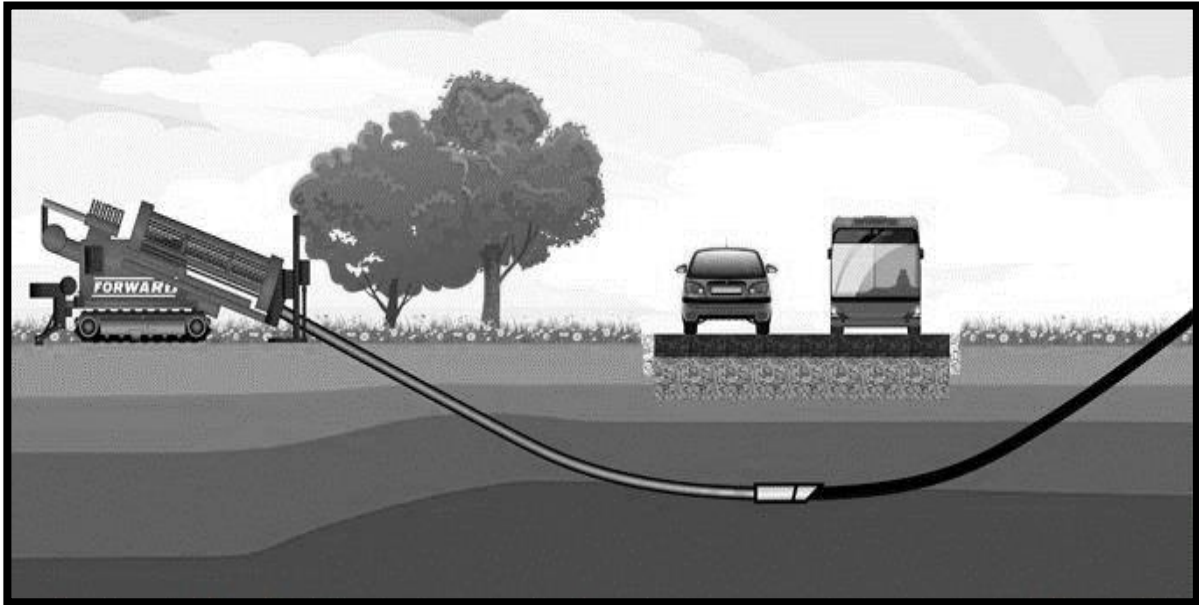


Figure 19: Horizontal Directional Earth Drilling
(SA Drilling: 2020: online).

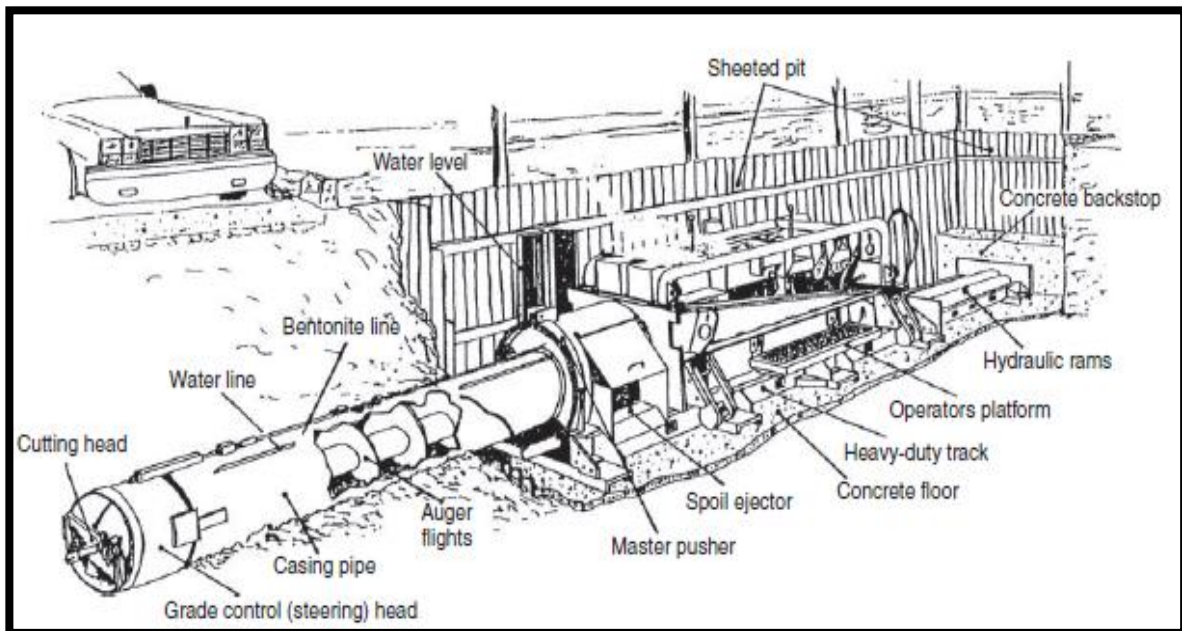


Figure 20: Horizontal Auger Earth Boring Machine
(Najafi, 2010: 17).

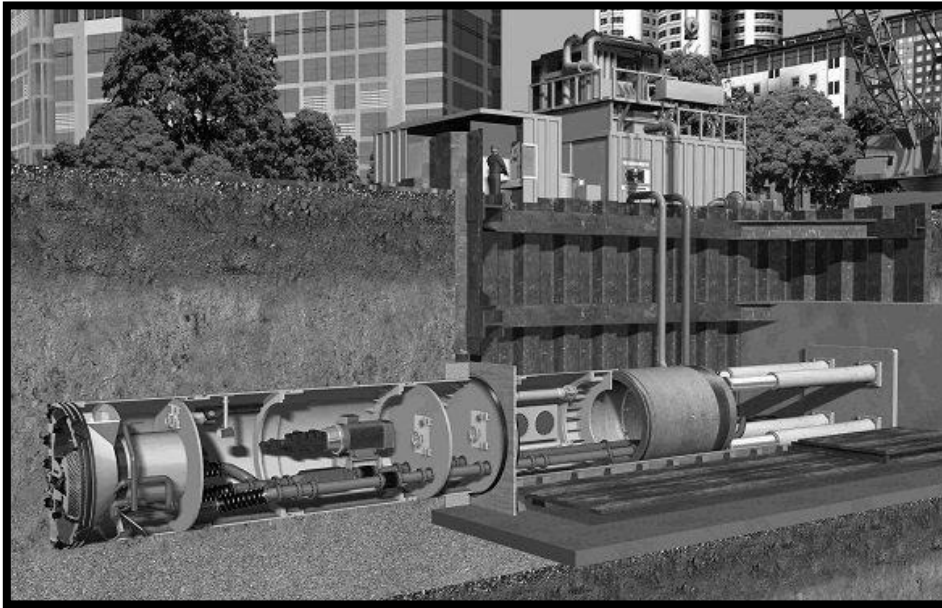


Figure 21: Microtunneling
(Brightway, 2017:online).

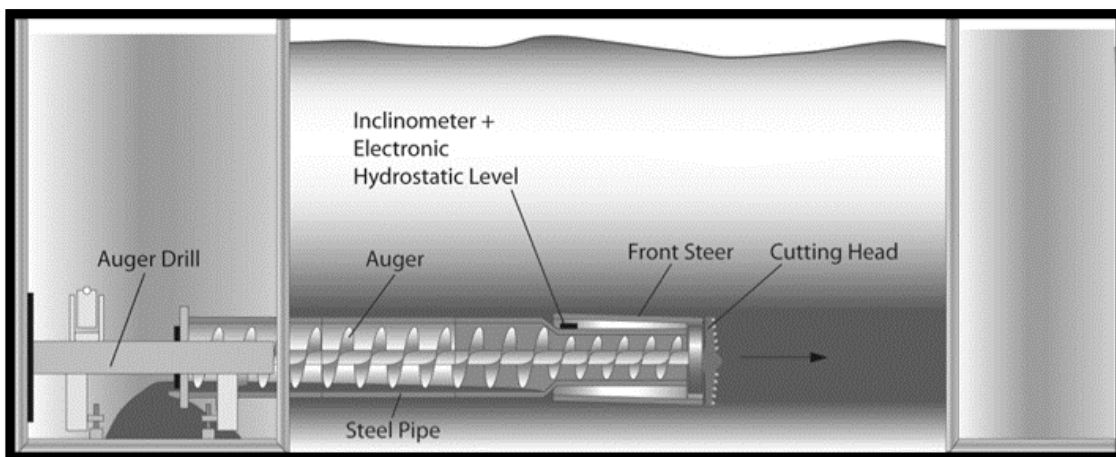


Figure 22: Pilot Tube Microtunneling
(PE100, 2015: online).

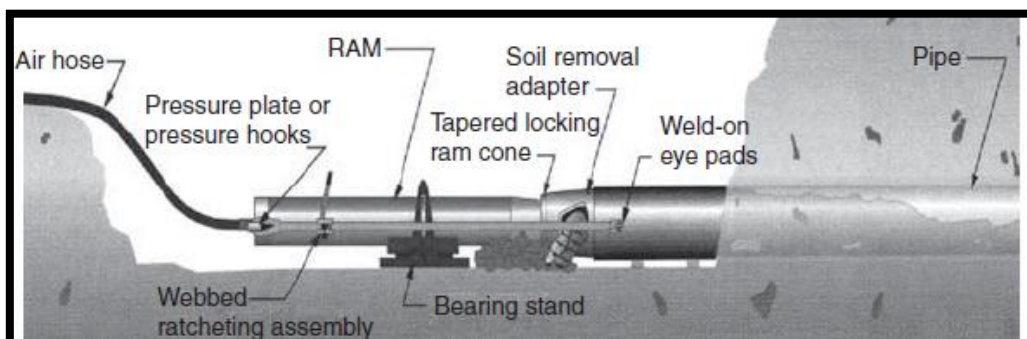


Figure 23: Pipe Ramming
(Najafi, 2010: 27).

4.7 SUMMARY

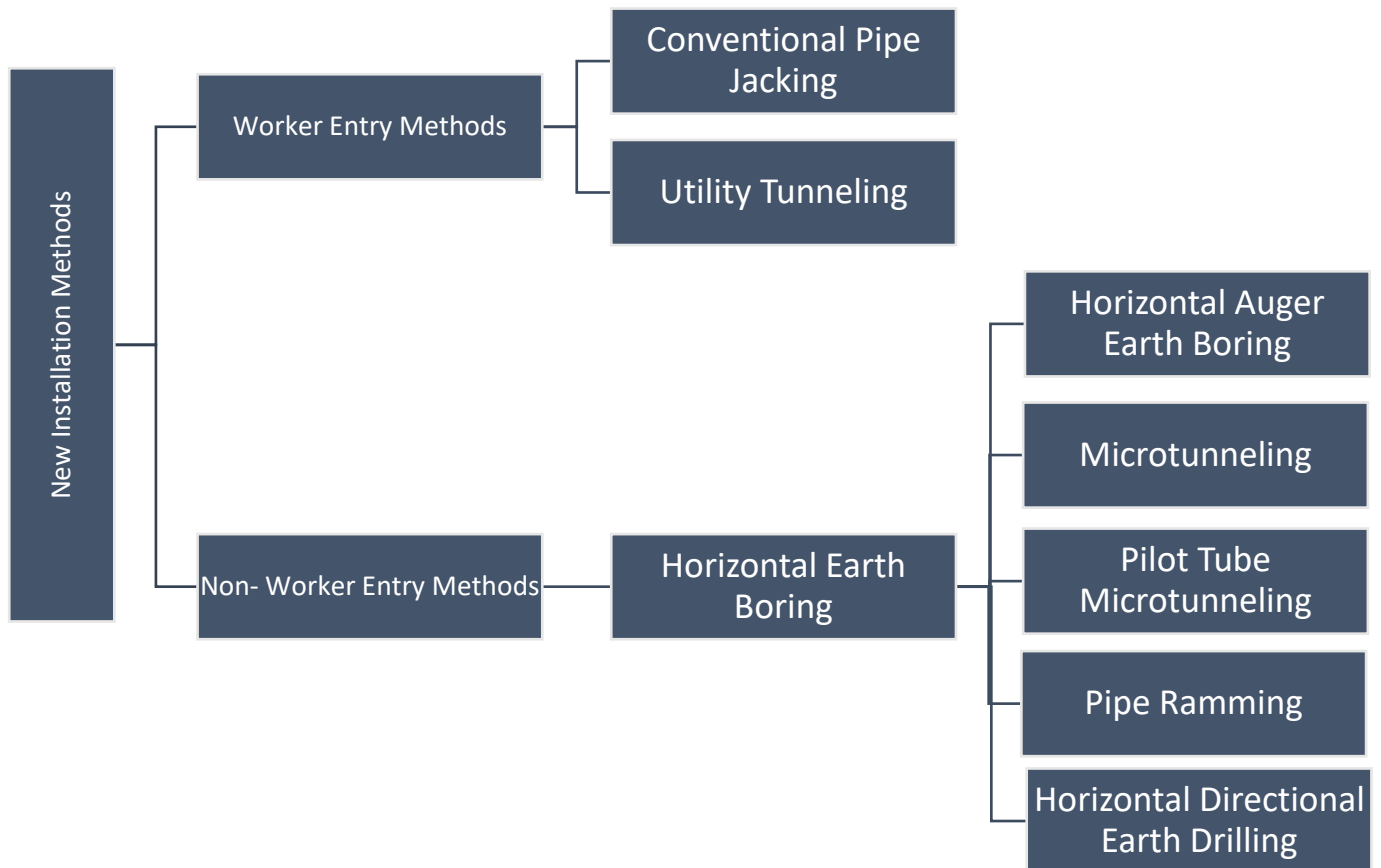


Figure 24: Summary of the Methods for New Installation of Pipelines

This chapter outlines the different trenchless methods used for the installation of new pipelines or utilities. Each method has their own limitations and advantages. The type of method implemented for the installation of new pipeline services is dependent on the project conditions. The type, diameter and lengths required for the pipeline will be the primary conditions. The secondary conditions will be project specifics such as space allocation, location, ground conditions, budget allocation, structural requirements, design criteria, surrounding infrastructure and existing utilities.

The design and operations procedure plays a vital role in the success of new trenchless projects. The contractor is dependent on the design team in order to mitigate or limit possible risks. The trenchless method requires the complete dedication and integration of the entire design team and main contractor compared to the traditional method. The trenchless method requires a higher capital, administrative and labour cost compared to the traditional method. The trenchless method requires a bigger scope of work to make it feasible.

The trenchless method can cover greater lengths within a better time frame. Both methods can provide the same quality for the final product. The possible deciding factor between the traditional method compared to the trenchless method will be the cost involved between the construction programme for the two methods.

The contractor carries the most risk for the entire duration of the trenchless project. Therefore, the contractor requires knowledge in geotechnical engineering, material science, soil management, spatial management, programme management and a basic understanding of all the trenchless methods. Using trenchless methods to install new pipelines is a specialised field.

CHAPTER 5: REPLACEMENT OF SERVICE PIPELINES

5.1 INTRODUCTION

This chapter outlines the methods and procedures for the rehabilitation and replacement of existing service lines. These methods are used in the application of sewerage pipelines, stormwater pipelines, water supply pipelines, and oil and gas pipelines. The type of method to be implemented depends on the specific conditions, limitations and capabilities of the existing service pipeline system or the rehabilitation project itself. The key things to consider before the implementation of any replacement method would be:

- The type and composition of the existing pipeline network
- The surrounding soil and earth conditions
- The rate of deterioration of the pipeline
- The most cost-effective method for the current application
- The plans for future pipeline applications
- Availability of specialised contractors and technology
- Project specifications

The primary methods for pipe rehabilitation and replacement can be categorized into three types, namely (Najafi, 2010: 52; Neenu, 2017: online):

- Pipe Cracking/ Pipe Bursting
- Slip Lining
- Cured-In-Place Pipes (CIPP)

5.2 PIPE RENEWAL AND PIPE REPLACEMENT METHODS

Pipeline renewal methods are used to upgrade, renovate or rehabilitate existing pipelines. Renewal methods (rehabilitation) are used to extend the durability of pipelines and replacement methods are used to replace existing pipelines without extending their initial durability (Aegio, 2018: online; Efrat, 2018a: 1)

The renewal process of existing pipelines can include anything from simply cleaning the network to total replacement. The increased work on existing networks within developed areas helps to introduce the rapid growth of trenchless rehabilitation. These techniques originated in Europe and Japan due to the older infrastructure and congestion of services (Efrat, 2018a: 1).

Renewal and replacement methods are known as on-line methods. Pipe renewal and pipe rehabilitation methods have the following advantages and limitations compared to new installation methods (Efrat, 2018a: 1).

Advantages:

- Avoiding the determination of a new path for the service line.
- The line is determined from the start, which reduces steering and control problems.
- Replacing damaged service lines and decreasing maintenance cost and time.
- Avoiding underground congestion of service lines by having too many newly installed service lines underground.
- Providing the possibility to install an alternative pipe or cable.
- Allowing for the upscaling of the service line's size or diameter

(Eysaman, 2020: online).

Limitations:

- Maintain the services of the existing line during replacement or renewal.
- Connections of the existing service line.
- The limitations on the pipeline material itself.
- Disturbances to adjacent utilities.
- Bypass of service supply will be required.
- Disruption of services during reconnection of old and new pipelines or services.
- Limitations to upgrading flow, pressure or size of the existing service.

(Najafi, 2010: 67; Efrat, 2018b: 1; Eysaman, 2020: online).

5.2.1 PIPE CRACKING/PIPE BURSTING

Pipe cracking or pipe bursting is a pipe replacement method. The method uses a hammer to break the inside of the existing pipeline and pushes the fragments into the surrounding soil. The new pipe is pushed or pulled within the broken pipeline simultaneously (SASTT, 2013b: 7; Trenchless Technologies C.C., 2005c: online).

There are four types of pipe bursting methods, namely (Najafi, 2010: 232; Eysaman, 2020: online; SASTT, 2013b: 9):

- Pneumatic Pipe Bursting
- Hydraulic Pipe Bursting
- Statical Pipe Bursting
- Insertion Method

Pneumactical Pipe Bursting

This method uses a soil movement hammer that is driven by a compressed air system. The cone-shaped head is hammered by a percussive action. Each percussive hammering action pushes the head forward over a short distance. The hammering head moves forward and breaks down the existing pipeline from the inside. There is an expander attached to the cone-shaped head. The expander with the percussive hammering pushes the burst existing pipe pieces into the surrounding soil. This creates a space to pull through the new pipeline. The expander can be attached to the front of the head or the back. The front end is used for pipes with a diameter of 300mm or less. The back end is used for pipelines exceeding this diameter.

An air-pressure hose is inserted through the new pipeline and connected to the cone-shaped head. The cone-shaped head is attached to the beginning of the new pipeline. A winched cable is inserted through the existing pipeline and attached to the front end of the head. The tension that is applied to the cable allows the cone-shaped head to keep its alignment within the existing pipe and be pressed against the inside wall of the pipe. It is therefore used as a guide. The air-pressure hose is connected to the air compressor and provides percussive hammering to move the head forward (Najafi, 2010: 231; Ariaratnam & Chan, 2005: online).

Static Pipe Bursting

This method uses a static pull system, where a large tensile force is applied to the cone-shaped head by a pulling rod or cable that is inserted through the existing pipe. The head uses the horizontal pulling force to break the inside of the existing pipeline and creates a space for the new pipeline.

Steel rods are introduced into the existing pipeline from the pulling shaft. The rods are screwed together until the line reaches the other excavated pit, known as the insertion pit. The head is connected to the rods and the new pipeline is connected to the back of the head. The hydraulic unit pulls the rods towards the pulling shaft. The rod sections are unscrewed, one by one, as they reach the pulling shaft again. The process is repeated until the head reaches the pulling shaft (Najafi, 2010: 233; Ariaratnam & Chan, 2005: online).

Hydraulic Pipe Bursting

This method moves the bursting process from the driving pit to the pulling shaft in sequences. The process is repeated until the existing pipe is replaced. In this method, a portion of the pipe is burst in two steps. The portion of the pipe matches the length of the bursting head. The front part of the bursting head is pulled through the existing pipeline and starts the first step of the bursting process. The back part of the bursting head is expanded in diameter and breaks down the existing pipeline even further. This is the second step. The bursting head is pulled onward with a hydraulic winched cable, which is inserted through the existing pipeline from the pulling pit. The cable is connected to the front of the bursting head and the new pipeline is connected to the back (Kramer, McDonald & Thomson, 1992: 128).

Insertion Method

This method uses a jack that pushes the new pipeline into the existing pipeline. The new pipeline consists of five sections that is known as a drive train. The first section is a steel guide pipe that maintains the alignment within the existing pipe. The second part is known as the cracker, which fractures the existing pipe and is followed by the third section, the cone expander. This attachment expands the fractured pipeline to the surrounding area. The fourth section is the hydraulic cylinder that acts as a front jack. It provides the horizontal thrust power in order to break apart or burst the existing pipe. The hydraulic cylinder has a pipe

adapter that links the new pipeline to the jack. The last section contains a lubricant injector that is connected to the pipe adapter. It injects lubricant such as polymer or bentonite around the circular space of the new pipeline. The lubricant reduces friction and allows the installation of the new pipeline within clay or difficult soil (Kramer, McDonald & Thomson, 1992: 129).

Flexible hose sections feed the lubricant from the lubricant system, through the new pipeline to the front of the jack. The jack uses the new pipeline as a support in order to advance the drive train. This method makes use of a jacking pit and a receiving pit. The new pipeline is jacked behind the drive train, piece by piece by the jacking frame located within the jacking pit. The process is repeated until the drive train reaches the receiving pit. The lead train is dismantled within the receiving pit as it reaches the pit (Kramer, McDonald & Thomson, 1992: 129).

Pipe bursting can be used for size-to-size replacement or upsizing the diameter of the existing pipeline. This method can be applied for pipes with a diameter range from 100mm to 1200mm and is used for pipe length of up to 120m in length. This is not the most suitable method for hard, closely compacted soil or soil located close to the water table. This method is more complicated when other utilities are located close by or the existing pipeline has collapsed underground (Kramer, McDonald & Thomson, 1992: 130; Trenchless Technologies C.C., 2005c: online).

Pipe bursting is the insertion of a cone-shaped drilling head into the existing pipeline. The base of the cone is larger than the diameter of the existing pipe and slightly larger than the diameter of the new pipe. This reduces the friction and provide space for controlling the hammer head. The back end of the cone is connected to the new pipeline and the front of the cone to a rod or cable. The hammer head and new pipe are launched from the starting pit and the cable is pulled from the end pit (Kramer, McDonald & Thomson, 1992: 129; Trenchless Technologies C.C., 2005c: online).

Pipe cracking or pipe bursting can also be performed with a normal HDD machine. The pipe reamer attached to the rod used for cutting the soil in new installation methods can also be used to cut an existing pipeline. The replacement pipe is then pulled though behind the reamer as it disintegrates the existing pipeline (Kramer, McDonald & Thomson, 1992: 130).

5.2.2 SLIP LINING

Slip lining is a rehabilitation method of inserting a smaller diameter pipeline or material lining within the existing pipeline. The angular space between the existing pipe and coating/ pipe is then grouted. This method is broadly used for the insertion of any lining or coating within the existing pipeline. The lining or coating can range from different types of materials. The insertion of a smaller diameter pipe within a larger diameter pipe is also known as Close-Fit Pipes (CFP) (SASTT, 2013a: 3; Trenchless Technologies C.C., 2005e: online).

This method is used for structural applications where the existing pipe has no joints or segments.

This method is simple and more inexpensive than the other alternatives. There are two types of slip lining methods, namely (Trenchless Technologies C.C, 2005e: online):

- Continuous Slip Lining Method – This involves accessing the deteriorated pipe at certain points along the path and inserting High Density Polyethylene (HDPE) or Polyvinyl Chloride (PVC) pipes.
- Segmental Slip Lining Method – This involves inserting segments of pipes with a flush joint sleeve.

Coating or lining is also a method of spraying a thin cement-mortar or polymer coating within worker-entry and non-worker-entry pipelines. The coating and lining used within this method can provide improved hydraulic properties and corrosion protection. The lining can improve the structural integrity of the pipeline and re-seal joints or connection point (SASTT, 2013a: 3).

There are four types of coatings and linings used within this method, namely (Najafi, 2010: 231):

- Cement-mortar
- Epoxy
- Polyurea
- Polyurethane

These four main types of coatings or linings can be used together. Even though slip lining can provide long-term strength, moisture can weaken the curing process. Moisture can be better controlled above-surface, but poses a problem for pipelines below the natural ground level. A lining should have a high moisture tolerance and the tolerance can be enhanced by making use of an epoxy primer.

Cement-mortar Linings

The lining is applied by making use of a rotating sprayer head that is connected to a hose. The hose is connected to a lining rig that uses air pressure to apply the lining to the inside of the existing pipeline. The lining rig moves through the existing pipeline at a constant slow speed. The thickness of the lining is directly dependent on the speed at which the machine moves within the pipeline. A uniform thickness is applied to the inside of the existing pipeline. After the lining rig, a drag towel machine follows, which provides a smooth finish to the lining. The smooth finish increases the hydraulic capacity of the existing pipeline, but causes a slight internal diameter reduction (Najafi, 2010: 106; SASTT, 2013a: 3).

Epoxy Linings

This lining is applied using the exact same method as with the cement-mortar lining, although the spray head and lining rig may differ slightly. Epoxy linings consist of two compounds, a base and a hardener. The two components are mixed together to form the final epoxy lining used in the rig. This lining is classified as a non-structural technique but reduces the corrosion of the existing pipeline. The corrosion of the existing pipeline can be significantly reduced if the pipe is cleaned properly and the epoxy lining is applied correctly (Najafi, 2010: 109; Advanced Pipe Repairs, 2019: online).

Polyurea

This method is applied using a spray head connected to a hose. The hose is connected to an air-pressure pump. The spray head and hose enters the existing pipeline.

This type of slip lining is rapidly growing due to its ability to reduce existing pipe moisture, infiltration of moisture and the installation speed. The combination of Isocyanate and Amine resin make up the components of Polyurea. This lining, unlike the other slip linings

mentioned, is highly flexible even though it is a hardening material. This lining is moisture tolerant and has a low viscosity. The low viscosity makes this liquid easier to pump and easier to apply to complicated spaces as directed by the spray head. The finished lining is hard, glossy and smooth when properly cured (Najafi, 2010: 110; Advanced Pipe Repairs, 2019: online).

Polyurethane

This lining is the exothermic reaction of poly-isocyanates and hydroxyl end-groups. This lining provides a fast curing process that can be implemented within cold temperatures and provides an unlimited build-up of layers. The lining is flexible and provides good abrasion resistance (Najafi, 2010: 113).

Table 7: Comparison of Slip Lining Methods
(Najafi, 2010: 115).

	Cement- Mortar	Epoxy	Polyurea	Polyurethane
Corrosion Protection	Limited	Limited	Effective	Effective
Pipe Cleaning	Scraper Method	Jetting / Scraper	Jetting / Scraper	Jetting / Scraper
Lining Environment	Wet Pipe	Dry Pipe	Dry Pipe	Dry Pipe
Typical Lining Thickness	4-12mm	2-4mm	2-5mm	2-5mm
Curing Time	24h	16h	1h	2h
Application Method	Mechanical or Hand	Sprayed	Spray	Spray
Curing Procedure	Moist curing	Temperature	Not Required	Not Required
Structural	No	No	Yes	Yes
Bonding to Piping Material	Good	Strong	Extremely Strong	Weakest

5.2.3 CURED-IN-PLACE PIPES (CIPP)

This is another rehabilitation process for existing pipelines. This method is a thermoset resin system that uses felt, fibreglass or polyester tubes of a certain thickness. After the existing pipeline has been thoroughly inspected and cleaned, the soft-impregnated tube is inserted by inverting the tube within the existing pipeline using air or water. An alternative method is pulling the tube into place within the existing pipeline by using a winch or cable. The tube is then inflated using air or water. The tube is then cured-in-place using hot water, steam or ultraviolet lighting. The tube forms a tight fit within the host pipe. The flexible fabric tube with the resin forms the primary structural properties of the new pipeline (Wessler Engineering, 2022: online; ESI Africa, 2012: online).

The resin can be divided into three groups, namely (Wessler Engineering, 2022; ESI Africa, 2012):

- Epoxy resin.
- Unsaturated polyester resin.
- Vinyl ester.

There are two basic methods used for Cured-in-Place installations:

- Pulled-in-place process
- Inversion process.

Pulled-in-Place Process

The tube is pulled through from an existing access point to the next access point. The tube is usually pulled by a power winch and water or air is then used to inflate the tube. The pulling force should not exceed the recommendation of the manufacturer. The pulling force creates extra friction between the tube and existing pipe. This can cause damage to the tube, especially at curves, offsets, connecting services or any other friction producing pipe conditions. The size and thickness of the tube should be taken into consideration (Wessler Engineering, 2022: online; ESI Africa, 2012: online).

Inversion Process

The impregnated tube is inserted through an existing access point and is installed using pressure. The volume of the water or air allows the tube to fully extend to the next access point. The speed of inversion should be controlled and pre-determined to prevent damage to tube. A temperature measuring device is placed at the access point to monitor the curing process (Wessler Engineering, 2022: online; ESI Africa, 2012: online; Trenchless Technologies C.C, 2005a: online).

Cured-in-place pipes provide the following:

- Chemical resistance.
- Good physical properties.
- Economic characteristics.
- Corrosion resistance.
- Structural properties.
- High temperature tolerance.

(Wessler Engineering, 2022: online; ESI Africa, 2012: online; Trenchless Technologies C.C, 2005a: online).

Cured-in-Place can be used for water, sewer, gas and electrical applications. The method restores deteriorated, leaking and outdated pipelines for a lifespan of about 50 years. The flexibility of the tube allows it to move around corners, filling cracks, bridging gaps and covering pipe defects (Wessler Engineering, 2022: online ; ESI Africa, 2012: online).

This method requires little to no digging and can be the quickest method for repairing pipelines. This method does not allow for the change in the diameter of the pipeline such as Slip Lining. According to Wessler Engineering (2022:online) a company that specialises in CIPP, this method is 40% to 60% cheaper compared to the Traditional Open Trench Method (Wessler Engineering, 2022: online).

5.3 PLANNING A TRENCHLESS RENEWAL/REPLACEMENT PROJECT

The consideration for using a renewal or replacement method, instead of doing a new installation, requires proper planning and evaluation of the current network. An existing pipeline system can have a few different defects. The defects can range from structural, operational to maintenance related. It is important to determine the type of defects during the planning phase (Draper & Scholvin, 2012: 12).

The process of planning for a renewal or replacement of an existing line includes the project clarification, project planning, project design, procurement of materials, construction and close-out. During the planning and design phase, decisions must be made regarding overall project size, complexity of the existing network, location, time available, quality required and the costs of the method (Najafi, 2010: 240).

5.3.1 PLANNING PHASE

Effective planning will ensure that the project meets the needs of the client. The activities involved in the planning phase are determining project objectives, investigating the background of the project, identifying the risk, collecting data and evaluating the design (Draper & Scholvin, 2012: 12).

Background Assessment

This section of project planning identifies and evaluates background factors that can influence the project. Collecting information on the ground conditions, surface access and available space is crucial for the beginning of the planning phase. The background assessment usually contains factors that determine the limitations of the methods under consideration. Existing pipeline installation information such as the age of the pipeline, type and class of the existing pipeline, diameter, infill material and compaction around the pipe can assist with determining these limitations (Najafi, 2010: 240).

Screening of Alternatives

This involves the screening of potential solutions based on the background factors and the needs of the client. Each available solution for the renewal or replacement method will be

analysed for its implementation potential. The screening process eliminates the non-potential methods and collects additional design data.

Data Collection

This activity involves gathering information required to screen alternatives. The data will be used for consideration during the design phase. Data that can be collected may include pipe, flow, subsurface and physical conditions of the existing pipe network. The data collection can be accomplished by CCTV, surface surveying or geotechnical investigations (Najafi, 2010: 240; GeoEngineers, 2022: online).

The Evaluation and Selection of The Method

This activity during planning, involves the final analysis of the potential renewal and replacement method and proceeding into the design phase. The data gathered during screening and data already known contribute to choosing a method of implementation (Draper & Scholvin, 2012: 15).

5.3.2 DESIGN PHASE

Pipe renewal or replacement involves a set of structural factors during the design phase. Design factors include groundwater, soil and traffic loads. The structural design of the new pipeline includes properties such as the pipe thickness, material capabilities, structural load resistance and long-term performance. Unfortunately, there is no single design consideration that can be used for all structural conditions for the design of a renewal or replacement method (Najafi, 2010: 241; GeoEngineers, 2022: online).

This phase starts with collecting information on the existing pipeline, the current or required flow rate, lateral connections, existing trench width and manhole locations. The design needs to include a utility survey of existing service lines in the area. The design phase is usually concluded by the engineer compiling drawings of the proposed rehabilitation project. The drawings should include specifications and all relevant information required by the contractor. Information includes the existing pipeline layout, surrounding environment, existing pipe diameter, existing pipe diameters and nearby utilities or structures. This

information is usually gathered by closed circuit television (CCTV) systems (Najafi, 2010: 252; GeoEngineers, 2022: online).

Two classifications describe the structural condition of the existing pipe:

Partially Deteriorated Pipe

This type of pipe can be defined as being cracked on the outside and corroded on the inside. The pipe has no missing sections in the main pipeline and can resist the existing loads and supporting the existing ground conditions. The chosen replacement or renewal method for a partially deteriorated pipe should be able to resist the load experienced by the groundwater and the pressure spanning across all the holes and cracks within the existing pipeline.

Fully Deteriorated Pipe

This type of pipe cannot support the structural load of the surrounding soil or reach the structural support needed after the implantation of a renewal method over its lifetime. Fully deteriorated pipe has sections missing, and has lost its original form or collapsed (GeoEngineers, 2022: online).

5.3.3 UTILITY SURVEY PHASE

The presence of existing pipelines, services and structures have a substantial impact on the success of replacement methods. It is important for the appointed engineer to attempt to identify and locate the existing utilities as accurately as possible. The exact location of the existing service lines and structures will only be identified during the construction phase.

The recognition of existing utilities is critical for:

- The location of the existing service lines may affect the location of entry and exit shafts.
- Reducing the damage done to the existing services due to the implementation of the renewal method.
- The presence of certain types of existing utilities will limit the use of pipe bursting as an alternative method.

- Reduces the risk of injury to workers and the public by avoiding damage to existing structures.
- The contractor to determine the number of utilities that could be exposed and will need to be restored or repaired if damage occurs.

5.3.4 CONSTRUCTION PHASE

After the completion of the design phase, the selection of renewal or replacement method is implemented and construction commences. The construction phase refers to the actual installation or implementation of the chosen rehabilitation or replacement method. During the construction phase, there are a few considerations that must be considered by the contractor. The following need to be considered during the construction (Illko & O'Shannesy, 2021: online):

- Traffic control requirements
- Quality control and assurance
- Risk assessment plan
- Downtime limits and service reinstatement requirements of the existing utilities
- Erosion and sediment control
- Protection plan for existing service lines and structures
- Construction monitoring reports
- Field testing of all service lines during the entirety of the project
- Site restoration and spoil material removal
- Space allocation and machinery placement planning
- Reinstating of services and operation inspection at close out

5.3.5 CLOSE-OUT PHASE

The close-out phase during a replacement/ renewal method refers to ensuring the new pipeline provides the necessary services effectively and that it is working properly. The new pipeline needs to be properly sealed or enclosed to prevent leakage into the surrounding soil and all defects need to be addressed. This phase involves the testing of the new pipeline to ensure its structural, operational, quality and life expectancy have been achieved.

(Illko & O'Shannesy, 2021: online).

5.4 CHARACTERISTICS AND APPLICATION OF THESE METHODS

Renewal and replacement methods are used to reline, rehabilitate, upgrade or renovate existing pipelines. These methods can also be used to change the physical properties of the existing pipeline and are done in situ. The main advantage, the renewal method has over the replacement method, is that open trench excavation is limited or non-existent. Pipe bursting is more cost-effective when the existing pipe has too many structural failures, additional capacity and flow are required or there are fewer connections to be reconnected.

Replacement methods still have a greater advantage over the traditional open trench excavation method for pipe replacement. Even though pipe bursting or pipe cracking still requires an entry and end shaft, it is still considered more cost-effective since it moves faster, is more efficient and less expensive. The replacement method is effective with sewer pipelines, due to the depths at which these pipes are installed (Najafi, 2010: 54).

The application of renewal or replacement methods can be summarised (See Table 8 & Table 9).

Table 8: Specific Applications for Renewal and Replacement Methods
(Najafi, 2010: 54).

	Method	Joint Complications	Corrosion	Cracks/ Holes	Infiltration & Exfiltration	Structural Complications	Inadequate Load Resistance	Extension of the Life of Existing Pipe
Renewal	Cured-in-place	Minimal	Yes	Yes	Yes	Yes	Minimal	Yes
	Slip Lining	Minimal	Yes	Yes	Yes	Yes	No	Yes
Replacement	Pipe Bursting / Pipe Cracking	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 9: Main Characteristics of Renewal and Replacement Methods with Typical Application thereof
(Najafi, 2010: 55).

	Method	Diameter	Max Spanning Distance	Material	Applications
Renewal	Cured-in-place	100mm – 2 700 mm	900 m	Resin Fabric	Gravity & Pressure Pipelines
	Slip Lining	100mm – 2 500 mm	300 – 600 m	HDPE, PVC, GRP	Gravity & Pressure Pipelines
Replacement	Pipe Bursting / Pipe Cracking	100mm – 1 200 mm	450 m	HDPE, PVC, DIP, GRP	Gravity & Pressure Pipelines

5.4.1 PIPE CRACKING/PIPE BURSTING

5.4.1.1 Advantages

This replacement method can have a considerable saving on social, traffic or road costs. This method improves productivity and causes less of an impact on business and environmental factors. The elimination for deep excavation for repairing the existing pipeline can reduce costs for the maintenance of existing pipelines.

5.4.1.2 Limitations

This method still requires the excavation of an entry and exit shaft, such as with all trenchless methods. There might be additional excavation where connections or points need repairs. A collapsed pipe may also require excavation to pull through the pulling cable or rod. Soil that is very expansive within a small time frame can also make pipe bursting or pipe cracking more difficult.

5.4.2 SLIP LINING

5.4.2.1 Advantages

The lining within the newly rehabilitated pipe can increase the flow capacity of the existing pipe. The lining can provide protection against future corrosion and protect the existing pipeline against further deterioration. There is a limited reduction in the diameter of the pipe (Farr, 2005: online).

5.4.2.2 Limitations

The inside of the existing pipeline must be dry and free of any standing liquid or fluids. This method does not enhance the structural resistance of the existing pipeline. The complete cure time for the linings can reach up to 16 hours on long spans. Corners and bends within the existing pipelines can cause difficulties (Farr, 2005: online).

5.4.3 CURED-IN-PLACE PIPES (CIPP)

5.4.3.1 Advantages

The resin-impregnated tube increases the flow capacity of the pipeline and also assists with preventing corrosion. This method works with almost all types and classes of pipes. This method has less excavation than the traditional method or the replacement method. The resin tube is stronger than the epoxy used within the slip lining.

5.4.3.2 Limitations

The CIPP method will not be effectively installed when the entire existing pipeline has collapsed. The collapsed pipe or section can prevent the air or water within the tube from passing the boundaries within the existing pipeline. This method does not correct any structural defects. The installation process of the CIPP method must be perfectly installed to provide effective repair. Multiple access points within the existing pipeline are therefore required for successful implementation.

5.5 DRAWBACKS OF THESE METHODS

Trenchless replacement methods have drawbacks that impose a great risk on a project. Replacement methods are dependent on a lot more factors than new installation methods. The ground conditions, groundwater conditions, the type of pipe to be replaced, the depth of the current pipeline and the availability of experienced contractors (Farr, 2005: online; Heinselman, 2016: online).

Even though replacing an existing pipeline could be proven to be an easier installation compared to a new pipeline installation, this is not always the case. Replacing an existing pipeline requires extensive soil and groundwater investigation and research. This involves gathering the necessary technical information on the soil and subsurface. This information is used during the design phase and determines the trench layout, infill material and the compaction, which is important in determining the best method for implementation. These soil investigations include soil boring, standard penetration tests (SPT), groundwater level determination, trench layout and trench infill material classification. These tests and studies acquire additional costs for replacement methods and can cause a bigger drawback than the new installation methods (Farr, 2005: online; Heinselman, 2016: online).

Ground movement is a big risk associated with replacement methods. Replacement methods are commonly used for one-size upsize above the diameter of the existing pipe. Larger upsizing results in greater ground movement compared to new installation methods. It is important to consider project environments, depth of the installation and ground conditions when replacing a pipe. Other factors include expansive soils, and collapsed pipe segments, concrete encasement of pipes and sleeves. Adjacent utility lines can also cause drawbacks (Farr, 2005: online; Heinselman, 2016: online).

A risk assessment needs to be completed for the preferred replacement method. The unknown subsurface conditions cause the most risks associated with underground pipeline construction. The main risks of replacement methods are the damage to nearby utilities, failure to conclude the project with the preferred method of replacement and time or budget overruns. The damage to nearby utilities and facilities increases under adverse ground conditions, design faults, incorrect location of the initiation of the replacement method and improper construction techniques (Farr, 2005: online; Heinselman, 2016: online).

Other risks associated with this method are:

- Bursting or lining of the curve
- Point repairs with the existing pipeline
- Excessively long bursting or lining lengths
- Collapsed replacement pipe
- The presence of nearby utilities and facilities
- Ground movement tolerance of the area
- Reduced safety risks to operators and workers
- Minimal or no machinery methods
- Working space available for method
- Flow bypass system required
- Discharge or dewatering required
- Shaft depths and requirements for replacement method
- The line and grade of the existing pipeline

Replacement methods can be performed successfully and safely since there are well-known solutions to all the above-mentioned risks and problems. Therefore, the development of a

risk management plan is needed to address the risks. The plan includes the quantification of the event happening and the degree of impact. It includes the measures to eliminate, mitigate or transfer the risks (Farr, 2005: online; Easy-Sight, 2020: online).

Replacement methods tend to be faster, more efficient and have fewer social costs than new installation methods. The replacement method causes less traffic disturbances, less social interruptions and less environmental instabilities. The limitations of replacement methods are far more than new installation methods. The replacement methods can only be implemented within a limited scope of works, certain depths, limited diameter and restricted pipe lengths (Farr, 2005: online; Easy-Sight, 2020: online).



Figure 25: Slip Lining Process
(Najafi, 2010: 107)



Figure 26: Cured-In-Place Process
(Najafi, 2010: 58)

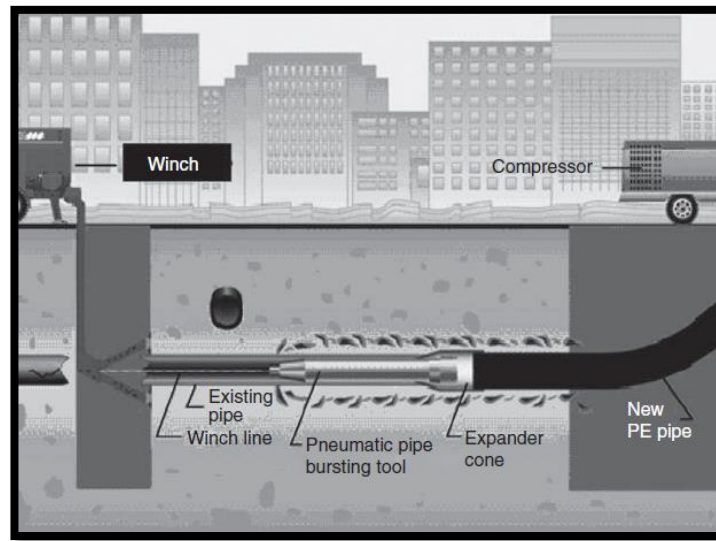


Figure 27: Pipe Bursting
(Najafi, 2010: 64).

5.6 SUMMARY

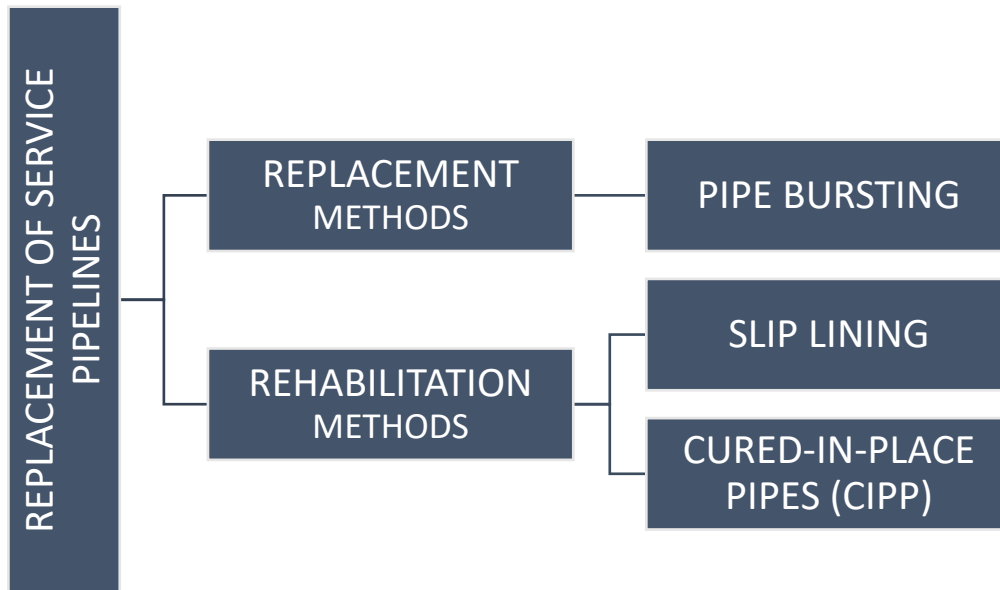


Figure 28: Summary of the Methods for Replacement of existing pipelines

This chapter outlines the different methods used for the replacement and rehabilitation of existing pipelines. These methods might prove to be more efficient and faster compared to new installation methods. Replacement methods have more limitations, which means the implementation of these methods are limited within a certain scope of works. Replacement and rehabilitation methods are considered the newer methods within Trenchless Technology. From this chapter, it is clear that replacement and rehabilitation methods could play a vital role in the maintenance and upgrading of existing pipeline networks. Pipe Bursting is a method that is favoured above the other methods, as it replaces the entire network with a new pipeline system.

PART 4: DATA COLLECTION

CHAPTER 6: THE FINANCIAL AND ECONOMIC IMPACT OF TRENCHLESS TECHNOLOGY

6.1 INTRODUCTION

This chapter outlines the data collection and data analysis of the empirical study. As discussed in Chapter 2, the empirical study was accomplished by questionnaires that were handed to a group of professionals. The group of respondents form part of the Southern African Society for Trenchless Technology (SASTT) and represent the professionals within the field. The questionnaire created the opportunity to collect data and compare it to the information gathered within the literature review (Bhandari, 2022: online).

6.2 DATA COLLECTION

The aim of the questionnaire was to attempt to answer the research question and meet the research objective. The questions were pre-determined and aimed to obtain the knowledge and contribution of each respondent. The answers were used as numerical data to determine the final recommendation of the research study. The questionnaire was sent to 40 respondents and 20 respondents completed the survey. This is a completion rate of 50%, but one respondent was disqualified from the research study, therefore the final completion rate was 47.5% (Bhandari, 2022: online).

6.3 DATA ANALYSIS

The data collected from the questionnaire was analysed to answer the research question. The questionnaire was divided into seven parts, namely:

- Part 1 – This section determined the general information and statistics of the group of respondents. It determined the general characteristics and information of the participating respondent group.
- Part 2 – This section determined the financial viability of new pipeline installations.
- Part 3 – This section determined the financial viability of renewal and replacement methods.

- Part 4 – This section determined the important specifications during a project.
- Part 5 – This section determined the financial aspects of the traditional method.
- Part 6 – This section determined the financial aspects of Trenchless Technology
- Part 7 – This section determined the preference between the traditional method and Trenchless Technology.

The survey started by requesting that the respondents voluntarily grant their permission to participate in the anonymous survey. They further agreed that the purpose of the research had been explained to them and the information they provided would be kept confidential. They agreed to the academic publication of the results. The table below represents that 19 respondents agreed to the terms of the survey. One respondent was disqualified due to not agreeing to the terms of the survey. The results of this respondent were not included in the results.

Table 10: Voluntary Permission of Each Respondent

Answer Choices	Responses	
Yes	100,00%	19
No	0,00%	0
	Answered	19
	Skipped	0

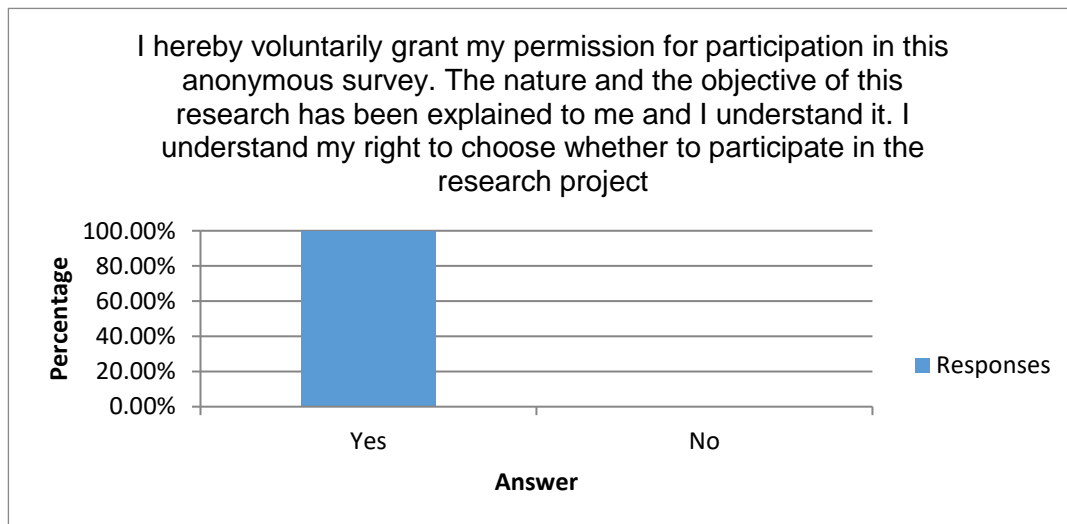


Figure 29: Answer for Voluntary Participation

6.4 PART 1: GENERAL INFORMATION

6.4.1 Q1 – PROFESSION

This determined the professional field in which the respondents were involved. The table below represents the actual answers given by each respondent. The results show that 11 respondents were involved in the field of Trenchless Technology. The other eight were involved in the field of Civil Engineering. This means that 57.89% were involved in the field of Trenchless Technology and 42.11% were involved within the Civil Industry at the time the survey was taken. The majority of the respondents were involved in the field of Trenchless Technology.

Table 11: Q1 - Results of Respondents - Profession

	Profession:
	Open-Ended Response
1	Chief operating officer
2	CCTV Pipe inspector
3	HDD & Microtunneling specialist
4	Site agent
5	Estimator
6	Construction Health and Safety Manager
7	National Sales Manager
8	HDD Operator
9	Trenchless Tech Business Owner
10	Pipe lining manufacturer training provider
11	Civil Engineering Technologist
12	Civil Eng.
13	Horizontal Directional Earth Drilling and Civils
14	HDD Contractor
15	Trenchless Tech Business Owner
16	Civil Contractor
17	Civil Engineer
18	Horizontal Directional Earth Drilling
19	Civil Engineering

6.4.2 Q2 – YEARS OF EXPERIENCE

This question determined the average year of experience of each respondent. The average years of experience was 20.63 years. The lowest value of experience was three years and the highest was 50 years of experience. When the experience of each respondent is compared to their corresponding profession in Question No. 1, the highest and lowest years of experience belong to the Civil Industry. The highest total years of experience of 201 years, belonged to the Trenchless Technology profession. The Civil Industry had a sum of 191 years of experience in total.

Table 12: Q2 - Results of Respondents - Years of Experience

	Years of Experience:
	Open-Ended Response
1	26
2	15
3	28
4	3
5	10
6	11
7	16
8	12
9	15
10	25
11	50
12	30
13	17
14	19
15	11
16	40
17	20
18	17
19	27

6.4.3 Q3 – SECTOR OF CONSTRUCTION

This question determined the involvement of each respondent within the sectors of construction. The respondents could select multiple answers, as they might have specialised in different fields. All respondents answered the question. Most of the respondents were involved in the field of Civil Construction at 83.33%. The involvement of respondents within the Development and Mining Sector was the lowest at 5.56%. The Construction industry showed an involvement of 33.33%. The other sectors of construction included the Trenchless Technology industry at 33.33%.

Table 13: Q3 - Results of Respondents - Sector of Construction

In which sector are you currently involved?		
Answer Choices	Responses	
Building Construction	33,33%	6
Civil Construction	83,33%	15
Development	5,56%	1
Mining	5,56%	1
Other (please specify)	33,33%	6
	Answered	19
	Skipped	0

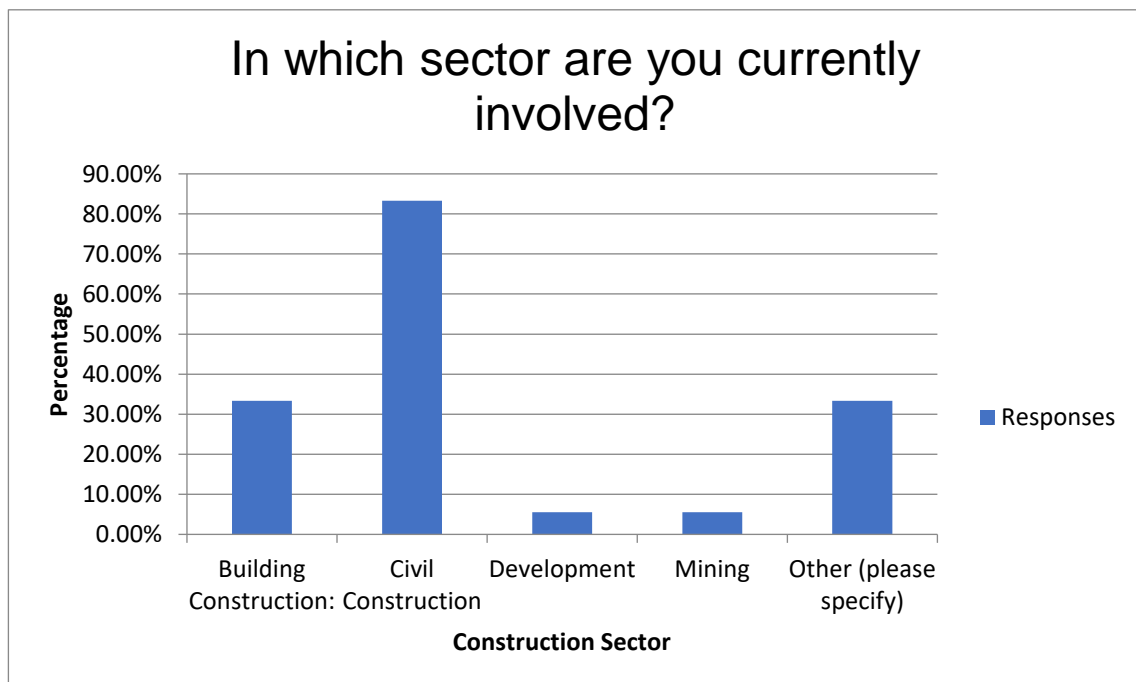


Figure 30: Q3 - Results of Respondents - Sector of Construction

6.4.4 Q4 – GEOGRAPHICAL LOCATION

This question determined the geographical location of each respondent. This question assisted with determining in which provinces Civil Works was the most common and determined the extent of the implementation within South Africa. The respondents could choose multiple selections. The most common provinces were Western Cape at 77.78% and Gauteng at 61.11%. The provinces of Kwazulu-Natal and Eastern Cape were tied at second with 38.89%, followed by the Free State and North West at 27.78%. The rest of the provinces made up the remaining 22.22% of the geographical locations. There were 27.78% of respondents that claimed they did work outside of South Africa. These locations were mainly focused within Africa.

Table 14: Q4 - Results of Respondents - Geographical Location

In which geographical location(s) are you based or have done Civil Projects?		
Answer Choices	Responses	
Gauteng	61,11%	11
Free State	27,78%	5
Limpopo	22,22%	4
North West	27,78%	5
Northern Cape	22,22%	4
KwaZulu - Natal	38,89%	7
Eastern Cape	38,89%	7
Mpumalanga	22,22%	4
Western Cape	77,78%	14
Other (please specify)	27,78%	5
	Answered	19
	Skipped	0

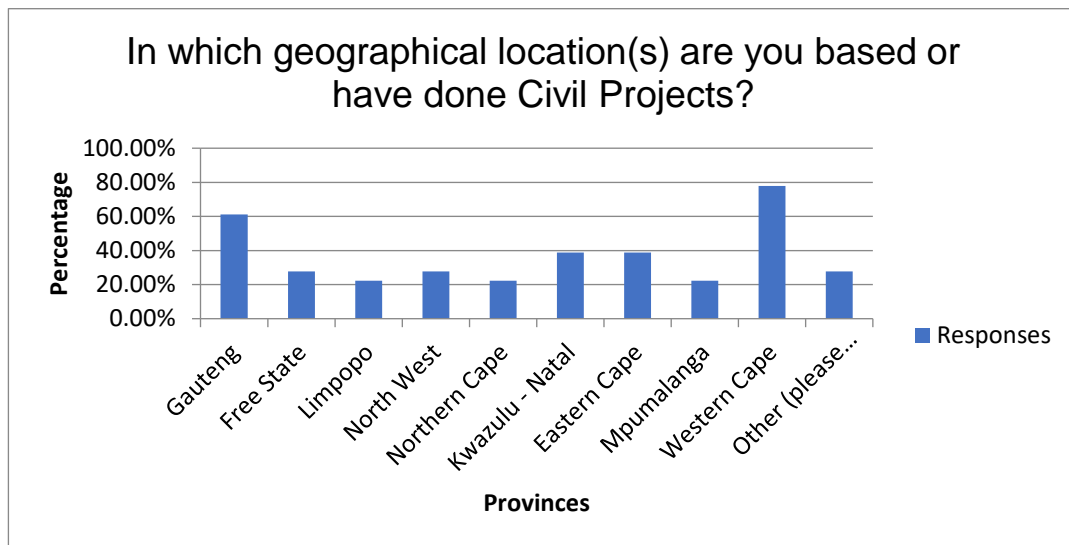


Figure 31: Q4 - Results of Respondents - Geographical Locations

6.4.5 Q5 – TYPE OF SERVICES PROVIDED

This question determined the types of services provided by each respondent. The results showed that all respondents worked with the service provision of water. Sewerage (94.44%) and stormwater (88.89%) were high in terms of services provided. There was a high average among telecommunication and electrical services at 61.11%. The provision of Gas within South Africa was fairly uncommon.

Table 15: Q5 - Results of Respondents - Type of Services

Which of the following services have you provided or were involved with?		
Answer Choices	Responses	
Water	100,00%	18
Stormwater	88,89%	16
Sewerage	94,44%	17
Gas	22,22%	4
Telecommunication	61,11%	11
Electrical	61,11%	11
Other (please specify)	16,67%	3
	Answered	19
	Skipped	0

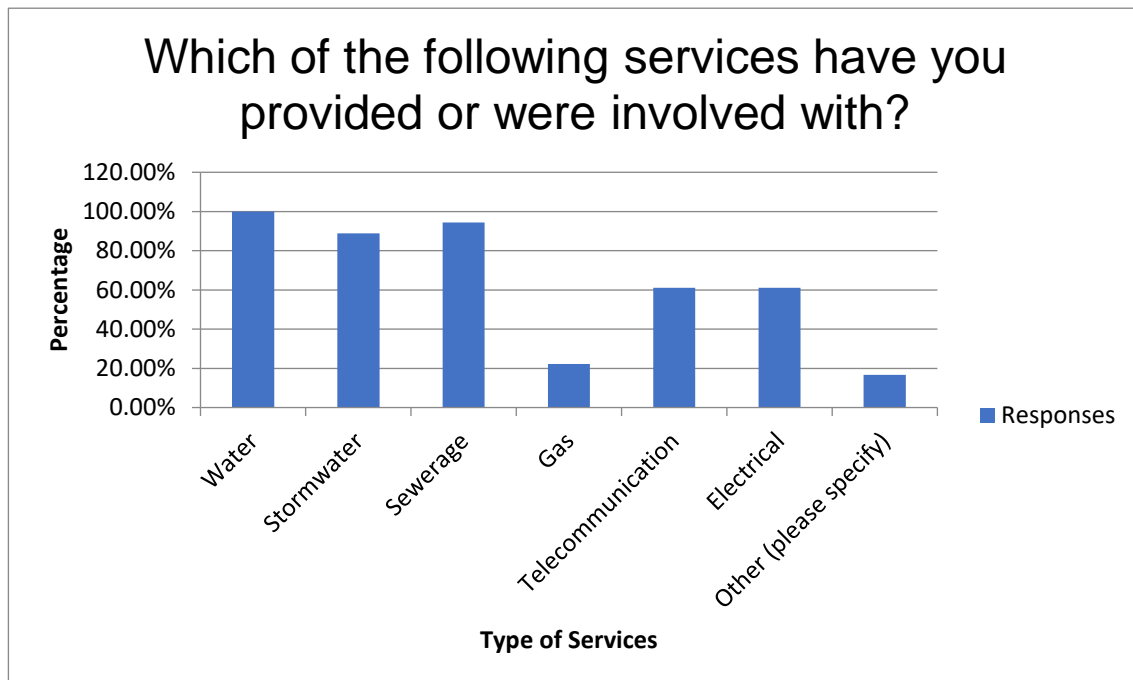


Figure 32: Q5 - Results of Respondents - Type of Services

6.4.6 Q6 – TYPE OF PIPING MATERIAL

This question determined the type of piping material used by the respondents. All respondents have worked with High Density Polyethylene within their perspective sectors. The highest piping material utilised was hard plastic piping, with Polyvinyl Chloride Pipes being the second most common piping material used. The next piping material most commonly used was Reinforced Concrete Pipes. Clay, Iron and Steel pipes showed the least amount of utilisation within the industry. Glass Fibre Reinforced Plastic Pipes showed that it is more commonly used in overseas countries than in South Africa.

Table 16: Q6 - Results of Respondents - Type of Piping Material

Which of the following type of pipes have you installed or worked with?		
Answer Choices	Responses	
Steel Casing Pipes	50,00%	9
Reinforced Concrete Pipes	61,11%	11
Clay Pipes	50,00%	9
Iron Pipes (DIP)	33,33%	6
Polyvinyl Chloride Pipes (PVC)	83,33%	15
High Density Poly (HDPE)	100,00%	18
Glass Fibre Reinforced Plastic Pipes (GRP)	38,89%	7
Other (please specify)	16,67%	3
	Answered	19
	Skipped	0

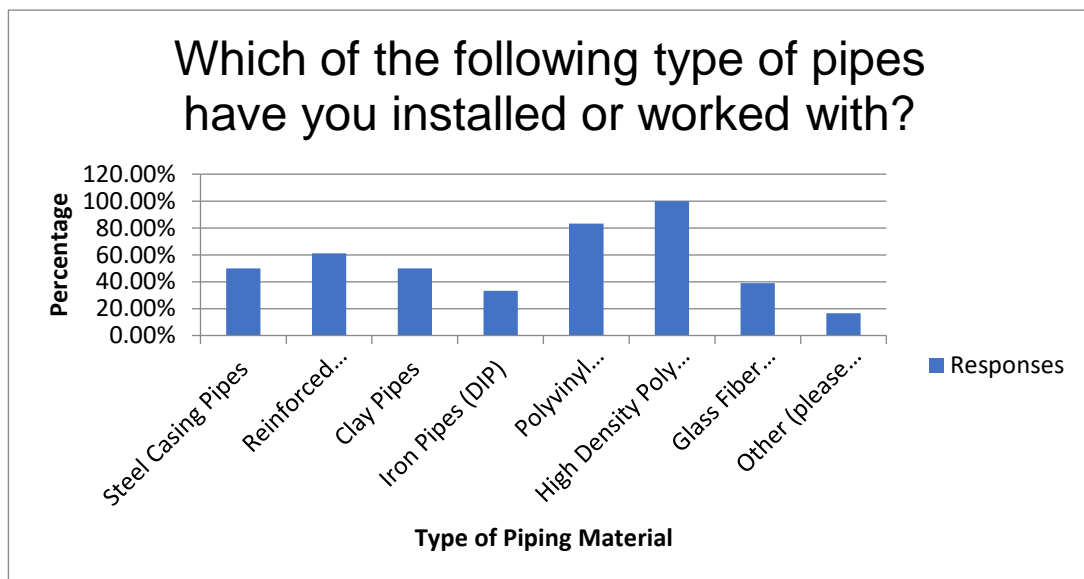


Figure 33: Q6 - Results of Respondents - Type of Piping Material

6.5 PART 2: NEW PIPELINE INSTALLATIONS

6.5.1 Q7 – NEW PIPELINE INSTALLATIONS

This question was divided into two sections. This question determined the type of service associated with each method of new pipeline installations and the type of piping material associated with each method of new pipeline installations. The graph below represents the responses provided by the respondents in terms of the type of services with each method of new pipeline installations.

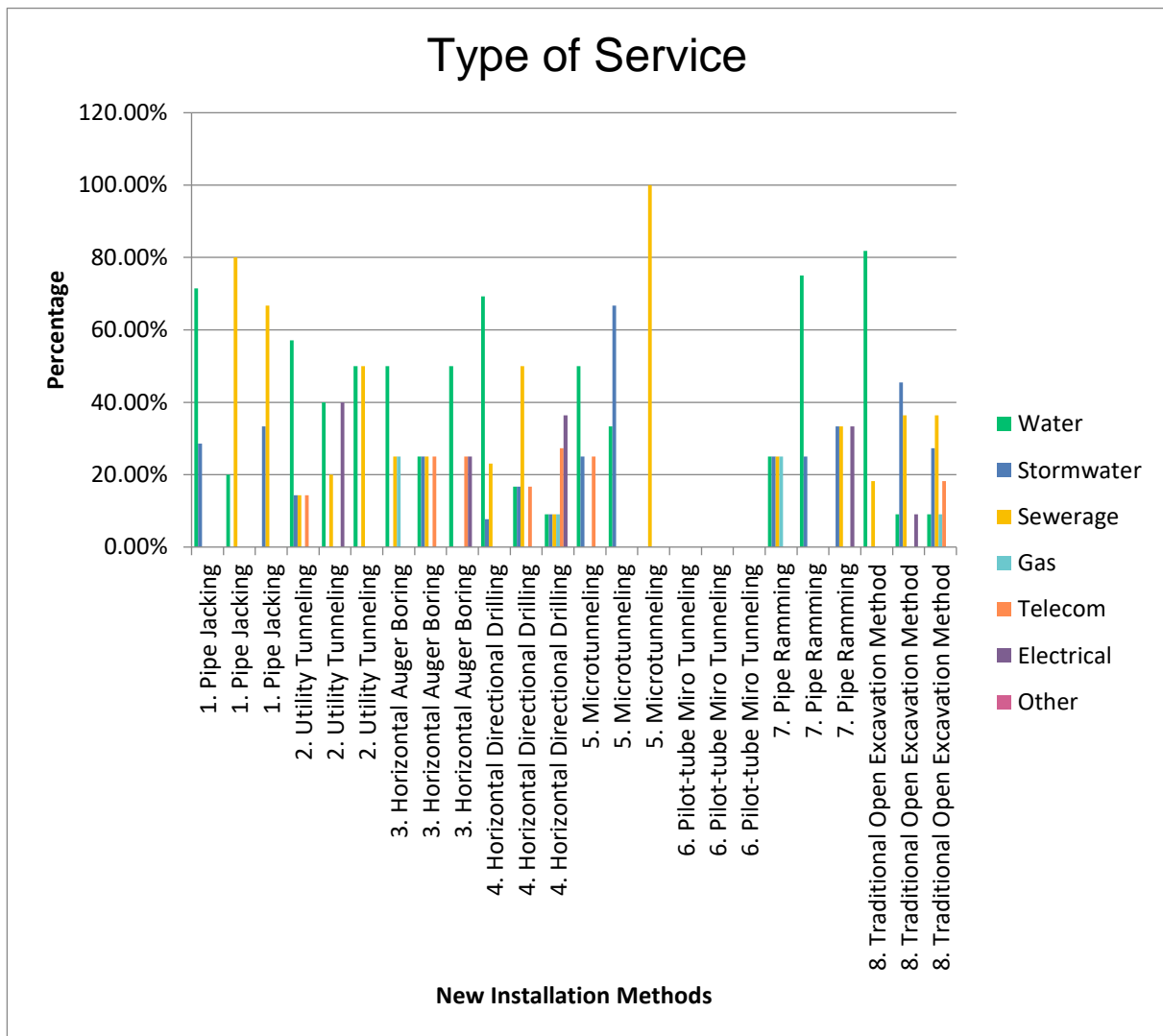


Figure 34: Q7.1 - Results of Respondents - New Installations - Type of Services

1. Pipe Jacking

This method was associated with the service provision of Water, Stormwater and Sewerage. The other three services had no score against the method of pipe jacking. This method was determined to be a common method used as the responses represent high percentages.

2. Utility Tunnelling

This method was associated with all type of services, except for Gas. The majority of services were still Water, Stormwater and Sewerage. The Telecommunication and Electrical services used this method, even though only half of the respondents documented using this method. This method was not as commonly implemented or utilised as the other methods.

3. Horizontal Auger Drilling

This method was associated with all type of services, except for Gas. The majority of services associated with Horizontal Auger Drilling were Water. The other services were spread out evenly. This method was more commonly implemented or utilised than Utility Tunnelling, but remained on the lower side.

4. Horizontal Directional Earth Drilling

This method was associated with all types of services, except for Gas. This method showed that it was commonly implemented or utilised due to the high number of responses. This method was associated with an average over all types of services.

5. Microtunneling

This method was associated with all type of services, except for Gas and Electrical. This method is rarely used by the respondents as the data showed that not all respondents answered this section of the question.

6. Pilot Tube Microtunneling

This method was not chosen by any respondent. The lack of any data associated with this method, represents that this method is not implemented within South Africa.

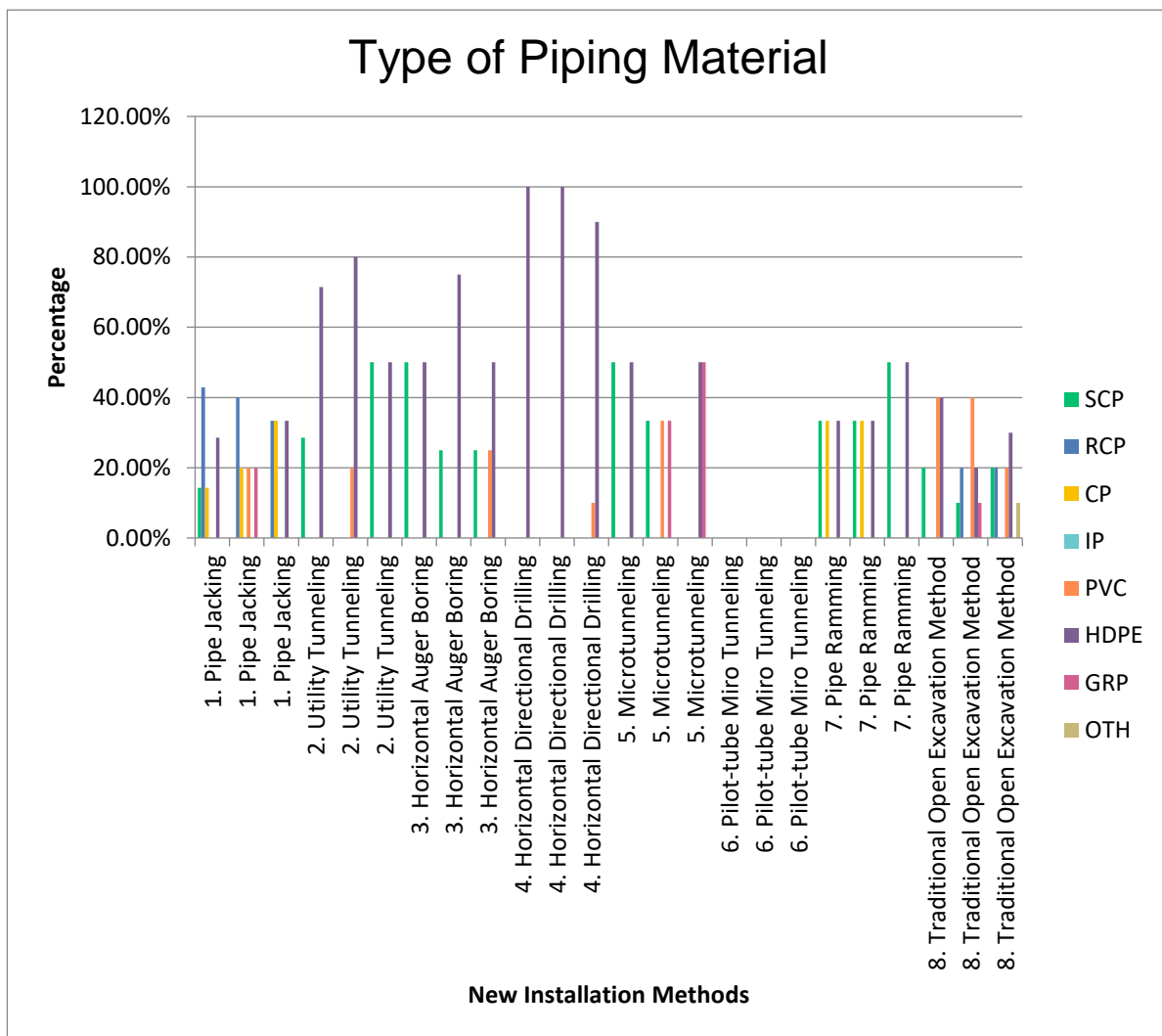
7. Pipe Ramming

This method was associated with all types of services, except for Gas and Telecommunication. This method was used for the installation of Electrical Services. This method was used as much as Pipe Jacking due to the high percentage received for each service.

8. Traditional Open Excavation Method

This method was associated with all types of services, except for Gas. The high percentages indicate that this method is still used for new pipeline installations. There was still a higher overall interest in the other methods, which are all trenchless methods compared to the traditional method.

Figure 35 illustrates the type of piping materials associated with each new pipeline installation method.



Steel Casing Pipes	SCP	Iron Pipes	IP	Glass Fibre Reinforced Plastic Pipes	GRP
Concrete Pipes	RCP	Polyvinyl Chloride Pipes	PVC	Other	OTH
Clay Pipes	CP	High Density Poly	HDPE		

Figure 35: Q7.2 - Results of Respondents - Type of Piping Material

1. Pipe Jacking

Reinforced concrete pipes and High Density Polyethylene were the piping associated with this method. Steel and Clay pipes showed a lower application with this method. This could represent the impact force of pipe jacking on structurally weaker pipes.

2. Utility Tunnelling

High Density Polyethylene, Polyvinyl Chloride and steel pipes were the only piping material associated with this method.

3. Horizontal Auger Earth Boring

High Density Polyethylene, Polyvinyl Chloride and steel pipes were the only piping material associated with this method.

4. Horizontal Directional Earth Drilling

High Density Polyethylene and Polyvinyl Chloride pipes were the only piping material associated with this method.

5. Microtunneling

This method included Steel Casing, High Density Polyethylene, Polyvinyl Chloride and Glass Fibre Reinforced Plastic piping material.

6. Pilot Tube Microtunneling

No piping material was associated with this method. The lack of any data associated with this method, represents that this method is not implemented within South Africa or was not commonly used.

7. Pipe Ramming

Steel, Clay and High Density Polyethylene pipes were the only piping material associated with this method.

8. Traditional Open Excavation Method

This method was associated with all piping material, except with Reinforced Concrete pipes. The high percentages indicated that this method is still used for a variety of piping material, especially for Iron pipes. This method still covers the installation of a wider variety of piping material compared to trenchless methods.

6.6 PART 3: RENEWAL AND REPLACEMENT METHODS

6.6.1 Q8 – RENEWAL AND REPLACEMENT METHODS

This question was divided into two sections. This question determined the type of service associated with each method of renewal and replacement of pipelines. The second section determined the type of piping material associated with each method of renewal and replacement of pipelines. Figure 36 represents the responses provided by the respondents in terms of the type of services with each method of renewal and replacement of pipelines.

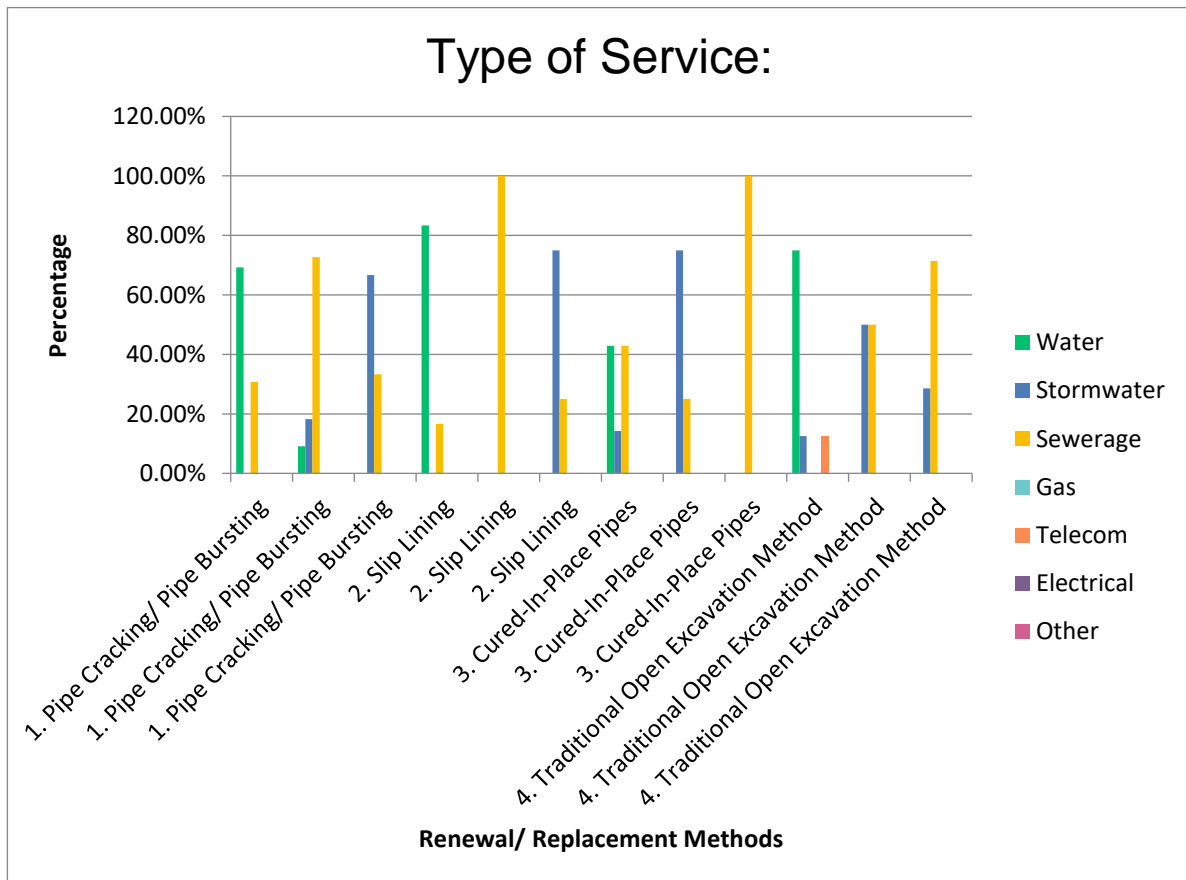


Figure 36: Q8.1 - Results of Respondents - Type of Service

1. Pipe Cracking/ Pipe Bursting

This method was used for the provision of Water, Stormwater and Sewerage. The high percentage represent that the three service provisions were spread equally, showing this method to be common for the renewal or replacement of the three main services.

2. Slip Lining

This method was used for the provision of Water, Stormwater and Sewerage. The highest percentage represents that this method was more associated with Sewerage services than Water or Stormwater.

3. Cured-In-Place Pipes

This method was used for the provision of Water, Stormwater and Sewerage. The highest percentage represents that this method was more associated with Sewerage services than Water or Stormwater.

4. Traditional Open Excavation Method

This method was associated with all the services, except for Gas. The overall percentages of the service provision for this method were lower, compared to the other renewal and replacement methods.

Figure 37 illustrates the type of piping materials associated with each renewal and replacement method.

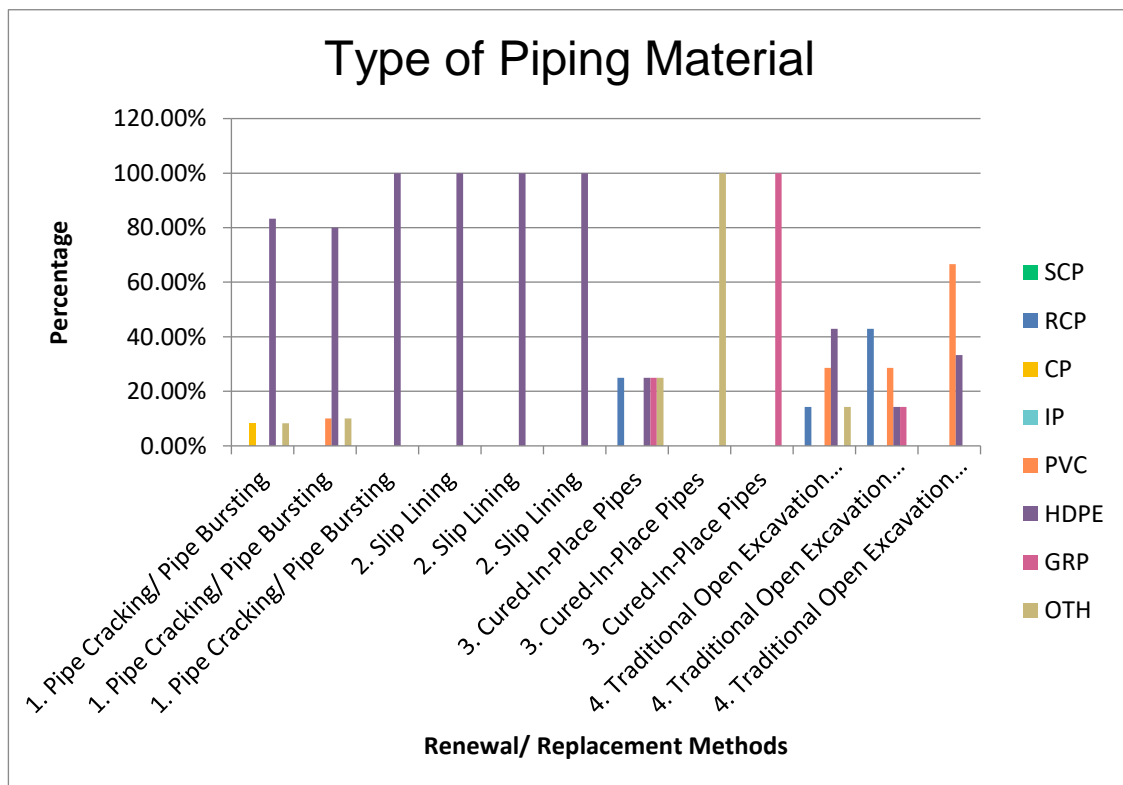


Figure 37: Q8.2 - Results of Respondents - Type of Piping Material

1. Pipe Cracking/ Pipe Bursting

This method was associated with High Density Polyethylene pipes. Clay and Polyvinyl Chloride pipes showed a lower percentage of responses.

2. Slip Lining

This method was associated with High Density Polyethylene pipes. This method was not chosen for any other piping material by the respondents.

3. Cured-In-Place Pipes

This method was associated with all plastic piping material. The majority of respondents chose either Pipe Cracking or Slip Lining. They stated within the comment section that this was the best method for all High Density Polyethylene and Polyvinyl Chloride pipes.

4. Traditional Open Excavation Method

This method was associated with all different piping materials. The overall percentages showed that there is a higher percentage of interest with Pipe Cracking and Slip-Lining than the traditional method.

6.7 PART 4: IMPORTANCE OF PROJECT SPECIFICATIONS

6.7.1 Q9 – PROJECT SPECIFICATIONS FOR NEW PIPELINE INSTALLATIONS

This next question determined the importance of each project specification for new pipeline installations. Project specifications can determine the financial implication of new pipeline installations. Table 17 represents the results obtained from the respondents. Figure 38 represents the graphical results of the respondents as indicated in Table 17. The results indicate that the planning, design and construction phase of new pipeline installations are considered the most vital. The respondents rated Quality above Time and Cost. The respondents rated the Geographical Survey as more vital than general information of ground conditions. The respondents felt that specialised labour was more important than general labour.

Table 17: Q9 - Results of Respondents - Project Specifications for New Pipeline Installations

Please rate the importance of the following with regards to pipeline/ service line installations.								
	Slight		Average		Vital		Total	Weighted Average
Planning	0,00%	0	6,25%	1	93,75%	18	16	2,94
Design	0,00%	0	6,25%	1	93,75%	18	16	2,94
Execution or Construction	0,00%	0	25,00%	4	75,00%	18	16	2,75
Cost	0,00%	0	31,25%	5	68,75%	18	16	2,69
Time	0,00%	0	37,50%	6	62,50%	18	16	2,63
Quality	0,00%	0	18,75%	3	81,25%	18	16	2,81
Geographical Survey	0,00%	0	20,00%	3	80,00%	18	15	2,8
Ground conditions	6,25%	1	18,75%	3	75,00%	18	16	2,69
General Labour	12,50%	2	62,50%	10	25,00%	18	16	2,13
Specialised Labour	12,50%	2	12,50%	2	75,00%	18	16	2,63
							Answered	19
							Skipped	0

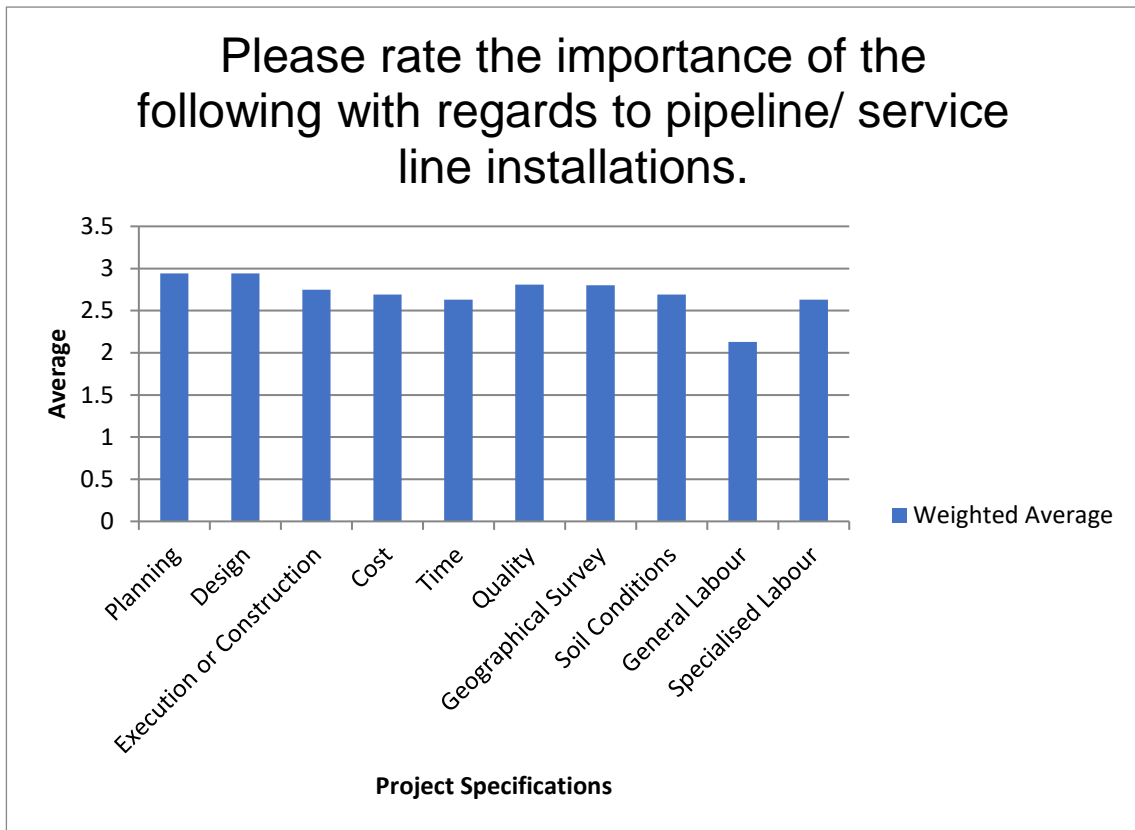


Figure 38: Q9 - Results of Respondents - Project Specifications for New Pipeline Installations

6.7.2 Q10 – PROJECT SPECIFICATIONS FOR RENEWAL & REPLACEMENT METHODS

This next question determined the importance of each project specification for renewal and replacement installations. The project specifications assisted with determining the importance of each aspect of the installation. Table 18 showed the results of each respondent. Figure 39 is the graphical representation of the results in Table 18. The results indicate that planning and design during the installation for renewal and replacement methods were vital. The respondents chose Quality over Time and Cost for renewal and replacement projects. They determined that the Geographical Survey is just as important as the information regarding ground conditions. Specialised labour was considered more important than general labour.

Table 18: Q10 - Results of Respondents - Project Specifications for Renewal and Replacement Methods

Please rate the importance of the following with regards to pipeline/ service line rehabilitation or renewal.								
	Slight		Average		Vital		Total	Weighted Average
Planning	0,00%	0	18,75%	3	81,25%	13	19	2,81
Design	0,00%	0	25,00%	4	75,00%	12	19	2,75
Cost	0,00%	0	25,00%	4	75,00%	12	19	2,75
Time	6,25%	1	37,50%	6	56,25%	9	19	2,5
Quality	0,00%	0	12,50%	2	87,50%	14	19	2,88
Geographical Survey	6,25%	1	37,50%	6	56,25%	9	19	2,5
Ground conditions	6,25%	1	37,50%	6	56,25%	9	19	2,5
General Labour	18,75%	3	56,25%	9	25,00%	4	19	2,06
Specialised Labour	6,25%	1	12,50%	2	81,25%	13	19	2,75
							Answered	19
							Skipped	0

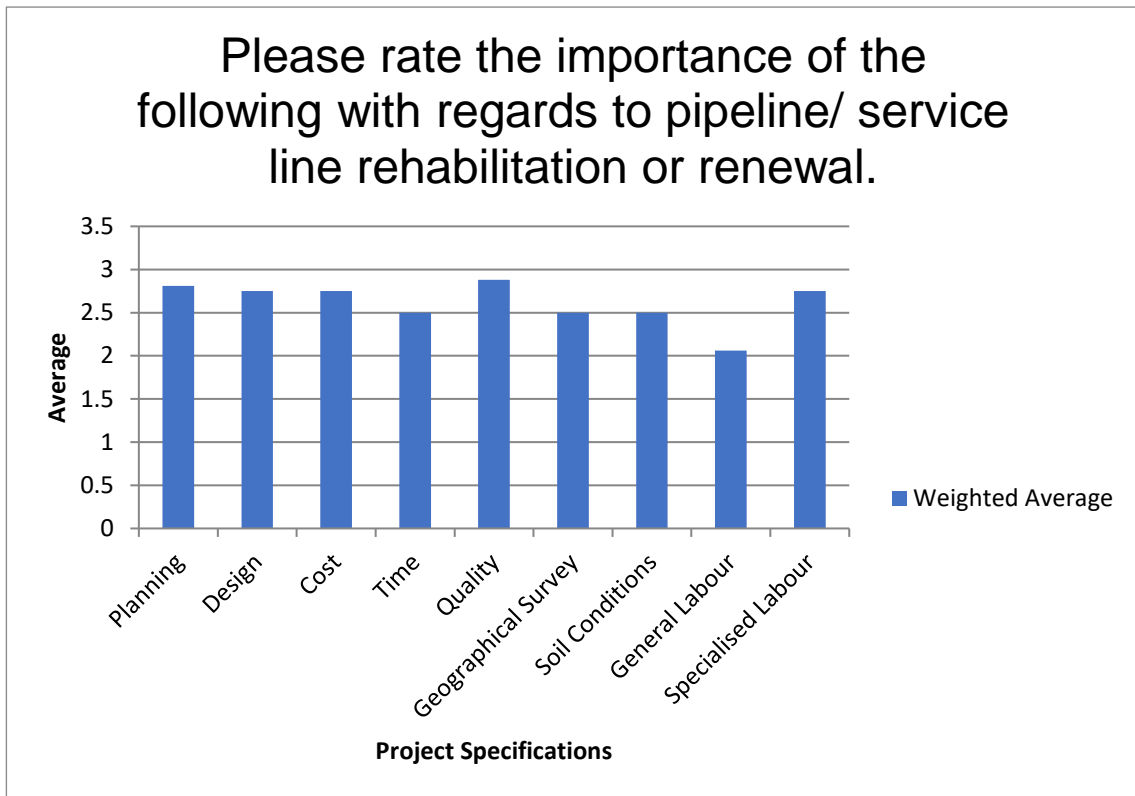


Figure 39: Q10 - Results of Respondents - Project Specifications for Renewal and Replacement Methods

6.8 PART 5: THE FINANCIAL ASPECT OF THE TRADITIONAL MEHTOD

6.8.1 Q11 - LOWEST CONTRACT VALUE

This question determined the lowest contract value using the traditional method. The comparison between the lowest contract of the traditional and trenchless methods determines which one of the methods is more financially viable. Table 19 shows the results of the respondents. The highest percentage (47.37%) was allocated to projects smaller than R 1 million. Projects between R 1 million and R 10 million scored 36.84%. Projects between R10 million and R 100 million scored 15.79%. Figure 40 represents the final results. There were no results obtained for projects over the contract value of R 100 million.

Table 19: Q11 - Results of Respondents - Lowest Contract Value

What is the lowest contract value, of a single project, executed by your company that involved the traditional method of excavation within the last year?		
Answer Choices	Responses	
< R 1 million	47,37%	9
R 1 million - R 10 million	36,84%	7
R 10 million - R 100 million	15,79%	3
> R 100 Million	0,00%	0
	Answered	19
	Skipped	0

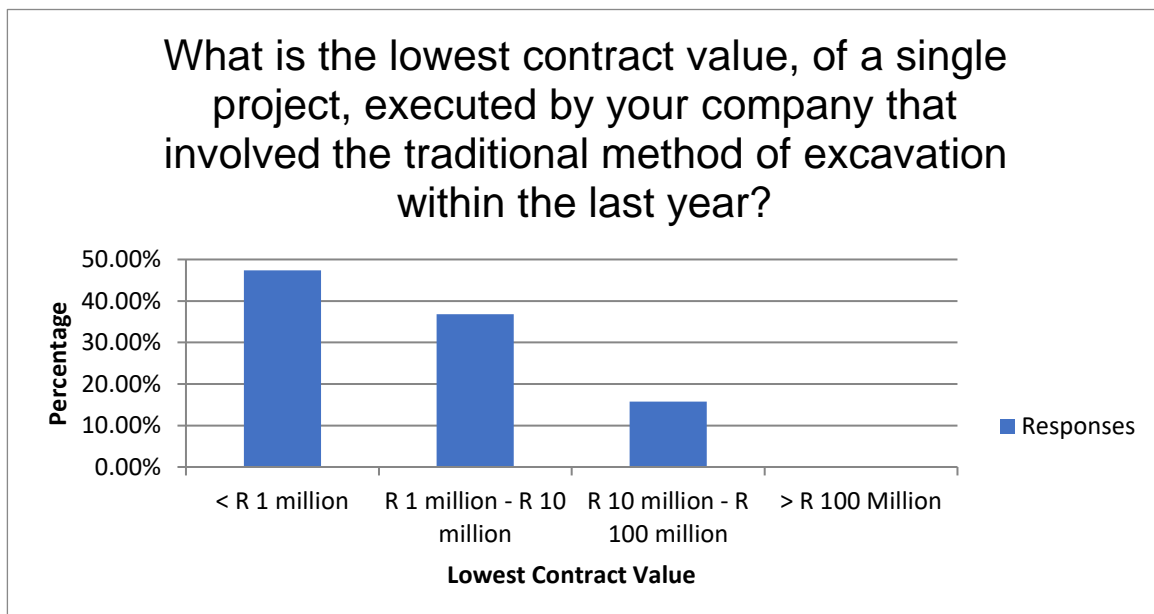


Figure 40: Q11 - Results of Respondents - Lowest Contract Value

6.8.2 Q12 – HIGHEST CONTRACT VALUE

This question determined the highest contract value using the traditional method. The comparison between the highest contract value of the traditional and trenchless methods determines which one of the methods is more financially viable. Table 20 shows the results obtained from the questionnaire. The highest percentage (63.16%) was associated with the range of R 1 million to R10 million. A percentage of 21.05% was associated with the range of R 10 million to R 100 million. The lowest percentage of 15.79% was calculated for contract values below R 1 million. There were no results obtained for contract values exceeding R100 million.

Table 20: Q12 - Results of Respondents - Highest Contract Value

What is the highest contract value, of a single project, executed by your company that involved the traditional method of excavation within the last year?		
Answer Choices	Responses	
< R 1 million	15,79%	3
R 1 million - R 10 million	63,16%	12
R 10 million - R 100 million	21,05%	4
> R 100 Million	0,00%	0
	Answered	19
	Skipped	0

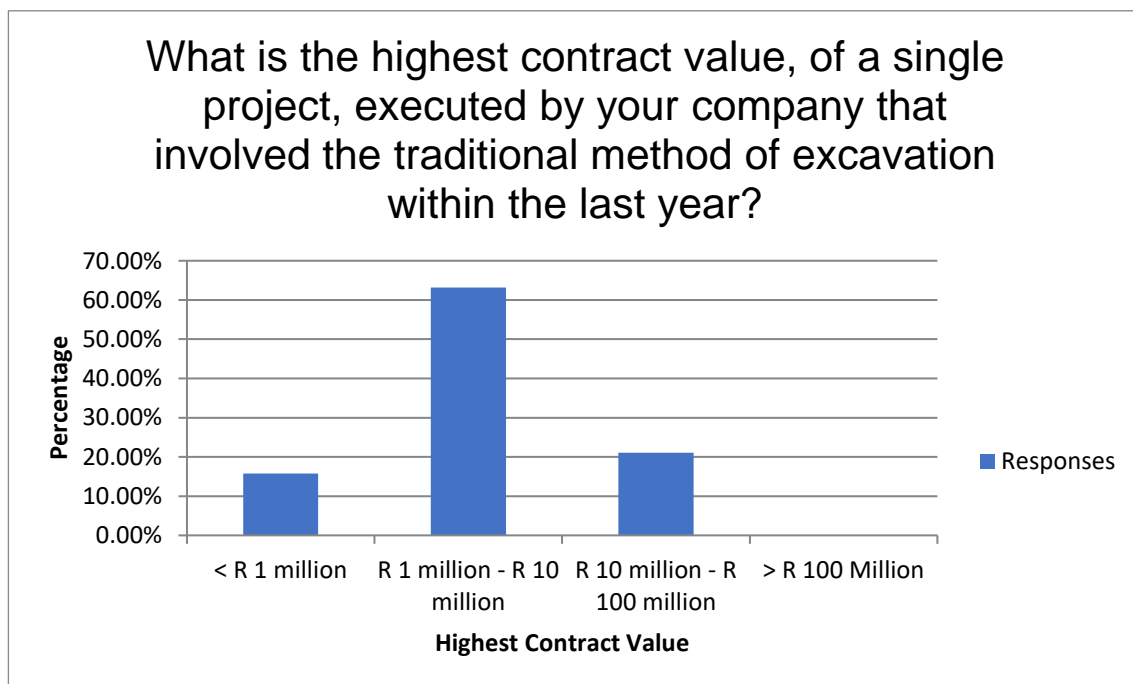


Figure 41:Q12 - Results of Respondents - Highest Contract Value

6.8.3 Q13 – AVERAGE CONTRACT VALUE

This question determined the average contract value using the traditional method. The comparison between the average contract value of the traditional and trenchless methods assists in determining financial viability. The highest percentage of 52.63%, was allocated to contract values below R 1 million. The percentage of 26.32% was allocated to values between R 1 million and R 10 million. The lowest percentage was allocated at 21.05% for contract values between R 10 million to R100 million. No results were obtained for contract values exceeding R100 million.

Table 21: Q13 - Results of Respondents - Average Contract Value

What is the average contract value executed by your company that involved the traditional method of excavation within the last year?		
Answer Choices	Responses	
< R 1 million	52,63%	10
R 1 million - R 10 million	26,32%	5
R 10 million - R 100 million	21,05%	4
> R 100 Million	0,00%	0
	Answered	19
	Skipped	0

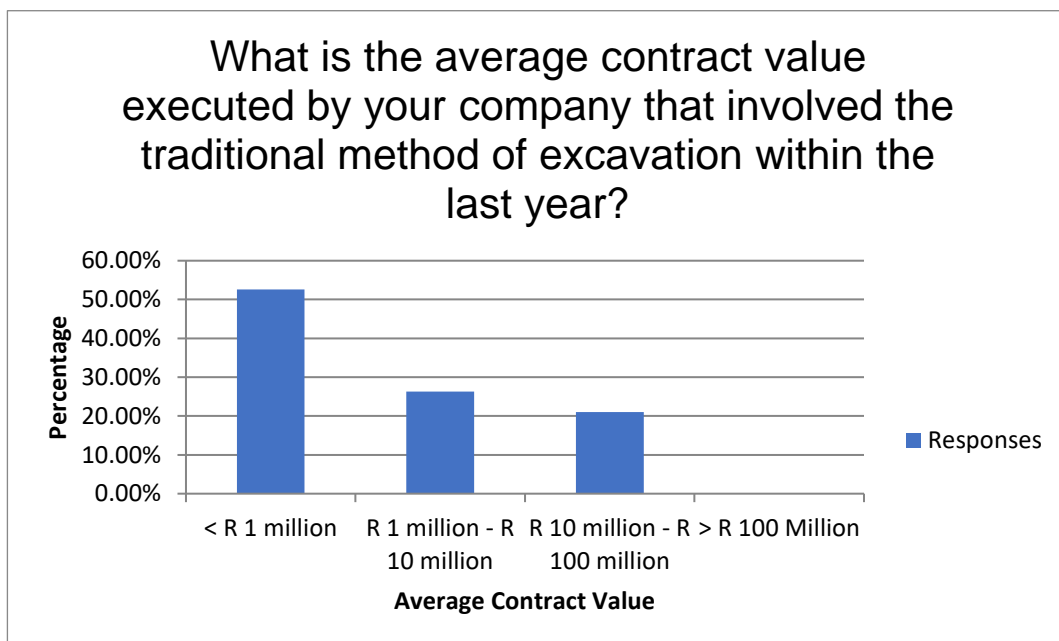


Figure 42: Q13 - Results of Respondents - Average Contract Value

6.8.4 Q14 – AVERAGE COST PER METRE

This question determined the average cost per metre of a pipeline using the traditional method. This was to determine the average cost of an average pipeline installation using the traditional method. An average cost exceeding R 3 000.00 p/m had 36.84% of the responses. The cost per metre less than R 1 000.00 obtained a result of 26.32%. The range from R 2 000.00 to R 3 000.00 per metre obtained a result of 21.05%. The lowest percentage (15.79%) was allocated to the range of R 2 000.00 to R 3 000.00 per metre.

Table 22: Q14 - Results of Respondents - Average Cost per Metre

What was the average cost per metre, all-inclusive, for the installation of a service line that involved the traditional method of excavation on the last project executed by your company?		
Answer Choices	Responses	
<1 000	26,32%	5
1 000 - 2 000	15,79%	3
2 000 - 3 000	21,05%	4
> 3000	36,84%	7
	Answered	19
	Skipped	0

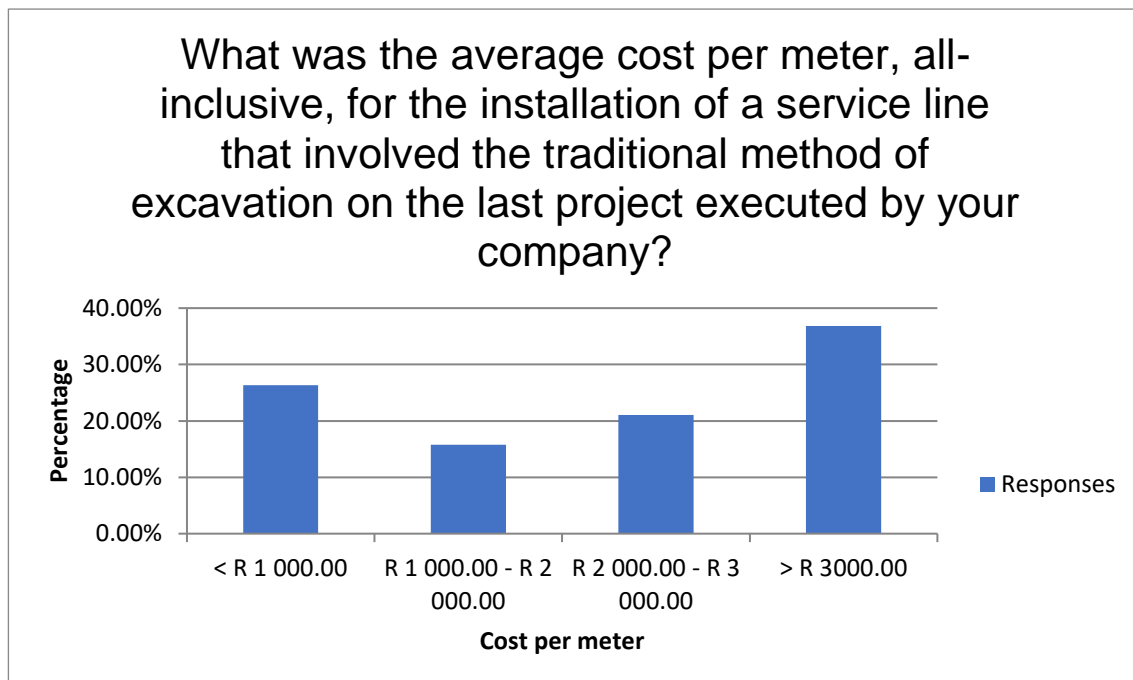


Figure 43: Q14 - Results of Respondents - Average Cost per Metre

6.8.5 Q15 – COST ON THREE MAIN PROJECT DETERMINANTS

This question determined the cost on the three main project determinants for the traditional method. The three determinants were Labour, Machinery/ Equipment and Site Establishment. Machinery and equipment scored the highest factor at 2.17%. Labour followed closely at 2.09%. Site Establishment received the lowest percentage at 1.77%.

Table 23: Q15 - Results of Respondents - Cost on Three Main Project Determinants

Based on your own personal experience. Please rank the following in order on which the most cost is spent when implementing the traditional method based on the projects you have been involved in:								
	1		2		3		Total	Score
Labour	36,36%	4	36,36%	4	27,27%	3	11	2,09
Machinery / Equipment	33,33%	4	50,00%	6	16,67%	2	12	2,17
Site Establishment	30,77%	4	15,38%	2	53,85%	7	13	1,77
Answered								19
Skipped								0

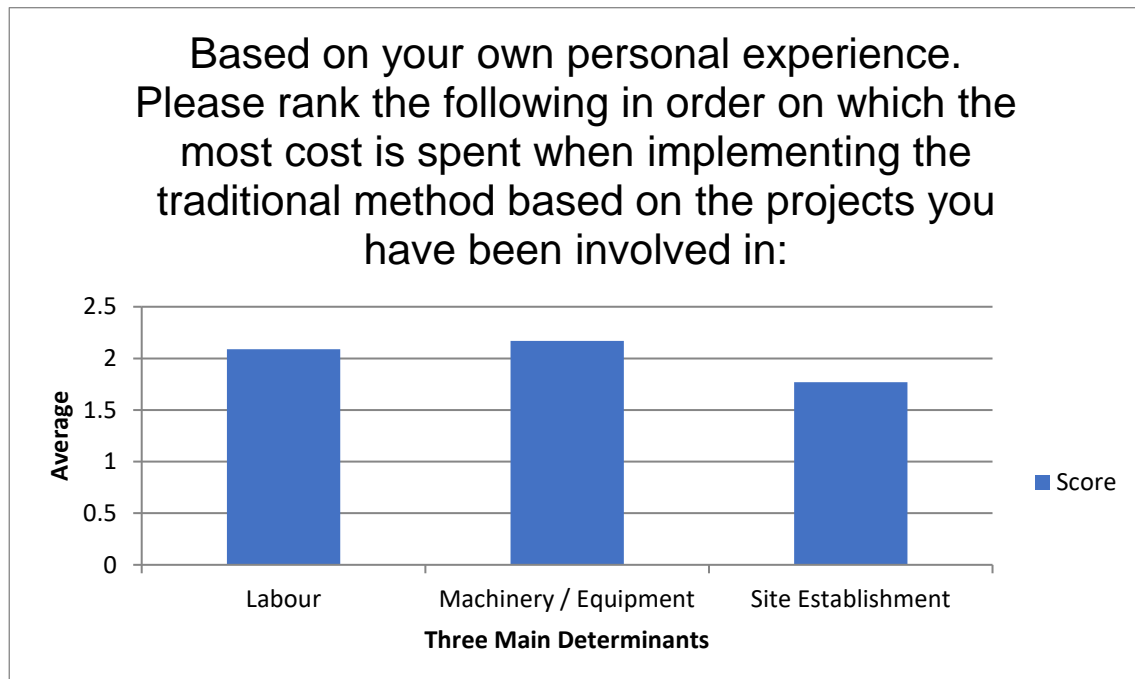


Figure 44: Q15 - Results of Respondents - Cost on Three Main Project Determinants

6.9 PART 6: THE FINANCIAL ASPECT OF TRENCHLESS TECHNOLOGY

6.9.1 Q16 – LOWEST CONTRACT VALUE

This question determined the lowest contract value associated with Trenchless Technology. The highest percentage was allocated to a contract value smaller than R 1 million and 15.79% was allocated to contract values ranging from R 1 million to R 100 million. No results were obtained for contract values exceeding R 100 million.

Table 24: Q16 - Results of Respondents - Lowest Contract Value

What is the lowest contract value, of a single project, executed by your company that involved Trenchless Technology installation within the last year?		
Answer Choices	Responses	
< R 1 million	68,42%	13
R 1 million - R 10 million	15,79%	3
R 10 million - R 100 million	15,79%	3
> R 100 million	0,00%	0
	Answered	19
	Skipped	0

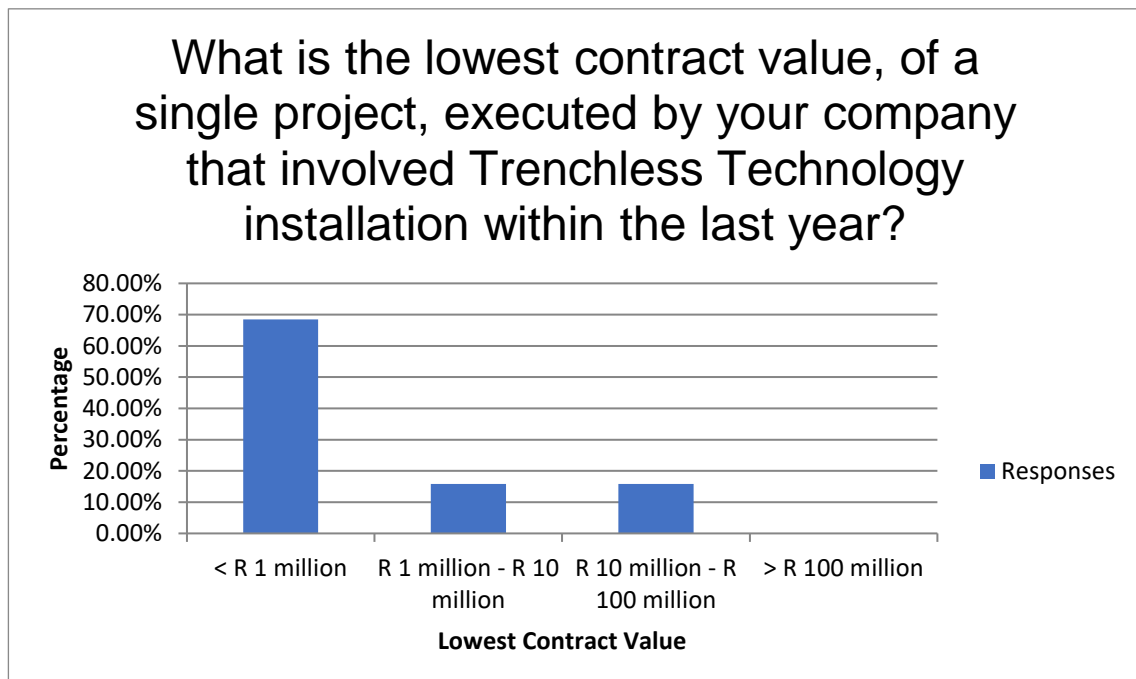


Figure 45: Q16 - Results of Respondents - Lowest Contract Value

6.9.2 Q17 – METHOD USED IN LOWEST CONTRACT VALUE

This question is linked to Question 16 of the survey. The respondents needed to provide which method of Trenchless Technology was related to the lowest contract value they completed. The highest percentage was allocated to Horizontal Directional Earth Drilling at 31.58%. Pipe Cracking is the second highest at 26.32%. Slip Lining and Cured-In-Place received an average of 15.79%. Pipe Jacking received the lowest average of 10.53%.

Table 25: Q17 - Results of Respondents - Method for Lowest Contract Value

Which method of installation was used in the project mentioned in Question 16?		
Answer Choices	Responses	
Pipe Jacking	10,53%	2
Utility Tunnelling	0,00%	0
Horizontal Auger Earth Boring	0,00%	0
Horizontal Directional Earth Drilling	31,58%	6
Micro Tunnelling	0,00%	0
Pilot Tube Micro Tunnelling	0,00%	0
Pipe Ramming	0,00%	0
Pipe Cracking / Pipe Bursting	26,32%	5
Slip Lining	15,79%	3
Cured-In-Place Pipes	15,79%	3
	Answered	19
	Skipped	0

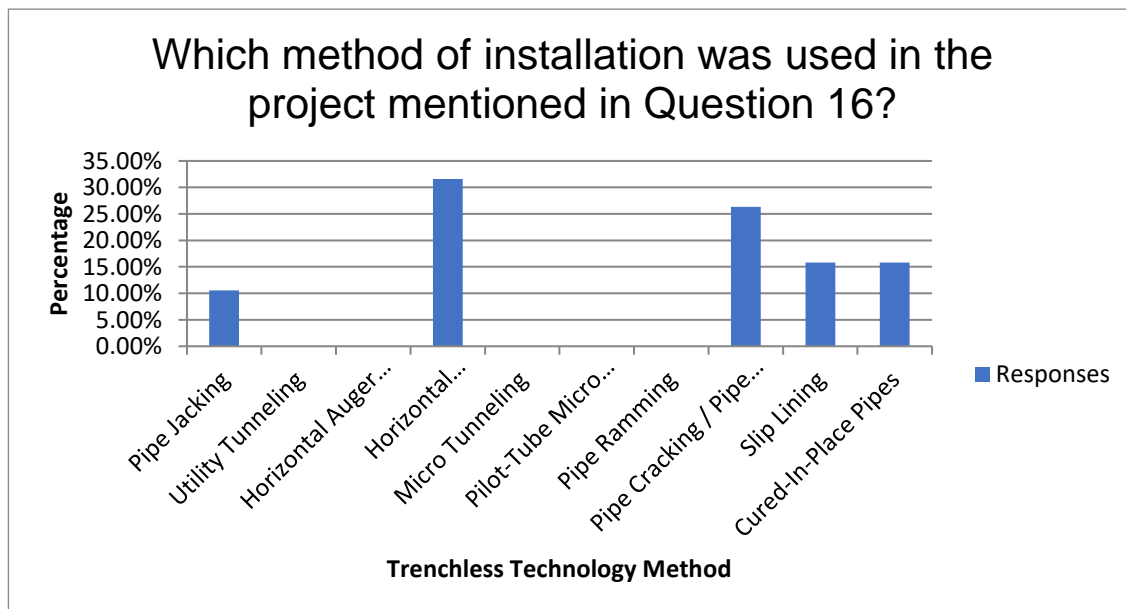


Figure 46: Q17 - Results of Respondents - Method for Lowest Contract Value

6.9.3 Q18 – AVERAGE CONTRACT VALUE

The average contract value associated with Trenchless Technology was determined in Question 18. The average percentage of 52.63% was allocated to contract values under R 1 million. The second highest percentage was allocated to contract values ranging from R 1 million to R10 million at 26.32%. The percentage of 21.05% was allocated to contract values from R10 million to R 100 million.

Table 26: Q18 - Results of Respondents - Average Contract Value

What is the average contract value executed by your company that involved all Trenchless Technology installations within the last year?		
Answer Choices	Responses	
< R 1 million	52,63%	8
R 1 million - R 10 million	26,32%	3
R 10 million - R 100 million	21,05%	2
> R 100 million	0,00%	0
	Answered	19
	Skipped	0

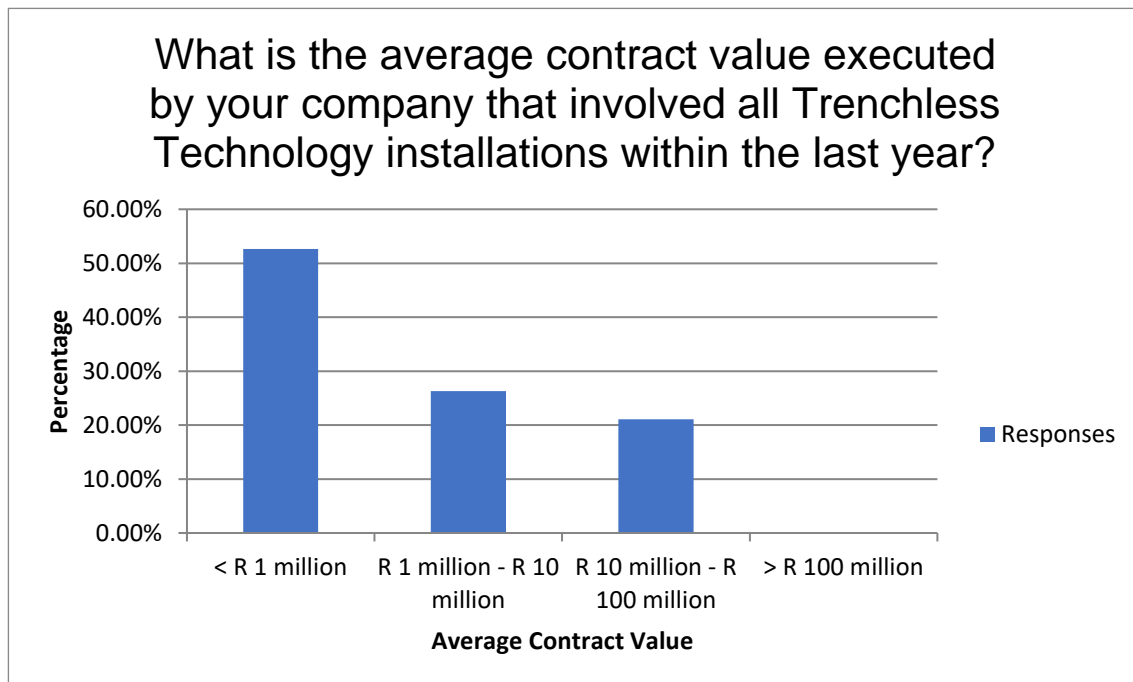


Figure 47: Q18 - Results of Respondents - Average Contract Value

6.9.4 Q19 – METHOD USED IN AVERAGE CONTRACT VALUE

This question determined the Trenchless Technology method used by the respondents to determine the average contract value. The highest percentage (31.58%) was allocated to Horizontal Directional Earth Drilling. The second highest percentage was allocated to Cured-In-Place Pipes at 26.32%. Pipe Cracking received a result of 21.05%. Pipe Jacking, Utility Tunnelling, Micro Tunnelling and Slip Lining received an average of 5.26%.

Table 27: Q19 - Results of Respondents - Method for Average Contract Value

Which method of installation was used in the project mentioned in Question 18?		
Answer Choices	Responses	
Pipe Jacking	5,26%	1
Utility Tunnelling	5,26%	1
Horizontal Auger Earth Boring	0,00%	0
Horizontal Directional Earth Drilling	31,58%	6
Micro Tunnelling	5,26%	1
Pilot Tube Micro Tunnelling	0,00%	0
Pipe Ramming	0,00%	0
Pipe Cracking / Pipe Bursting	21,05%	4
Slip Lining	5,26%	1
Cured-In-Place Pipes	26,32%	5
	Answered	19
	Skipped	0

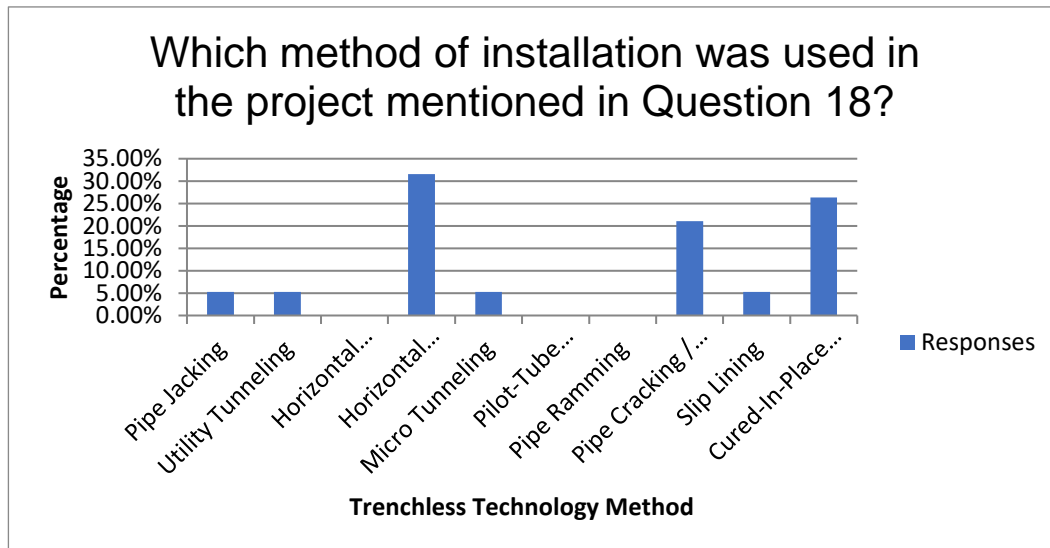


Figure 48: Q18 - Results of Respondents - Method for Average Contract Value

6.9.5 Q20 – HIGHEST CONTRACT VALUE

This question determined the highest contract value associated with Trenchless Technology methods. The highest results were allocated to contract values from R 1 million to R 10 million at 42.11%. The range of R 10 million to R 100million scored 31.58%. Contract values below R 1 million scored an average of 21.05% and contract values exceeding R 100 million scored 5.26%.

Table 28: Q20 - Results of Respondents - Highest Contract Value

What is the highest contract value, of a single project, executed by your company that involved Trenchless Technology installation within the last year?		
Answer Choices	Responses	
< R 1 million	21,05%	2
R 1 million - R 10 million	42,11%	6
R 10 million - R 100 million	31,58%	4
> R 100 million	5,26%	1
	Answered	19
	Skipped	0

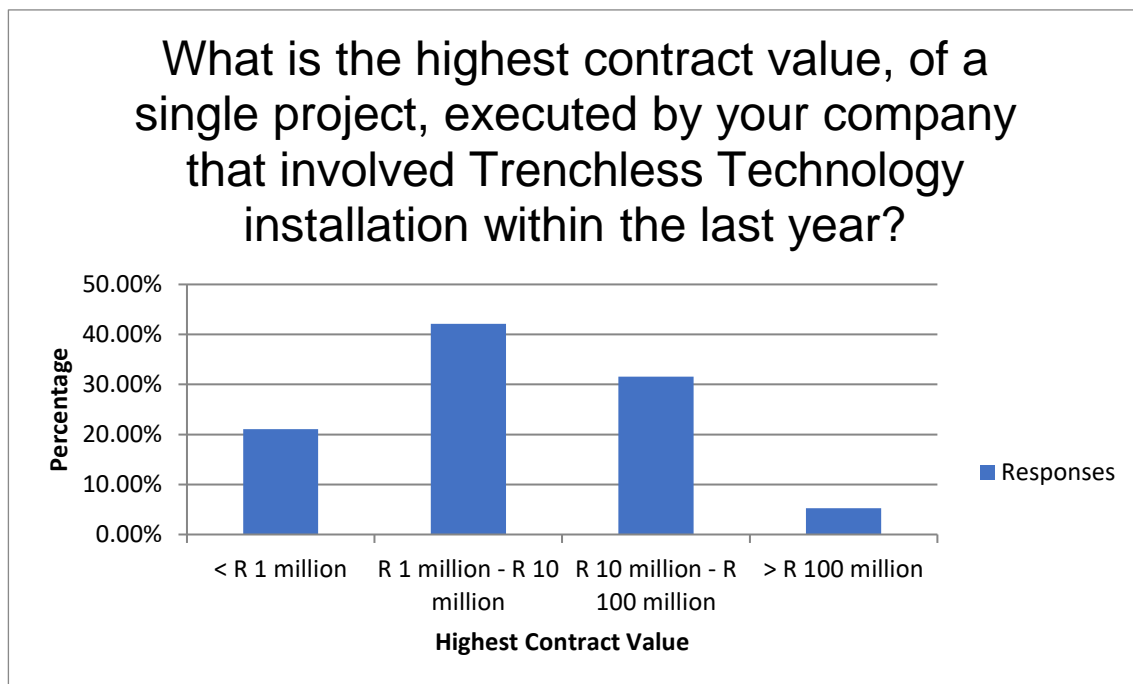


Figure 49: Q20 - Results of Respondents - Highest Contract Value

6.9.6 Q21 - METHOD USED IN HIGHEST CONTRACT VALUE

This question determined the method used by the respondent during the highest contract value they executed. Horizontal Directional Earth Drilling scored the highest percentage of 31.58%. Cured-In-Place was the second highest score at 26.32%. Pipe Jacking, Micro Tunnelling and Slip Lining received the same average of 10.53%. Pipe Ramming and Pipe Cracking received an average of 5.26%.

Table 29: Q21 - Results of Respondents - Method for Highest Contract Value

Which method of installation was used in the project mentioned in Question 20?		
Answer Choices	Responses	
Pipe Jacking	10,53%	2
Utility Tunnelling	0,00%	0
Horizontal Auger Earth Boring	0,00%	0
Horizontal Directional Earth Drilling	31,58%	6
Micro Tunnelling	10,53%	2
Pilot Tube Micro Tunnelling	0,00%	0
Pipe Ramming	5,26%	1
Pipe Cracking / Pipe Bursting	5,26%	1
Slip Lining	10,53%	2
Cured-In-Place Pipes	26,32%	5
	Answered	19
	Skipped	0

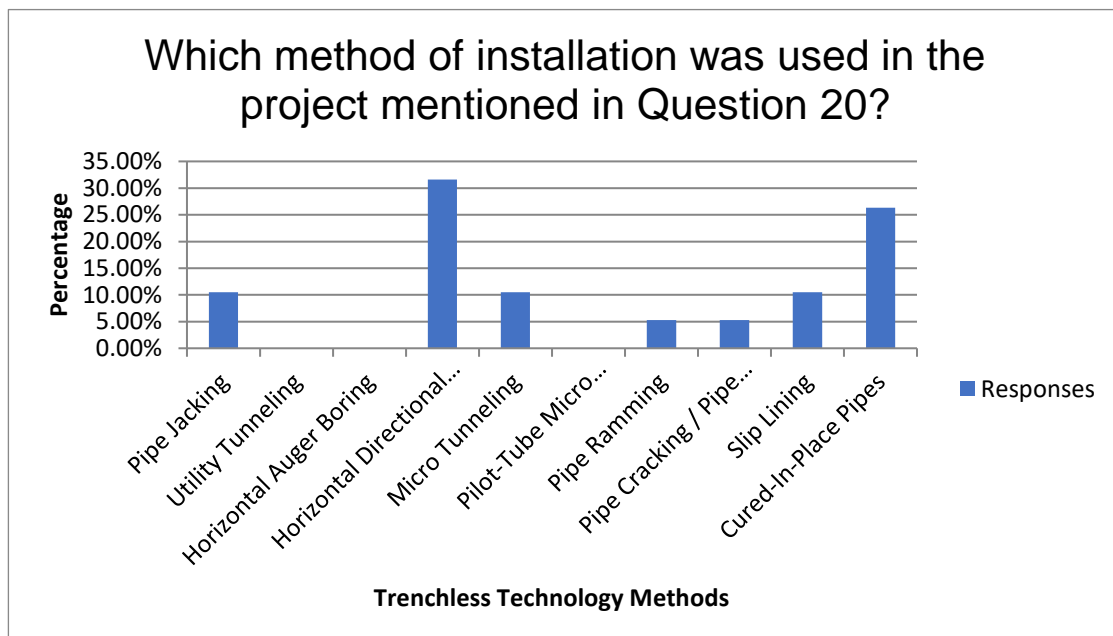


Figure 50: Q21 - Results of Respondents - Method for Highest Contract Value

6.9.7 Q22 – AVERAGE COST PER METRE ON LAST PROJECT

This question determined the average cost per metre, the respondents spent on each Trenchless Technology Method. Table 30 represents the results obtained from the respondents.

Table 30: Q22 - Results of Respondents - Average Cost per Metre

What was the average cost per metre, all-inclusive, for the installation of a service line that involved Trenchless Technology on the last project executed by your company?									
Please Choose the R/m									
	<1 000		1 000 -2 000		2 000 - 3 000		> 3 000		Total
Pipe Jacking	0,00%	0	25,00%	1	25,00%	1	50,00%	2	4
Utility Tunnelling	0,00%	0	0,00%	0	0,00%	0	100,00%	2	2
Horizontal Auger Earth Boring	0,00%	0	50,00%	1	0,00%	0	50,00%	1	2
Horizontal Directional Earth Drilling	0,00%	0	66,67%	4	16,67%	1	16,67%	1	6
Micro Tunnelling	0,00%	0	0,00%	0	33,33%	1	66,67%	2	3
Pilot Tube Micro Tunnelling	0,00%	0	0,00%	0	100,00%	1	0,00%	0	1
Pipe Ramming	0,00%	0	0,00%	0	100,00%	1	0,00%	0	1
Pipe Cracking / Pipe Bursting	0,00%	0	33,33%	1	66,67%	2	0,00%	0	3
Slip Lining	0,00%	0	100,00%	3	0,00%	0	0,00%	0	3
Cured-In-Place Pipes	0,00%	0	25,00%	1	75,00%	3	0,00%	0	4
								Answered	19
								Skipped	0

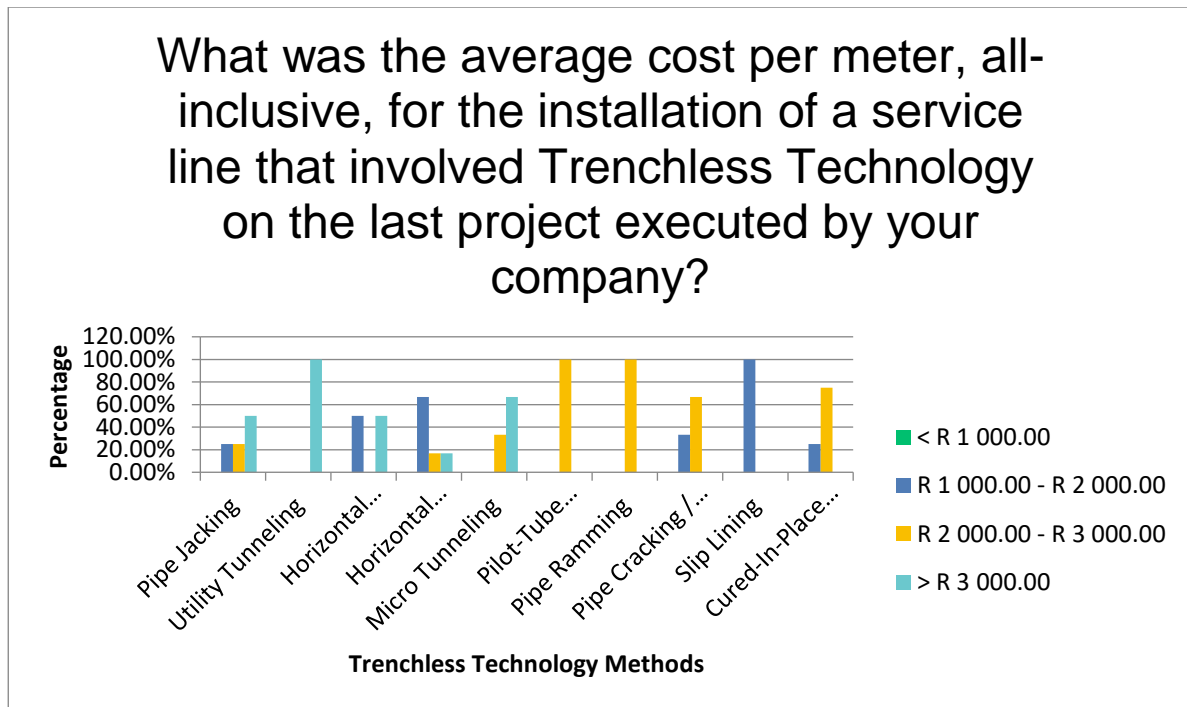


Figure 51: Q22 - Results of Respondents - Average Cost per Metre

1. Pipe Jacking

This method received a rate of 50% for a cost per metre exceeding R3 000.00 (Rand). The range of R1 000.00 to R2 000.00 and the range of R 2 000.00 to R 3 000.00 received an average of 25%.

2. Utility Tunnelling

This method received a result of 100% for the cost per metre exceeding R 3 000.00 per metre.

3. Horizontal Auger Earth Boring

This method received 50% for the range of R 1 000.00 to R 2 000.00 per metre and the cost per metre exceeding R 3 000.00.

4. Horizontal Directional Earth Drilling

This method had 75% allocated to the range of R 1 000.00 to R 2 000.00 per metre and 15% was allocated from R 2 000.00 to R 3 000.00 per metre.

5. Microtunneling

This method scored an average of 70% for the cost per metre exceeding R 3 000.00. The remaining 30% was allocated to the R2 000.00 to R3 000.00 per metre range.

6. Pilot – Tube Microtunneling

This method scored 100% for the range of R2 000.00 to R3 000.00 per metre.

7. Pipe Ramming

This method scored 100% for the range of R2 000.00 to R3 000.00 per metre.

8. Pipe Cracking

This method scored 70% for the range of R2 000.00 to R3 000.00 per metre. The remainder was allocated to R 1 000.00 to R 2 000.00 per metre.

9. Slip Lining

This method scored 100% for the range of R1 000.00 to R2000.00.

10. Cured-In-Place Pipes

This method scored 70% for the range of R2 000.00 to R3 000.00 per metre. The range of R 1 000.00 to R 2 000.00 per metre scored the remainder 30%.

6.9.8 Q23 – COST ON THREE MAIN PROJECT DETERMINANTS

This question determined the cost on the three main project determinants. Table 31 represents the results of the respondents. The highest score was given to Machinery and Equipment at 2.15%. Labour scored the second highest at 2% and Site Establishment scored 1.83%.

Table 31: Q23 - Results of Respondents - Cost on Three Main Project Determinants

Based on your own personal experience. Please rank the following in order on which the most cost is spent when implementing any trenchless method based on the projects you have been involved in:								
	1		2		3		Total	Score
Labour	16.67%	2	66.67%	8	16.67%	2	12	2
Machinery / Equipment	46.15%	6	23.08%	3	30.77%	4	13	2.15
Site Establishment	33.33%	4	16.67%	2	50.00%	6	12	1.83
							Answered	19
							Skipped	0



Figure 52: Q23 - Results of Respondents - Cost on Three Main Project Determinants

6.9.9 Q24 – OPTION BETWEEN RENEWAL OR REPLACEMENT METHODS

This question determined which renewal or replacement method is preferred by the respondents. Pipe Cracking scored 36.84% of the responses. Slip Lining and Cured-In-Place both received 31.58% of the results.

Table 32: Q24 - Results of Respondents - Option Between Renewal or Replacement Methods

In your opinion, which of the following replacement/rehabilitation methods is the most cost effective:		
Answer Choices	Responses	
Pipe Cracking / Pipe Bursting	36.84%	7
Slip Lining	31.58%	6
Cured-In-Place Pipes	31.58%	6
Answered	19	
Skipped	0	

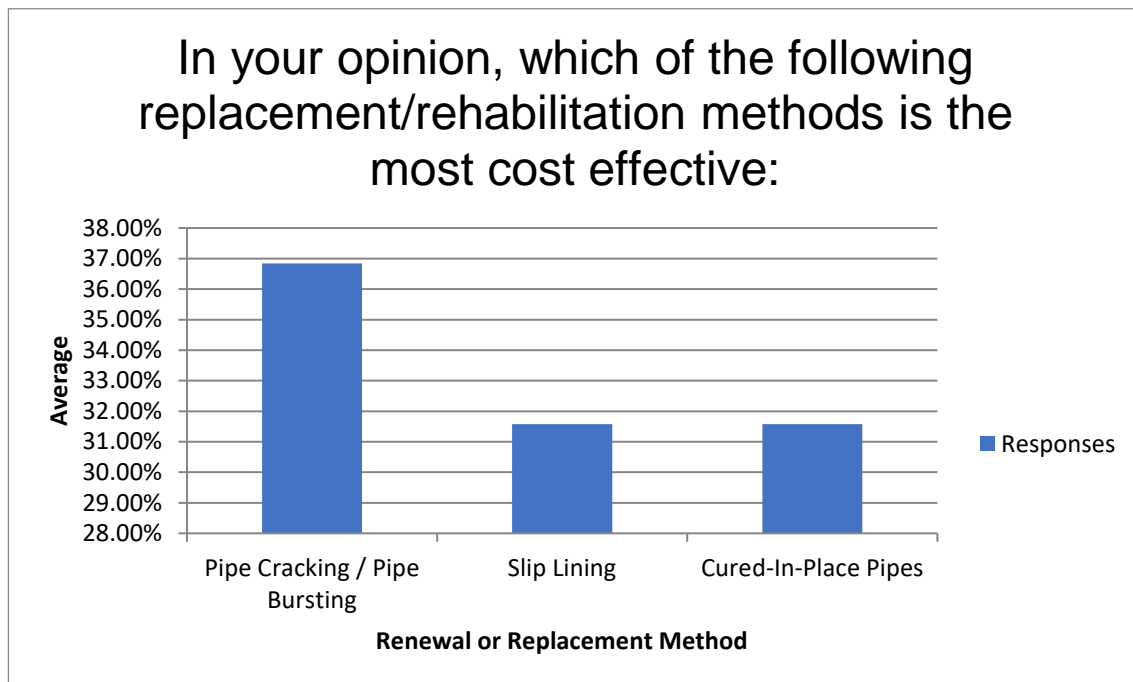


Figure 53: Q24 - Results of Respondents - Option Between Renewal or Replacement Methods

6.10 PART 7: TRENCHLESS TECHNOLOGY AGAINST THE TRADITIONAL METHOD

6.10.1 Q25 – TRENCHLESS AGAINST THE TRADITIONAL METHOD

This question determined the overall opinion of the respondents. It determined the overall preference between Trenchless Technology and the traditional method based on a standard question. This was done to determine the overall choice between the two options. Question 1 determined that the respondents liked to use Trenchless Technology regardless of any specifications or limitations. Question 2 determined that Trenchless Technology is the most effective for the installation of new pipelines and the repair and replacement of existing pipelines. It was determined that Trenchless Technology provided the best quality of workmanship and completed projects faster compared to the traditional method. It was determined that the traditional method was cheaper in terms of labour and salaries than the trenchless method. The trenchless method was more expensive in terms of machinery and equipment. Even though the trenchless method has a higher capital cost, it was still the method that provided the respondents with a higher profit margin. The method was also preferred by all respondents and recommended to all their clients.

Table 33: Q25 - Results of Respondents - Trenchless Technology or Traditional Method

Choice between Trenchless Technology and the Traditional Method?						
		Trenchless Technology		Traditional Method		Total
1	Which method do you prefer to use regardless of any specifications or limitations on a project?	100.00%	19	0.00%	0	19
2	Which method do you believe to be the most effective for the installation of new services?	68.42%	13	31.58%	6	19
3	Which method do you believe to be the most effective for the repair of existing service lines?	84.21%	16	15.79%	3	19
4	Which method provides the best quality of workmanship?	89.47%	17	10.53%	2	19
5	Which method is the fastest for the completion of a project?	94.74%	18	5.26%	1	19
6	Which method is the most expensive in terms of labour, salaries, fees etc?	26.32%	5	73.68%	14	19
7	Which method is the most expensive in terms of machinery/equipment?	84.21%	16	15.79%	3	19
8	Which method has provided you with a better profit margin on projects?	94.74%	18	5.26%	1	19
9	Which method has the highest capital cost?	84.21%	16	15.79%	3	19
10	Which method do you consider the most cost-effective option for your client?	84.21%	16	15.79%	3	19
					Answered	19
					Skipped	0

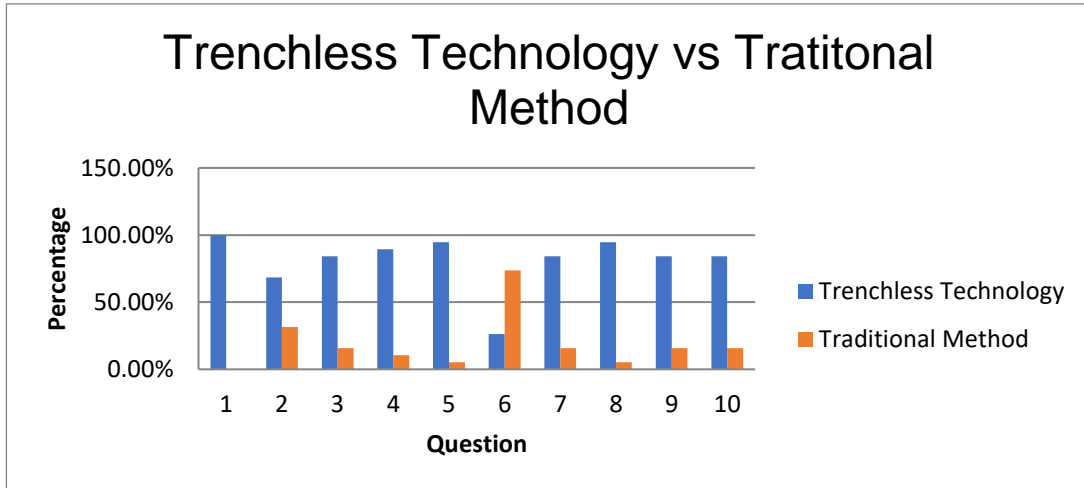


Figure 54: Q25 - Results of Respondents - Trenchless Technology or Traditional Method

6.11 SUMMARY

This chapter analysed the results of the survey and represented the findings graphically. The next chapter will analyse each question and section of the survey. The data analysis within this chapter will assist with the determination of the problem statement. The analysis will also assist with determining the future potential for the research field. This chapter outlined the main relationship between the traditional and trenchless methods. The results of the empirical study showed that the respondents are involved in Trenchless Technology projects within South Africa. The interest and involvement within the field could represent the possibility of Trenchless Technology being an alternative method to the traditional method.

The next chapter takes all the results from the twenty-three questions and compiles a summary of each part of the questionnaire. The summary will allow better data interpretation and results analysis. The next chapter will assist in determining the achievement of the research objective and verifying the research problem statement.

PART 5: DISCUSSION OF RESULTS/ EMPIRICAL STUDY

CHAPTER 7: RESULTS SUMMARY AND DISCUSSION

7.1 INTRODUCTION

This chapter analyses the results in Chapter 6 and determines the result summary for each section of the survey. The summary will assist in determining the outcome of the research problem and the recommendations for the research field. The survey consisted of seven parts that covered the relationship between the traditional and trenchless methods.

7.2 PART 1 – GENERAL INFORMATION

This part consisted of six questions. The first question requested the profession of the respondents. The majority of the respondents were involved in the Civil Industry and later moved over to the Trenchless Technology industry. This is not unusual as Civil Engineering tends to be the major field of knowledge related to Trenchless Technology. Almost all respondents moved from years in the Civil Engineering industry to the Trenchless Technology field. The first question showed that most respondents were involved in the field of Trenchless Technology.

The second question determined the years of experience of the respondents. The years of experience were analysed next to the profession of each respondent. The highest and lowest value of years of experience was allocated to the field of Civil Engineering. The values were added for the Civil Engineering field and the Trenchless Technology field. The highest total years of experience was allocated to Trenchless Technology. This could indicate that the respondents with lower years of experience had just entered the Civil Engineering field and the higher years of experience showed that the respondents remained within the field of Civil Engineering. During the middle of their career/profession path, they moved into the Trenchless Technology field. The respondents showed that they tended to remain within the field of Civil Engineering or Trenchless Technology.

The third question determined the major sector of the respondents. The results indicated that the majority of respondents were involved within the Civil Construction Industry. This could indicate that although the majority are involved within the Trenchless Technology field, they

tended to still complete projects within the standard field of Civil Engineering. This could possibly also conclude that the field of Trenchless Technology might not be big enough within South Africa to sustain a company on its own and respondents have to result to other forms of work within the Civil Construction Industry.

The fourth question determined the geographical location of the group. The majority of the respondents operated within the provinces of Gauteng and Western Cape. This could be possible since both provinces provide great opportunities for business growth and generating an income. The other provinces are expanding and showing an increased investment in Trenchless Technology.

The fifth question determined the type of services the respondents installed. The basic services included water, stormwater and sewerage. The results indicated that gas is not a service provided within South Africa and does not have the same popularity as in other countries. Telecommunication and Electrical services showed an increase in installation rates.

The sixth question determined the type of piping material used within the industry. The most used piping material was plastic and reinforced concrete pipes. Glass fibre pipes are not commonly used in South Africa. Iron and clay pipes were less likely to be used.

7.3 PART 1 – RESULTS SUMMARY

Part 1 of the questionnaire showed the general information for the group of respondents. This assists with determining the general status of the group as a whole. The general information indicated that the group of respondents were professionals within the field of Civil Engineering with a high average of experience. The information also showed that the respondents operated within all nine provinces of South Africa but focused on the main provinces. Part 1 indicated that all respondents had worked with a variety of piping material and installed a variety of services.

7.4 PART 2 – NEW PIPELINE INSTALLATIONS

This part consisted of one question that was divided into two sections. The question dealt with different methods of new pipeline installations. The eight methods are listed below:

1. Pipe Jacking
2. Utility Tunnelling
3. Horizontal Auger Earth Boring
4. Horizontal Directional Earth Drilling
5. Microtunneling
6. Pilot tube Microtunneling
7. Pipe Ramming
8. Traditional Open Excavation Method

The first section of the question determined the type of service associated with each method. None of the methods were used for the installation of gas lines, as South Africa does not make use of this service. The most common services associated with new pipeline installations were the three wet services. Electrical and Telecommunication showed an increased interest in the services.

Pipe Jacking and Pipe Ramming were the most common methods for the installation of any service. Pilot Tube Microtunneling received no responses from the respondents. Utility Tunnelling, Microtunnelling and Horizontal Auger Drilling received the lowest responses. The traditional method and Horizontal Directional Earth Drilling were also considered common or preferred methods.

The second section of the question determined the type of piping material associated with each method. Pipe Jacking and Pipe Ramming were more commonly used for reinforced concrete pipes while Horizontal Directional Earth Drilling focused more on plastic pipes. Pilot Tube Microtunneling received no responses for the type of piping material. Utility Tunnelling, Microtunnelling and Horizontal Auger Drilling can be utilised with a wider variety of piping material, but the overall interest was limited. The traditional method was associated with both plastic and reinforced concrete pipes.

7.5 PART 2 – RESULT SUMMARY

Part 2 clearly indicated that South Africa does not install gas lines or make use of Pilot Tube Microtunneling. The three basic services, water, sewerage and stormwater, were the most common services provided by the respondents. Pipe Jacking and Horizontal Directional Earth Drilling were the two most common methods used by the respondents for the installation of new pipelines. Pipe Jacking is mostly used for reinforced concrete pipes while Horizontal Directional Earth Drilling focuses on plastic pipes.

7.6 PART 3 - RENEWAL AND REPLACEMENT METHODS

This part consisted of one question that was divided into two sections. The question dealt with the different renewal and replacement methods. The four methods are listed below:

1. Pipe Cracking/ Pipe Bursting
2. Slip Lining
3. Cured-In-Place Pipes
4. Traditional Open Excavation Method

The first section of the question determined the type of service associated with each renewal and replacement method. Three of the services received no responses, namely, gas, telecommunication and electrical. These three service lines are difficult to repair or replace. The best method would be to replace the entire network of pipelines. Water, stormwater and sewerage were associated with renewal and replacement methods, as they are distributed by means of plastic pipes. Cured-In-Place received the most responses from the respondents. Pipe Cracking/ Pipe Bursting had a lower interest, but is still a preferred method (Hicks, Jamali & Kaushal. 2022: online).

The second section of the question determined the type of piping material associated with each renewal and replacement method. The piping materials mostly associated with renewal and replacement methods were High Density Polyethylene and Polyvinyl Chloride pipes. The other types of piping material did not receive many responses (Hicks, Jamali & Kaushal. 2022: online).

7.7 PART 3 – RESULT SUMMARY

Part 3 determined that renewal and replacement methods are not a suitable solution for the repair of gas, telecommunication and electrical service lines. The epoxy and materials used with these three methods do not bond with piping materials other than plastic. If the material does not bond with the pipes properly, a watertight solution cannot be accomplished. These three methods are only used for the repair of the three basic services. These methods focus on the renewal and replacement of plastic pipes. The most common method used by the respondents was the Cured-In-Place method. Pipe Cracking was a close second option for the respondents.

7.8 PART 4 – IMPORTANCE OF PROJECT SPECIFICATIONS

This part consisted of two questions. Project specifications can play a vital role in the selection or applicability of which Trenchless Technology method to implement. The first question dealt with the importance of project specifications for new pipeline installations. The results indicated that planning through to the actual construction is the most important. Quality was chosen over time and cost. The respondents determined that the details and information on the ground conditions were vital in determining the method that would be implemented. The respondents felt that specialised labour was more important than standard labour (Jung & Sinha. 2007: online).

The second question dealt with the project specifications for renewal and replacement methods. The same results were observed for the renewal and replacement methods as for the new installation methods. The respondents believed that planning through to construction plays a vital role in the selection process. The respondents also considered quality over time and cost to be important during the repair and maintenance of pipelines. The respondents felt that specialised labour was important for renewal and replacement methods (Jung & Sinha. 2007: online).

7.9 PART 4 – RESULTS SUMMARY

Part 4 determined the importance of project specifications. It was clear that both new installation methods and renewal and replacement methods had the same results. The respondents felt that the planning all the way to construction is vital for the success of the projects and the selection of which method to implement. This part indicated that project

specifications play a vital role in determining which methods can be used. Certain methods are only applicable within certain project specifications and scopes. The respondents determined that quality was more important than time and cost. Both new installation methods and renewal and replacement methods require specialised operators and workers.

7.10 PART 5 - THE FINANCIAL ASPECT OF THE TRADITIONAL METHOD

This part consisted of five questions. This part of the survey determined the financial aspect of the traditional method. This part plays a key role in the determination of the problem statement. The first question dealt with the lowest contract value associated with the traditional method. The lowest contract value was smaller than R 1 million. The second question determined the highest contract value associated with the traditional method. The highest contract value was in the range of R 1 million to R 10 million. The third question determined the average contract value. The respondents stated that the average contract value for projects using the traditional method was below R 1 million (Industrial Development Corporation, 2017a: 20).

The fourth question determined the average cost per metre for projects using the traditional method. The cost exceeds R 3 000.00 p/m. The last question determined the cost of the three main project determinants. Machinery and Labour received the highest responses in terms of which project determinants cost the most. Site establishment was on the lower side.

In order to compare the financial aspect of the traditional method against the trenchless method, a cost comparison can be done using different criteria. The following three examples can be used as a baseline to calculate the cost per metre for the traditional method. All three calculations make provision for the installation using the traditional method including labour, machinery and equipment. The piping material has been excluded from the calculation. See Chapter 7.14 for a more detailed calculation comparing the traditional method to the trenchless method using different piping diameters.

Calculation No. 1 – The cost of installation using the traditional method with G5 and crushed stone infilling in soft rock and hard rock

CALCULATION NO.1					
BASIC CALCULATION FOR THE TRADITIONAL METHOD					
A 1000mm wide x 1000mm long x 1000mm deep trench with G5 and crushed stone infilling, without piping, in soft rock & hard rock Priced by an Independent Local Contractor.					
1	PRELIMINARIES & GENERAL - ALLOWANCE OF 10%	Item	1	R 1 560.76	R 1 560.76
2	EARTHWORKS				
	<u>Trench excavation in earth not exceeding 2m deep</u>				
	Trenches	m ³	1	R 96.41	R 96.41
	<u>Extra over pipeline excavations in earth for excavation in</u>				
	Soft rock @ 70%	m ³	0.7	R 657.65	R 460.36
	Hard rock @ 30%	m ³	0.3	R 1 242.57	R 372.77
	<u>Extra over all trench pipeline excavation for hauling off</u>				
	Excess material from trench pipeline excavation and/or stockpiles on site to be hauled off site to a location selected by the contractor	m ³	1	R 340.00	R 340.00
	<u>Risk of collapse of trench pipeline excavation</u>				
	Sides and pipeline excavations not exceeding 1,5m deep	m ²	2	R 15.00	R 30.00
	<u>Keeping trench pipeline excavation free from water</u>				
	Removing water from trenches	Item	1	R 4 500.00	R 4 500.00
	<u>PIPE FILLING, ETC</u>				
	<u>Filling for pipes obtained from trench pipeline excavation and/or</u>				
	<u>prescribed stockpiles on site, compacted to 93% Mod</u>				
	<u>AASHTO density</u>				
	Infilling to pipelines, etc	m ³	0.6	R 105.97	R 63.58
	<u>G5 filling provided by the contractor, compacted to</u>				
	<u>at least 93% Mod AASHTO density</u>				
	150mm Imported G5 Material	m ³	0.15	R 431.40	R 64.71
	<u>19mm Crushed stone filling</u>				
	250mm crushed stone to pipeline trenches	m ³	0.25	R 431.13	R 107.78
	<u>Compaction of ground surfaces under pipeline</u>				
	Compaction under pipeline, etc including scarifying for a depth of at least 150mm, breaking down oversize material, adding suitable material where necessary and compacting.	m ²	1	R 21.02	R 21.02
	<u>Prescribed density tests on pipe filling</u>				
	Density test	No	20	R 475.00	R 9 500.00
	<u>SOIL POISONING</u>				
	<u>Soil insecticide</u>				
	To bottoms and sides of pipeline trenches	m ²	3	R 17.00	R 51.00
3	SERVICES				

	Excluded for Calculation	Item	1	R -	R -
4	LABOUR				
	General Labour	Item	1	Incl. above	R -
	Specialised Labour	Item	1	Incl. above	R -
5	EQUIPMENT				
	Manual Tools	Item	1	Incl. above	R -
	Machinery	Item	1	Incl. above	R -
6	OTHER SERVICES				
	Transport	Item	1	Incl. above	R -
	Welding of Joints	Item	1	Incl. above	R -
	Protective Coating or Sealant	Item	1	Incl. above	R -
	Encasing	Item	1	Incl. above	R -
7	TESTING				
	Testing water Pipes	Item	1	Incl. above	R -
	Pressure Testing	Item	1	Incl. above	R -
					<u>R 17 168.39</u>

Calculation No. 2 - The cost of installation by using the traditional method with G5 and crushed stone infilling in hard rock

CALCULATION NO.2					
BASIC CALCULATION FOR THE TRADITIONAL METHOD					
A 1000mm wide x 1000mm long x 1000mm deep trench with G5 and crushed stone infilling, without piping, in hard rock.					
Priced by an Independent Local Contractor.					
1	PRELIMINARIES & GENERAL - ALLOWANCE OF 10%	Item	1	R 1 601.71	R 1 602.71
2	EARTHWORKS				
	<u>Trench excavation in earth not exceeding 2m deep</u>				
	Trenches	m ³	1.0	R 96.41	R 96.41
	<u>Extra over pipeline excavations in earth for excavation in</u>				
	Soft rock @ 0%	m ³	0	R 657.65	R -
	Hard rock @ 100%	m ³	1.0	R 1 242.57	R 1 242.57
	<u>Extra over all trench pipeline excavation for hauling off</u>				
	Excess material from trench pipeline excavation and/or stockpiles on site be hauled off site to a location selected by the contractor	m ³	1.0	R 340.00	R 340.00
	<u>Risk of collapse of trench pipeline excavation</u>				
	Sides and pipeline excavations not exceeding 1,5m deep	m ²	2	R 15.00	R 30.00
	<u>Keeping trench pipeline excavation free from water</u>				
	Removing water from trenches	Item	1	R 4 500.00	R 4 500.00
	<u>PIPE FILLING, ETC</u>				
	<u>Filling for pipes obtained from trench pipeline excavation and/or prescribed stockpiles on site, compacted to 93% Mod AASHTO density</u>				
	Infilling to pipelines, etc	m ³	0.6	R 105.97	R 63.58
	<u>G5 filling provided by the contractor, compacted to at least 93% Mod AASHTO density</u>				
	150mm Imported G5 Material	m ³	0.15	R 431.40	R 64.71
	<u>19mm Crushed stone filling</u>				
	250mm crushed stone to pipeline trenches	m ³	0.25	R 431.13	R 107.78
	<u>Compaction of ground surfaces under pipeline</u>				
	Compaction under pipeline, etc including scarifying for a depth of at least 150mm, breaking down oversize material, adding suitable material where necessary and Compacting.	m ²	1	R 21.02	R 21.02
	<u>Prescribed density tests on pipe filling</u>				
	Density test	No	20	R 475.00	R 9 500.00
	<u>SOIL POISONING</u>				
	<u>Soil insecticide</u>				
	To bottoms and sides of pipeline trenches	m ²	3	R 17.00	R 51.00
3	SERVICES				
	Excluded for Calculation	Item	1	R -	R -
4	LABOUR				
	General Labour	Item	1	Incl. above	R -

	Specialised Labour	Item	1	Incl. above	R -
5	EQUIPMENT				
	Manual Tools	Item	1	Incl. above	R -
	Machinery	Item	1	Incl. above	R -
6	OTHER SERVICES				
	Transport	Item	1	Incl. above	R -
	Welding of Joints	Item	1	Incl. above	R -
	Protective Coating or Sealant	Item	1	Incl. above	R -
	Encasing	Item	1	Incl. above	R -
7	TESTING				
	Testing water Pipes	Item	1	Incl. above	R -
	Pressure Testing	Item	1	Incl. above	R -
					<u>R 17 619.78</u>

Calculation No.3 - The cost of installation by using the traditional method with G5, G7 and crushed stone infilling in soft rock and hard rock

CALCULATION NO.3					
BASIC CALCULATION FOR THE TRADITIONAL METHOD					
A 1000mm wide x 1000mm long x 1000mm deep trench with G5, G7 and crushed stone infilling, without piping, in soft rock & hard rock Priced by an Independent Local Contractor.					
1	PRELIMINARIES & GENERAL - ALLOWANCE OF 10%	Item	1	R 1 566.30	R 1 567.30
2	EARTHWORKS				
	<u>Trench excavation in earth not exceeding 2m deep</u>				
	Trenches	m ³	1	R 96.41	R 96.41
	<u>Extra over pipeline excavations in earth for excavation in</u>				
	Soft rock @ 70%	m ³	0.7	R 657.65	R 460.36
	Hard rock @ 30%	m ³	0.3	R 1 242.57	R 372.77
	<u>Extra over all trench pipeline excavation for hauling off</u>				
	Excess material from trench pipeline excavation and/or stockpiles on site to be hauled off site to a location selected by the contractor	m ³	1	R 340.00	R 340.00
	<u>Risk of collapse of trench pipeline excavation</u>				
	Sides and pipeline excavations not exceeding 1,5m deep	m ²	2	R 15.00	R 30.00
	<u>Keeping trench pipeline excavation free from water</u>				
	Removing water from trenches	Item	1	R 4 500.00	R 4 500.00
	<u>PIPE FILLING, ETC</u>				
	<u>Filling for pipes obtained from trench pipeline excavation and/or prescribed stockpiles on site, compacted to 93% Mod AASHTO density</u>				
	Infilling to pipelines, etc	m ³	0.4	R 105.97	R 42.39
	<u>G5 filling provided by the contractor, compacted to at least 93% Mod AASHTO density</u>				
	150mm Imported G5 Material	m ³	0.15	R 431.40	R 64.71
	<u>G7 earth filling supplied by the contractor, compacted to at least 93% Mod AASHTO density</u>				
	150mm Imported G7 Material	m ³	0.2	R 382.65	R 76.53
	<u>19mm Crushed stone filling</u>				
	250mm crushed stone to pipeline trenches	m ³	0.25	R 431.13	R 107.78
	<u>Compaction of ground surfaces under pipeline</u>				
	Compaction under pipeline, etc including scarifying for a depth of at least 150mm, breaking down oversize material, adding suitable material where necessary and Compacting.	m ²	1	R 21.02	R 21.02
	<u>Prescribed density tests on pipe filling</u>				
	Density test	No	20	R 475.00	R 9 500.00
	<u>SOIL POISONING</u>				
	<u>Soil insecticide</u>				
	To bottoms and sides of pipeline trenches	m ²	3	R 17.00	R 51.00
3	SERVICES				

	Excluded for Calculation	Item	1	R -	R -
4	LABOUR				
	General Labour	Item	1	Incl. above	R -
	Specialised Labour	Item	1	Incl. above	R -
5	EQUIPMENT				
	Manual Tools	Item	1	Incl. above	R -
	Machinery	Item	1	Incl. above	R -
6	OTHER SERVICES				
	Transport	Item	1	Incl. above	R -
	Welding of Joints	Item	1	Incl. above	R -
	Protective Coating or Sealant	Item	1	Incl. above	R -
	Encasing	Item	1	Incl. above	R -
7	TESTING				
	Testing water Pipes	Item	1	Incl. above	R -
	Pressure Testing	Item	1	Incl. above	R -
					R 17 230.26

7.11 PART 5 – RESULTS SUMMARY

This part determined that the average and lowest contract value of the traditional method was R 1 million. The highest contract value does not exceed R 10 million. This means that the average contract value of the respondents does not exceed R 1 million. The average cost for the traditional method exceeds R 3 000.00 p/m. The respondents spent most of their project costs on labour and machinery.

The three calculations indicate that the traditional method is dependent on the presence of soft and hard rock in the excavations. The difficulty of the excavation directly determines the labour and machinery costs. The required infilling can increase the cost per metre. The importing and procurement of the type of soil can directly influence the cost of the traditional method. All three calculations include an allowance for Preliminary and General costs. Calculation No.1 shows a cost of R17 168.39 per m³ for the excavation using the traditional method in ideal ground conditions. Calculation No.2 has the highest cost at R17 619.78 per m³ for excavating in a hard rock environment. The comparison between the two calculations shows that ground conditions can influence the cost. Calculation No.3 shows that the nature of the infilling can change the rate per m³, but the nature of the soil plays a more crucial role in cost determination.

7.12 PART 6 - THE FINANCIAL ASPECT OF TRENCHLESS TECHNOLOGY

This part consisted of nine questions. The first question determined the lowest contract value associated with Trenchless Technology. The lowest contract value was smaller than R 1 million. The next question determined the method of Trenchless Technology used during the lowest contract value. The most common method was Horizontal Directional Earth Drilling followed by Pipe Cracking. Cured-In-Place and Pipe Jacking also accumulated high results (Industrial Development Corporation, 2017b: 9).

The next question determined the average contract value associated with Trenchless Technology methods. The average contract value was below R 1 million. The next question determined the type of method associated with the average contract value. The methods in order were Horizontal Directional Earth Drilling, Cured-In-Place pipes and Pipe Cracking. The fifth question determined the highest contract value associated with Trenchless Technology. The highest contract value was calculated in the range of R 1 million to R 10million. The methods associated with the highest contract value were Horizontal Directional Earth Drilling, Cured-In-Place pipes and Pipe Jacking.

The average cost per metre was calculated for each method of new installations and renewal and replacement methods. Pilot Tube Microtunneling and Pipe Ramming seem to be the most uncommon methods used for most installations. Utility Tunnelling and Horizontal Auger Earth Boring were considered to have a lower interest compared to other methods. The three renewal and replacement methods received higher interest. Pipe Cracking and Cured-In-Place pipes range from R 2 000.00 to R 3 000.00 per metre. Slip Lining seemed to be cheaper at a range of R 1 000.00 to R 2 000.00 per metre. Horizontal Directional Earth Drilling and Pipe Jacking were the most common methods with respondents. Pipe Jacking can exceed R 3 000.00 per metre, while Horizontal Directional Earth Drilling ranges from R 1 000.00 to R 2 000.00 per metre.

In order to compare the financial aspect of Trenchless Technology against the traditional method, a cost comparison can be done using different criteria. The following two examples can be used as a baseline to calculate the cost per metre for the trenchless method. All three calculations make provision for the installation using Pipe Jacking and Horizontal Directional Earth Drilling. Both calculations make provision for labour, machinery

and equipment. The piping material has been excluded from the calculation. See Chapter 7.14 for a more detailed calculation comparing the traditional method to the trenchless method using different piping diameters.

Calculation No. 1 – The cost of installation by using Pipe Jacking in hard rock

CALCULATION NO.2					
BASIC CALCUALTION FOR PIPE JACKING					
Pipe Jacking in earth, without piping, in hard rock Priced by an Independent Trenchless Contractor					
1	PRELIMINARIES & GENERAL				
	Site Establishment	Item	1	R5 000.00	R5 000.00
	De-establishment	Item	1	R5 000.00	R5 000.00
	Other: Allowance @ 20%	Item	1	R640.00	R640.00
2	EARTHWORKS				
	<u>Extra over pipeline excavations in earth for excavation in</u>				
	Soft rock @ 70%	m ³	0	R700.00	-
	Hard rock @ 30%	m ³	1	R1 500.00	R1 500.00
3	SERVICES				
	Excluded for Calculation	Item	1	-	-
4	LABOUR				
	General Labour @ 5 Labourer	Item	5	R250.00	R1 250.00
	Specialised Labour @ 1 Operator	Item	1	R450.00	R450.00
5	EQUIPMENT				
	Manual Tools	Item	1	-	-
	Machinery	Item	1	Incl. above	-
6	OTHER SERVICES				
	Transport - Included in Site Establishment	Item	1	Incl. above	-
	Welding of Joints	Item	1	Incl. above	-
	Protective Coating or Sealant	Item	1	Incl. above	-
	Encasing	Item	1	Incl. above	-
7	TESTING				
	Testing water Pipes	Item	1	Incl. above	-
	Pressure Testing	Item	1	Incl. above	-
					<u>R13 840.00</u>

Calculation No. 2 – The cost of installation by using Horizontal Drilling in hard rock

CALCULATION NO.1					
BASIC CALCULATION FOR HORIZONTAL DRILLING					
Horizontal Drilling in earth, without piping, in hard rock Priced by an Independent Trenchless Contractor					
1	PRELIMINARIES & GENERAL				
	Site Establishment	Item	1	R5 000.00	R5 000.00
	De-establishment	Item	1	R5 000.00	R5 000.00
	Other: Allowance @ 20%	Item	1	R440.00	R440.00
2	EARTHWORKS				
	<u>Extra over pipeline excavations in earth for excavation in</u>				
	Soft rock @ 70%	m ³	0	R700.00	-
	Hard rock @ 30%	m ³	1	R1 500.00	R1 500.00
3	SERVICES				
	Excluded for Calculation	Item	1	-	-
4	LABOUR				
	General Labour @ 1 Labourer	Item	1	R250.00	R250.00
	Specialised Labour @ 1 Operator	Item	1	R450.00	R450.00
5	EQUIPMENT				
	Manual Tools	Item	1	-	-
	Machinery	Item	1	Incl. above	-
6	OTHER SERVICES				
	Transport - Included in Site Establishment	Item	1	Incl. above	-
	Welding of Joints	Item	1	Incl. above	-
	Protective Coating or Sealant	Item	1	Incl. above	-
	Encasing	Item	1	Incl. above	-
7	TESTING				
	Testing water Pipes	Item	1	Incl. above	-
	Pressure Testing	Item	1	Incl. above	-
					<u>R12 640.00</u>

The next question determined the cost of the three project determinants for Trenchless Technology. The highest cost is spent on Machinery, closely followed by Labour. The least amount of cost was spent on Site Establishment. The last question determined the option between the three renewal and replacement methods. Pipe Cracking was the option chosen by most respondents. Slip lining and Cured-In-Place pipes were not that popular.

7.13 PART 6 – RESULT SUMMARY

This part determined that the lowest and average contract value of Trenchless Technology was R 1 million. The highest contract value was R 10 million. This showed that both the traditional and trenchless methods had the same average contract value of R 1 million. This could indicate that the number of trenchless projects available are equal to the number of traditional projects done by the respondents or that there was no increased demand for the utilisation of the trenchless method.

Pipe Jacking tied with the traditional method at exceeding R 3 000.00 p/m. Even though the most common method (Pipe Jacking) costs the same as the traditional method, the respondents tended to implement the next viable option. Horizontal Directional Earth Drilling is the cheapest new installation method at a range of R 1 000.00 to R 2 000.00 p/m. Horizontal Directional Earth Drilling is the method that has been used within South Africa for the longest period of time. The other trenchless methods are newer, and interest is still growing.

Cured-in-place and Pipe Cracking range between R 2 000.00 to R 3 000.00 p/m for renewal and replacement methods, but Slip Lining proved to be the cheapest method at a range of R 1 000.00 to R 2 000.00 p/m. The respondents stated that the most cost was spent on machinery and labour when it comes to Trenchless Technology. The respondents chose Pipe Cracking as their preferred renewal and replacement method.

The two calculations show a difference in cost per m³ at R12 640.00 for Horizontal Directional Earth Drilling compared to R 13 840.00 for Pipe Jacking. The difference in cost was determined by the amount of labour required by each method. Pipe Jacking requires more unskilled labour compared to the Horizontal Directional Earth Drilling method, but both methods require a skilled operator. The increased number of unskilled labour is used within the pit itself during the Pipe Jacking method. They are needed to manage the hydraulic jacks and insert new piping material as each section is jacked forward.

When comparing these two calculations to the three calculations for the traditional method under Chapter 7.10, it can be seen that the traditional method is more expensive in terms of excavation. The establishment of the equipment during the trenchless methods is more expensive when compared to the traditional method, but the cost of excavations in the traditional method exceeds the non-existent cost of excavations in the trenchless method.

Therefore, the entire sum cost of the traditional method tends to be more expensive than the cost of the two most commonly used trenchless methods.

7.14 PART 7 - TRENCHLESS TECHNOLOGY VS THE TRADITIONAL METHOD

This part consisted of ten short questions. It determined the preference of the respondents between the traditional and trenchless methods. The first question determined the personal choice of each respondent between the two options. All respondents chose Trenchless Technology as their preferred method. The next question determined which method the respondents believed to be the most effective for new pipeline installations. The majority of respondents chose the trenchless method. The third question determined which method was the most effective for repairing existing pipelines. The majority of respondents chose the trenchless method (Hay, 2013: 15).

The next four questions focused on the three main project determinants of Quality, Time and Cost. The fourth question determined which method provides the better quality of work. The fifth question determined which method was the fastest in terms of installation and repairs. The sixth question determined which method is the most expensive in terms of salaries and wages. The seventh question determined the cost of machinery or equipment for each method. In terms of Quality and Time, the respondents chose the trenchless method. In terms of salaries and wages, the respondents chose the traditional method. This could possibly indicate that although the trenchless method made use of specialised operators, the traditional method was still more expensive, as this method required a large number of workers. The machinery and equipment costs were still higher for the trenchless method. In general, the traditional method was chosen for cost (Hay, 2013: 23).

The last three questions focused on the benefits of these two methods for the respondents. Question 8 determined which method produced the best profit margin for respondents. The majority of respondents chose the trenchless method. Question 9 determined that the trenchless method has the highest capital cost. The machinery and equipment used for the trenchless method was determined to be more advanced than the equipment used for the traditional method. The last question determined whether the respondents would recommend the trenchless or traditional method to their clients. The majority of the group would recommend the trenchless method to their clients (Hay, 2013: 35).

COST COMPARISON FOR THE TRADITIONAL VS TRENCHLESS METHOD						
Cost Comparison for the installation of 100m pipe with a diameter of 110mm at a depth of 600mm						
			TRADITIONAL		TRENCHLESS	
		QTY	Rate	Total	Rate	Total
1. Preliminaries & General				R 64 650.00		R 74 550.00
Site Establishment	Item	1	2 000.00	2 000.00	11 000.00	11 000.00
Insurance and guarantees	Item	1	7 400.00	7 400.00	7 400.00	7 400.00
Site Facilities	Item	1	1 750.00	1 750.00	350.00	350.00
Health & Safety	Item	1	10 000.00	10 000.00	3 300.00	3 300.00
Surveying of Services	Item	1	15 000.00	15 000.00	15 000.00	15 000.00
Soil Investigation	Item	1	25 000.00	25 000.00	25 000.00	25 000.00
Preparation of as-built drawings	Item	1	1 500.00	1 500.00	1 500.00	1 500.00
De-establishment	Item	1	2 000.00	2 000.00	11 000.00	11 000.00
2. Earthworks				R 79 326.72		R 50 400.00
Site Clearance	m2	60	76.50	4 590.00	R -	R -
Trenches for Pipes	m3	36	96.41	3 470.76	R -	R -
Dewatering of Trenches	Item	1	5 000.00	5 000.00	R -	R -
Infilling of Trenches	m3	30	345.32	10 359.60	R -	R -
Compaction of excavated soil	m2	60	25.04	1 502.40	R -	R -
Carting away excavated soil	m3	6	340.00	2 040.00	R -	R -
Risk of Collapse	m2	120	15.00	1 800.00	R -	R -
Soil Tests	No	28	475.00	13 300.00	R -	R -
Soil Poisoning	m2	180	17.00	3 060.00	R -	R -
Extra over for Rock	m3	36	950.11	34 203.96	1 400.00	50 400.00
3. Services				R 15 500.00		R 15 500.00
Sewerage	m	100	155.00	15 500.00	155.00	15 500.00

Electrical	m	0	R -	R -	R -	R -
Water	m	0	R -	R -	R -	R -
Stormwater	m	0	R -	R -	R -	R -
Gas	m	0	R -	R -	R -	R -
4. Labour				R 9 750.00		R 4 500.00
General Labour	Item	1	7 500.00	7 500.00	750.00	750.00
Specialised Labour	Item	1	2 250.00	2 250.00	3 750.00	3 750.00
5. Equipment				R -		R -
Manual Tools	Item	1	Incl. above	R -	Incl. above	R -
Machinery	Item	1	Incl. above	R -	Incl. above	R -
6. Other Services				R -		R -
Transport	Item	1	Incl. above	R -	Incl. above	R -
Welding of Joints	Item	1	Incl. above	R -	Incl. above	R -
Protective Coating or Sealant	Item	1	Incl. above	R -	Incl. above	R -
Encasing	Item	1	Incl. above	R -	Incl. above	R -
7. Testing				R -		R -
Testing Water Pipes	Item	1	Incl. above	R -	Incl. above	R -
Pressure Testing	Item	1	Incl. above	R -	Incl. above	R -

ESTIMATED TOTAL COSTRUCTION COST (CARRIED TO SUMMARY)

R 169 226.72

R 144 950.00

SUMMARY					
Length of Pipeline	m			100	
Construction Start Date	Date			01-01-2025	
Construction End Date	Date			05-01-2025	
SUMMARY OF CONSTRUCTION COSTS					
	TRADITIONAL		TRENCHLESS		
	Cost (R)	Rate per m (R)	Cost (R)	Rate per m (R)	Cost Difference %
1. Preliminaries & General	R 64 650.00	R 646.50	R 74 550.00	R 745.50	-14.22%
2. Earthworks	R 79 326.72	R 793.27	R 50 400.00	R 504.00	44.60%
3. Services	R 15 500.00	R 155.00	R 15 500.00	R 155.00	0.00%
4. Labour	R 9 750.00	R 97.50	R 4 500.00	R 45.00	73.68%
5. Equipment	R -	R -	R -	R -	0.00%
6. Other Services	R -	R -	R -	R -	0.00%
7. Testing	R -	R -	R -	R -	0.00%
ESTIMATE OF CONSTRUCTION COSTS (EXCLUDING CONTINGENCY)	R 169 226.72	R 1 692.27	R 144 950.00	R 1 449.50	15.45%
Contingency @ 10%	R 16 922.67	R 169.23	R 14 495.00	R 144.95	15.45%
ESTIMATE OF CONSTRUCTION COSTS (EXCLUDING ESCALATION)	R 186 149.39	R 1 861.49	R 159 445.00	R 1 594.45	15.45%
Escalation @ 5%	R 9 307.47	R 93.07	R 7 972.25	R 79.72	15.45%
ESTIMATE OF CONSTRUCTION COSTS (EXCLUDING VAT)	R 195 456.86	R 1 954.57	R 167 417.25	R 1 674.17	15.45%
Vat @ 15%	R 29 318.53	R 293.19	R 25 112.59	R 251.13	15.45%
ESTIMATE OF CONSTRUCTION COSTS (INCLUDING VAT)	R 224 775.39	R 2 247.75	R 192 529.84	R 1 925.30	15.45%

COST COMPARISON FOR THE TRADITIONAL VS TRENCHLESS METHOD						
Cost Comparison for the installation of 100m pipe with a diameter of 300mm at a depth of 1000mm						
			TRADITIONAL		TRENCHLESS	
			Rate	Total	Rate	Total
1. Preliminaries & General				R 70 400.00		R 74 550.00
Site Establishment	Item	1	4 000.00	4 000.00	11 000.00	11 000.00
Insurance and guarantees	Item	1	7 400.00	7 400.00	7 400.00	7 400.00
Site Facilities	Item	1	3 500.00	3 500.00	350.00	350.00
Health & Safety	Item	1	10 000.00	10 000.00	3 300.00	3 300.00
Surveying of Services	Item	1	15 000.00	15 000.00	15 000.00	15 000.00
Soil Investigation	Item	1	25 000.00	25 000.00	25 000.00	25 000.00
Preparation of as-built drawings	Item	1	1 500.00	1 500.00	1 500.00	1 500.00
De-establishment	Item	1	4 000.00	4 000.00	11 000.00	11 000.00
2. Earthworks				R 121 508.14		R 100 800.00
Site Clearance	m2	60	76.50	4 590.00	-	-
Trenches for Pipes	m3	60	105.02	6 301.20	-	-
Dewatering of Trenches	Item	1	5 000.00	5 000.00	-	-
Infilling of Trenches	m3	54	345.32	18 647.28	-	-
Compaction of excavated soil	m2	60	25.04	1 502.40	-	-
Carting away excavated soil	m3	6	340.00	2 040.00	-	-
Risk of Collapse	m2	200	15.00	3 000.00	-	-
Soil Tests	No	28	475.00	13 300.00	-	-
Soil Poisoning	m2	260	17.00	4 420.00	-	-
Extra over for Rock	m3	60	1 045.12	62 707.26	1 680.00	100 800.00

3. Services				R 62 000.00		R 62 000.00
Sewerage	m	100	620.00	62 000.00	620.00	62 000.00
Electrical	m	0	-	-	-	-
Water	m	0	-	-	-	-
Stormwater	m	0	-	-	-	-
Gas	m	0	-	-	-	-
4. Labour				R 48 750.00		R 22 500.00
General Labour	Item	1	37 500.00	37 500.00	3 750.00	3 750.00
Specialised Labour	Item	1	11 250.00	11 250.00	18 750.00	18 750.00
5. Equipment				R -		R -
Manual Tools	Item	1	Incl. above	-	Incl. above	-
Machinery	Item	1	Incl. above	-	Incl. above	-
6. Other Services				R -		R -
Transport	Item	1	Incl. above	-	Incl. above	-
Welding of Joints	Item	1	Incl. above	-	Incl. above	-
Protective Coating or Sealant	Item	1	Incl. above	-	Incl. above	-
Encasing	Item	1	Incl. above	-	Incl. above	-
7. Testing				R -		R -
Testing Water Pipes	Item	1	Incl. above	-	Incl. above	-
Pressure Testing	Item	1	Incl. above	-	Incl. above	-

ESTIMATED TOTAL COSTRUCTION COST (CARRIED TO SUMMARY)

R 302 658.14

R 259 850.00

SUMMARY				
Length of Pipeline	m			100
Construction Start Date	Date			01-01-2025
Construction End Date	Date			05-01-2025

SUMMARY OF CONSTRUCTION COSTS

	<u>TRADITIONAL</u>		<u>TRENCHLESS</u>		Cost Difference %
	Cost (R)	Rate per m (R)	Cost (R)	Rate per m (R)	
1. Preliminaries & General	R 70 400.00	R 704.00	R 74 550.00	R 745.50	-5.73%
2. Earthworks	R 121 508.14	R 1 215.08	R 100 800.00	R 1 008.00	18.63%
3. Services	R 62 000.00	R 620.00	R 62 000.00	R 620.00	0.00%
4. Labour	R 48 750.00	R 487.50	R 22 500.00	R 225.00	73.68%
5. Equipment	R -	R -	R -	R -	0.00%
6. Other Services	R -	R -	R -	R -	0.00%
7. Testing	R -	R -	R -	R -	0.00%
ESTIMATE OF CONSTRUCTION COSTS (EXCLUDING CONTINGENCY)	R 302 658.14	R 3 026.58	R 259 850.00	R 2 598.50	15.22%
Contingency @ 10%	R 30 265.81	R 302.66	R 25 985.00	R 259.85	15.22%
ESTIMATE OF CONSTRUCTION COSTS (EXCLUDING ESCALATION)	R 332 923.95	R 3 329.24	R 285 835.00	R 2 858.35	15.22%
Escalation @ 5%	R 16 646.20	R 166.46	R 14 291.75	R 142.92	15.22%
ESTIMATE OF CONSTRUCTION COSTS (EXCLUDING VAT)	R 349 570.15	R 3 495.70	R 300 126.75	R 3 001.27	15.22%
Vat @ 15%	R 52 435.52	R 524.36	R 45 019.01	R 450.19	15.22%
ESTIMATE OF CONSTRUCTION COSTS (INCLUDING VAT)	R 402 005.67	R 4 020.06	R 345 145.76	R 3 451.46	15.22%

The two cost comparisons above determine the average cost per metre of a 110mm and 300mm diameter pipe installed at a depth of 1m below ground level. The two calculations compare the two methods for the new installation of pipelines. The costs for the traditional and trenchless methods were priced by independent contractors that did not form part of the research group. These two calculations are more detailed and provide more information and costing for both methods. Both examples are based on the same project specifications. The length of the pipeline and soil properties are kept constant.

The main cost differences within each calculation are the Preliminary & General, Earthworks and Labour costs. Both contractors' price in the same range for the supply and delivery of the material. The change in diameter of the pipeline increases exponentially for both methods. The material costs, therefore, remain fairly constant for both methods. The cost for other services and testing of both methods are included within the rates provided by both contractors. The labour costs associated with the traditional method is determined by the difficulty of working with the diameter of piping. A bigger diameter pipe requires more unskilled labour due to the size, weight and workability of the piping. The trenchless method requires less unskilled labour as the machine or equipment assists with the change in diameter of the piping. The trenchless method uses different attachments or machinery for bigger diameter piping.

The Earthwork costs within most of the trenchless methods are limited when compared to the traditional method. Both methods need to make provision for hard rock and soft rock. The difference in cost, where the traditional method is preferred above most trenchless methods, would be the establishment costs. Both methods require the same amount of insurance and guarantees as the contractors are obligated to provide these documents regardless of the method. The soil investigation and surveying services still need to be executed and provided by the engineer for both methods. The Health & Safety and Site facility costs are less for the traditional method than the trenchless method. These costs are directly determined by the amount of people on site. The traditional method has more site staff which results in higher costs.

Provision for a Contingency and Escalations costs have been applied to both methods. The cost difference percentage between the two methods is 15.45% for the 110mm diameter pipeline and 15.22% for the 300mm diameter pipeline. The less commonly used diameter of pipes has a higher cost difference. This is mainly due to the extra material costs charged by the suppliers for rarely used piping.

The calculations are based on sewage pipelines. Other types of services used in South Africa such as water, stormwater and electrical will be determined using the same format for the calculation. Since both methods will use the same diameter or type of pipeline, the costs will be identical to one another. The type of pipeline or service is determined by project specifications and not the method chosen for installation.

From the results of the research study, the rehabilitation or repair of pipelines can be a financially viable solution but only for maintenance or as needed for a temporary solution. Most respondents did suggest that a new installation is their preferred method. The respondents indicated that rehabilitation and replacement methods carry more risks and are more complicated. It is often difficult to determine the exact deterioration or current condition of the existing pipeline. The bends and junctions within the pipeline make it difficult to navigate underground as these methods are not steerable. The speed and quality of the trenchless method is also the reason for the recommendation to the client by the contractors. The respondents believe that relying on the machinery more than manual labour has more benefits for pipeline projects

7.15 PART 7 – RESULT SUMMARY

This part determined the overall preference of the respondents between the traditional and trenchless method. The majority of respondents preferred the trenchless method above the traditional method. The respondents reported that even though the trenchless method was the most expensive overall, they still preferred this method. They reported a higher profit margin and better quality when using the trenchless method. The majority of the responses pointed to the trenchless method. The traditional method was only chosen as the most affordable method when it came to wages and machinery costs.

7.16 SUMMARY

This chapter outlined and determined the results of each part of the survey. The survey consisted of seven individual parts that should assist with determining the outcome of the research problem statement. This chapter provided a summary of the data analysis and data interpretation from the empirical study. Each part represented the results from the respondents and assisted with determining the success of the research study.

This Chapter will be used to determine the conclusion and recommendations for the research study. From the summaries of each part of the questionnaire, it is clear that there are two methods to consider for new pipeline installations and two methods for the renewal and replacement of pipelines. The project specifications play a role in the selection process of the methods.

PART 6: CONCLUSION

CHAPTER 8: CONCLUSION AND RECOMMENDATIONS

8.1 INTRODUCTION

This chapter combines the data discussion and results of the empirical study to determine the results of the research problem statement. It further examines the information gathered from the literature review to assist with determining the outcome of the research study. This research study was conducted to expand the research field of Trenchless Technology within South Africa.

The main purpose was to give an introductory explanation and accurate illustration of the basic principles of Trenchless Technology to implement and manage the system within the construction industry of South Africa. The research study aimed to determine the advantages and disadvantages of implementing Trenchless Technology over the Traditional Open Trench Method. The other goal was to determine if it is financially viable to implement Trenchless Technology.

8.2 RESEARCH QUESTION

The two research questions were determined at the beginning as mentioned in Chapter 1 and a third was added after the research study was concluded. The three research questions are as follows:

1. What is Trenchless Technology?

The term Trenchless Technology has been defined accurately through the literature review and empirical study. Trenchless Technology can be defined as the guided drilling process of forming an arc or straight profile under the earth's surface for the installation of new underground service pipelines or the replacement/repair thereof. The drilling process is always in a horizontal direction. The drilling process only makes use of entry and exit shafts, thereby reducing the number of excavations and trenching needed within the earth. The process causes minimal disruptions above the earth's surface. The process has proven to reach great depths and lengths under the earth and can be used under infrastructure and natural obstacles. Trenchless Technology is used for the installation of new pipelines and the repair and maintenance of existing pipelines.

2. What are the advantages and disadvantages of Trenchless Technology compared with the Open Trench Method?

Advantages of Trenchless Technology (Kramer, Liu & Provencio. 2018):

- Drilling method eliminates excavations or trenching within the earth.
- It reduces damage to the earth's surface.
- It reduces the damage caused to buildings, roads, highways and other service lines.
- It reduces the implication of poorly compacted trench pipeline excavation.
- It reduces the number of resources and machinery needed.
- It avoids traffic impacts and the need for traffic diversion routes.
- It can save underground space by replacing the existing service line.
- It reduces the environmental impact.
- It is faster and can cover longer distances.
- Less money is spent on labour and staff-related costs.
- Provides a quality product to clients.
- A better profit margin for contractors.
- Costs less than the traditional method in most circumstances.
- Renewal and replacement methods are more effective than the traditional method.
- Growing interest in the field.
- Great technology advancements.
- Room for improvement on installation and rehabilitation.

Disadvantages of Trenchless Technology (Kramer, Liu & Provencio. 2018):

- The capital cost of Trenchless Technology is very high.
- Machinery and establishment costs are high for Trenchless Technology.
- Project specifications are vital for the selection of the method.
- Trenchless Technology greatly depends on project information.
- The traditional method is more cost effective on smaller and simpler projects.
- Less resources and machinery required on smaller projects, compared to choosing Trenchless Technology.
- Requires less experienced labour to implement the traditional method.

As seen in the research study most respondents prefer the trenchless method to the traditional method. The majority of the respondents were involved in the Civil and Construction industries. They started with basic manual excavations before the discovery of the trenchless method. It is evident from the research study and calculations that the elimination of earthworks when implementing the trenchless method has a significant advantage over the traditional method. The trenchless method also reduces the cost associated with damages and risks to surrounding structures and the public. The trenchless method allows traffic and services to continue with minimal delay. The biggest disadvantage is the high repair and maintenance costs of the machinery itself. Project specification can be the biggest deciding factor for implementation between the two methods.

Even though the traditional method would be the quickest decision made by most people involved within the construction or civil industry for the installation of pipelines, the trenchless method can be justified by the speed of application, the reduced staff-related costs, and less social costs and environmental impact. The costs associated with the trenchless method can be managed by accurate soil investigations and geographical studies.

3. Is it financially viable to implement Trenchless Technology within the construction and civil industry of South Africa?

It is financially viable to implement Trenchless Technology within the civil industry of South Africa. From the literature review and empirical study, it is evident that Trenchless Technology provides more advantages than the traditional method. Please refer to 8.4 for the full discussion and analysis.

8.3 HYPOTHESIS

The three-hypotheses formed part of the research study. The hypotheses are discussed and analysed below:

1. Trenchless Technology might be a new method that contributes to the construction industry by implementing technology for pipeline installations.

Trenchless Technology could be a method that contributes to the construction industry by installing and rehabilitating pipelines. It is clear from the literature and empirical study that Trenchless Technology could be implemented. The respondents that participated in the research study concluded and provided evidence of implementing and utilising Trenchless Technology methods within the Civil Engineering industry of South Africa. The majority of respondents have been involved and participated in Trenchless Technology projects within South Africa (Otieno. 2014: online).

2. Trenchless Technology might provide more advantages and less disadvantages when compared to the Traditional Method.

According to the literature review and the responses from the empirical study, Trenchless Technology provides more advantages and fewer disadvantages. The empirical study suggested that the respondents still preferred to implement and utilise trenchless methods. Trenchless Technology is a more effective method for the installation or repair of pipelines, if the project specifications allow for any of the methods to be implemented or used for the specific project (Rees, 2011: 42).

3. Trenchless Technology might be a financially viable solution for installing new pipe services or for replacing existing underground services or pipe networks.

Trenchless Technology can be considered a financially viable alternative to the traditional method. The financial viability of the method depends on the project specifications and scope of the project. The correct method needs to be selected for the project. The cost spent on machinery and labour influences the viability. The experience of the contractor can also determine the success of the project (Otieno. 2014: online).

8.4 KEY RESEARCH FINDINGS

The key research findings need to be linked to the research problem statement. The research problem statement was as follows:

The financial viability of implementing Trenchless Technology within the construction industry in South Africa compared to the traditional Open Trench Method.

It is evident from the literature review that Trenchless Technology has more advantages than the traditional method. The limited disadvantages of Trenchless Technology complements the decision to implement the process. Trenchless Technology is divided into two main categories - new pipeline installation methods and renewal/replacement methods.

New pipeline methods consist of seven methods. These seven methods have their own unique application characteristics and drawbacks. It is clear from the characteristics in Table 6 (Chapter 4) that each method could be implemented within a wide variety of applications.

Utility Tunnelling and Microtunneling are two methods that are more common in Europe and Asia. These two methods are associated with the construction of service or transport tunnels. South Africa does not make use of service or underground transport tunnels. Microtunneling and Utility Tunnelling are expensive methods to implement within the Civil industry. The machinery cost associated with Microtunneling and the labour costs with Utility Tunnelling, make these two methods unfeasible for pipeline installations in South Africa. The high costs associated with these two methods needs to be justified by the service or transport tunnels they create. These methods could be feasible for projects involving underground subway transportation tunnels. Pilot Tube Microtunneling has the highest accuracy for determining the gradient of the pipeline but has very high capital costs due to the technology used with this method. The lasers connected to the drill heads and locator beacons are very expensive (Kraay & Radditz, 2006: 38).

The two most common methods used in South Africa are Pipe Jacking and Horizontal Directional Earth Drilling are easier to implement according to the respondents. The other two similar methods, Pipe Ramming and Horizontal Auger Drilling are not commonly used within South Africa. Horizontal Directional Earth Drilling has been used for the provision of the three basic services such as water, sewerage and stormwater. The method can be

implemented for the installation of electrical, telecommunication and gas lines. Pipe Jacking is more commonly used for stormwater and sewerage applications (Kraay & Radditz. 2006: 24).

Pipe Jacking is associated with piping material with bigger diameters compared to Horizontal Directional Earth Drilling. Pipe Jacking is used for harder piping material such as concrete pipes. The force the jacking frame exerts on the pipeline, limits the type of piping materials that can be jacked. Pipe Jacking spans shorter lengths than Horizontal Directional Earth Drilling. If the method is implemented for longer spans, more access points are needed.

Horizontal Directional Earth Drilling can be implemented for piping material of a smaller diameter. This method is suitable for softer piping material such as PVC and HDPE. This method can reach great lengths due to the continuous connection of drilling rods.

The renewal/replacement methods are into three methods. These three methods have their own unique application characteristics and drawbacks. It is clear from Table 8 and Table 9 (Chapter 5) that these methods have similar characteristics.

Cured-In-Place can span the longest distance and cover the largest diameter. Pipe Cracking has the lowest spanning distance and smallest diameter range. Cured-In-Place does not correct the structural defects of the pipe, whereas Pipe Cracking replaces the entire existing pipeline with a new pipeline. The new pipeline increases the life expectancy compared to using Cured-In-Place. Cured-In-Place is a method that requires numerous access points.

Slip Lining is a method that is not commonly used or implemented. The other two methods are more effective and faster for the renewal/replacement of pipelines. Cured-In-Place is the preferred method to Slip Lining, as Slip Lining has more limitations and restrictions. Cured-In-Place can move easier along bends and curves. Slip Lining is only effective in long straight spans.

The empirical study provided the insight and knowledge from a group of respondents involved within the Trenchless Technology industry in South Africa. The respondents provided clear evidence that Trenchless Technology was being implemented within South Africa. There are actually companies that specialise and operate as Trenchless Technology contractors. The results showed that the majority of respondents came from a Civil Engineering background and have a number of years of experience. This means that even

though Trenchless Technology is a new process within the global construction industry, South Africa has been exposed to the industry for a number of years. The installation of fibre cables using Horizontal Directional Earth Drilling seems to be the first evidence of Trenchless Technology used within South Africa. The respondents have performed and worked throughout the whole of South Africa.

The results showed that South Africa still focuses on the three main services provided by pipelines, namely, water, sewerage and stormwater. The electrical and telecommunication is still limited within our developing country. Gas installation is non-existent. The results indicated that the respondents mainly use plastic and concrete pipes with Trenchless Technology. The two most common methods were Pipe Jacking and Horizontal Directional Earth Drilling. Pipe Jacking was associated with concrete pipes and Horizontal Directional Earth Drilling with plastic pipes. Utility Tunnelling and Microtunneling are not commonly used in South Africa and are mostly associated with Europe and Asia. The respondents would much rather implement Pipe Jacking over Pipe Ramming and Horizontal Directional Earth Drilling over Horizontal Auger Drilling. When the methods are compared, they differ slightly in how they operate but are similar in technique. The contractors within the South African industry tend to focus more on Pipe Jacking and Horizontal Directional Earth Drilling.

The empirical study showed that the three methods used for renewal and replacement of service pipelines are being implemented within South Africa. The respondents showed an interest and understanding for all three methods. The most common method implemented by the respondents was Cured-In-Place followed by Pipe Cracking. The results showed that these three methods are associated with plastic and concrete pipes. Cured-In-Place was associated with plastic pipes. The epoxy and resin used with this method tends to structurally bond better with plastic pipes. Pipe Cracking was associated with concrete pipes, since the epoxy and resin compounds bond easier with concrete pipes. The other types of piping material cannot be renewed or rehabilitated with Slip Lining or Cured-In-Place. Other types of piping material can only be repaired or maintained by implementing Pipe Cracking.

The overall contract values are the same for Trenchless Technology projects and Traditional Open Trench projects. This could indicate that there is still a need to expand the use of Trenchless Technology or that the trenchless method is as popular and commonly used as the traditional method. Due to Trenchless Technology still being new in South Africa, the results indicate that there is a need to expand the usage and implementation of the process.

In terms of finances, the trenchless method could be viable. The traditional and Pipe Jacking method are combined at a rate of more than R 3 000.00 per metre. Horizontal Directional Earth Drilling is at the lower range of R 1 000.00 to R 2 000.00 per metre. Cured-In-Place and Pipe Cracking are combined at a range of R 2 000.00 to R 3 000.00 per metre. Slip Lining was estimated at a range of R 1 000.00 to R 2 000.00 per metre. The graph below represents the cost comparison between the different methods.

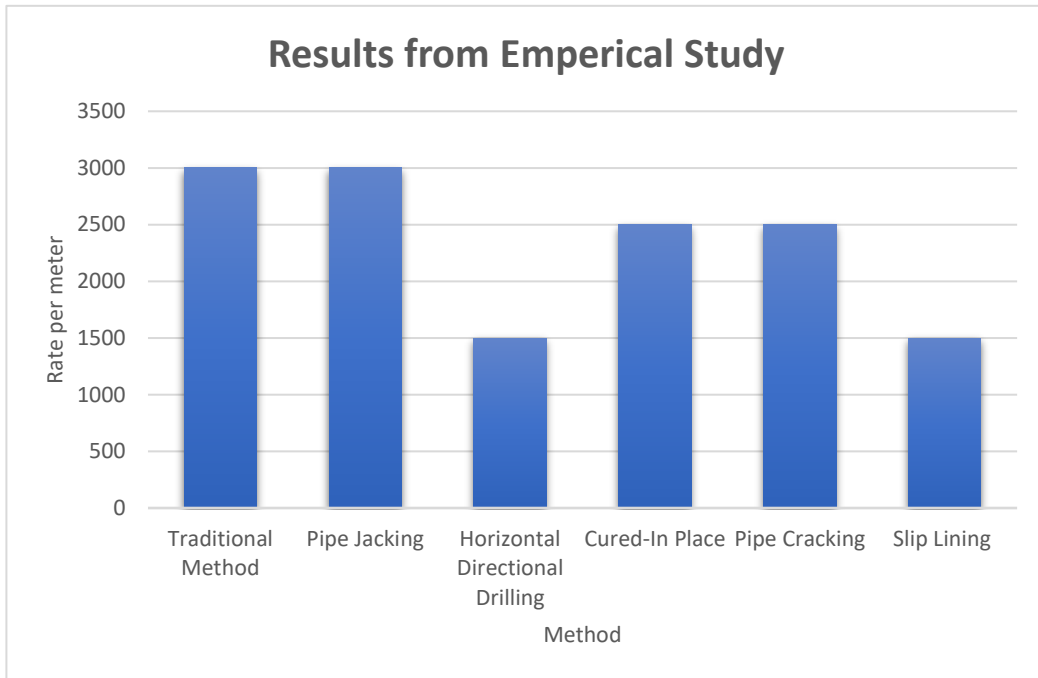


Figure 55: Results from Empirical Study

Even though Trenchless Technology can be more cost effective than the Traditional method, project specifications determine which method can be used or implemented. The respondents determined that certain methods are only applicable within certain project specifications and scope of works. The results did indicate that the respondents still preferred Trenchless Technology. They reported a higher profit margin and faster completion rates when implementing trenchless methods. The overall quality of the end product to their client increased. The drawback was the high capital and labour costs. Other respondents felt that the capital costs are recovered quickly since Trenchless Technology is a growing industry.

The table below represents the average cost comparison between the traditional method and the trenchless method in terms of pipe diameters. The rates represent the cost per metre as obtained from the data provided by the respondents during the empirical study. It is important to note that the rates are dependent on project specifications and scope of works, therefore the table only represents an estimate. In some cases, the trenchless method

cannot be implemented or considered. In these cases, it can happen that the trenchless method will be more expensive to implement over the traditional method. If the trenchless method can be implemented, it appears to be more financially feasible than the traditional method.

Table 34: Cost Comparison between the Traditional and Trenchless Methods

COST COMPARISON BETWEEN THE TRADITIONAL AND TRENCHLESS METHOD (R/M)			
Pipe Size (mm)	Traditional Method (R/m)	Trenchless Method (R/m)	Cost Difference %
50	R 1 125.53	R 955.43	16.35%
110	R 2 247.75	R 1 925.30	15.45%
150	R 2 344.86	R 1 938.41	18.98%
200	R 4 502.12	R 3 821.70	16.35%
250	R 3 751.77	R 3 235.90	14.77%
300	R 4 020.06	R 3 451.46	15.22%
500	R 7 503.54	R 6 471.80	14.77%
1200	R 15 007.08	R 12 662.22	16.95%
1800	R 28 138.28	R 23 260.97	18.98%
2500	R 56 276.55	R 47 771.27	16.35%

When comparing the two calculations in Chapter 7 under heading 7.14 to the results from the questionnaire and calculations done under heading 7.10 and 7.12 for both methods, it is clear that the results indicate a financial benefit that favours the trenchless method. Even though the capital costs for purchasing trenchless equipment is high, the cost is not written off against a single or a few projects. The cost is recovered over an extensive number of projects or projects with very high contract values. There is a bigger demand for infrastructure and service development for more developed countries. International trenchless companies have succeeded with turning a profit on trenchless projects (AECOM, 2020: 2)

This research study suggested that Trenchless Technology could be a financially viable alternative to the traditional method. Trenchless Technology lacks credit and attention within the Civil Industry of South Africa (WK Construction SA, 2022: online).

It is clear from the literature review that Pipe Jacking and Horizontal Directional Earth Drilling will be financially viable in terms of new installation methods. These two methods cover the installation of the most common piping materials and basic service provisions. This is the best-fit scenario for South Africa, since the country is still developing (WK Construction SA, 2022: online).

Horizontal Directional Earth Drilling is the cheapest option. Pipe Jacking and the traditional method have the same rates per metre. The respondents reported that Pipe Jacking is still the considered process, as it provides more advantages than the traditional method. The biggest advantages were time and quality.

Cured-In-Place and Pipe Cracking have the same cost per metre but are still cheaper options compared to the traditional method. These two methods are considered the best alternative for repairs and maintenance to pipelines. Pipe Cracking is the better option, as replacing the pipeline with new piping material will increase the life expectancy of the overall pipeline. Cured-In-Place becomes more difficult to implement if there are a vast number of access points in the network (WK Construction SA, 2022: online).

When determining which trenchless method to implement, the contractor must first analyse and consider the project specifications. The project determinants will point to the best method with thorough research and consideration. The respondents stated that Trenchless Technology requires growth and needs to be brought under the attention of the public and private sector. The immense number of benefits of this method should be disclosed to the

consumer sector of the construction industry. The more growth and involvement within the field of Trenchless Technology, the bigger the economic and financial feasibility.

8.5 PURPOSE AND OBJECTIVE OF THE STUDY

The purpose of this study was to understand the basic principles of Trenchless Technology so that it can be successfully implemented within the construction industry of South Africa. The study was further used to highlight the advantages and disadvantages of both main methods for pipeline installations and rehabilitation. The last part of the objective was to determine if Trenchless Technology could be an economic benefit to South Africa (WSP, 2022: online).

The literature review in the research study provides the basic principles of Trenchless Technology and highlights the advantages and disadvantages of the method. The empirical study represented that South Africa could execute this process in a way that is economical. The respondents involved within the empirical study provided evidence that they have executed Trenchless Technology projects and generated a profit as a company (WSP, 2022: online).

The development of an estimated framework for Trenchless Technology proved to be more complicated than anticipated. There are too many variables that can generate an immense number of outcomes when determining which exact method to implement. The respondents provided insight within the empirical study about the selection process. The only way to successfully determine which method to implement, is through experience and exposure within the field of Trenchless Technology. The respondents stated that the only way they have been able to function within this new field with limited research and information, was by trial and error through projects (Rolkon, 2020: online). The research study can be used as a basic introduction and assist with determining which methods to consider for the selection and which methods are not applicable at all for the specific project. The purpose and objective are discussed in Chapter 1 and the section above. From the discussion, it is clear that the research goal has been achieved.

8.6 FURTHER RESEARCH

There is an opportunity for further research. This study proved that the field of Trenchless Technology is a vast topic. The entire field of Trenchless Technology proved to be too large for this specific research study. Therefore, only an introduction and small insight into the field of Trenchless Technology could be discussed within this research study. The continued growth and expansion of the machinery and methods of Trenchless Technology could provide future research areas.

Even though the topic is vast, the limited amount of resources and published information was a challenge for the research study. It limited the extent and sources that could be used during the literature review. Future publications and research is crucial to the field of Trenchless Technology (City of Cape Town, 2016: 20).

Trenchless Technology is divided into many different methods. Further research can be dedicated to each of the trenchless methods individually and analysed separately. South Africa is still in the early stages of Trenchless Technology. There is still room and possibilities for our country to implement Trenchless Technology as comprehensively and extensively as more developed countries.

8.7 SUMMARY

This chapter clearly indicates that Trenchless Technology could be a financially feasible alternative to the traditional method. It is evident from the literature review and empirical study that Trenchless Technology has a place within the Civil Engineering industry of South Africa.

Since water and electricity supply and delivery are becoming problematic, our country needs to address and search for alternatives or solutions for our resources. South Africa is a country that needs to maintain its water and electricity supply in order to protect its economy. Trenchless Technology could assist with repairing and maintaining the current water network and upgrading the municipal service lines. Renewal and replacement methods have reduced costs associated with maintenance and repair by 30% (Van Rooyen, 2018: 3).

Even though this research study only provides an introductory framework for the selection process of methods, it can determine the method to be considered or discarded in its entirety. It is clear that Trenchless Technology can be a financially viable alternative if the implementation and execution of the process are done correctly. Companies that specialise in Trenchless Technology try to reduce their capital costs as quickly as possible by using their machinery. The quicker the capital costs are reduced, the quicker the company can show a profit margin. Trenchless Technology requires more attention and awareness within the construction industry. There is potential for Trenchless Technology to be used within the private and public sectors of South Africa and to be beneficial to our country (Webb, 2005: online; South Africa; Department of Statistics South Africa. 2017: 3).

In 2012, AECOM did an assessment of a 13km fibre cement sewerage line between Blaauwberg and Milnerton in Cape Town. The diameters of the service line ranged from 300 to 900mm. The line was installed between 1960 and 1970 and required rehabilitation. The service line passed under various roads and the Sable Square Shopping Centre (Bizcommunity, 2019: online).

The Cured-In-Place method was used to rehabilitate the pipeline. The project was completed within seven cost-effective sections and covered over 700m. The project was completed within the agreed programme and within the contract value (Bizcommunity, 2019: online).



Figure 56: The Sanddrift Project done by AECOM in Cape Town using CIPP (Bizcommunity, 2019: online)

Trenchless Engineering did a survey during 2022 to determine the top 50 Engineering Firms in Trenchless Technology in North America and Canada. The table below represents the amount of projects undertaken by the fifty Trenchless firms in North America and Canada during the year 2022. The projects included both new installations and rehabilitation methods used by Trenchless Technology. The table clearly shows that the traditional method falls within the Other category at 1 477 projects and Direct Piping Installations at 81 projects. There are trenchless methods that fall below the amount of projects executed using the traditional method such as Pipe Ramming and Microtunneling. Horizontal Directional Earth Drilling has the highest project count at more than 7 290. The most surprising was the Pipe Rehabilitation method that exceeds 12 million linear feet during the year 2022 (Trenchless Technology, 2022: online).

Figure 1: Total Projects by Method (only top 50 reflected in totals)

AUGER BORING	632+
DIRECT PIPE	81
GUIDED BORING/PILOT TUBE	248
HDD	7,290+
MICROTUNNELING	440+
PIPE RAMMING	204
*UTILITY TUNNELING	291
NON-JACK METHODS	206
PIPE BURSTING/SPLITTING	171
PIPELINE REHABILITATION (WATER, STORM, SEWER, OIL & GAS, ETC.)	12,912,670+ LF
PIPELINE EVALUATION STUDIES (WATER, STORM, SEWER, OIL & GAS, ETC.)	63,729,096+ LF
SUBSURFACE UTILITY ENGINEERING	6,830+
OTHER	1,477+

*Utility Tunneling defined as 10-ft diameter or less.

Figure 57: Total Amount of Projects executed by the Top 50 Trenchless Technology firms in America & Canada. (Trenchless Technology, 2022: online).

The Figure below shows the amount of revenue generated from 2013 to 2022 by all fifty engineering firms for every year. In 2022, the company that ranked first had over \$220 million in net revenue for trenchless work in America and Canada and the firm in last place over \$2 million. These firms did more than \$1.528 billion in trenchless work during 2022 compared to \$ 1.436 billion in 2021. The table shows constant stability within the trenchless market. The revenue generated by these companies cover their operational and management costs for using Trenchless Technology. It is clear from the American and Canadian survey that there is a constant increase in the trenchless market for developed countries (Trenchless Technology, 2022: online)

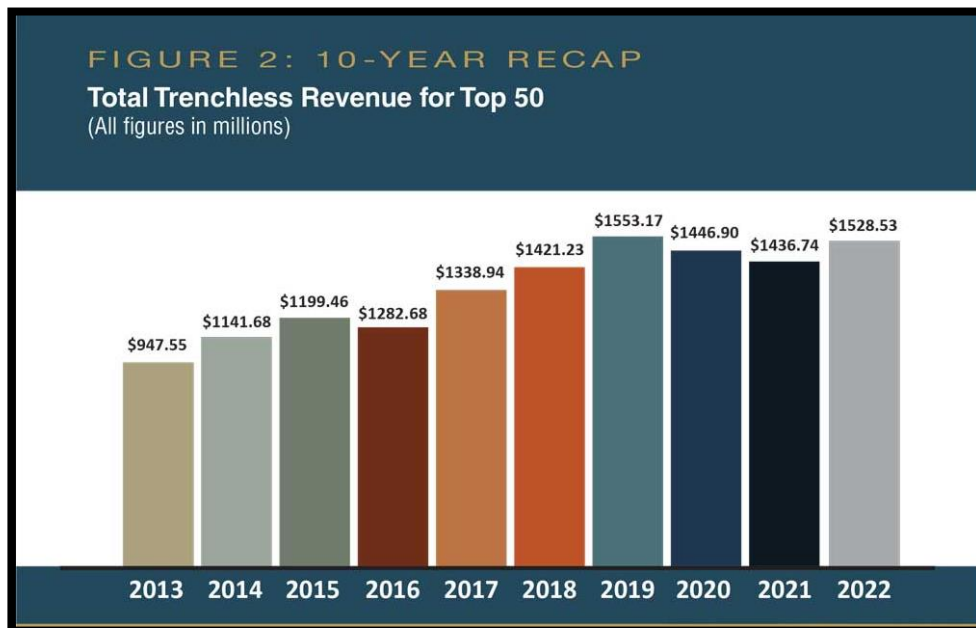


Figure 58: Total Revenue for the Top 50 Trenchless Technology Firms in America & Canada. (Trenchless Technology, 2022: online).

8.8 CONCLUSION

South Africa might not be able to produce high value projects using new trenchless installation methods (Chapter 4), as the demand for infrastructure and services currently is not in high compared to developed countries. These methods are used for the installation of advanced and enormous pipeline networks. Unfortunately, implementing these methods within the current state of our country, would not be highly beneficial or profitable for any contractor. These methods appear to require high capital and equipment costs, just by comparing the revenue and project values associated with the firms in North America and Canada. The costs associated with new installations using the trenchless method can be justified or reduced when there is a need for faster installations, roads or structures obstructions or a reduced carbon footprint needed.

South Africa first needs to have a bigger infrastructure system and an approved budget set aside for implementing advanced services and utilities. The respondents that are involved with Trenchless Technology in South Africa did not report very high valued projects and the availability of information regarding projects using new installation methods was limited. The number of trenchless projects done in South Africa is insignificant when viewed globally. Therefore, the opportunities for contractors using Tunnel Boring Machines or Microtunneling is limited. There are, however, small opportunities for using Auger boring, Horizontal Directional Earth Drilling and Pipe Jacking, but even these methods cannot provide enough evidence to disregard the traditional method as a whole.

The increased application and integration of Pipe Renewal and Pipe Rehabilitation (Chapter 5) might prove to be more financially feasible for South Africa due to the reduced operational and management costs associated with the methods. Our underground pipeline networks have not been replaced or thoroughly maintained through the years. The increased population and expansion of cities are contributing to more pressure on our networks and service providers. The methods mentioned in Chapter 5 have proven to provide a faster, more cost-effective, safe, reliable and environmentally friendly solution (Sharer, 2023).

The financial feasibility of Trenchless Technology is project specific and should only be considered if the traditional method cannot be implemented, specifically focusing on South Africa. We first need to look at maintaining and rehabilitating the current pipelines/services before we can even consider new installation methods.

REFERENCES

AECOM. 2020. *Delivering Complex Tunnel: Projects around the world*. United States of America: AECOM University.

Advanced Pipe Repairs. 2019. *How CIPP and Slip Lining Stack Up*. [online]. United States of America: Advanced Pipe Repairs. Available from: <<https://www.advancedpiperepair.com/how-cipp-and-slip-lining-stack-up/>> [Accessed: 10 October 2022].

Aegion. 2018. *Aegion SA's trenchless pipeline rehabilitation technology, ultra-fast, non-disruptive solution to SA's ageing infrastructure*. [online]. South Africa: Cape Business News. Available from: <<https://www.cbn.co.za/industry-news/manufacturing/aegion-sa-s-trenchless-pipeline-rehabilitation-technology-ultra-fast-non-disruptive-solution-to-sa-s-ageing-infrastructure/>> [Accessed: 09 September 2019].

Allouche, E., Murray, C., Vos, B. & Dalgleish, R. 2019. *Meet the Experts: Horizontal Directional Earth Drilling*. [online]. Canada: Trenchless Technology. Available from: <<https://trenchlesstechnology.com/meet-the-experts-horizontal-directional-drilling-hdd/>> [Accessed: 09 September 2019].

Alok, S. & Mishra, S.B. 2017. *Handbook of Research Methodology*. India. Educreation.

Anupoju, S. 2020. *Types of Soil Excavation Tools and Machines in Construction*. [online]. India: The Constructor. Available from: <<https://theconstructor.org/construction/types-of-soil-excavation-tools-machines/12307/>> [Accessed: 3 February 2022].

Apeldoorn, S. 2013. Comparing the Costs – Trenchless Versus Traditional Methods. *IMIESA*, 38(4), pp.55-57, April.

Ariaratnam, S.T. & Chan, W. 2005. *Engineering of trenchless pipe replacement projects for infrastructure renewal*. India: Research Gate. Available from: <https://www.researchgate.net/publication/288722146_Engineering_of_trenchless_pipe_replacement_projects_for_infrastructure_renewal> [Accessed: 24 November 2022].

Bayat, A. 2020. *Using Data to Reduce Risk in Trenchless Construction*. [online]. United States of America: Trenchless Technology. Available from: <

<https://trenchlesstechnology.com/using-data-to-reduce-risk-in-trenchless-construction/>
[Accessed: 3 August 2022].

Bayer, H.J. 2005. *HDD Practice Handbook*. Germany: Vulkan-Verlag.

Bizcommunity. 2019. *SASTT awards AECOM for trenchless innovation at Sanddrift*. [online]. South Africa: Bizcommunity Available from: www.bizcommunity.com/Article/196/494/194951.html [Accessed: 16 May 2024].

Bhandari, P. 2022. *Data Collection - Definition, Methods & Examples*. [online]. Great Britain: Scribbr. Available from: <https://www.scribbr.com/methodology/data-collection/> [Accessed: 24 November 2022].

Bloc Contractors. 2020. *Why Trenchless Technology is a Better Method For Renewing Pipes & Lines Over Traditional Methods*. South Africa: Bloc Contractors. Available from: <https://www.bloc.co.za/blog-posts/trenchless-technology-is-a-better-method-for-renewing-pipes> [Accessed: 3 February 2022].

Brightway. 2017. *Useful Information About Micro Tunnelling Machines (MTBMs)*. [online]. China: Brightway. Available from: <http://www.slurrytreatmentplant.com/news/industry-news/84.html> [Accessed: 24 November 2022].

Bruce, M.H. 2002. *Pilot Tube Microtunnelings Cost Effective Advantage for New Installation of Urban Sewers*. [online]. United States of America: Research Gate. Available from: https://www.researchgate.net/publication/268596229_Pilot_Tube_Microtunnelings_Cost_Effective_Advantage_for_New_Installation_of_Urban_Sewers [Accessed: 24 November 2022].

Castro Facilitator. 2020. *Trenchless Technology: An overview of the Methods*. [online]. India: Castro Facilitator. Available from: <https://constrofacilitator.com/trenchless-technology-an-overview-of-the-methods/> [Accessed: 24 November 2022].

Choudhury, A. 2020. *Points to be Considered While Organizing a Questionnaire*. [online]. United States of America: Your Article Library. Available from:

<<https://www.yourarticlelibrary.com/social-research/data-collection/points-to-be-considered-while-organizing-a-questionnaire/64513>> [Accessed: 20 November 2022].

City of Cape Town. 2016. *State of Cape Town Report 2016*. Cape Town: City of Cape Town.

Crofts, F.S. & Gyons, A.M.N. 2001. *A framework for establishing appropriate Trenchless Technology Guidelines and Standards in Southern Africa*. South Africa: Water Research Commission.

Department of Water and Sanitation. 2017. *National Water Investment Framework*. Government Printer, 1(1). pp.1-18, September.

Department of Water and Sanitation. 2018. *National Sanitation and Water Plan*. Government Printer, 1(1), pp.1-64, March.

Doherty, D.J. 2017. Risk-Based Engineering for Trenchless Installation Projects, *North East Journal of Trenchless Technology Practices*, Fall 2017, pp. 34-37. United States of America: Hayley & Aldrich.

Drain, S. 2022. *What People Get Wrong About Trenchless Technology*. . [online]. United Kingdom: Kobus. Available from: <<https://kobuspipepuller.com/category/insights/>> [Accessed: 10 December 2022].

Draper, P. & Scholvin, S. 2012. *The Economic Gateway to Africa? Geography, Strategy and South Africa's Regional Economic Relations*. SAIIA. South Africa: SAIIA.

Easy-Sight. 2020. *Problems in the Trenchless Technology Industry*. [online]. United States of America: Easy-Sight. Available from: <<https://www.pipedetect.com/problems-in-the-trenchless-technology-industry.html>> [Accessed: 24 November 2022].

Eco Builder. 2011. 'No trenches, less emissions' *Eco Builder*, February, p. 18-19.

Edge Underground. 2021. *What are the safety benefits of microtunnelling compared to other pipeline installation methods?*. [online]. Australia: Edge. Available from:

<<https://edgeunderground.co/news/what-are-the-safety-benefits-of-microtunnelling-compared-to-other-pipeline-installation-methods/>> [Accessed: 24 November 2022].

Efrat, S. 2018a. Pipe Replacement in South Africa. In: *No-Dig Conference*, Cape Town 23-24 August 2011. South Africa: The Southern African Society for Trenchless Technology, p. 1-13.

Efrat, S. 2018b. (SASTT President). *Personal Interview about the current state of Trenchless Technology in South Africa*. 8 October 2018, Cape Town.

Environmental Protection Agency. 2006. *Water Technology Fact Sheet*. United States of America: EPA.

ESI Africa. 2012. *Trenchless methods for subsurface installations*. [online]. South Africa: ESI. Available from: <<https://www.esi-africa.com/top-stories/trenchless-methods-for-subsurface-installations/>> [Accessed: 10 September 2022].

Eysaman, K. 2020. *Trenchless Technology Construction Methods and Improvements*. [online]. United States of America: RKK. Available from: <<https://www.rkk.com/blog/trenchless-technology-construction-methods-and-improvements/>> [Accessed: 10 September 2022].

Farr, A. 2005. *Trenchless Methods finding success in South Africa*. [online]. United States of America: Trenchless Technology. Available from: <<https://trenchlesstechnology.com/trenchless-methods-finding-success-in-south-africa/>> [Accessed: 10 September 2022].

Farr, A. 2012. *A brief history of Directional Drilling. The Birth and Development of the HDD Market*. [online]. United States of America: Trenchless Technology. Available from: <<https://trenchlesstechnology.com/brief-history-horizontal-directional-drilling/>> [Accessed: 10 September 2022].

IMESA. 2017. *Trenchless News*. South Africa: South African Association of Trenchless Technology.

Industrial Development Corporation. 2017a. Economic Trends: Key Trends in the South African Economy. *IDC*. March 2017, pp. 1-28.

Industrial Development Corporation. 2017b. Infrastructure-led growth as a tool for economic transformation. In: BMF Gauteng Policy Conference, Johannesburg 19 May 2017. South Africa: IDC. p. 1-24.

INNSPub. 2022. *Standards of a Quality Research*. [online]. United Kingdom: INNSPub. Available from: <<https://innspub.net/standards-of-a-quality-research/>> [Accessed: 24 November 2022].

French Society for Trenchless Technology (FSTT). 2004. *Microtunneling and Horizontal Drilling*. Great Britain: Hermes Science Publishing Ltd.

GeoEngineers. 2022. *Pipeline Services*. [online]. United States of America: GeoEng. Available from: <<https://www.geoengineers.com/practice-areas/pipeline-planning-design-installation/>> [Accessed: 10 June 2022].

Hay, S. 2013. *A Comparative Study of Trenchless Technologies versus Traditional Open Trenching for the Replacement of Ageing Portable Water Pipelines*. Thesis (Magister Technologies). Durban: University of Technology.

Heinselman, W. 2016. What's the Biggest Problem with Trenchless Technology? [online]. United States of America: Express. Available from: <<https://www.expresssewer.com/blog/whats-the-biggest-problem-with-trenchless-technology>> [Accessed: 10 September 2022].

Hicks, J, Jamali, K & Kaushal, V. 2022. *A Comparative Review of Trenchless Cured-in-Place Pipe (CIPP) With Spray Applied Pipe Lining (SAPL) Renewal Methods for Pipelines*. [online]. India: Frontier. Available from: <<https://www.frontiersin.org/articles/10.3389/frwa.2022.904821/full>> [Accessed: 15 April 2022].

Illko, B & O'Shannesy. 2021. *Don't Let Your Trenchless Project Take a Wrong Turn*. [online]. Australia: Golder. Available from: <<https://www.golder.com/insights/dont-let-your-trenchless-project-take-a-wrong-turn/>> [Accessed: 15 April 2022].

Jain, H. 2022. *Advantages and Disadvantages of Pipe Jacking*. [online]. India: Piping Mart. Available from: <<https://blog.thepipingmart.com/metals/advantages-and-disadvantages-of-pipe-jacking/>> [Accessed: 24 November 2022].

Jung, Yeun & Sinha, S. 2007. *Evaluation of Trenchless Technology Methods for Municipal Infrastructure System*. [online]. United States of America: Research Gate. Available from: <https://www.researchgate.net/publication/245289199_Evaluation_of_Trenchless_Technology_Methods_for_Municipal_Infrastructure_System> [Accessed: 10 September 2022].

King, M. 2012. *5 Advantages to Choosing Horizontal Directional Earth Drilling*. [online]. United States of America: SSC. Available from: <<https://symbiontservice.com/2012/10/25/horizontal-directional-drilling/>> [Accessed: 24 November 2022].

Kraay, A. & Radditz, C. 2006. Poverty Traps, Aid, and Growth. *Journal of Development Economics*. March 2006. pp. 1-52.

Kramer, S., Liu, J. & Provencio, G. 2018. Advantages and Disadvantages of Trenchless Construction Approach as Compared to the Traditional Open Cut Installation of Underground Utility Systems. *Creative Construction Conference: CCC 2018 Conference*, Alabama, 30 June–3 July.

Kramer, S.R., McDonald, W.J. & Thomson, J.C. 1992. *An Introduction to Trenchless Technology*. New York: Chapman & Hall.

McCombes, S. 2022. *Sampling Methods - Types, Techniques & Examples*. [online]. Great Britain: Scribbr. Available from: <<https://www.scribbr.com/methodology/sampling-methods/>> [Accessed: 24 November 2022].

Meskele, T & Stuedlein, A. 2012. *Preliminary Design and Engineering of Pipe Ramming Installations*. India: Research Gate. Available from: <https://www.researchgate.net/publication/273745933_Preliminary_Design_and_Engineering_of_Pipe_Ramming_Installations> [Accessed: 24 November 2022].

Midwest Mole. 2022. *Why Trenchless?*. [online]. United States of America: Midwest Mole. Available from: <<https://midwestmole.com/why-trenchless/>> [Accessed: 10 September 2022].

Mishra, G. 2020. *Work Procedure of Excavation at Construction Site*. [online]. India: The Constructor. Available from: <<https://theconstructor.org/practical-guide/work-procedure-excavation/1632/>> [Accessed: 10 September 2022].

Mishra, T. 2019. *Utility Tunnelling Vs. Pipe Jacking Trenchless Construction Methods*. [online]. India: Trenchless Pedia. Available from: <<https://www.trenchlesspedia.com/utility-tunneling-vs-pipe-jacking-trenchless-construction-methods/2/4199>> [Accessed: 10 September 2022].

Najafi, M. 2010. *Trenchless Technology Piping: Installation and Inspection*. United States of America: The McGraw-Hill Company.

Najafi, M. 2012. Tom Iseley: Father of the Trenchless Technology Industry. *The Journal of Pipeline Systems Engineering and Practice*, 3(2), pp. 34-35, May.

Najafi, M. 2013. *Trenchless Technology: Planning, Equipment, and Methods*. United States of America: The McGraw-Hill Company.

Nanan, K. 2020a. *The Planning Process: How to Prepare for a Successful Trenchless Construction Project*. [online]. India: Trenchless Pedia. Available from: <<https://www.trenchlesspedia.com/the-planning-process-how-to-prepare-for-a-trenchless-project/2/3471>> [Accessed: 10 September 2022].

Nanan, K. 2020b. *When should I choose pipe ramming as my preferred trenchless method?* [online]. India: Trenchless Pedia. Available from: <<https://www.trenchlesspedia.com/when-should-i-choose-pipe-ramming-as-my-preferred-trenchless-method/7/3688>> [Accessed: 10 September 2022].

Neenu, S.K. 2017. *Trenchless Renewal Methods for Replacement, Renovation of Pipelines* [online]. India: The Constructor. Available from: <<https://theconstructor.org/practical-guide/trenchless-renewal-methods/15574/>> [Accessed: 3 February 2021].

Oosthuizen, A.C. & Richardson S. 2011. *Sinkholes and subsidence in South Africa*. Cape Town: Council for Geoscience.

Oosthuizen, A.C. & van Rooy, J.L. 2015. Hazard of sinkhole formation in the Centurion CBD using the Simplified Method of Scenario Supposition. *Journal of the South African Institution of Civil Engineering*, 57(2). p. 69-75, June.

Otieno, P. 2014. *Trenchless Technologies Grows from Strength to Strength*. [online]. South Africa: Construction Review. Available from:

<<https://constructionreviewonline.com/products/trenchless-technologies-grows-strength-strength/>> [Accessed: 10 September 2022].

Patel, H., Pitroda, Dr. J. & Bhavsar, J. J. 2014. *A Study on Trenchless Technology: Eliminates the Need For Excavation*. [online]. India: Research Gate. Available from:

<https://www.researchgate.net/publication/281493425_A_STUDY_ON_TRENCHLESS_TECHNOLOGY_ELIMINATE_THE_NEED_FOR_EXCAVATION> [Accessed: 07 September 2019].

PE100. 2015. *Pilot Tube Microtunneling*. [online]. Europe: PE100. Available from:

<<https://www.pe100plus.com/PE-Pipes/Technical-guidance/Trenchless/Methods/Installation/Pilot Tube-Microtunnelling-i1304.html>> [Accessed: 24 November 2022].

Pipe Jacking Association. 2017. An introduction to pipe jacking and microtunnelling. *PJA*. January 2017, pp. 1-24.

Ponto, J. 2015. *Understanding and Evaluating Survey Research*. [online]. United States of America: PMC. Available from: <<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4601897/>> [Accessed: 24 November 2022].

Rees, A. 2011. Greening the globe with trenchless. *Trenchless International*. January 2011, pp. 42-44.

Rig Worker. 2022. *The HDD Process*. [online]. United States of America: Rig Worker. Available from:< <https://www.rigworker.com/horizontal-directional/the-hdd-process.html>>[Accessed: 24 November 2022].

Rolkon. 2020. *The Rolkon Way*. [online]. South Africa: Rolkon. Available from: <<https://rolkon.co.za/the-rolkon-way/>> [Accessed: 24 November 2022].

Roosenburg, N. 2004. *Innovation and Economic Growth*. Stanford University. January 2004, pp. 1-6.

SA Drilling. 2020. *Horizontal Directional Earth Drilling*. [online]. South Africa: SA Drilling. Available from: <<https://www.sadrilling.co.za/horizontal-directional-drilling/>> [Accessed: 24 November 2022].

Skonberg, E.R. & Muindi, T.M. 2014. *Pipeline Design for Installation by Horizontal Directional Earth Drilling*. 2nd ed. United States of America: ASCE.

South Africa. Department of Statistics South Africa. 2017. *Poverty Trends in South Africa: An examination of absolute poverty between 2006 and 2015*. Pretoria: Government Printer.

South Africa. Department of Statistics South Africa. 2017. *The State of Basic Service Delivery in South Africa: In-depth analysis of the Community Survey*. Pretoria: Government Printer.

Smith, C. 2021. *Horizontal Directional Earth Drilling vs. Auger Boring*. [online]. United States of America: Trenchless Technology. Available from: <<https://trenchlesstechnology.com/horizontal-directional-drilling-vs-auger-boring/>> [Accessed: 24 November 2022].

Southern African Society for Trenchless Technology (SASTT). 2013a. *SASTT Technical Standard – TT1 Slip Lining*. 1st ed. South Africa: SASTT.

Southern African Society for Trenchless Technology (SASTT). 2013b. *SASTT Technical Standard – TT2 Pipe Bursting*. 1st ed. South Africa: SASTT.

Southern African Society for Trenchless Technology (SASTT). 2017c. *SASTT Technical Standard – TT3 HDD*. 1st ed. South Africa: SASTT.

Southern African Society for Trenchless Technology (SASTT). 2020d. *Southern African Society for Trenchless Technology*. [online]. South Africa: SASTT. Available from: <<https://sastt.org.za/about/>> [Accessed: 04 September 2022].

Sharer, H. 2023. *Understanding Trenchless Technology: What it is and How it's Changing Construction and Excavation*. [online]. Available from: <www.tffn.net/what-is-trenchless-technology/> [Accessed: 10 May 2024].

Sullivan, D. 2018a. *An Overview of the Utility Tunnelling Method in Trenchless Construction*. [online]. United States of America: Trenchless Pedia. Available from: <<https://www.trenchlesspedia.com/the-utility-tunneling-method/2/3644>> [Accessed: 01 September 2019].

Sullivan, D. 2018b. *Who Invented Trenchless Technology?*. [online]. United States of America: The Crossing Group. Available from: <<https://www.trenchlesspedia.com/who-invented-trenchless-technology/2/3544>> [Accessed: 01 September 2019].

The International Society for Trenchless Technology (ISTT). 2022. *What is ISTT?*. [online]. United Kingdom: ISTT. Available from: <<https://www.istt.com/index/what-is-istt>> [Accessed: 06 September 2022].

The Pipe Shark. 2020. *The Pros and Cons of Trenchless Solutions*. [online]. United States of America: Pipe Shark. Available from: <<https://thepipeshark.com/the-pros-and-cons-of-trenchless-solutions/>> [Accessed: 24 November 2022].

The National Academics of Science. 2022. *The Behavioural and Social Sciences: Achievements and Opportunities*. [online]. United States of America: NIH. Available from: <<https://www.ncbi.nlm.nih.gov/books/NBK546485/>> [Accessed: 24 November 2022].

Trenchless Technologies C.C. 2005a. *CIPP*. [online]. South Africa: Trenchless Technologies C.C. Available from: <<http://www.trenchless.co.za/cipp.htm>> [Accessed: 04 September 2019].

Trenchless Technologies C.C. 2005b. *Horizontal Boring*. [online]. South Africa: Trenchless Technologies C.C. Available from: <<http://www.trenchless.co.za/boring.htm>> [Accessed: 04 September 2019].

Trenchless Technologies C.C. 2005c. *Pipe Cracking*. [online]. South Africa: Trenchless Technologies C.C. Available from: <<http://www.trenchless.co.za/pipecrack.htm>> [Accessed: 04 September 2019].

Trenchless Technologies C.C. 2005d. *Pipe Ramming*. [online]. South Africa: Trenchless Technologies C.C. Available from: <<http://www.trenchless.co.za/piperamming.htm>> [Accessed: 04 September 2019].

Trenchless Technologies C.C. 2005e. *Slip Lining*. [online]. South Africa: Trenchless Technologies C.C. Available from: <<http://www.trenchless.co.za/slipline.htm>> [Accessed: 04 September 2019].

Trenchless Technologies C.C. 2005f. *Trenchless Technology Techniques*. [online]. South Africa: Trenchless Technologies C.C. Available from: <<http://www.trenchless.co.za/about.htm>> [Accessed: 04 September 2019].

Trenchless Technology. 2022. *Trenchless Technology's 2022 Top 50 Engineering Firms Survey Reveals Positive Trend for the Market*. [online]. United States of America: Trenchless Technology. Available from: <www.trenchlesstechnology.com/2022-top-50-trenchless-engineers-survey/> [Accessed: 10 May 2024].

University Libraries. 2018. *Research Methods Guide: Research Design & Method*. [online]. United States of America: University Libraries. Available from: <<https://guides.lib.vt.edu/researchmethods/design-method>> [Accessed: 24 November 2022].

Vaardini, S. 2015. *Application of Trenchless Technology in Urban Infrastructure*. [online]. India: Research Gate. Available from: <https://www.researchgate.net/publication/282003570_Application_of_Trenchless_Technology_In_Urban_Infrastructure> [Accessed: 24 November 2022].

Van Rooyen, N. 2018. *Unlocking Economic Growth in South Africa Using Trenchless Technology*. South Africa: The Southern African Society for Trenchless Technology.

Vos, B. 2020. *What are the biggest risks involved with trenchless crossing installations?* [online]. United States of America: Trenchless Pedia. Available from: <<https://www.trenchlesspedia.com/what-are-the-biggest-risks-involved-with-trenchless-crossing-installations/7/461>> [Accessed: 2 July 2022].

Water Technology. 2013. *Total and Wavin technology selected for water mains upgrade in South Africa.* [online]. South Africa: Water Technology. Available from: <<https://www.water-technology.net/uncategorised/newstotal-wavin-to-perform-water-mains-upgrade-in-south-africa/>> [Accessed: 24 November 2022].

Water World. 2006. *Tunnelling Used to Minimize Disruption During Pipeline Projects.* [online]. United States of America: WaterWorld. Available from: <<https://www.waterworld.com/drinking-water/distribution/article/16191008/tunneling-used-to-minimize-disruption-during-pipeline-projects>> [Accessed: 24 November 2022].

Webb, M. 2005. *SA's water and sewer systems raise concern.* [online]. South Africa: Engineering News. Available from: <https://www.engineeringnews.co.za/article/sas-water-and-sewer-systems-raise-concern-2005-04-01> [Accessed: 24 November 2022].

Wesser, J. 2020. *The Importance of Soil Compaction in Construction.* [online]. United States of America: Mintek. Available from: <<https://mintekresources.com/importance-of-soil-compaction-in-construction/>> [Accessed: 24 November 2022].

Wessler Engineering. 2022. *What is Cured in Place Pipe (CIPP)?* [online]. United States of America: Wessler Engineering. Available from: <<https://info.wesslerengineering.com/blog/cured-in-place-pipe-cipp>> [Accessed: 19 September 2022].

Willoughby, D.A. 2005. *Horizontal Directional Earth Drilling.* United States of America: The McGraw-Hill Company.

WK Construction SA. 2022. *Trenchless Technologies.* [online]. South Africa: WK Construction SA. Available from: <<https://www.wkcsa.co.za/index.php/what-we-do/trenchless-technologies>> [Accessed: 24 November 2022].

WSP. 2022. *Trenchless Tunnelling Technology*. [online]. United States of America: WSP. Available from: < <https://www.wsp.com/en-us/services/trenchless-tunnelling-technolog>> [Accessed: 24 November 2022].

Zhou, Z. 2014. *Testing of Trenchless Detection Techniques for Buried Metal Pipelines*. [online]. China: Southwest Petroleum University. Available from: <https://www.researchgate.net/publication/335826739_Testing_of_Trenchless_Detection_Techniques_for_Buried_Metal_Pipelines> [Accessed: 24 November 2022].

APPENDIX A

Letter to the South African Society for Trenchless Technology

Southern African Society for Trenchless Technology
P.O. Box 738
Roslouw
0109

Dear Sir/ Madam

ASSESSMENT OF TRENCHLESS TECHNOLOGY AND OPEN TRENCH PIPELINE EXCAVATION IN SOUTH AFRICA

I am a Doctorate of Philosophy student within the Faculty of Engineering, Built Environment & Information Technology at the University of Pretoria, conducting research to assess if South Africa can utilise and implement Trenchless Technology over the traditional open excavation method.

My research titled, Trenchless Technology vs Open Trench Methodology: Implementation in South Africa's Construction Industry, is about the comparison between the Traditional Open Excavation method and Trenchless Technology.

The study aims to determine if Trenchless Technology is a financially viable option to implement over the traditional method for the installation of new pipe services or for replacing existing underground pipe services.

I would appreciate your assistance and permission to distribute the questionnaire to the members of the SASTT.

The participation of each member is voluntary and can be withdrawn at any time. All information provided within the questionnaire will be kept confidential. The collected data will be analysed as a group and not individually. Only the overall group results will be published, therefore, assuring anonymity

Please feel free to contact me should you have any concerns.

Kind regards,
Marique Grobbelaar
mariquek@gmail.com
083 278 2909
PhD Student
Department of Construction Economics
Faculty of Engineering, Built Environment & Information Technology
University of Pretoria
South Africa

APPENDIX B

Letter from the Southern African Society for Trenchless Technology



Southern African Society for Trenchless Technology 1053 Hyde Ave. ELDORAIGNE 1057

President: Abraham Avenant Tel: +27(0)21761 3474 Cell: 083660 6527 Fax: +27(0)21797 1151 E-mail: aaavenant@sastt.co.za

Secretary: Rina Stead N.a Cell: 082551 7458 Fax: +27 (0)86 668 4026 E-mail: director@sastt.org.za

Home page: <http://www.sastt.org.za>

Department of Construction Economics
Faculty of Engineering, Built Environment & Information Technology
University of Pretoria
Private Bag X20
Hatfield
0028

Dear Marique

**RE: ASSESSMENT OF TRENCHLESS TECHNOLOGY AND OPEN TRENCH
EXCAVATIONS IN SOUTH AFRICA**

We have received your letter about your request for conducting a research study in the field of Trenchless Technology. The SASTT (South African Society for Trenchless Technology) will gladly assist and participate in the study and doesn't have any objections to your request.

We understand that participation in the research study is voluntary, and we can withdraw at any time. The Society will distribute the questionnaire on your behalf, to our members, via email with a link to the online survey for data and information collection. We will include the cover letter as requested.

We are happy to support any initiative that will grow the trenchless industry.

A handwritten signature in black ink, appearing to read 'Neil Van Rooyen', is written over a horizontal line.

Kind Regards,

Neil Van Rooyen
Vice President
South African Society for Trenchless Technology

A handwritten signature in black ink, appearing to read 'Abraham Avenant', is written over a horizontal line.

Kind Regards,

Abraham Avenant
President
South African Society for Trenchless Technology

WHY DIG TRENCHES WHEN YOU CAN GO TRENCHLESS

APPENDIX C

Letter of Approval from EBIT



Faculty of Engineering, Built Environment and Information Technology

Fakulteit Ingenieurswese, Bou-omgewing en
Inligtingtegnologie / Lefapha la Boetšenere,
Tikologo ya Kago le Theknoloṽi ya Tshedimošo

16 November 2022

Reference number: EBIT/222/2022

Mrs M Grobbelaar
Department: Construction Economics
University of Pretoria
Pretoria
0083

Dear Mrs M Grobbelaar,

FACULTY COMMITTEE FOR RESEARCH ETHICS AND INTEGRITY

Your recent application to the EBIT Research Ethics Committee refers.

Approval is granted for the application with reference number that appears above.

1. This means that the research project entitled "Trenchless Technology vs Open Trench Methodology: Implementation in South Africa's Construction Industry" has been approved as submitted. It is important to note what approval implies. This is expanded on in the points that follow.
2. This approval does not imply that the researcher, student or lecturer is relieved of any accountability in terms of the Code of Ethics for Scholarly Activities of the University of Pretoria, or the Policy and Procedures for Responsible Research of the University of Pretoria. These documents are available on the website of the EBIT Research Ethics Committee.
3. If action is taken beyond the approved application, approval is withdrawn automatically.
4. According to the regulations, any relevant problem arising from the study or research methodology as well as any amendments or changes, must be brought to the attention of the EBIT Research Ethics Office.
5. The Committee must be notified on completion of the project.

Modifications required

When submitting a revised application, please submit a cover letter (under Documents) that indicates point by point how each comment was addressed (with reference to the application form and/or documents provided). Original application can be downloaded and make changes. Changes to the application should also be highlighted in yellow with the highlighting tool of Word), not in track changes. Only PDF is to be submitted and not in Word doc. If any revised version of a specific document is submitted, the previous version needs to be removed.

Reviewer 1:

From the application and attached documents it is not clear whether the applicant or the SASTT (South African Society for Trenchless Technology) will administer the survey to members. Clarify who will take responsibility for administering the survey.

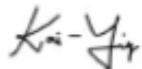
It appears that emails will be sent to members with the cover letter, informed consent, and questionnaire attached to the email, with the expectation that members should complete both the informed consent and questionnaire and email these back. If so, this mode makes it difficult for members to participate and to link questionnaires with informed consent forms.

Rather use online survey software (e.g., Qualtrix, Survey Monkey or Forms), include the cover letter in the body of the email, with an informed consent box that should be ticked in order for the questionnaire to load.

Reviewer 2:

The mailing list provided by SASTT is assumed with compliance to POPIA, ie it's members have already given consent to allow SASTT to distribute their emails to third party. This is not clear in the permission letter, so the applicant/researcher cannot use the mailing list but rather ask SASTT to send out the questionnaire on behalf of the researcher. If SASTT has permission to distribute their mailing list to a third party (ie the researcher) then it needs to be stated clearly in the permission letter and then the researcher needs to also include it in the cover letter of the online questionnaire (see reviewer 1's comment) indicating the email was provided by SASTT so the participants know where you obtain their contact email address from.

The Committee wishes you every success with the research project.



Prof K.-Y. Chan

Chair: Faculty Committee for Research Ethics and Integrity

FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY

APPENDIX D

Questionnaire loaded onto the Electronic Survey Platform

Dear Sir/ Madam

ASSESSMENT OF TRENCHLESS TECHNOLOGY AND OPEN TRENCH PIPELINE EXCAVATION IN SOUTH AFRICA

I am a Doctorate of Philosophy student within the Faculty of Engineering, Built Environment & Information Technology at the University of Pretoria, conducting research to assess if South Africa can utilise and implement Trenchless Technology over the traditional open excavation method.

My research titled, Trenchless Technology vs Open Trench Methodology: Implementation in South Africa's Construction Industry is about the comparison between the traditional open excavation method and Trenchless Technology.

The study aims to determine if Trenchless Technology is a financially viable option to implement over the traditional method for the installation of new pipe services or for replacing existing underground pipe services.

The purpose of this questionnaire is to determine the probability of the above-mentioned aim by gathering data for research.

As a selected participant in this specific professional field your feedback and insight are valuable and will assist in the development of the construction industry within South Africa.

Your participation is voluntary and can be withdrawn at any time. All information provided within the questionnaire will be kept confidential. The collected data will be analysed as a group and not individually. Only the overall group results will be published, therefore, assuring anonymity

It would be highly appreciated if you could complete the attached questionnaire. The estimated time of completion for the questionnaire is not more than 15 minutes.

I hereby voluntarily grant my permission for participation in this anonymous survey. The nature and the objective of this research have been explained to me and I understand it.

I understand my right to choose whether to participate in the research project and that the information provided will be handled confidentially. I am aware that the results of the survey may be used for academic publication.

- Yes
- No

Please feel free to contact me should you have any concerns.

Kind regards,
Marique Grobbelaar
mariquek@gmail.com
083 278 2909
PhD Student
Department of Construction Economics
Faculty of Engineering, Built Environment & Information Technology
University of Pretoria

South Africa

Definition:

Trenchless Technology is a term defining the installation or repair of services without or with limited excavation within the earth.

Traditional Excavation method or Open Trench Methodology is a term defining the installation or repair of services by open excavations within the earth by using manual labour or earth moving machinery.

(Please Note: Multiple answers/selections may be provided for questions, unless otherwise stated)

PART 1: GENERAL INFORMATION

Profession: _____ Years of Experience: _____

Question 1:

In which sector are you currently involved?	Please mark with X
• Building Construction:	
• Civil Construction:	
• Development:	
• Mining:	
• Other (Specify):	

Question 2:

In which geographical location(s) are you based or have you done Civil Projects?	Please mark with X
• Gauteng	
• Free State	
• Limpopo	
• North West	
• Northern Cape	
• KwaZulu-Natal	
• Eastern Cape	
• Mpumalanga	
• Western Cape	
• Other (Specify):	

Question 3:

Which of the following services have you provided or were you involved with?	Please mark with X
• Water	
• Stormwater	
• Sewerage	
• Gas	
• Telecommunication	
• Electrical	
• Other (Specify):	

Question 4:

Which of the following type of pipes have you installed or worked with?	Please mark with X
<ul style="list-style-type: none">• Steel Casing Pipes	
<ul style="list-style-type: none">• Reinforced Concrete Pipes	
<ul style="list-style-type: none">• Clay Pipes	
<ul style="list-style-type: none">• Iron Pipes (DIP)	
<ul style="list-style-type: none">• Polyvinyl Chloride Pipes (PVC)	
<ul style="list-style-type: none">• High Density Poly (HDPE)	
<ul style="list-style-type: none">• Glass Fibre Reinforced Plastic Pipes (GRP)	
<ul style="list-style-type: none">• Other (Specify):	

PART 2: NEW PIPELINE INSTALLATIONS

Question 5:

Which of the following new pipeline installation methods have you used on a project?	Please mark with X	The type of service: Please mark with X	Type of Piping Material								
			Please cross over your selection								
			Steel Casing Pipes	SCP	Iron Pipes			IP	Glass Fibre Reinforced Plastic Pipes		GRP
			Concrete Pipes	RCP	Polyvinyl Chloride Pipes			PVC	Other		OTH
Clay Pipes	CP	High-Density Poly			HDPE						
Pipe Jacking		Water		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Stormwater		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Sewerage		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Gas		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Telecom		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Electrical		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Other		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
Utility Tunnelling		Water		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Stormwater		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Sewerage		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Gas		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Telecom		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Electrical		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Other		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
Horizontal Auger Earth Boring		Water		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Stormwater		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Sewerage		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Gas		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Telecom		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Electrical		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Other		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH

Which of the following new pipeline installation methods have you used on a project?	Please mark with X	The type of service: Please mark with X	Type of Piping Material								
			Please cross over your selection								
			Steel Casing Pipes	SCP	Iron Pipes		IP	Glass Reinforced Pipes	Fibre Plastic	GRP	
			Concrete Pipes	RCP	Polyvinyl Chloride Pipes	PVC	Other		OTH		
			Clay Pipes	CP	High Density Poly		HDPE				
Horizontal Directional Earth Drilling		Water		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Stormwater		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Sewerage		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Gas		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Telecom		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Electrical		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Other		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
Microtunneling		Water		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Stormwater		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Sewerage		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Gas		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Telecom		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Electrical		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Other		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
Pilot tube Miro Tunnelling		Water		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Stormwater		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Sewerage		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Gas		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Telecom		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Electrical		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Other		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH

Which of the following new pipeline installation methods have you used on a project?	Please mark with X	The type of service:		Type of Piping Material							
		Please mark with X	Please cross over your selection								
			Steel Casing Pipes	SCP	Iron Pipes			IP	Glass Fibre Reinforced Plastic Pipes		GRP
			Concrete Pipes	RCP	Polyvinyl Chloride Pipes		PVC	Other		OTH	
Clay Pipes	CP	High-Density Poly		HDPE							
Pipe Ramming		Water		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Stormwater		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Sewerage		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Gas		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Telecom		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Electrical		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Other		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
Traditional Open Excavation Method		Water		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Stormwater		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Sewerage		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Gas		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Telecom		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Electrical		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Other		SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH

PART 3: RENEWAL AND REPLACEMENT METHODS

Question 6:

Which of the following renewal or replacement installation methods have you used on a project for pipelines?	Please mark with X	The type of service: Please mark with X	Type of Piping Material								
			Please cross over your selection								
			Steel Casing Pipes	SCP	Iron Pipes			IP	Glass Fibre Reinforced Plastic Pipes		GRP
			Concrete Pipes	RCP	Polyvinyl Chloride Pipes		PVC	Other		OTH	
Clay Pipes	CP	High Density Poly		HDPE							
Pipe Cracking/ Pipe Bursting		Water	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH	
		Stormwater	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH	
		Sewerage	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH	
		Gas	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH	
		Telecom	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH	
		Electrical	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH	
		Other	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH	
Slip Lining		Water	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH	
		Stormwater	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH	
		Sewerage	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH	
		Gas	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH	
		Telecom	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH	
		Electrical	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH	
		Other	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH	
Cured-In-Place Pipes		Water	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH	
		Stormwater	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH	
		Sewerage	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH	
		Gas	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH	
		Telecom	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH	
		Electrical	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH	
		Other	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH	

Which of the following renewal or replacement installation methods have you used on a project for pipelines?	Please mark with X	The type of service: Please mark with X	Type of Piping Material							
			Please cross over your selection							
			Steel Casing Pipes	SCP	Iron Pipes	IP	Glass Fibre Reinforced Plastic Pipes	GRP		
			Concrete Pipes	RCP	Polyvinyl Chloride Pipes	PVC	Other	OTH		
Clay Pipes	CP	High Density Poly	HDPE							
Traditional Open Excavation Method		Water	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Stormwater	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Sewerage	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Gas	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Telecom	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Electrical	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH
		Other	SCP	RCP	CP	IP	PVC	HDPE	GRP	OTH

PART 4: IMPORTANCE OF PROJECT SPECIFICATIONS

Question 7:

Please rate the importance of the following with regards to pipeline/ service line installations.			
1 = Slight 2=Average 3 = Vital			
• Planning	1	2	3
• Design	1	2	3
• Execution or Construction	1	2	3
• Cost	1	2	3
• Time	1	2	3
• Quality	1	2	3
• Geographical Survey	1	2	3
• Ground conditions	1	2	3
• General Labour	1	2	3
• Specialised Labour	1	2	3

Question 8:

Please rate the importance of the following with regards to pipeline/ service line rehabilitation or renewal.			
1 = Slight 2=Average 3 = Vital			
• Planning	1	2	3
• Design	1	2	3
• Execution or Construction	1	2	3
• Cost	1	2	3
• Time	1	2	3
• Quality	1	2	3
• Geographical Survey	1	2	3
• Ground conditions	1	2	3
• General Labour	1	2	3
• Specialised Labour	1	2	3

PART 5: THE FINANCIAL ASPECT OF THE TRADITIONAL METHOD

Question 9:

What is the lowest contract value of a single project executed by your company that involved the traditional method of excavation within the last year?

Contract Value	Please mark with an X
< R 1 million	
R 1 million – R10 million	
R 10 million – R 100 million	
> R100 million	

Question 10:

What is the highest contract value of a single project executed by your company that involved the traditional method of excavation within the last year?

Contract Value	Please mark with an X
< R 1 million	
R 1 million – R10 million	
R 10 million – R 100 million	
> R100 million	

Question 11:

What is the average contract value executed by your company that involved the traditional method of excavation within the last year?

Contract Value	Please mark with an X
< R 1 million	
R 1 million – R10 million	
R 10 million – R 100 million	
> R100 million	

Question 12:

What was the average cost per metre, all-inclusive, for the installation of a service line that involved the traditional method of excavation on the last project executed by your company?

Cost per metre	Please mark with an X
< R 1 000	
R 1 000 – R 2 000	
R 2 000 – R 3 000	
> R 3 000.00	

Question 13:

Based on your own personal experience. Please rank the following based on which the most cost is spent when implementing the traditional method based on the projects you have been involved in:

- Labour
- Machinery/ Equipment
- Site Establishment

1 st	
2 nd	
3 rd	

PART 6: THE FINANCIAL ASPECT OF TRENCHLESS TECHNOLOGY

Question 14:

What is the lowest contract value of a single project executed by your company that involved Trenchless Technology installation within the last year?

Contract Value	Please mark with an X
< R 1 million	
R 1 million – R10 million	
R 10 million – R 100 million	
> R100 million	

Question 15:

Which method of installation was used in the project mentioned in Question 14?

	Please mark with X
• Pipe Jacking	
• Utility Tunnelling	
• Horizontal Auger Earth Boring	
• Horizontal Directional Earth Drilling	
• Micro Tunnelling	
• Pilot Tube Micro Tunnelling	
• Pipe Ramming	
• Pipe Cracking/ Pipe Bursting	
• Slip Lining	
• Cured-In-Place Pipes	

Question 16:

What is the average contract value executed by your company that involved all Trenchless Technology installations within the last year?

Contract Value	Please mark with an X
< R 1 million	
R 1 million – R10 million	
R 10 million – R 100 million	
> R100 million	

Question 17:

Which methods of installation were used in the project mentioned in Question 16?

	Please mark with X
• Pipe Jacking	
• Utility Tunnelling	
• Horizontal Auger Earth Boring	
• Horizontal Directional Earth Drilling	
• Micro Tunnelling	
• Pilot Tube Micro Tunnelling	
• Pipe Ramming	
• Pipe Cracking/ Pipe Bursting	
• Slip Lining	
• Cured-In-Place Pipes	

Question 18:

What is the highest contract value of a single project executed by your company that involved Trenchless Technology installation within the last year?

Contract Value	Please mark with an X
< R 1 million	
R 1 million – R10 million	
R 10 million – R 100 million	
> R100 million	

Question 19:

Which methods of installation were used in the project mentioned in Question 18?

	Please mark with X
• Pipe Jacking	
• Utility Tunnelling	
• Horizontal Auger Earth Boring	
• Horizontal Directional Earth Drilling	
• Micro Tunnelling	
• Pilot Tube Micro Tunnelling	
• Pipe Ramming	
• Pipe Cracking/ Pipe Bursting	
• Slip Lining	
• Cured-In-Place Pipes	

Question 20:

What was the average cost per metre, all-inclusive, for the installation of a service line that involved Trenchless Technology on the last project executed by your company?

	Cost per metre			
	Please mark with an X			
	< R 1 000	R 1 000 – R 2 000	R 2 000 -R 3 000	> R 3 000
• Pipe Jacking				
• Utility Tunnelling				
• Horizontal Auger Earth Boring				
• Horizontal Directional Earth Drilling				
• Micro Tunnelling				
• Pilot Tube Micro Tunnelling				
• Pipe Ramming				
• Pipe Cracking/ Pipe Bursting				
• Slip Lining				
• Cured-In-Place Pipes				

Question 21:

Based on your own personal experience. Please rank the following based on which the most cost is spent when implementing any trenchless method based on the projects you have been involved in:

- Labour
- Machinery/ Equipment
- Site Establishment

1 st	
2 nd	
3 rd	

Question 22:

In your opinion, which of the following replacement/rehabilitation methods is the most cost effective:

(Please select one)

	Please mark with X
• Pipe Cracking/ Pipe Bursting	
• Slip Lining	
• Cured-In-Place Pipes	

PART 7: TRENCHLESS TECHNOLOGY AGAINST THE TRADITIONAL METHOD

Question 23:

	Trenchless Technology	Traditional Method	If possible, please provide a short reason
Which method do you prefer to use regardless of any specifications or limitations on a project?			
Which method do you believe to be the most effective for the installation of new services?			
Which method do you believe to be the most effective for the repair of existing service lines?			
Which method provides the best quality of workmanship?			
Which method is the fastest for the completion of a project?			
Which method is the most expensive in terms of labour, salaries, fees etc?			
Which method is the most expensive in terms of machinery/equipment?			
Which method has provided you with a better profit margin on projects?			
Which method has the highest capital cost?			
Which method do you consider the most cost-effective option for your client?			

APPENDIX E

Certificate of Editing

Declaration of Professional Editing

21 August 2024



This letter serves to confirm that Marique Grobbelaar submitted a thesis to me for editing. The thesis is entitled, 'TRENCHLESS TECHNOLOGY VS OPEN TRENCH METHODOLOGY: IMPLEMENTATION IN SOUTH AFRICA'S CONSTRUCTION INDUSTRY'.

The following aspects were edited:

- Spelling
- Grammar
- Consistency of layout
- Sentence structure
- Logical sequencing
- **References** (Reference checking involves proofreading and some editing with regards to the simple formatting of the references into the referencing style required i.e. changing the order of the elements - author, date, title, series, place, publisher, journal, volume, issue, pagination etc.)

My involvement is restricted to language use and spelling, completeness and consistency, referencing style, and formatting of headings, captions and tables of contents. I did no structural re-writing of the content and did not influence the academic content in any way. While comments and corrections are suggested by the editor the accuracy of content and formatting in the final document remains the responsibility of the student.

Should you have any further queries, please do not hesitate to contact me.

Kind regards,

Kim Smit

- Tel: +27 (0)78 493 6554
 - Email: editorialkms@gmail.com
- Member of the Freelance panel for the University of South Africa
Associate Member of the Professional Editor's Guild

APPENDIX F

TURNITIN Report

Final Draft

ORIGINALITY REPORT

10 %	7 %	7 %	%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	ndl.ethernet.edu.et Internet Source	2 %
2	Steven R. Kramer, William J. McDonald, James C. Thomson. "An Introduction to Trenchless Technology", Springer Nature, 1992 Publication	1 %
3	repository.up.ac.za Internet Source	<1 %
4	businessdocbox.com Internet Source	<1 %
5	Arjan de Haan. "Reclaiming Social Policy", Springer Science and Business Media LLC, 2007 Publication	<1 %
6	"Pipe Bursting Projects", American Society of Civil Engineers (ASCE), 2007 Publication	<1 %
7	Marcos Antonio Ferruzzi, Mário Sacomano Neto, Eduardo Eugênio Spers, Mateus Canniatti Ponchio. "Reasons for outsourcing	<1 %