

A Comparative Analysis of  
Horizontal Directional Drilling Construction Methods

in Mainland China

by

Maureen Cassin Carlin

A Dissertation Presented in Partial Fulfillment  
of the Requirements for the Degree  
Doctor of Philosophy

Approved November 2014 by the  
Graduate Supervisory Committee:

Samuel Ariaratnam, Chair  
Oswald Chong  
Wylie Bearup

ARIZONA STATE UNIVERSITY

December 2014



## ABSTRACT

As a developing nation, China is currently faced with the challenge of providing safe, reliable and adequate energy resources to the county's growing urban areas as well as to its expanding rural populations. To meet this demand, the country has initiated massive construction projects to expand its national energy infrastructure, particularly in the form of natural gas pipeline. The most notable of these projects is the ongoing West-East Gas Pipeline Project. This project is currently in its third phase, which will supply clean and efficient natural gas to nearly sixty million users located in the densely populated Yangtze River Delta.

Trenchless Technologies, in particular the construction method of Horizontal Directional Drilling (HDD), have played a critical role in executing this project by providing economical, practical and environmentally responsible ways to install buried pipeline systems. HDD has proven to be the most popular method selected to overcome challenges along the path of the pipeline, which include mountainous terrain, extensive farmland and numerous bodies of water. The Yangtze River, among other large-scale water bodies, have proven to be the most difficult obstacle for the pipeline installation as it widens and changes course numerous times along its path to the East China Sea. The purpose of this study is to examine those practices being used in China in order to compare those to those long used practices in the North American in order to understand the advantages of Chinese advancements.

Developing countries would benefit from the Chinese advancements for large-scale HDD installation. In developed areas, such as North America, studying Chinese execution may allow for new ideas to help to improve long established methods. These factors

combined further solidify China's role as the global leader in trenchless technology methods and provide the opportunity for Chinese HDD contractors to contribute to the world's knowledge for best practices of the Horizontal Directional Drilling method.



## DEDICATION

To my Mother and Father, thank you for  
your support and encouragement along the way provided me with the will to persevere.

To my Husband, thank you  
for standing by me and supporting me in this and everything I do.

## ACKNOWLEDGEMENTS

I would like to thank Dr. Samuel T. Ariaratnam for taking me under his wing and aiding me with completing my thesis in an organized and professional manner. Additionally, I am very grateful for all of the opportunities you have given me to promote my research, whether it was through technical papers, attending industry conferences, or professional networking. My research would not have been feasible without the guidance of Dr. Sam. Thank you for giving me the opportunity to conduct this research nor experience the culture of Mainland China. I am forever indebted to you for this opportunity.

I also would like to pay tribute to my other committee members, Dr. Wylie Bearup and Dr. Oswald Chong, for their support and guidance throughout my studies. Dr. Wylie, your lifelong commitment to the civil engineering discipline is remarkable, and I respect the path you have taken throughout your career that has positioned you to be where you are today. Dr. Oswald, thank you for being an open ear for me to discuss the challenges of research and providing valuable feedback along the way.

I would like to thank Dr. Baosong Ma and graduate research team at the China University of Geosciences-Wuhan. Your guidance and friendship throughout the last two years is highly appreciated and proved to be invaluable to the international collaboration effort. Thank you for helping me travel throughout China and visit jobsites that I would not have been able to visit without your guidance.

Deep gratitude is owed to Alan Snider and Paul Greenwell and many other employees of Laney Directional Drilling for providing me with the incredible opportunity to learn the ins and outs of the HDD methodology. In addition, I would like to thank Gabes

Construction and Ranger Directional Services for sharing project information of some of their great HDD executions.

Thank you to everyone I have worked closely with in the Center for Research in Underground Systems and Technology for making my time at Arizona State University more pleasurable. Many thanks are also due to all of the graduate students and faculty members at the School of Sustainable Engineering and the Built Environment who have become my friends. I value the good times and the experiences we have shared. I wish you all the best of luck.

## TABLE OF CONTENTS

	Page
LIST OF TABLES .....	xvi
LIST OF FIGURES .....	xvi
CHAPTER	
1. INTRODUCTION .....	1
2. OVERVIEW OF TRENCHLESS TECHNOLOGIES .....	7
2.1 Horizontal Directional Drilling.....	8
2.2 History of HDD.....	9
2.3 HDD Methodology .....	12
2.3.1 Step 01: Pilot Hole.....	12
2.3.2 Step 02: Hole Opening / Pre-Reaming.....	14
2.3.3 Step 03: Pullback .....	14
2.4 Design Considerations .....	15
2.5 Equipment Selection.....	18
2.5.1 Rig Selection.....	18
2.5.2 Tracking Equipment.....	20
2.5.3 Steering Tools .....	22
2.6 Project Considerations .....	22
2.6.1 Site and Equipment Layout.....	23

CHAPTER	Page
2.6.2 Fluid Management System .....	23
2.6.3 Site Restoration.....	25
2.7 Advantages, Limitations and Challenges.....	25
3. SCOPE OF STUDY .....	28
3.1 History of Trenchless Technology in China .....	30
3.2 Pipeline Development in China .....	31
3.3 Research Methodology .....	37
3.4 Limitations and Advantages .....	38
4. LITERATURE REVIEW .....	39
4.1 General Construction Practices in China .....	40
4.1.1 Market Structure of Construction Industry .....	41
4.1.2 Economic Influences of the Chinese Industry .....	48
4.1.3 Labor Considerations for the Chinese Industry .....	52
4.1.4 Project Management in the Chinese Industry .....	66
4.2 Comparative Studies of Construction Practices in China .....	78
4.2.1 Safety .....	78
4.2.2 Productivity.....	90
4.2.3 Legal .....	905

CHAPTER	Page
4.3	Infrastructure and Trenchless Technologies in China .....102
4.4	Chinese Investigations in Infrastructure Construction.....107
4.5	Chinese Investigations in Trenchless Technologies .....114
4.6	International Collaboration Efforts .....135
5.	PROJECT CASE STUDIES.....143
5.1	Yangtze River Crossing, Jiangyin City, Jiangsu Province, CN.....149
5.1.1	Company Profile.....149
5.1.2	Project Background .....149
5.1.3	Design and Construction .....150
5.1.4	Crossing Details .....150
5.1.5	Safety and Quality Control.....152
5.1.6	Construction Approach.....153
5.1.7	Worker Information.....159
5.1.8	Project Challenges.....161
5.1.9	Schedule and Results.....161
5.2	Weihe River Crossing, Weinan, Shanxi Province, CN.....163
5.2.1	Company Profile.....163
5.2.2	Project Background .....163

CHAPTER	Page
5.2.3	Design and Construction.....164
5.2.4	Crossing Details .....164
5.2.5	Safety and Quality Control .....165
5.2.6	Construction Approach .....167
5.2.7	Worker Information .....169
5.2.8	Project Challenges .....170
5.2.9	Schedule and Results .....170
5.3	Qin River Crossing, Zhengzhou, Henan Province, CN .....171
5.3.1	Company Profile .....171
5.3.2	Project Background.....171
5.3.3	Design and Construction.....172
5.3.4	Crossing Details .....172
5.3.5	Safety and Quality Control .....174
5.3.6	Construction Approach .....174
5.3.7	Worker Information .....180
5.3.8	Project Challenges .....181
5.3.9	Schedule and Results .....182
5.4	Yangtze River Crossing, Wuhan City, Hubei Province, CN .....183

CHAPTER	Page
5.4.1 Company Profile .....	183
5.4.2 Project Background.....	183
5.4.3 Design and Construction.....	184
5.4.4 Crossing Details .....	184
5.4.5 Safety and Quality Control .....	186
5.4.6 Worker Information .....	194
5.4.7 Project Challenges .....	194
5.4.8 Schedule and Results .....	200
5.5 Lake Houston Crossing, Houston, TX, USA.....	202
5.5.1 Company Profile .....	202
5.5.2 Project Background.....	202
5.5.3 Design and Construction.....	203
5.5.4 Crossing Details .....	203
5.5.5 Safety and Quality Control .....	207
5.5.6 Construction Approach .....	208
5.5.7 Worker Information .....	212
5.5.8 Project Challenges .....	212
5.5.9 Schedule and Results .....	213



CHAPTER	Page
5.6 Sabine River Crossing, Liberty, TX USA .....	215
5.6.1 Company Profile .....	215
5.6.2 Project Background.....	215
5.6.3 Design and Construction.....	215
5.6.4 Crossing Details .....	216
5.6.5 Safety and Quality Control .....	216
5.6.6 Construction Approach .....	217
5.6.7 Worker Information .....	223
5.6.8 Project Challenges .....	223
5.6.9 Schedule and Results .....	224
5.7 Walnut Grove Crossing, Walnut Grove, CA, USA .....	225
5.7.1 Company Profile .....	225
5.7.2 Project Background.....	225
5.7.3 Design and Construction.....	226
5.7.4 Crossing Details .....	227
5.7.5 Safety and Quality Control .....	227
5.7.6 Construction Approach .....	228
5.7.7 Worker Information .....	231

CHAPTER	Page
5.7.8 Project Challenges .....	232
5.7.9 Schedule and Results .....	232
6. COMPARATIVE ANALYSIS.....	234
6.1 Introduction.....	234
6.2 Design .....	234
6.2.1 Geotechnical Site Investigation .....	234
6.2.2 Design Analysis and Calculations .....	236
6.3 HDD Application and Process .....	240
6.3.1 Site Preparation.....	244
6.3.2 Pilot Bore and Tracking.....	251
6.3.3 Reaming/Hole Enlargement .....	252
6.3.4 Pipe Layout, Fabrication, and Testing.....	255
6.3.5 Pullback .....	260
6.3.6 Demobilization, Site Cleanup, and Restoration.....	261
6.4 Equipment and Materials .....	262
6.4.1 Rig Selection.....	262
6.4.2 Drill Pipe.....	262
6.4.3 Drill Bits and Downhole Tools.....	263

CHAPTER	Page
6.4.4	Drilling Fluid Delivery and Containment Systems.....266
6.4.5	Drilling Fluid and Additives .....273
6.4.6	Bore Tracking Equipment.....276
6.5	Jobsite Safety and Quality Control .....276
6.5.1	Safety .....276
6.5.2	Hydrostatic Testing, Inspections and Acceptance .....281
6.5.3	Reporting.....283
6.6	Worker Considerations .....285
6.6.1	General .....285
6.6.2	Crew Sizing.....286
6.6.3	Pay Wages and Benefits.....288
6.6.4	Working Hours.....292
6.6.5	Living Conditions .....294
6.6.6	Education .....295
7.	CONCLUSIONS AND RECOMENNDATIONS.....297
7.1	International Significance .....312
7.2	Opportunities for Continued International Collaboration.....314
7.3	Future of HDD in China .....314

CHAPTER	Page
REFERENCES .....	317

## LIST OF TABLES

Table	Page
2.1: HDD Main Features.....	19
3.1: China’s Energy Consumption by Fuel Type, 2007.....	34
4.1: Trend of Fatalities and Safety Risks in the Chinese Construction Industry .....	80
4.2: Typical Safety Risk Factors for Construction Activities .....	83
4.3: Top Five Safety Risk Factors in China and Australia .....	84
4.4: Workshop Topics.....	139
5.1: Yangtze River Crossing Project Parameters.....	151
5.2: Onsite Worker Breakdown .....	160
5.3: Weihe River Crossing Project Parameters.....	165
5.4: Qin River Crossing Project Parameters .....	173
5.5: Yangtze River Crossing Project Parameters .....	186
5.6: Results of Yangtze River HDD Crossing .....	200
5.7: Lake Houston Crossing Project Parameters.....	204
5.8: Sabine River Crossing Project Parameters .....	217
5.9: Walnut Grove Crossing Project Parameters .....	228
6.1: Approved Path Parameters.....	252
6.2: Case Study 1 Reaming Summary (Actual).....	253
6.3: Case Study 1 Reaming Summary (Theoretical US Approach).....	254
6.4: Quick Facts: Construction Equipment Operators .....	288
6.5: Quick Facts: Construction Laborers and Helpers .....	289
6.6: Quick Facts: Heavy and Tractor-Trailer Truck Drivers .....	289

## LIST OF FIGURES

Figure	Page
1.1: Population Density of China.....	1
1.2: Chinese Workers Working of Horizontal Directional Drill Rig.....	2
2.1: Examples of Utility Construction in China.....	7
2.2: HDD Schematic.....	8
2.3: HDD Founder, Martin Cherrington/ First HDD Drill Rig.....	10
2.4: Titan Contracting Drill Crew, Year Unknown.....	11
2.5: Step 01 – Pilot Hole Schematic.....	13
2.6: Step 02 – Hole Opening / Reaming Schematic.....	14
2.7: Step 03 – Pullback Schematic.....	15
2.8: Sample HDD Profile.....	16
2.9: Schematic of HDD Rig.....	18
2.10: Walk-Over System Schematic.....	20
2.11: TruTracker® Wire Line System Schematic.....	21
3.1: Work on the West-to-East Pipelines.....	33
3.2: CNPC Inspector on HDD Pipeline Installation.....	35
3.3: CNPC Operated Pipelines.....	37
4.1: Domestic Market Size of the Chinese Construction Industry From 1979 to 2008....	44
4.2: Layout of the Comprehensive Transportation Corridor of Yangtze River.....	49
4.3: Educational Attainment of Rural Migrant Workers, 2004.....	53
4.4: Wage Profile of Rural Migrant Workers in China, 2002.....	54
4.5: The Flowcharts of Risk Management of Tunnel and Underground Works.....	76

Figure	Page
4.6: ZWGP Pipeline Route Map .....	111
4.7: The Technical Frame and Process of The Geologic Hazard Risk Assessment .....	113
4.8: The Generalized Geologic Map.....	115
4.9: Elevation of the Drill Path .....	123
4.10: Interaction Analysis Between Drill Pipe and Soil .....	133
4.11: Participants of the CTRD.....	136
5.1: Research Team at China University of Geosciences -Wuhan .....	143
5.2: Vermeer® Manufacturing Facilities in Beijing, China.....	144
5.3: Hong Kong–Zhuhai–Macau Bridge.....	146
5.4: Figure 5.4.: CUG Student Adjacent to Pipe Roofing System.....	146
5.5: Map of Chinese Crossing Case Study Sites.....	148
5.6: Profile View of Soil Conditionn and Drill Path.....	151
5.7: CNPC Quality Control and Safety Representatives .....	153
5.8: Spacing of Buried Pipelines Schematic .....	153
5.9: Main Rig - American Augers® DD-1100RS Drill Rig.....	154
5.10: Plan View of Project Site and Intersect Location.....	156
5.11: Onsite Workers Preparing ParaTrack 2® Tracing Lines .....	156
5.12: Onsite Mud Recycling System .....	157
5.13: Pipe Stringing Operations During Final Pullback .....	158
5.14: Nighttime Pullback Operations.....	159
5.15: Quality Control Testing Equipment for Drill Fluid Monitoring.....	166
5.16: Main Rig - Shanghai Goodeng GD5000-LL Drill Rig.....	168

Figure	Page
5.17: Overhead View of Custom Fluid Recycling System .....	168
5.18: CUG Student and Engineering Consultant Reviewing Drill Path .....	172
5.19: Onsite Safety/Inspection Professional .....	175
5.20: Jobsite Layout .....	176
5.21: Chinese Manufactured Lianyungang In-Rig Drill Rig .....	176
5.22: Auxiliary Drill Rig Located on Exit Side .....	177
5.23: Custom Built Fluid Mixing Tanks .....	178
5.24: Pilot Hole Steering Unit.....	178
5.25: 48” Reaming Unit .....	180
5.26: Onsite Workers During Recovery Operations .....	181
5.27: Profile Section of Crossing.....	185
5.28: Overview of Entry Side Construction Site .....	188
5.29: Casing Tamping Field on the South Bank.....	189
5.30: Casing Tamping Field on the North Bank.....	189
5.31: Time-Consuming Chart of Reaming.....	191
5.32: Mud Jetting Nipple for Hole-Flushing.....	192
5.33: Carried Rock Debris During Excavation .....	192
5.34: Successful Pipeline Pullback .....	193
5.35: Broken Drill Pipe .....	195
5.36: Stuck Reamer .....	195
5.37: Fractured Drill Pipe .....	196
5.38: Reinstall Center Locator inside Casing on the South Bank.....	196



Figure	Page
5.39: Plan View of Crossing Plan.....	202
5.40: Alignment of Drill Path Across River.....	205
5.41: Arial View of Entry Side.....	206
5.42: Arial View of Exit Side.....	206
5.43: LDD 750 Drill Rig.....	209
5.44: Product Pipe During Pullback.....	212
5.45: Ranger Onsite Management.....	218
5.46: Main Drill Rig.....	219
5.47: Steering Operations.....	220
5.48: Product Pipe During Pullback.....	222
5.49: Successful Pipeline Pullback.....	222
5.50: Site Map.....	226
5.51: Site Overview.....	227
5.52: Tracking Survey of Exit Path.....	230
5.53: Main Drill Rig.....	229
5.54: Project Completion Report.....	233
6.1: Force Analysis Along Drill Path.....	238
6.2: Stress Analysis Along Drill Path.....	238
6.3: Model Analysis of Pipe String Operations.....	239
6.4: Annular and Limit Pressure Chart.....	240
6.5: Example Factor of Safety Chart.....	240
6.6: Fencing and Designated Entry for Chinese Site.....	245

Figure	Page
6.7: Safety Fencing for Chinese Site.....	245
6.8: Onsite Logistics Planning Board .....	246
6.9: Onsite Signage – Material Storage Area.....	247
6.10: Onsite Signage – Additional Storage Area .....	247
6.11: Typical Timber Matting for Site Access.....	248
6.12: Application of Timber Matting for Total Project Drill Area .....	249
6.13: Flooded Jobsite Without Timber Matting in China .....	249
6.14: Preformed Concrete Panels Used for Walking Paths .....	250
6.15: Hand Laid Walking Path.....	251
6.16: Onsite Welding Operations.....	256
6.17: Low Profile Pipe Rollers.....	257
6.18: Plated Pipe Roller .....	258
6.19: Product Staging During Welding Operations (Example 1) .....	259
6.20: Product Staging During Welding Operations (Example 2) .....	259
6.21: Drill Pipe – China .....	263
6.22: Rusted Barrel Reamer – China .....	265
6.23: Refurbished Galvanized Mill-Tooth Reamer .....	265
6.24: Galvanized Barrel Reamer – China .....	266
6.25: Cuttings Canal Path System.....	269
6.26: Cuttings Retention Ponding Systems (Example 1).....	270
6.27: Schematic of Cuttings Path.....	270
6.28: Cuttings Retention Ponding Systems (Example 2).....	271

Figure	Page
6.29: Onsite Water Well .....	272
6.30: CNPC Fluid Quality Control Team Members .....	275
6.31: Sinopec Fluid Quality Control Team Members.....	275
6.32: Onsite Temporary Facility Construction .....	279
6.33: Site Overview with Safety Taping at Trench Locations.....	280
6.34: Trenching Adjacent to Tower Crane .....	280
6.35: Standard Sinopec Uniform.....	281
6.36: Onsite Continuous Welding Inspections.....	282
6.37: Hand Written Quality Control Report .....	284
6.38: Onsite Workers During Drilling Operations.....	287
6.39: Sinopec Drill / Engineering Team .....	287
6.40: Average Minimum Wage in Earnings Per Month .....	291
6.41: Working Days Per Week For Rural Migrant Workers, 2002 .....	293
6.42: Daily Working Hours Per Week For Rural Migrant Workers, 2002.....	293
6.43: Educational Attainment of Rural Migrant Workers, 2004 .....	296
7.1: China and United States Energy Consumption 1990-2040 .....	307
7.2: World Energy Consumption by Fuel Type 1990-2040 .....	307
7.3: World Coal Production, 2010-2040.....	308
7.4: World Coal Consumption by Leading Consuming Countries 2010-2040.....	309
7.5: Non-OECD Domestic Product Growth Rates, 2010-2040 .....	310
7.6: China Coal Consumption and U.S. Coal Consumption, 2010-2040 .....	310
7.7: Natural Gas Production in China, Canada, and the US, 2010 and 2040 .....	311

Figure	Page
7.8: International Russia / China Pipeline.....	313
7.9 Potential Pipeline Route for International Pipeline to China.....	313
7.10: Closing Ceremonies at Pipeline Project Completion.....	316

## 1. INTRODUCTION

As a developing nation, China is currently faced with the challenge of providing safe, reliable and adequate energy resources to the country's growing urban areas as well as to its expanding rural populations. (Refer to Figure 1.1 for geographical population density of China.) To meet this demand, the country has initiated massive construction projects to expand its national energy infrastructure, particularly in the form of natural gas pipeline. The most notable of these projects is the ongoing West-East Gas Pipeline Project. This project is currently in its third phase, which will supply clean and efficient natural gas to nearly sixty million users located in the densely populated Yangtze River Delta.

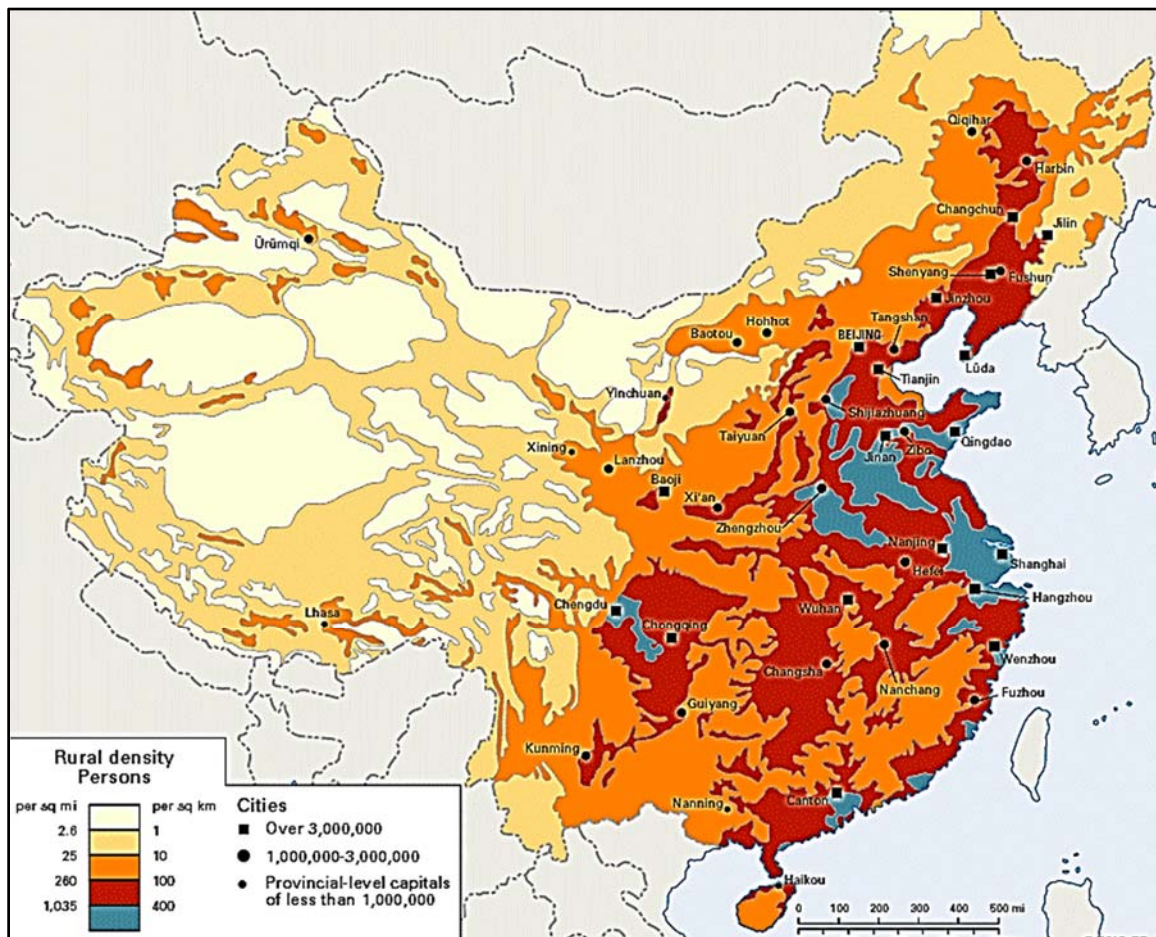


Figure 1.1: Population Density of China (Encyclopedia Britannica, 2014)

Trenchless Technologies, in particular the construction method of horizontal directional drilling (HDD), have played a critical role in executing this project by providing economical, practical and environmentally responsible ways to install buried pipeline systems. HDD has proven to be the most popular method selected to overcome challenges along the path of the pipeline, which include mountainous terrain, extensive farmland and numerous bodies of water. The Yangtze River, among other large-scale water bodies, have proven to be the most difficult obstacle for the pipeline installation as it widens and changes course numerous times along its path to the East China Sea. Refer to Figure 1.2: Chinese Workers Working of Horizontal Directional Drill Rig for visual.



Figure 1.2: Chinese Workers Working of Horizontal Directional Drill Rig

China's rapid adoption and advancement in large diameter natural gas pipeline installation has resulted in numerous successful pipeline projects which include a series of recently executed record-breaking HDD installations. It is expected that records will

continue to be broken as large-scale pipeline installations continue and competition between China National Petroleum Corporation, Sinopec (China Petroleum & Chemical Corporation), and China National Offshore Oil Corporation increase. Thus, China's role as the global leader in large-scale horizontal directional drilling will not only continue, but will grow in the foreseeable future

With this said, it can be expected that there are vast opportunities for Chinese HDD contractors to continue to test the limits of the HDD technologies through equipment advancement, record setting executions, and number of crossings attempted. Chinese manufacturers of maxi-rig equipment will continue to test the boundaries of how "large" future drill rigs can be produced. HDD contractors will attempt crossings that are larger and further than ever before attempted. Finally, the Chinese government will continue to fund large-scale pipeline construction projects and will continue to tighten energy efficiency requirements for all parties.

Understanding the role that Chinese HDD contractors have played in the advancement of HDD in China role would be of great value to the global trenchless technology community. However, little is known about what construction practices Chinese contractors are actually utilizing. While Chinese academics and industry leaders have investigated various theoretical aspects of HDD design, little technical information has been published in the area of large-scale HDD execution in China with regards to tangible execution methods. In addition, first hand witness by North American experts in China is virtually non-existent. Thus, this study is believed to be the first of its kind to use a combination of technical publications, first hand visits to both North American and

Chinese jobsites, and comprehensive project questionnaires to gain a perspective of Chinese HDD construction methods.

The purpose of this study is to examine those practices being used in China in order to compare those to those long used practices in the North American in order to understand the advantages of Chinese advancements. Developing countries would benefit from the Chinese advancements for large-scale HDD installation. In developed areas, such as North America, studying Chinese execution may allow for new ideas to help to improve long established methods. These factors combined further solidify China's role as the global leader in trenchless technology methods and provide the opportunity for Chinese HDD contractors to contribute to the world's knowledge for best practices of the horizontal directional drilling method.

Chapter Two provides an overview of trenchless technologies. It begins with an overview of the history of horizontal directional drilling starting with the first river crossing in 1971. The HDD methodology is discussed including the pile hole execution, hole opening and reaming operations, an final pullback as well as an overview of design considerations. Equipment selection is included and includes drill selection, tracking equipment and steering tools. Project considerations such as site and equipment layout, fluid management system and site restoration are discussed in depth. This chapter concludes by highlighting the advantages, limitations and challenges of the HDD methodology.

Chapter Three defines the scope of this study by discussing what has been included in the study, why the information is innovative, and what the possible outcomes are of the study. This section includes a detailed history of trenchless technology in China and



pipeline development in China with regards to environmental, political, and economic influences. The research methodology overviews data collection in the form of interviews, case studies, site visits, and questionnaires and the limitations and advantages associated with the selected methodologies.

Chapter Four includes a comprehensive literature review that is a critical piece of the overall findings. This section includes general topics such as construction practices in china and the market structure of construction industry. Key topics include the economic, labor, and management influences of the Chinese construction industry. Comparative studies of construction practices in china with regards to safety, productivity and legal were included to provide an overview of previous work in the area of comparative analysis of construction studies in other sectors. Infrastructure construction and trenchless technologies in china, Chinese investigations in infrastructure construction, and Chinese investigations in trenchless technologies provide an overview of what construction efforts are currently underway and what studies have been performed by Chinese academic and industry experts have studied with regards to these topics. The final section overviews international collaboration efforts in the area of trenchless technologies and critical infrastructure.

Chapter Five presents the results from the field data collection and case studies. Seven major case studies including three from the United States and three from Mainland China are presented. These case studies reflect the information obtained directly through on-site visits and comprehensive project questionnaires. Additional, supplemental case study information has been included as obtained from previous academic publication and industry profiles. Case studies include discussion of the HDD company profile, project

background, project organization, crossing details, safety and quality control, construction approach, worker information, project challenges and schedule and results.

Chapters Six and Seven complete this study with a detailed comparative analysis of the Chinese practices as compared to those in North America and the results and conclusions based on that comparison. Specific areas of comparison are project organization, safety and quality control construction approach, and worker environment considerations. Based on these areas, conclusions and recommendations included the applicability of Chinese practices in both domestic and international markets, the future of HDD practices in China and directions for future research. Directions on future research in this area are extensive. Chapter seven provides an overview of the expected energy and HDD growth over the upcoming years and how that translates into international opportunities for further collaboration in trenchless technologies and critical underground infrastructure.

## 2. OVERVIEW OF TRENCHLESS TECHNOLOGIES

Trenchless technologies are considered a “family of construction methods” used to evaluate, service, renovate, and replace buried infrastructure with reduced impact to people and the environment. Specific trenchless technologies include pipe jacking, pipe lining, micro tunneling, and horizontal directional drilling. This investigation focuses on horizontal directional drilling (HDD,) which is widely considered to be the most applied trenchless technology globally. Figure 2.1: Examples of Utility Construction in China shows areas of need for Trenchless Technologies in Mainland China.

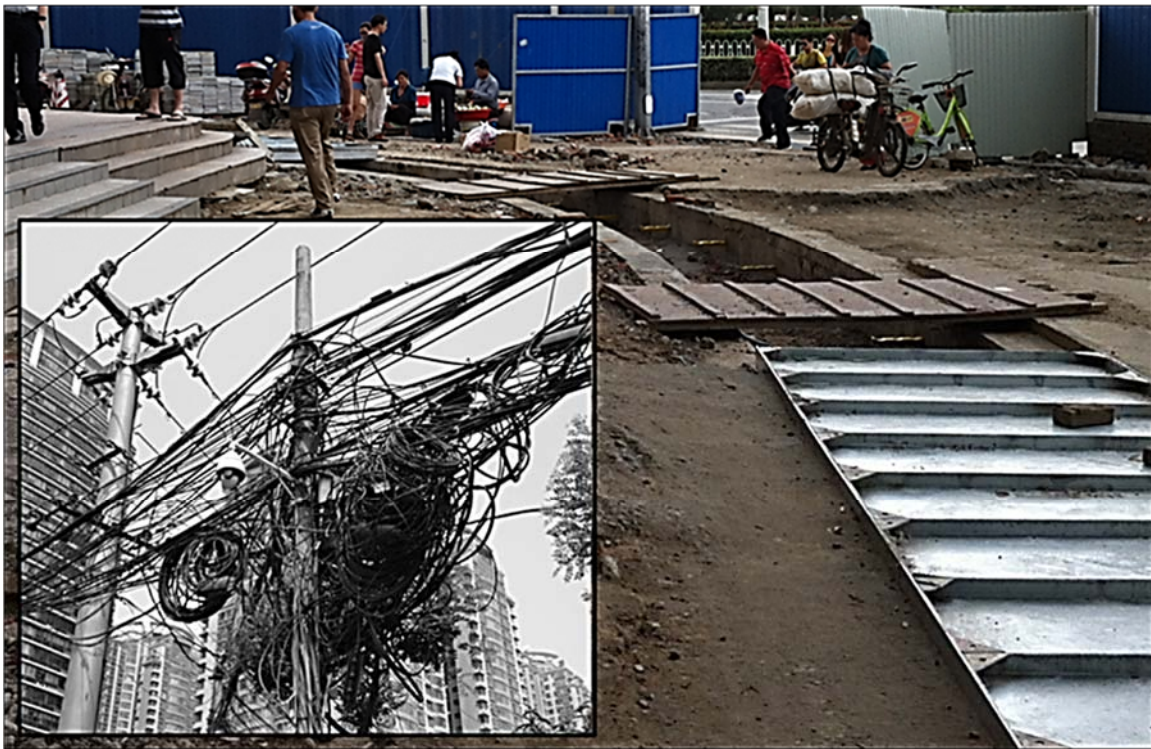


Figure 2.2: Examples of Utility Construction in China

The application of these technologies have benefits over traditional open-cut methods including reduced ground excavation, construction site footprint, and other social and environmental costs. Traditional open trench practices for installing and repairing underground infrastructure require a substantial amount of ground restoration, which tends

to inflate direct project costs along with social and environmental costs. Although open trench installation has its place, namely in rural areas with limited congestion, trenchless technologies have proven to be highly effective in urban and environmentally sensitive areas.

It is well known that infrastructure is the backbone of modern civilization. Specifically, underground infrastructure underpins human societal health and its economic potential. As such, sustainable underground infrastructure is essential to a viable society. (Olson, 2012.) This is a fact that is at the forefront of Chinese efforts to improve the quality of life to the citizen of the most populated country. Massive infrastructure projects are currently underway in China at an unprecedented level, allowing trenchless technologies to contribute to the overall development of China's natural gas, oil and water systems.

## 2.1 Horizontal Directional Drilling

Horizontal directional drill construction trenchless method of installing pipelines in areas where traditional open cut excavations are not feasible for environmental or logistical reasons. It is commonly used for installation of pipelines beneath rivers, highways, railroads and other environmentally sensitive areas, including steep bluffs where elevation changes over short distances compromise the conventional cut and cover installation. Refer to Figure 2.2 for schematic.



Figure 2.3: HDD Schematic (Tracto-Technik GmbH & Co. KG)

HDD technology enables the installation of conduits and pipelines ranging from up to 60” in diameter over distances greater than 12,000’. Drill equipment is a key factor in horizontal directional drilling as the amount of force that can be “pulled” by the drill rig (or rigs) determines the capabilities of a potential HDD crossing. Drill rigs range in size from small, one-man operated systems capable of pulling small diameter conduits several hundred feet to much larger rigs known as “maxi” rigs. Maxi rigs can exceed 1,800,000 pounds of thrust / force pullback and require large labor crews to complete installations.

## **2.2 History of HDD**

As the need for water and sewer services grew during the 1950s, 1960s, and 1970s, civil engineers were faced with the task of connecting treatment plants on one side of the river with customers on the other side (Bennett, 2003.) In “How the HDD Industry Began,” author Martin Cherrington describes how he conceived the use of horizontal directional drilling as a practical alternative to conventional trenching methods beginning in the 1960’s. (Cherrington) While working for a contractor in the Los Angeles area in 1963, Cherrington realized that there might be potential for using drilling technology to greatly enhance the efficiency of placing cables and conduits underground. This observation would spark an idea that ultimately would launch a whole new industry, horizontal directional drilling. In 1964, Cherrington built his first drill rig and formed Titan contractors, a company specializing in utility road boring in Sacramento, California. (Refer to Figure 2.3 for photograph of Martin Cherrington and the first HDD drill rig.)

With the hope of testing a revolutionary new idea using the discarded downhole drilling tools, Cherrington assembled his crew and horizontal drilling equipment and applied new techniques to those available oil field directional drilling technology and methods. After much experimentation, Cherrington and his crews confirmed that given the optimum entry angle, proper drilling techniques and the right downhole tool assembly a barrier such as a river could be crossed using horizontal drilling techniques.

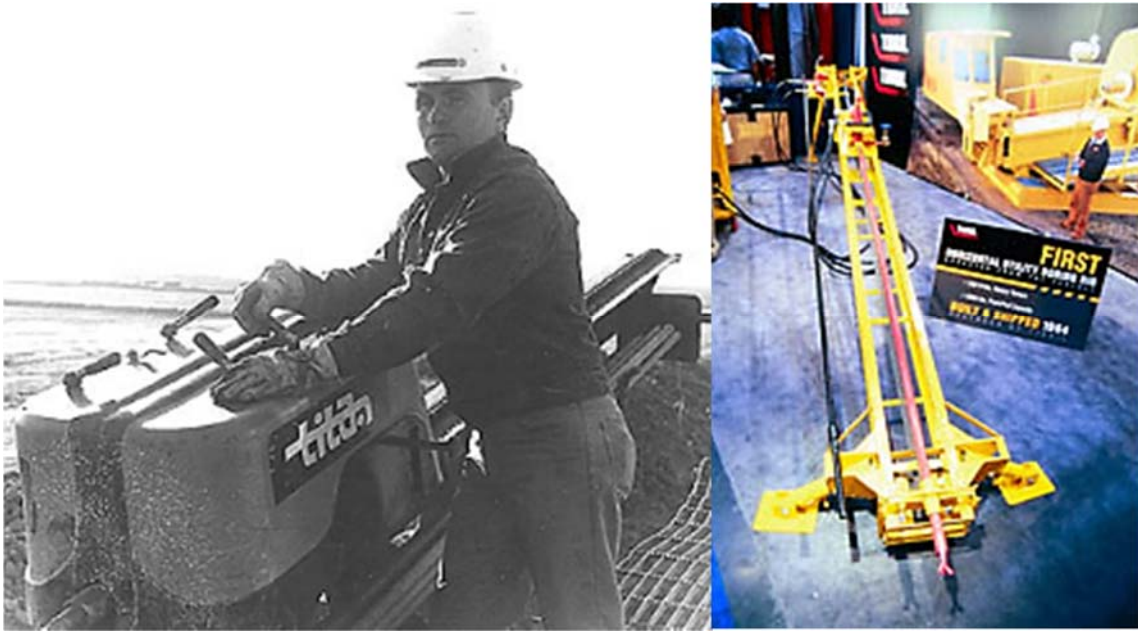


Figure 2.4: HDD Founder, Martin Cherrington (Left)  
First HDD Drill Rig (Right) (Cherrington, 2013)

The first river crossing was accomplished in 1971 beneath the Pajaro River near Watsonville, California. The project was for the Pacific Gas and Electric Company and involved the installation of approximately 600 linear feet of four-inch diameter steel pipeline. From 1971, when the first river crossing was completed, through 1979, only thirty-six (36) crossings were made successfully using HDD technology. After the 1970s, a noticeable development was observed in tracking systems, and machine tools



and accessories. Refer to Figure 2.5: Titan Contracting Drill Crew for advancement in HDD technologies. Also, HDD machine were manufactured in different sizes including Mini, Midi, and Maxi HDD sizes, which enabled using the machines in urbanized and congested areas. For the reasons mentioned earlier, HDD became more cost-effective and commonly used in most installations of utilities and conduits in urban and congested areas.



Figure 2.6: Titan Contracting Drill Crew, Year Unknown (Cherrington, 2013)

A total of 12 HDD operational units were manufactured in 1984 compared to a 2,000 HDD operational units in 1995 (Allouche 2000). Approximately 17,800 HDD units were manufactured and sold during the period between 1992 and 2001 in North America (Baik, 2003). The number of HDD rigs manufactured worldwide recently comes to 32,135 units in 2011, with 80% of these rigs manufactured in USA (Carpenter 2011.)

HDD, as it would become known, would ultimately revolutionize the way the construction industry would come to install underground utilities and pipelines in cities and under large natural obstacles like the Mississippi River, Houston Ship Channel, and even Pearl Harbor. Today, HDD executions are widely used for all types of pipeline construction in both urban areas and rural locations. HDD has become even more spotlighted as environmental regulators push for alternative construction methods that reduce impacts to the environment. While HDD originated in the United States, its use has gained global attention and is being utilized for larger, longer and more remote installations than Martin Cherrington ever envisioned.

### **2.3 HDD Methodology**

The HDD process is relatively simple and consists of three basic steps needed to install a pipeline crossing. These steps include the pilot hole, hole opening or reaming, and pullback.

#### **2.3.1 Step 01: Pilot Hole**

The pilot hole is the first step in the HDD process. The pilot hole is drilled along a predetermined alignment in which the entry and exit points are located using traditional survey methods. Control of the drill bit is achieved by using a non-rotating drill string with an asymmetrical leading edge. This leading edge creates a steering bias to be held in a precise position during drilling. The pilot hole is surveyed by two separate methods: downhole survey tools using an instrument referred to as a probe and a secondary tracking system such as ParaTrack 2<sup>®</sup> that involves placing a wire along the ground surface for creating a magnetic field. Both methods of survey are calculated after each section of drill pipe has been drilled (approximately 30'). Refer to Figure 2.5 for schematic.



## PILOT HOLE

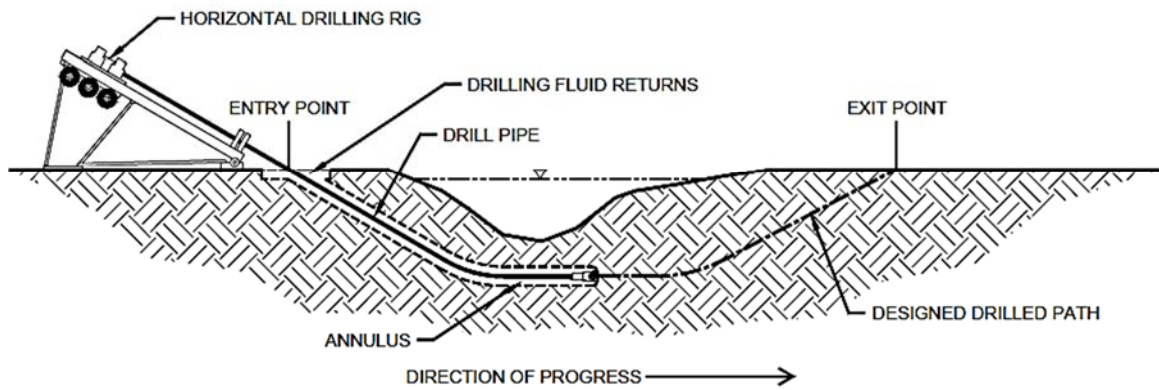


Figure 2.7: Step 01 – Pilot Hole Schematic (Hair, 2008)

The pilot hole consists of drilling an initial hole (typically 6 ½” to 9 7/8”) along the drill path of the proposed crossing. However, advancements in equipment technology now allow pilot hole sizes to be much greater, eliminating the need for the second step all together. The tooling required for the pilot hole depends largely of the type of soil conditions. Soft conditions such as sand and clay can be considered jettable, and therefore no rock tooling would be required. In the case of rock conditions, the use of a mud motor would be required and one of several categories of rock tooling. In this case, drilling fluid is pumped through the annulus of the drill pipe, which then aids a positive displacement mud motor in cutting through the rock strata. Drilling fluid also helps lubricate the drill stem, suspend and carry the drilled cuttings to the surface, and form a wall cake to keep the hole open.

A successful pilot hole provides pertinent data for determining the possible success of the crossing. Data obtained from the pilot hole includes the rate of penetration and confirmation of geotechnical strata. The contractor can use this data to plan for opening the hole to the required diameter.

### 2.3.2 Step 02: Hole Opening / Reaming

The second step consists of one or more hole-opening passes. There are two types of tools that enlarge the pilot hole: fly-cutters, used for most soil formations, and rock hole opening tools, used for very dense soil and rock formations. Typically, a hole opening tool is attached to the same drill pipe string that drilled the pilot hole and then is rotated and pulled back towards the drill rig from the exit point. Refer to Figure 2.6 for schematic.

#### PRERREAMING

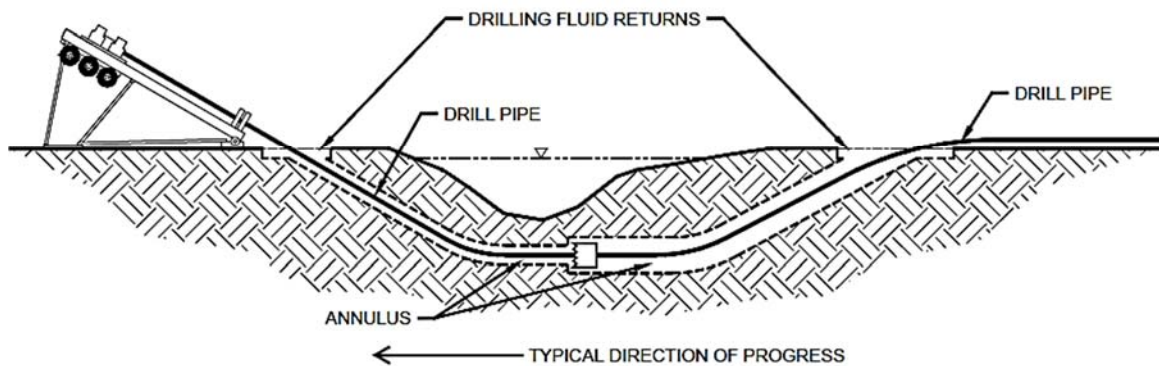


Figure 2.8: Step 02 – Hole Opening / Reaming Schematic (Hair, 2008)

The drill pipe is typically added behind the hole opening tool at exit to keep drill pipe in the hole for the entire length of the crossing while completing the reaming operation. This process of pulling fly-cutters or hole opening tools toward the drill rig while increasing the tool size with each subsequent pass continues until the hole has been enlarged to the appropriate diameter for installing the pipeline. The HDD contractor may also choose to ream away from the drill rig

### 2.3.3 Step 03: Pullback

The last step to completing a successful pipeline installation by HDD is the pullback of prefabricated pipeline into the enlarged hole. The pullback process is the most critical step of HDD. A reinforced pulling head is attached to the leading end of the product pipe and a swivel is connected between the pull head and the drill pipe. The swivel is placed between the drill pipe string and the product pipe to minimize rotation and torsion from being passed through to the pipeline. The pull section should be supported with a combination of roller stands, pipe handling equipment, and/or a floatation ditch to minimize tension and prevent the product pipe from being damaged during pullback. Refer to Figure 2.7 for schematic.

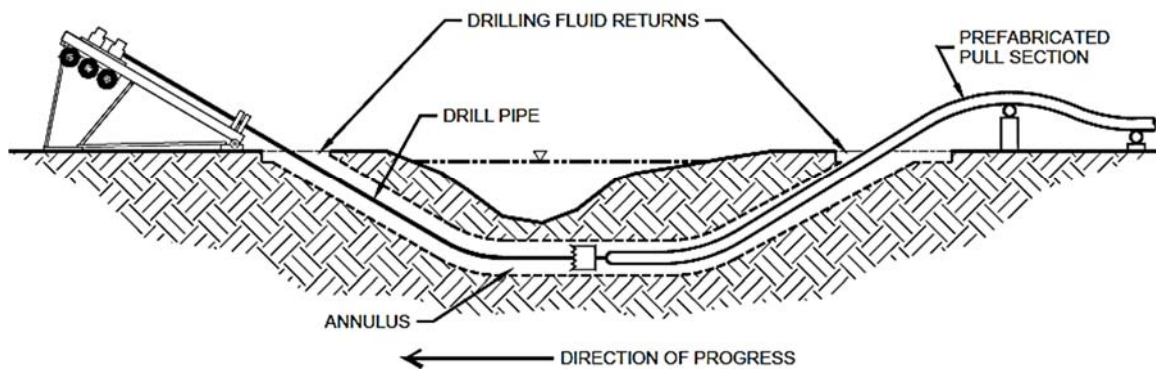


Figure 2.9: Step 03 – Pullback Schematic (Hair, 2008)

## 2.4 Design Considerations

Similar to vertical construction, the first consideration for a potential HDD crossing is soil conditions. Engineers and contractors should establish the suitability of soil conditions for HDD operations. The HDD method is ideally suited for soft soils such as clays and compacted sands. Subgrade soils consisting of large-grain materials, including gravel, cobbles, and boulders, are difficult to negotiate and may contribute to pipe damage and/or project failure. Prior knowledge of such soil conditions

increases the chance of a successful installation by enabling the contractor to better plan the type of drill bit, back reamer, and mud mixture to use.

If the soil conditions are determined to be applicable, potential sites should be visually inspected by walking the area prior to the commencement of the project. The following issues should be addressed during the site evaluation. A main consideration is to establish whether there is sufficient room at the site for entrance and exit pits as well as all equipment. This can be particularly challenging with regards to urban areas with limited space as well as large scale installations that require extensive fluid management systems and extended lengths for product stringing. In addition, contractors should review the site for evidence of substructures such as manhole covers, valve box covers, meter boxes, electrical transformers, conduits or drop lines from utility poles, and pavement patches. The HDD projects are often contracted in areas where the substructure density is relatively high and open-cut construction is risky.

Pipeline diameter, depth, and material are the most important conditions in HDD project and are considered in operation design during preconstruction services and during installation. Thus these factors are key parameters to developing HDD design profiles. Refer to Figure 2.8 for general idea of design profile components.

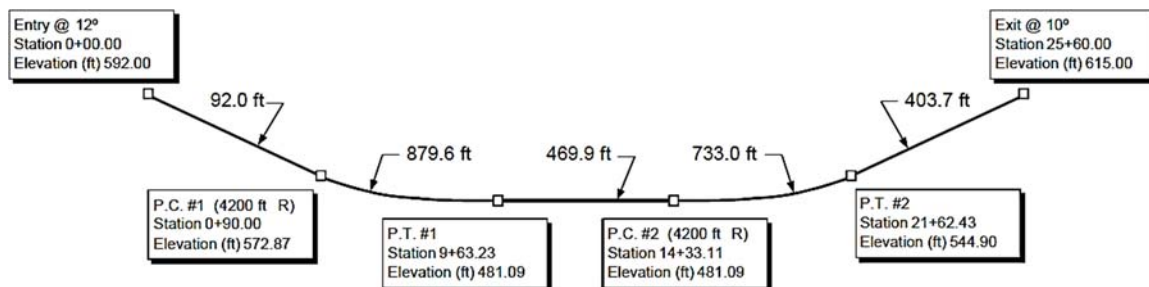


Figure 2.10: Sample HDD Profile

When designing a HDD crossing, there are numerous considerations that must be taken into account to ensure that all steps of the construction process will be successful. First, a sufficient cover depth is necessary to ensure drilling mud pressure in the borehole should not exceed that which can be supported by the overburden to prevent heaving or hydraulic fracturing of the soil. Next, the drill path should be aligned to minimize the frictional resistance during pull back and maximize the length of the pipe that can be installed during a single pull. This is accomplished through geometrical testing of entry and exit angles, total crossing length, total depth, and radius of the curvature. It is preferable that straight tangent sections be drilled before the introduction of a long radius curve. Under all circumstances, a minimum of one complete length of drill rod should be utilized before starting to level out the bore hole path to minimize stresses on the drill rod.

The radius of curvature is determined by the bending characteristics of the drill string and product line and increases with diameter. A rule-of-thumb in the industry is 1.2 m of radius of curvature for every millimeter of product line diameter (Guidelines 1999). The entrance angle of the drill string should be between 8° and 20° to the horizontal, with 12° considered optimal. Shallower angles may reduce the penetrating capabilities of the drilling rig, whereas steeper angles may result in steering difficulties, particularly in soft soils.

With regards to construction, HDD installations should be planned so that back reaming and pulling for a section can be completed on the same day if at all possible. This is to reduce the chance of the borehole collapsing over time as well as reducing the chances that the pipe will become “stuck” during pullback.

## 2.5 Equipment Selection

Correct equipment selection is a key factor in the success of a horizontal directional drill crossing. Correctly sized drill rig, tracking systems, and size and type of steering head, cutting tools, and reaming size must factor in soil conditions, length and diameter of crossing, and equipment availability.

### 2.5.1 Rig Selection

The horizontal directional drill rig (refer to schematic shown in Figure 2.9) is a critical factor in the execution of a HDD drill crossing. Specific sizes of HDD rigs can be used successfully for specific soil conditions, project conditions including diameter, depth, length of borehole, and product pipe to complete the job successfully. (Ariaratnam and Allouche, 2000.)

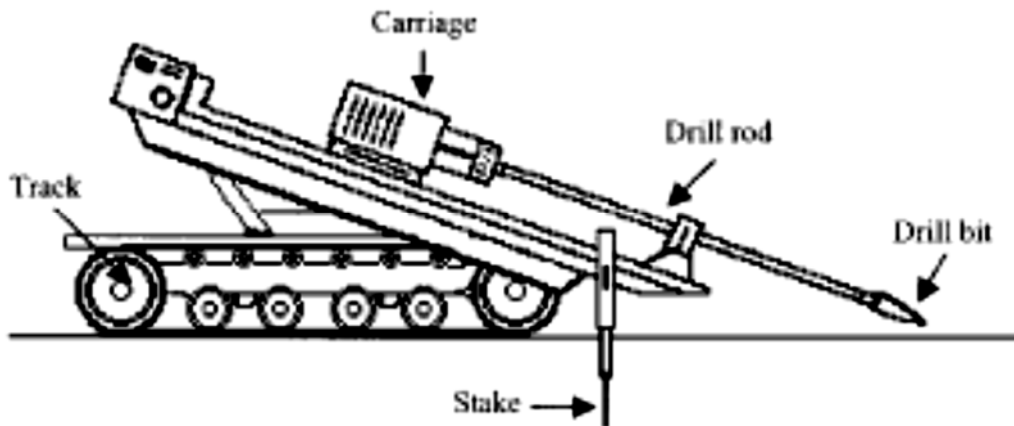


Figure 2.11: Schematic of HDD Rig (Ariaratnam, 2000)

The rig provides the torque, thrust, and pull-back force required to drive the drill string. The drill drive assembly resides on a carriage that travels under hydraulic power along the frame of the drill rig. Soil conditions, in addition to HDD project conditions (diameter, depth, length of borehole) can determine the size of HDD rig that should be used. Table 2.1: HDD Main Features shows the breakdown of rig categories

according to rig size. For soft soil in acceptable project conditions, smaller rigs are usually sufficient. While in hard soil conditions or in large diameter and/or long drive length and very deep lay down installations a Maxi-HDD should be used for successful and complete installation (Bennett and Ariaratnam 2008.)

Table 2.2: HDD Main Features (Adapted From Bennett and Ariaratnam 2008)

HDD Size	Diameter (in)	Depth (ft)	Drill Length (ft)	Torque (lb)	Thrust (lb)	Drill Weight (ton)
Mini	2"-12"	≤ 15	≤ 600	≤ 950	≤ 20,000	≤ 9
Midi	12"-24"	≤ 75	≤ 1,000	900-7,000	20,000-100,000	≤ 18
Maxi	24"-60"	≤ 200	Up to 6,000	≤ 80,000	100,000-1,000,000 +	≤ 30

HDD rig size can drill and install specific diameter, depth, and length of product pipe according to their capability in terms of thrust and torque force. Usually Mini-HDD is used to drill and to install conduits for power lines and telecommunications and for pipes less than 12" in diameter, with a depth of less than 15' and length less than 600'. Midi-HDD is able to drill and install product pipes 12" to 24" in diameter, with a depth of 15' to 75', and length of 600' to 2,000'. Maxi-HDD is able to drill and install product pipes 24" to 60" in diameter, with a depth of 75' to 200', and lengths greater than 2,000'. In extreme cases, the use of two (2) rigs are used. This is known as the intersect method and provides additional push and pull capacities as well as reduces the chance of hydraulic fracturing. The intersect method will be discussed in detail during the case study section of this report.

### 2.5.2 Tracking Equipment

Tracking refers to the ability to locate (survey) the position, depth, and orientation of the drilling head during the drilling process. Accurate tracking capability is essential to the completion of a successful bore. Two distinct tracking methods are commonly used in the industry. The first is known as a walk-over system (Figure 2.10) which consists of, a transmitter, receiver, and remote monitor. The transmitter is located in the borehole assembly near the front of the drill string

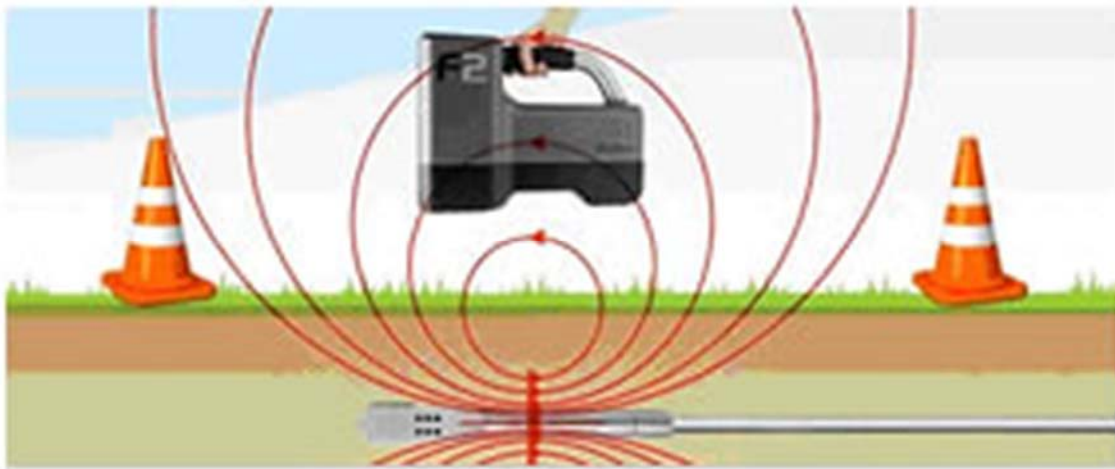


Figure 2.12: Walk-Over System Schematic ([www.aeyates.co.uk](http://www.aeyates.co.uk))

and emits a continuous magnetic signal. The receiver, a portable hand-held unit, measures the strength of the signal sent by the transmitter. This information allows the user to determine the location of the drill head in terms of position, depth, and orientation. Accuracy of this system may be assumed to be within  $\pm 5\%$  in terms of the drilling head's true depth (Allouche and Como 1997). Transmitters are available for operational depths of 10, 15, or 30 m. (Figure 2.10)

When access to a location directly above the borehole alignment is not possible, or when borehole depths exceed 30 m, a wire line magnetometer-



accelerometer navigation system is used. Figure 2.11 shows a schematic of one type of this system known as TruTracker<sup>®</sup>. This system uses three magnetometers to measure the position (or azimuth) of the tool in the earth's magnetic field and three accelerometers to measure the position (or inclination) of the tool in the earth's gravitational field. The steering tool sends the information by wire line to a computer at the surface, where the tool's azimuth and inclination are calculated. The information provided by a wire-line system is considered to be accurate within  $\pm 2\%$  in both plan and profile, regardless of the borehole's depth. Disadvantages of these systems include the high capital costs and need for expert operators.

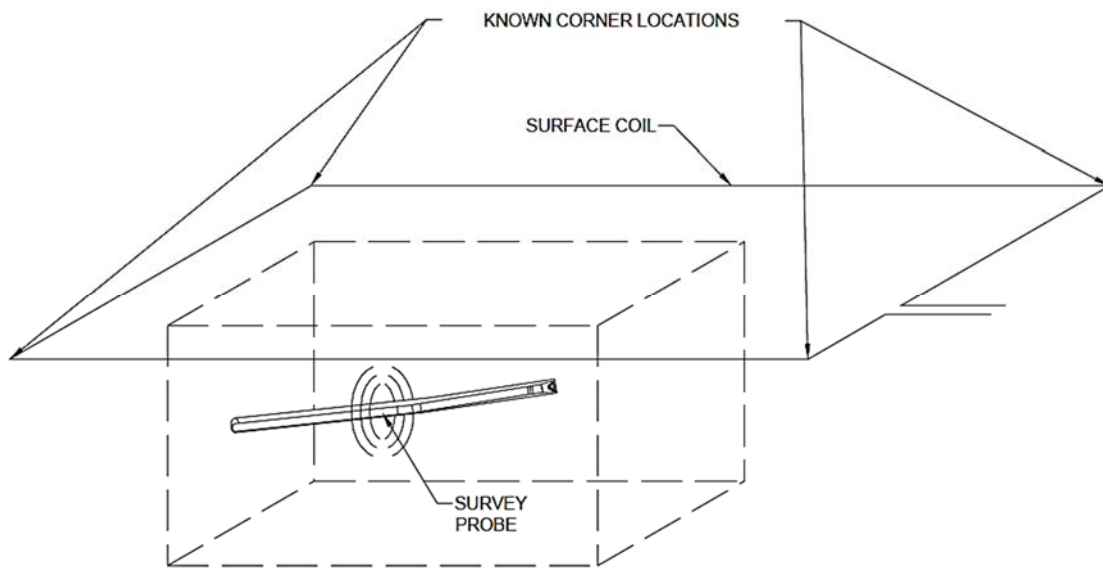


Figure 2.13: TruTracker<sup>®</sup> Wire Line System Schematic ([www.sharewellhdd.com](http://www.sharewellhdd.com))

A directional monitoring device, located near the head of the drill string, is used to track the position of the drill head. During the drilling process, the bore path is traced by interpreting signals sent by electronic sensors located near the drill head. At any stage along the drilling path, the operator may obtain information

regarding the position, depth, and orientation of the drilling tool, thereby allowing the navigation of the drill head to its target.

### **2.5.3 Steering Tools**

Two common types of downhole steering tools used in the industry are compaction heads and mud motors. Compaction heads are used in unconsolidated soils and soft to medium consolidated soil conditions (i.e., silt, clay, sand, and soft sandstone). To bore a straight hole, the drill string is rotated and pushed simultaneously. When a correction in direction is required, rotation stops and the drill head is preferentially oriented in the borehole.

The entire drill string is then pushed forward by the drill rig. As the slant on the face of the drill head is pushed against the soil, the entire assembly is deflected in the desired direction. After the steering correction occurs, rotation is resumed until another correction is required.

Mud motors, are used in ground conditions ranging from hard soil to medium rock (up to compressive strength of 120 MPa). This system uses a positive displacement motor, which generates torque and rotation at the drill bit from the flow output of the mud pump. Direction control is attained by a small bend in the drill string, just behind the cutting head, which serves the same function as the slant on the face of a compaction head.

## **2.6 Project Considerations**

The following describes additional considerations with regards to Horizontal Directional Drilling projects including site evaluation, site/equipment setup, fluid management systems, and site restoration.

### **2.6.1 Site and Equipment Layout**

Sufficient space is required on the rig side to safely set up and operate the equipment. The work space required depends on the type of rig used. A mini rig may require as little as 9.8' x 16.4' working space, whereas a large river crossing unit requires a minimum of 98' x 164' working area. In addition to space required for the rig itself, extensive onsite space is needed for drill pipe layout, a fluid management system including mixing tanks, storage tanks, an return tanks, and generators. For large and complex sits, spaces up to 200' in length and 100' in width are not uncommon.

A working space of similar dimensions to that on the rig side should be allocated on the pipe side in case there is a need to move the rig and attempt drilling from this end of the crossing. If at all possible, the crossing should be planned to ensure that drilling proceeds downhill, allowing the drilling mud to remain in the hole and minimizing inadvertent return. Sufficient space should be allocated to fabricate the product pipeline into one string, thus enabling pull back to be conducted in a single continuous operation. Tie-ins of successive strings during pull back may considerably increase the risk of an unsuccessful installation.

### **2.6.2 Fluid Management System**

During the boring process, drilling fluid is injected under pressure ahead of the advancing bit. Drilling fluid is composed of a carrier fluid (typically water) and solids (clay or polymer). Bentonite is the claylike substance that is typically used. The carrier fluid carries the solids down the borehole, creating a “mud cake” along the perimeter of the borehole, thereby stabilizing the borehole and

reducing friction during the pull-back operation. Drilling fluids also function as coolant for the electronics at the drill head and to suspend and transport drill cuttings to the surface and reduce the shear strength of the soil to enable easier displacement during the pull-back operation.

The collection and handling of drilling fluids and inadvertent returns has been one of the most debated topics in the HDD community in North America over the past few years. On one hand, the industry realizes the need to keep drilling fluids out of streams, streets, and municipal sewer lines. On the other hand, new tough regulations in some states present HDD contractors with escalating drilling fluid disposal expenses. Owners need to adopt an approach that addresses environmental concerns while avoiding unnecessary expenses and escalating drilling rates.

Drilling muds and additives to be used on a particular job should be identified in the proposal and material safety data sheets provided to the owner. Excess drilling mud slurry shall be contained in a lined pit or containment pond at exit and entry points until recycled or removed from the site. Entrance and exit pits should be of sufficient size to contain the expected return of drilling mud and spoils. Methods to be used in the collection, transportation, and disposal of drilling fluids and spoils are to be provided as part of the prequalification document. Excess drilling fluids should be disposed in compliance with local ordinances and regulations in an approved disposal site.

When working in an area of contaminated ground, the slurry should be tested for contamination and disposed of in a manner that meets government regulations. Precautions should be taken to keep drilling fluids out of streets, manholes, sanitary and storm sewers, and other drainage systems, including streams and rivers. Recycling of drilling fluids is an

acceptable alternative to disposal. The contractor shall make all diligent efforts to minimize the amount of drilling fluids and cuttings spilled during the drilling operation and shall provide complete cleanup of all drilling mud overflows or spills.

### **2.6.3 Site Restoration**

All surfaces affected by the work shall be restored to their preconstruction condition. Performance criteria for restoration work are to be similar to those employed in traditional open excavation work. Performance specifications should be developed so as to hold the contractor responsible for settlement/heave damage that may occur along the drill path. A recommended warranty period for all surface damage is 24 months after project completion.

The contractor is typically always required to provide a set of as-built drawings including both alignment and profile. These drawings are most often constructed from actual field readings. Raw data should be available for submission at any time upon the owner's request. As part of the "as-built" document, the contractor should specify the tracking equipment used, including method or confirmatory procedure used to ensure that the data was captured.

## **2.7 Advantages, Limitations and Challenges**

Advantages presented by directional drilling, such as reducing disturbance to traffic and businesses and elimination of restoration costs, make this technology an attractive alternative to open-cut excavation for the installation of pipelines and conduits in congested urban areas. There are many advantages of using HDD for installation of new underground pipelines. The main advantage includes its ability to install pipelines with extreme accuracy in congested urban settings. Accuracy is on par with that of traditional horizontal

directional drilling; however, the construction footprint associated with HDD is smaller. Furthermore, HDD is less expensive and less technology intensive than traditional open-cut methods (Abbott 2005). Another advantage of pilot tube technology is the ability to use the pilot tube jacking process in exploratory processes. Pilot tubes may be jacked through a proposed alignment to determine the soil suitability for installation of subsequent casings and augers. If difficult ground conditions are encountered, pilot tubes may be retracted and an alternative alignment may be proposed.

HDD is not without its limitations; however, and is not as versatile as traditional horizontal directional drilling when it comes to the soil conditions it can be used in. Soils with blow counts exceeding an N-value of 50 tend to be too hard for the standard penetration and displacement method and require the use of an air hammer to perform the installation. Cobbles and boulders exceeding 4" in diameter also add difficulty to advancement as well as problems with maintaining an accurate installation. Stability problems may be encountered when advancing through loose sands, but with adequate lubrication to reduce friction development and to maintain a stable borehole, installation in loose sands is possible. Sands below the water table also pose difficulties. As the second phase of HDD involves open faced casing advancement with an auger spoil removal process, sand and water flowing into the casings may result in stability problems and excessive ground settlement above the bore alignment.

Challenges are also present in HDD. Available work space is critical for any directional drilling operation due to the necessary equipment to complete boring operation and construction of drilling/slurry pits necessary to perform such an installation. During the design process a minimum 100' x 150' work space for both bore launching and

receiving was used as recommended by industry standard. According to the standards this is the minimum space necessary to house all equipment and conduct drilling operations.

(Applegate and Andrew, 2011)

Another deterrent to employing trenchless methods is the reduction in manpower requirements. Trenchless methods typically require fewer workers due to the application of the technologies and reduction in surface restoration needs. Cities cannot afford potential massive layoff of workers from construction companies in a country that currently has a high unemployment rate.

There are startup costs inherent to employing new construction technologies. Most Chinese contractors are reluctant to purchase equipment for initial projects or demonstrations on the “chance” that a trenchless project may be approved. Training must also be done to train workers on operating the equipment. In China, for example, foreign equipment manufacturers typically do not stock adequate or complete range of equipment packages, tooling and accessories to service potential projects due to high import duties, storage and maintenance costs. Then there is the additional cost of engaging foreign technical expertise to service such projects. These issues have created difficult obstacles to entry for Chinese contractors (Ariaratnam et al, 2006.)

### **3. SCOPE OF STUDY**

As a developing nation, China is currently faced with the challenge of providing safe, reliable and adequate energy resources to the county's growing urban areas as well as to its expanding rural populations. To meet this demand, the country has initiated massive construction projects to expand its national energy infrastructure, particularly in the form of natural gas pipeline. The most notable of these projects is the ongoing West-East Gas Pipeline Project. This project is currently in its third phase, which will supply clean and efficient natural gas to nearly sixty million users located in the densely populated Yangtze River Delta.

Trenchless Technologies, in particular the construction method of Horizontal Directional Drilling (HDD), have played a critical role in executing this project by providing economical, practical and environmentally responsible ways to install buried pipeline systems. HDD has proven to be the most popular method selected to overcome challenges along the path of the pipeline, which include mountainous terrain, extensive farmland and numerous bodies of water. The Yangtze River, among other large-scale water bodies, have proven to be the most difficult obstacle for the pipeline installation as it widens and

Understanding the role that Chinese HDD contractors have played in the advancement of HDD in China role would be of great value to the global trenchless technology community. However, little is known about what construction practices Chinese contractors are actually utilizing. While Chinese academics and industry leaders have investigated various theoretical aspects of HDD design, little technical information has been published in the area of large-scale HDD execution in China with regards to



tangible execution methods. In addition, first hand witness by North American experts in China is virtually non-existent. Thus, this study is believed to be the first of its kind to use a combination of technical publications, first hand visits to both North American and Chinese jobsites, and comprehensive project questionnaires to gain a perspective of Chinese HDD construction methods. The purpose of this study is to examine those practices being used in China in order to compare those to those long used practices in the North American in order to understand the advantages of Chinese advancements. Developing countries would benefit from the Chinese advancements for large-scale HDD installation. In developed areas, such as North America, studying Chinese execution may allow for new ideas to help to improve long established methods. These factors combined further solidify China's role as the global leader in trenchless technology methods and provide the opportunity for Chinese HDD contractors to contribute to the world's knowledge for best practices of the Horizontal Directional Drilling method.

A comprehensive literature review has been included as platform for this study as it is critical to understand the nature of the Chinese market specifically as it applies to infrastructure construction and trenchless technologies. Those standards of practice in China differ significantly than those in the United States, which contributes to the fundamental differences explored in this study. This literature review has been organized into six (6) sections. The first section provides an overview of Investigations in General Construction Practices in China and highlights factors such as organizational structure, management practices, safety, and labor. The next section highlights several Comparative Studies between Construction Practices in Developed Countries and China. General contract conditions, vertical construction productivity, and safety perceptions are

discusses. An Overview of Infrastructure Construction and Trenchless Technologies in China is provided with specific examples of Chinese Investigations in Pipelines Construction and Chinese Investigations in Trenchless Technologies in China. The final sections outline the status of HDD in China and discuss International Collaboration Efforts in the area of Critical Infrastructure and Trenchless Technologies.

### **3.1 History of Trenchless Technology in China**

In China, the horizontal directional drilling practices are relatively new; however, has developed significantly since its adoption in the early 1990's. The application and development process of horizontal directional drilling in China, can be roughly divided into four stages. Through 1985, little was known about the HDD process in Mainland China. During the second stage, from 1985-1994 modern horizontal directional drilling technology and equipment was introduced to China through business partnerships with North American manufacturers. After the middle 1990's, breakthroughs and gratifying successes had been achieved in the independent research of small horizontal directional drilling rigs, in some relevant departments such as the previous Geology and Mineral Department, Ministry of Construction, and Ministry of Metallurgical Industry, etc. The third stage is development and import period, in the "eleventh five-year plan" period, great advancements had been made in the series of products of large, medium and small horizontal directional drilling rigs in china.

Between the period of 2008 to 2010, water supply and sewer was found to be the largest underground infrastructure market in China. This is followed by oil and gas construction. A majority of the equipment was found to be manufactured domestically. Existing utilities and personal experience were cited as the greatest influence on risk.

Designers overwhelmingly cited existing utilities as playing a major role in risk. Additionally, the need for better utility locating technologies was identified.

As utility construction continues to grow, it is expected that the use of trenchless technologies will also increase due to their inherent cost and environmental advantages. Chinese equipment manufacturers are also starting to gain market share internationally. Trenchless technologies as a promising solution to the infrastructure problems can be much friendly with the environment compared to conventional open cut. However, the distinction of application of trenchless technologies is evident through the different areas in China. The current level of knowledge regarding trenchless technologies in China is limited and varies.

### **3.2 Pipeline Development in China**

In recent years, China has become the fastest growing country in the trenchless technology methods and horizontal directional. The following timeline highlights economic, social, and political factors that have contributed to this advancement:

2001: China entered the World Trade Organization and forever changed the country's role in global economics.

2002: Work began on the West-to-East Pipeline I. This pipeline was the country's first attempt to construct buried natural gas transmission pipelines stretching from the resource rich western territory to the populated eastern seaboard. (Figure 3.1)

01-06: China achieved an unprecedented annual GDP growth of nearly 10.0%. This led to a rapid increase in overall energy consumption due to increased urban populations, a spike in industrial operations, and an increase in personal

- transportation. Over this period, the total energy consumption grew by 71.5% (11.4% per annum). Meeting the challenges of safely and efficiently supplying energy to the county's growing urban populations and developing rural populations has become a leading priority for the country.
- 2005: China accounted for 14.7% of total world energy consumption. Since 2005, China has elevated its energy conservation and energy efficiency efforts to basic state policy.
- 06-10: The 11th Five-Year Plan set an energy-savings target of 20%, and the country has adopted administrative, legal, and economic measures to achieve this goal.
- 2008: Turning point for energy infrastructure development in China as the government initiated a massive \$586 billion (4 trillion yuan) infrastructure-intensive stimulus program in order to mitigate the 2008 global financial crisis. That year, China consumed 2.7 billion tons of coal, 43 percent of the world total and more than 2.5 times that of the United States, the second largest consumer.
- 2009: China surpassed the United States as the largest global energy consumer with coal, crude oil, and natural gas combining for over 90% of this consumption.
- 2011: China's oil consumption growth accounted for half of the world's oil consumption growth. Natural gas usage in China has also increased rapidly in recent years and China has looked to raise natural gas imports via pipeline and liquefied natural gas (LNG).
- 2040: It is estimated that china's energy consumption needs will more than double.



Figure 3.1: Work on the West-to-East Pipelines ([www.cnpc.com.cn/en](http://www.cnpc.com.cn/en))

By 2007, the global energy market had taken notice to the rapidly developing country and record levels of energy consumption were recorded. This consumption is presented in Table 3.1.

The year 2008 was a turning point for energy infrastructure development in China as the government initiated a massive \$586 (USD) billion dollar infrastructure-intensive stimulus program order to mitigate the 2008 global financial crisis. Buried pipelines construction for natural gas, crude oil and coal slurry transmission soared. That year, China consumed 2.7 billion tons of coal, 43 percent of the world total and more than 2.5 times that of the United States, the second largest consumer. By 2011, China's oil consumption growth accounted for half of the world's oil consumption growth. Natural gas usage in

China has also increased rapidly in recent years and China has raised natural gas imports via pipelines connecting China to its neighboring countries.

Table 3.1: China’s Energy Consumption by Fuel Type, 2007 (Mastny, 2010)

Energy Source	Energy Consumption (Quadrillion Btus)	Share of Total Energy Consumption (%)
Coal	51.3	69.5
Crude Oil	14.6	19.7
Renewable Energy	5.4	7.3
Natural Gas	6.6	3.5
Electricity Use	0.10	0.14
Total Energy Consumption	73.8	100

In 2009, China surpassed the United States to be the largest global energy consumer. By 2013, coal, crude oil, and natural gas combined for over 90% of this consumption and it is estimated that China’s energy consumption needs will more than double by the year 2040. This projection highlight’s the China’s growing challenge to safely and efficiently supply energy resources across the country. This effort will include new supplies to areas with developing rural populations as well as increased supplies to rapidly growing urban areas. Buried pipeline has become the selected method of transmission, as pipelines are more cost effective, more sustainable, and more efficient than the construction and operation of above ground railway or long-haul trucking. Figure 3.2 reflects a Chinese worker performing inspections on a pipeline.



Figure 3.2: CNPC Inspector on HDD Pipeline Installation ([www.cnpc.com.cn/en](http://www.cnpc.com.cn/en))

To meet the demand, the Chinese government has implemented massive buried pipeline construction initiatives, allowing China to become the fastest growing country in trenchless technology construction Methods. Horizontal Directional Drilling (HDD) has played a particularly critical role in executing large-scale pipeline construction by providing an economical, timely and environmentally responsible method to bypass challenges along the path of the pipelines. Thus, Chinese HDD contractors have played a critical role in the overall development of China's buried energy infrastructure. Understanding this role would be of great value to the global trenchless technology community. Developing countries would benefit from the Chinese advancements for large-

scale HDD installation. In developed areas, such as North America, studying Chinese execution may allow for new ideas to help to improve long established HDD best

The West–East Gas Pipeline is a massive ongoing pipeline project that includes the largest number of interconnected natural gas pipelines ever installed in China. The project was developed by China National Oil and Gas Exploration and Development Corp. (CNODC), a joint venture of China National Petroleum Corporation (CNPC) and Petro China. CNPC is the largest provider of oil and gas to the People's Republic of China and the parent company to Petro China, the ninth (9<sup>th</sup>) largest public company in the world as of May 2013. One of the main purposes of the project is to increase electricity production in the Yangtze River Delta area by using clean fuels in lieu of coal. This river basin is home to one-third of China's population and generates an estimated 20% of the country's annual GDP. Thus, the waterway is critical to China's national economic growth and is the major waterway connecting rural western China to the developed eastern seaboard.

China National Petroleum Corporation (CNPC) is the primary operator both crude oil and natural gas pipelines in China, holding over three-quarters of the market share. By the end of 2012, CNPC operated 41,508 miles of pipeline in China including 67% of all crude oil pipelines, 77% of all natural gas pipelines and 48% of all refined products pipelines. Just recently, CNPC's experience in large-scale pipeline construction and specialty expertise in Horizontal Directional Drilling has allowed the company to enter the slurry coal transmission pipeline market. (Refer to Figure 3.3)



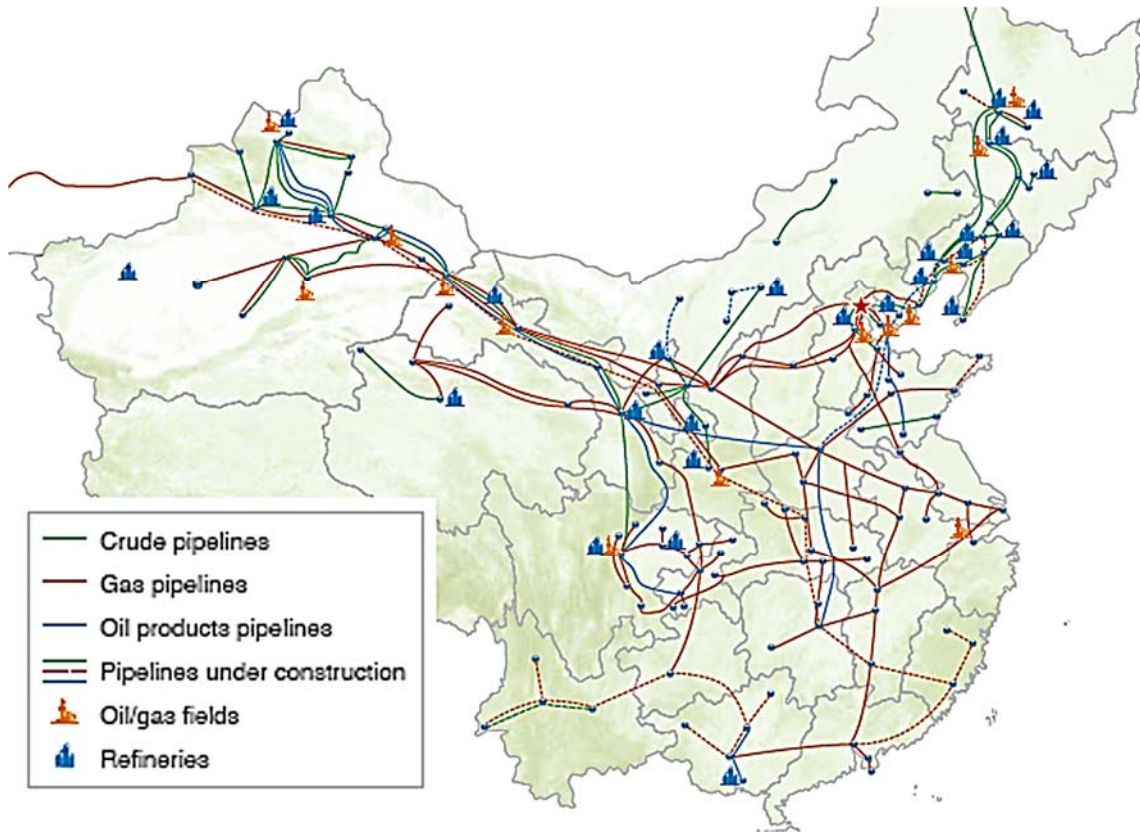


Figure 3.3: CNPC Operated Pipelines (Adapted from [www.cnpc.com.cn/en](http://www.cnpc.com.cn/en))

As CNPC continues to develop China's buried pipeline energy infrastructure system, they have had opportunities to test the limits of large-scale HDD capabilities with respect to length of installation, size of product, and speed of installation.

### 3.3 Research Methodology

In order to develop a strong understanding of the Chinese HDD construction methods, it was advantageous to collect field data from numerous HDD installations both in China and in North America. In depth questionnaires and interviews were invaluable to getting first hand perspectives of procedures as well as perceived results. Knowledge in these area of site considerations, manpower and labor conditions, and equipment usage and selection enables the means to perform an overall evaluation of the HDD process in China.

The result of these site visits as well as observance of related technical publications presents allows this study to perform a qualitative analysis. Qualitative research is collecting, analyzing and interpreting data by observing what people do and say. In addition, qualitative case studies have been formulated to provide specific project details from seven (7) comparable large scale HDD crossings. Four (4) of these are from Chinese executions and the remaining three (3) are similar North American projects. The case study approach was also adopted for its potential to provide rich understanding of the practice and value of project management in Chinese construction organizations.

### **3.4 Limitations and Advantages**

With any research endeavor, there are inherent limitations. This is particularly true in the case of international research in developing countries. Language barriers, availability of information, and cultural differences have all been considered for the analysis of this information and highlighted as necessary during examination. In addition, cultural differences play a large part in the evaluation of differing countries approaches.

#### **4. LITERATURE REVIEW**

To complete this literature review, several sources were used to provide a diverse representation of previous research in the area of Horizontal Directional Drilling Practices in China. North American resources included: HDD Consortium, Distribution Contractors Association, Directional Crossing Contractors Association, Equipment Manufacturers Institute, National Utility Contractors Association and North American Society for Trenchless Technology. Industry publications included Trenchless Technology Magazine and Underground Construction magazine.

The most abundant resources was publications provided by the American Society of Civil Engineers. ASCE Journals utilized include Journal of Geotechnical Engineering, Journal of Construction Engineering and Management, Journal of Professional Issues in Engineering Education and Practice, Journal of Architectural Engineering, Journal of Pipeline Systems and Trenchless Technologies, Practice Periodical on Structural Design and Construction. Additional Journals included: Journal of Geology and Exploration, Journal of Development Economics, International Journal of Project Management, International Journal of Human Resource Management, Journal of Construction Management Economy, and the Journal of Tunneling and Underground Space Technology.

Major Conference Proceedings that proved significant in this area included the Beijing International Trenchless Technology Symposium, ASCE Pipelines Conference, International Conference on Pipelines and Trenchless Technologies, both the North American and International No-Dig Conferences, and the Construction Research Congress 2010.

Chinese academic sources proved more difficult to locate; however, industry sources proved abundant. Chinese sources included the SINOPEC Safety Engineering Institute, China, National Petroleum Corporation Information Institute, Chinese Ministry of Housing and Urban-Rural Development (MOHURD), National Development and Reform Commission (NDRC), The National 12th Five-Year-Plan and Future Goals in 2020, and the General Office of the State Council (GOSC).

This literature review has been organized into six (6) sections. The first section provides an overview of Investigations in General Construction Practices in China. The next section highlights several Comparative Studies between Construction Practices in Developed Countries and China. An Overview of Infrastructure Construction and Trenchless Technologies in China is provided with specific examples of Chinese Investigations in Pipelines Construction and Chinese Investigations in Trenchless Technologies in China. The final section outlines International Collaboration Efforts in the area of Critical Infrastructure and Trenchless Technologies.

#### **4.1 General Construction Practices in China**

General construction practices in China have been included to provide a base line perspective of how the Chinese construction industry is structured, the economic influences that shape the industry, the labor considerations facing construction managers, and the management practices used by project teams. Nearly all studies in this area are focused on vertical construction in urban areas; however, still provide prospective for pipeline construction in developing regions. This section is essential to shaping understanding on the macro factors affecting pipeline construction in China.

#### **4.1.1 Market Structure of Construction Industry**

In the article “Strengths, Weaknesses, Opportunities, and Threats Analysis of Chinese Construction Companies in the Global Market,” authors Lu, Li and Shen highlight the growing trend of Chinese companies making significant inroads into the international construction market. However, comparing to their fast development, only few studies have been reported to introduce the Chinese international construction companies (CICCs) as an emerging competing force. This research, by conducting a strength, weakness, opportunity, and threat analysis, aims to help understand CICCs which have been stereotypically viewed as a somewhat heterogeneous group. Data supporting the analysis were derived from multiple sources including statistical reports, literature review, interviews, and in particular first-hand experience from those who are competing on the forefront. The research opens a window through which all players in the global construction market can perceive internal and external conditions of their Chinese counterpart (Lu et al, 2009.)

The goal of this research is to gain an insight into CICCs as an emerging competitor in the international construction market, through using SWOT analysis as a systematic framework for organizational study. By analyzing factors that are usually classified into four categories: strengths, weaknesses, opportunities, and threats, it is possible to produce a clear picture of internal and external conditions of CICCs. This research adopts the SWOT analysis as the basic methodology for gaining an insight into the internationalization of CICCs. It provides a systematic framework to understand internal and external conditions of CICCs. By offering four categories of generic factors, SWOT

enables an analyst to make references through which competitive conditions of an organization can be examined.

This article concludes that through conducting a thorough SWOT analysis, a picture of internal and external conditions of CICC's becomes clearer. The results reinforce that the strengths of Chinese construction companies are largely attributed to their access to low costs, cheap and hard-working laborers, cheap materials, good relationship with Asian and African countries, and strong support from home market and the Chinese government. While operating in the international construction market, CICC's present some weaknesses, which include relatively low international management capacity and limited experiences in conducting sophisticated procurement, creating financial solutions for clients, and managing sophisticated projects. They have not widely adopted ICT in managing their international business. They are eager to seek prompt and useful professional services when they encounter problems but Chinese professional service companies can only operate in China.

The overall weaknesses of Chinese construction industry can be attributed the fact that most Chinese construction enterprises not having sufficient exposure to and is behind in the adoption of advanced construction technologies, the technology index is below other sectors in China and other developed countries with excessive average number of construction enterprises' employees being unskilled workers who previously were farmers and have no proper training for construction (Xu et al., 2006). In addition, there are too many tasks on construction sites are being done manually instead of using machinery with skilled workers. In most situations, advanced equipment is used only for large or major projects. Finally, a lack of appropriate knowledge in engineering design,

project management, information system, application of computer software, construction laws, codes, standards, and drawings from management personnel and workers also results in problems in construction productivity, scheduling, quality, and safety on site.

Fast changing international construction market also presents opportunities and imposes threats to CICC's. Generally speaking, booming global construction expenses, together with the lower entry barriers, provide a significant external opportunity for CICC's to prosper. Increasing ODI by Chinese companies and the Chinese construction industry's reform toward an international practice provide internal opportunities. In addition, increasing collaboration and partnering among international competitors encourage CICC's to go out. Nonetheless, threats to CICC's are also considerable, which include intense competition in the market, management and technology, services, and, especially, talented people.

The next article "Development of the Chinese Construction Industry after the Cultural Revolution: Administration Framework, Economic Growth, and Market Structure, presents the results of an investigation on the development of the Chinese construction industry after the Cultural Revolution in terms of administration framework, economic growth, and market structure, with the consideration of Chinese currency inflation. The development was divided into three stages based on Chinese government policy changes on the construction industry. In each stage, the reform of administration framework was reviewed, and the market size and market structure in both the domestic and the international markets were analyzed. Value added and gross output value of domestic market (Figure 4.1), the number of contracts, contracting value, total turnover, and turnover in the market share of Chinese construction firms were used to describe the

development in various regions and to illustrate the growth of Chinese construction firms in the international market. The results of this study provide valuable knowledge to practitioners, scholars, and educators who are interested in exploring the development of the Chinese construction industry (Lu et al, 2009.)

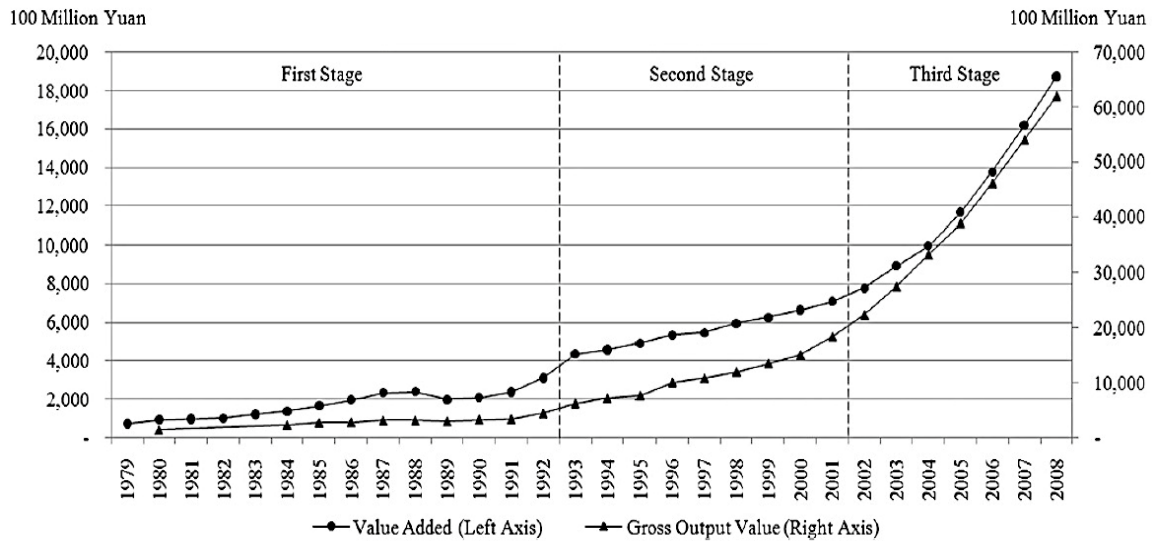


Figure 4.1: Domestic Market Size of the Chinese Construction Industry From 1979 to 2008 (Lu et al, 2009)

The article discusses that in recent years, China has experienced huge economic growth. As an important segment of the national economy, the construction industry has also increased greatly. From 2001 to 2008, the gross output value of the Chinese construction industry had an annual average growth rate (AAGR) of 22%, and it had surpassed the gross output value of the U.S. construction industry since 2007 based on the PPP (NBSC, 2009; Huang et al, 2011). Because the Chinese construction industry plays a more important role in the global market, many researchers have studied a variety of aspects of its development since the mid-1990s, including the administration framework (Mayo et al, 1995; Chen 1998; Bajaj et al, 2003; Xu et al. 2005), legal system (Lam and Chen 2004; Chui and Bai 2010), bidding system (Chen 1998; Shen and Song 1998; Shen



et al. 2004), economic growth (Li 2001; Huang and Bai 2010), market structure (Sha and Lin 2001; Zeng et al. 2005), and international expansion (Li et al. 2001; Low and Jiang 2003; Zhao et al. 2009; Lan and Bai 2011). However, most of these studies focused on specific areas of the Chinese construction industry within a short period of time, and some were conducted a decade previously.

This study presents a comprehensive investigation of the development of the Chinese construction industry after the Cultural Revolution, with the consideration of Chinese currency inflation, to identify the reforms of the administration framework, growth of the market size, and evolution of the market structure. The development was divided into three stages based on Chinese government policy changes in the construction industry. The first stage was from 1979 to 1992, the second stage was from 1993 to 2001, and the third stage was from 2002 to 2008.

During the first stage, the Chinese construction industry was largely controlled by the government under an assignment system. During this period, the value added and gross output value increased by 329 and 221%, respectively; however, with frequent fluctuations. State-Owned-Enterprises (SOEs) were the backbone in the domestic market, while Rural Construction Teams (RCTs) were declining under the reform. In the international market, Chinese contractors expanded their business from 11 countries in 1979 to 159 countries in 1992, with 80% of the contracting value and turnover in construction projects and 20% in labor services.

Since the unified construction laws were issued in 1992, the Chinese construction industry has been developing at a higher speed. The value added and gross output value experienced very smooth and steady growths and increased by 64 and 195%, until 2001.

In the international market, Chinese contractors expanded business all over the world and reached 188 countries. The percentage of the contracting value and turnover of construction projects tended to be very stable at around 76% of the total, while their number of contracts accounted for only 10% of the total. Labor services took 89% of contracts and only contributed 22% to the contracting value and turnover.

After the WTO accession in 2001, the domestic market had become more liberalized to foreign companies, and more Foreign Funded Firms (FFFs) had started business in the Chinese market. At the same time, Chinese contractors continued to exploit the international market. The value added and gross output value had the fastest and steadiest growth with AAGRs of 16 and 19%, respectively. The market share of SOEs and urban and rural collectives (URCs) continued to decrease, while other types of domestic firms (OTDFs) had gained more than 70% of the domestic market. In the international market, the contracting value of construction projects had reached over \$100 billion and the turnover had surpassed \$50 billion, while those of labor services had exceeded \$7 billion. Asia and Africa were still the largest international markets, and they had relatively high growth rates of turnover at 28 and 49% in 2008. North America was the only market with a declining turnover after China's WTO accession. Through a comprehensive investigation of the development of the Chinese construction industry in both the domestic and international markets, this study provides valuable knowledge to international practitioners, scholars, and educators on how the Chinese construction industry grew from a restricted and controlled market to a liberalized and internationalized market after the Cultural Revolution. The administration framework, economic growth, and market

structure of the Chinese construction industry were reviewed and analyzed using statistical data.

In “Market Structure, Ownership Structure, and Performance of China’s Construction Industry,” authors Liu, Shao and Liao, describe the construction industry is an important material production sector that plays a key role in Chinese national economy. However, the authors acknowledge that most construction companies currently have low performance. A literature review showed that most research efforts have been placed at the project and company level, whereas studies based on the industry level are often neglected. To address this issue, this study was conducted to investigate the performance of China’s construction industry at the industry level. The market structure, ownership structure of the construction industry, and associated industry performance under the market economy system with Chinese characteristics were studied (Liu et al, 2013.)

The results show that both structure and performance are positively correlated, and performance is more greatly affected by market structure than by ownership structure. This paper studies the construction industry performance from the industrial organization perspective in China. The results of this research can provide useful information to other developing countries that have similar structures of market and ownership. Statistics showed that China’s gross domestic product (GDP) increased from \$268.3 billion in 1978 to \$5,926.6 billion in 2010, making it the second largest economy in the world at the time. The contribution of the construction industry to overall GDP increased from 3.8% in 1978 to 6.66% in 2010 (National Bureau of Statistics, 2010.)

This article concludes that China’s construction industry plays an increasingly important role in the world. But its performance is poor compared with that of its foreign

counterparts. The SCP framework maintains that economic performance is a direct function of the market structure. The ownership theory argues that public enterprises perform less efficiently than private enterprises. Thus, it is controversial as to what factors should be chosen to represent China's construction industry performance. This paper postulates that the performance of China's construction industry relies on the market and ownership structure and puts forward the ownership structure and market structure-conduct-performance (SSCP) framework.

#### **4.1.2 Economic Influences of the Chinese Construction Industry**

Economic influences have played a critical role in the evolution of the modern construction industry most recently in the form of a major Chinese construction boom in the area of transportation infrastructure development. In "The Yangtze River Transportation-Economic Belt," authors Chen and Chen describe the Yangtze River's critical role in construction and development as the longest river in China and the third longest in the world. The Yangtze River basin (Figure 4.2) includes seven provinces and two major cities comprising a dense industrial zone which plays an important role in the Chinese economy. The region accounts for 18% of the country's land mass, 37% of the population and 41% of the nation's gross domestic product. The planned transportation system within the Yangtze River region consists of a network of railways, roads and waterways. At the time of this study, many of these facilities were in existence, planned or under construction.

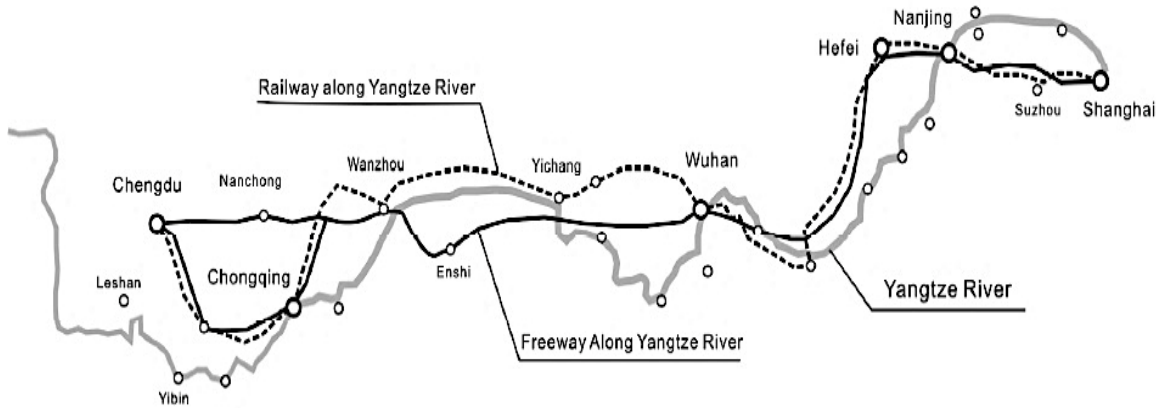


Figure 4.2: Layout of the Comprehensive Transportation Corridor of Yangtze River (Chen and Chen, 2008.)

The focus of this paper is to apply the concept of the “Transportation-Economic Belt” to analyze how the transportation corridor promotes the formation of an economic “belt” or linear region. Using the example of the Rhine River corridor in Europe, the relationship between the development of the transportation corridor and industrial development within the corridor was examined at various stages. The results of this examination were used to assess the possible strategies for managing development and mitigating the negative effects of growth within the Yangtze economic belt (Chen and Chen, 2008.)

Because of the Yangtze River’s natural advantages as a transportation corridor, it is the busiest shipping waterway in China. It traverses much of China in an East-West direction and its tributaries and extensive canal network provide good “feeder routes” to the north and south. For centuries, the region to the south of the river has been the economic heart of China. The navigable mileage accounts for 53% of China’s total navigable waterways, and it carries 80% of the country’s shipping volume. In 2004, the Yangtze waterway carried 20% of the freight volume within the Yangtze River basin/region.

The ongoing development of the Yangtze River region's economy was examined in light of this growth and evolution pattern. Due to its significant natural advantages, and its key location along the country's main east-west axis, the Yangtze River has the potential to be the largest economic belt surrounding an inland river in the world. While the downstream section has already reached a mature stage in the development of the transportation-economic belt, the middle and upstream sections are now in the formative stages. The administrative districts along the Yangtze River corridor should strengthen intraregional cooperation and initiate joint efforts to promote economic development within the belt by coordinating regional planning, and integrating their own resources and infrastructure into an overall comprehensive economic plan. This can be accomplished by improving and increasing the exchange of information, particularly on economic development issues that are relevant to the Yangtze River region. The paper emphasizes that upon completion of transportation infrastructure is critical to integration of the economic belt and to the accommodation of the large volumes of freight and passengers in an efficient manner.

The second article addressing economic influences on the Chinese construction market is "Transport Infrastructure and Economic Development: An Empirical Study for China." In this study, authors Qian and Harata describe the fast development of transport infrastructure to support the economic growth in China, which calls for more study on the relation between them. This study employs a production function method and a Vector Auto Regression (VAR) approach to study the relation with national empirical data. The result of production function method is discussable because the elasticity of infrastructure to the output is negligible and may be contradict to common knowledge. The explanation

for this includes the data limitation and potential unfixed effects. It is also shown that the more developed areas benefit more from infrastructure than undeveloped areas. The VAR method shows that the infrastructure counts for a significant part of economic growth and a shock in infrastructure might lead to significant short-term effect on economic growth but small long-term effect. The causality of the infrastructure and economic development is vague in statistic meaning but it seems more likely the infrastructure explains the economic growth but not reversely. The present study joins the discussion on the relation between transport infrastructure and economic development through some empirical analysis on China (Qian and Harata, 2010.)

The study tries to provide some empirical analysis on the relation between transport infrastructure and economic development using China's data. The production function method and VAR method are adopted due to their different attributes. The results of the production function method is discussable since it gives a quite small and negative elasticity of infrastructure at national level, which is unrealistic based on our common knowledge. This may be due to the limitations of small samples and not sufficient data to cover all transport infrastructures. It also implies there might be some significant unfixed effects during the estimation, which needs further study. The comparison between two specific regions shows positive effect of infrastructure on the economic development, and also the more developed areas turn out to benefit more from the improvement of infrastructure than under developed areas. The results derived from VAR method also indicates that the infrastructure counts for a significant part of economic development. And it also shows that a shock in infrastructure could lead to a significant short-term effect on economic growth but quite small in the long run. The causality between infrastructure and

economic development remains vague in statistics, which is also partly due to the small sample size. It seems more likely that the infrastructure explains economic development but not the other way round.

#### **4.1.3 Labor Considerations for the Chinese Construction Industry**

The next aspect investigated in this literature review is perhaps the most critical in understanding the Chinese construction industry. It is labor. In “Rural Migrant Workers in China: Scenario, Challenges and Public Policy,” author Shi examines the working conditions of rural migrant workers in China. It first describes the spectacular increase in the number of migrants, from an estimated 30 million in 1989 to about 130 million in 2006. The paper then provides some descriptive statistics on the regions of origin of migrants, their destinations, the sectors in which they are employed, as well as on their age, sex and level of education. (Refer to Figure 4.3 and Figure 4.4.) The paper goes on to discuss the difficult working conditions of many rural migrant workers in the Chinese labor market, in particular their low wages, the problems of wage arrears, the lack of written contracts, the long working hours, the short weekly rest periods, the low social security coverage, the poor housing conditions, and the difficulties they face in accessing public services. Finally, the author describes how the Chinese authorities have gradually loosened restrictions on rural-urban migration, and how new policies have been developed to try to improve the situation of migrant workers. However, he considers that the objective of decent work for migrant workers in China will remain a major challenge for years to come (Shi, 2008.)

Shi describes how through the 1970s, China remained primarily an agricultural economy, with the majority of its population living in rural areas. In 1978, when China launched its economic reform, its rural population accounted for 82 per cent of the total



population. With the fast growth of the population and the labor force, combined with the effects of land acquisition in the 1960s and 1970s, agricultural productivity was low.

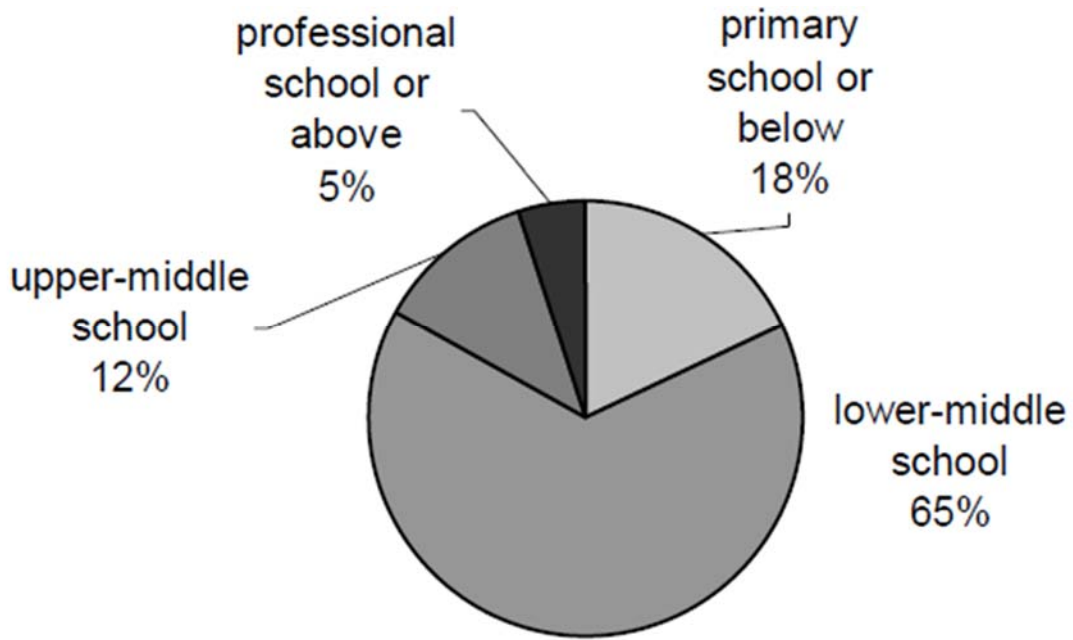


Figure 4.4: Educational Attainment of Rural Migrant Workers, 2004 (Shi, 2008.)

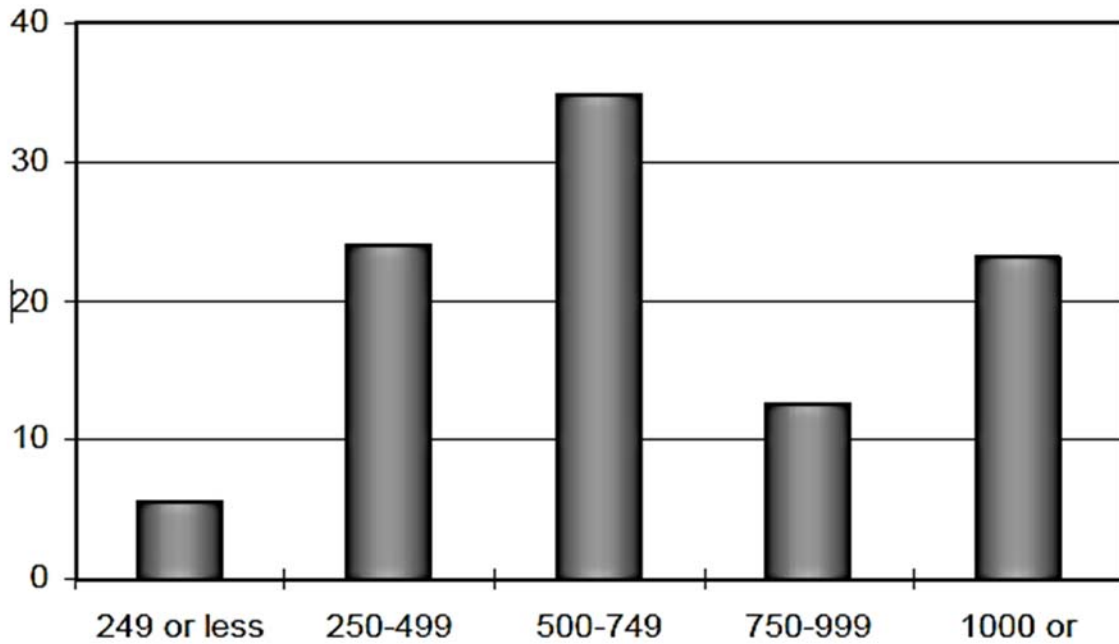


Figure 4.3: Wage Profile of Rural Migrant Workers in China, 2002 (Monthly Wage in Yuan, %) (Shi, 2008.)

The rural labor force was forcibly employed in food production, and the prices of food artificially kept below the market prices in order to accumulate surplus for industrialization. The income of Chinese rural households was therefore extremely low. Those with per capita incomes below the level of 1 USD per day in purchasing power parity (PPP) terms, accounted for over 80 per cent of the total rural population in the late 1970s (Chen and Ravallion, 2004). Outward migration was prohibited and rural people were not even allowed to stay in cities (Shi, 2008.)

Shi describes how the rural reforms of the late 1970s and early 1980s were characterized by decentralization of land, and provided a strong incentive for rural households to produce food more efficiently. However, the problem of surplus labor did not disappear and became even more challenging. One estimate is that there were about 150-200 million surplus laborers in rural China in the 1980s (Wang and Ding, 2005). One solution to this problem, favored by the Chinese government, was to develop township-village enterprises (TVEs) to absorb the surplus labor. As a result, a large number of rural laborers were transferred to TVEs and by the end of the 1980s, TVEs employed about 100 million workers. However, in the 1990s urban reforms, especially the restructuring of state-owned enterprises (SOEs), raised the competitiveness of urban industry, placing TVEs in a disadvantaged market position. The growth of TVEs was therefore slow in the 1990s. In light of the slow employment growth in TVEs, rural workers attempted to move to cities to find employment opportunities, even though migration was still not legalized. As a result, there was a large increase in the number of rural migrant workers in the early 1990s, which jumped from around 30 million in 1989 to 62 million in 1993. However, this process did not continue smoothly: from the mid-1990s, the reform of the SOEs, referred to above,

led to the dismissal of millions of urban workers. The urban unemployment rate rose to over 10 per cent, posing a threat to the Chinese government's policy of social stability.

Facing rising unemployment rates, city governments implemented a series of regulations to restrict urban enterprises from employing rural migrants and even forced enterprises to lay off migrant workers and employ more local urban workers instead. Some government regulations specified that certain jobs were to be closed to rural migrant workers and filled by local urban workers only. As a result, the number rural workers who migrated to urban areas and sought work increased less rapidly in the late 1990s. At the beginning of the new century, the Chinese government realized that measures aimed at inhibiting the movement of workers from rural to urban areas had generated many negative impacts on the development of the rural economy and damaged China's human rights image in the world. Recently, the central government issued a number of directives appealing to local governments to improve services for rural migrant workers. For instance, one regulation explicitly required local governments to implement guidelines on equal employment opportunities and rights protection for rural migrant workers. With implementation of this policy easing rural labor mobility and providing services for rural migrants, the number of rural migrant workers in urban areas recently reached a historical peak of 120 million. The overall number of rural out-migrants is even larger if their children and families are taken into account.

Since the beginning of the new century, which has seen fast economic growth and decreasing unemployment in urban areas, city governments have gradually been loosening restrictions on rural migration. The number of rural migrant workers in urban areas has reached the historically highest level recently. The new government, formed in 2003, has

placed more emphasis on rural development and the establishment of a harmonious society in China, and considers rural migration and urbanization as the most feasible solutions to the problem of underdevelopment in rural areas and unbalanced development between urban and rural areas. It is still very difficult for migrant workers to gain access to social security programs in urban enterprises and to public facilities such as public schools, which remain accessible only to local urban workers. Some cities such as Zhengzhou, Capital of Henan Province, temporarily opened public schools to rural migrant children in 2002 and quickly realized that there were not enough schools to accommodate the large number of children moving to the city from surrounding counties. The experiment was suspended.

Another effort made by the Chinese government was the abolition of various fees charged specifically to rural migrants. To curb the movement of rural migrants into cities, city governments required rural migrants to hold a series of cards for which they had to pay fees, particularly in the 1990s. The cards had various objectives, and included temporary residence cards. In addition, enterprises employing rural migrant workers had to pay further fees to governments including a city rural migrant reception fee. Since 2004, city governments have been required by the State Council to eliminate most of the cards previously issued to migrants and abolish all fees charged for rural migration. As few rural migrant workers are covered by social security, the government attempted to introduce some programs suitable for migrant workers. In the past two years, work-related injury insurance has been introduced for migrant workers in both public and private enterprises. A pension scheme applies to migrant workers in some cities, but the coverage is still narrow because coordination has been lacking to ensure transferability of pensions from one place to another. There are also plans to introduce medical insurance for migrant workers.

However, from the official point of view, given China's special situation, it will take a long time for migrant workers to enjoy the same social protection as local urban workers.

The Chinese government went on to provide training programs for rural migrant workers. Since 2004, the Chinese government has initiated training programs for rural migrant workers. The programs are implemented at ministerial level, and training costs are shared by the central government and provincial governments. For instance, the "Sunshine Project" started in 2004 trained 2.5 million rural migrant workers. The goal was to train 8 million further rural migrant workers every year over the period 2005-08. Furthermore, local governments began to provide free information, job-search assistance and consultation services for migrant workers to encourage rural surplus labor to move out of rural areas. The State Council set up a Joint Committee in 2006, to coordinate rural migration affairs among ministries. Each county was required to set up an office to deal with inquiries from workers planning to migrate out, on employment and rights protection. Moreover, city governments are now required to take responsibility for the schooling of the children of migrant workers. Some cities abolished additional school fees for migrant children and others planned to open all public schools to migrant children or provide subsidies to schools agreeing to accept migrant children. Moreover, with the financial support of local governments, law assistance agents have been established at city and county level to provide legal assistance to rural migrants having economic difficulties.

Overall, this paper provides a comprehensive picture of recent changes in the situation of rural migration in terms of size, distribution, wage level, social security coverage, working conditions, and relevant policies. This paper attempts to make a contribution in this direction by providing an update on information and data made available

on these issues in recent years. In conclusion, this paper highlights a number of issues and problems encountered by rural migrant workers are examined on the basis of survey data, and the challenges faced by the Chinese government are discussed. Migrant workers tend to be younger than local urban workers. The majority of migrants are male with lower educational attainment. They come from all regions and provinces, either pulled by higher wages in urban areas or pushed by increasing surplus labor in rural areas. Although the average incomes in the city are much higher than those obtained from farm work in the countryside, a proportion of them (20%) earn incomes below or close to the urban poverty line. The majority of migrant workers face considerable insecurity in terms of employment, income, social protection, and access to education for their children. Their housing conditions are much worse than those of local urban residents, and even worse than those they would have experienced in their place of origin if they had not migrated.

This paper concludes by saying that the Chinese government continues to face major challenges, government policies have changed dramatically in recent years, from being generally aimed at preventing or discouraging rural migration, to encouraging and being more supportive towards it, and whilst the actual situation of migrant workers has slowly improved, it will take a long time for the government to change the migrants' situation completely and provide them with opportunities and rights equal to those of local urban people in the areas of employment, payment, work conditions, social security, access to housing, and political rights.

In "Earnings, Education and Training in China: The Migrant Worker Experience, authors Messinis and Chen describe how swift economic reforms since 1978 have transformed China into the "world's most successful economy" as well as created a trend

of growing income disparities. The rural-urban divide has been a key feature of the rise in income inequality in China. Labor economics has highlighted a positive relation between human capital and wages. In an attempt to make this relation work for rural households, China has introduced mandatory schooling in 1986 and nation-wide training programs for potential migrants in 2004. However, the public education and training system discriminates against migrant workers who live in urban areas since public expenditures are allocated on the basis of the Hukou system of permanent residence (Messinis et al, 2009.)

China is characterized by a dual economy by which the vast rural population has considerably lower levels of incomes and considerably less access to key social services, namely education, medical and insurance services and social welfare. Most striking is the fact that 75 per cent of the 85 million illiterates and semi-illiterates in China were concentrated in the Western rural areas of the country (Communist Party's School 2005).

Sharp spatial disparities are also discernible in education. In rural China, education up to middle school (eight to nine years of education) became mandatory only in 1986 with the Law on Compulsory Education (Tsang 1996). According to a survey conducted by the Communist Party's School (2005) in the 16 provinces of China, the average years of education received by the rural population in China was below 7 years, almost three years lower than their urban counterparts. Likewise, less than one per cent of all laborers between the age of 15 and 64 in rural China received tertiary education, 13 per cent lower than their urban counterparts. Moreover, despite mandatory schooling to year nine (6 years of the primary school education and three years of middle school education),

less than 30 per cent of the rural children at the school age were able to finish their nine years of education. It was also found that increases in school fees, poverty and poor educational quality in rural areas were major contributors to the low levels of education achieved in rural China.

China's dual economy has also experienced a remarkable surge in domestic migration by workers who leave rural communities to seek jobs in big cities. Initially conceived as a solution to severe shortages of labor in fast-growth urban regions, migrant workers were granted special rights of temporary residence in the early 1990s. Since, worker migration has grown immensely (Sachs 2005). According to a Chinese Government report (The Research Group on China's Farmer Turn Workers 2006), the number of migrant workers increased from 30 million in 1989 to 62 million by 1993. In 2004, the number of migrant workers reached 118 million, or 23.8 per cent of the total rural labor force in China.

On the assumption that China's growth is sustainable, worker migration emerges as a major policy instrument via which rural China can catch up with the living standards enjoyed by much of the urban population. There is growing evidence of this potential. China's Ministry of Agriculture estimated that there were around 98 million of domestic migrant workers in 2003 and their remittance reached 370 billion RMB.

The empirical evidence in this paper can be summarized as follows. First, the paper found that the 'income-based' measure of earnings, as reported by workers, seems to be contaminated by measurement errors while the 'expenditure-based' measure seems consistent with economic theory that suggests that education and work experience are key determinants of labor income. Second, the completion of lower middle school or higher



education boosts wages by 12.1% and 10.3% respectively. However, the returns to education are much higher for low income workers. This suggests that education is more important than previously thought but its impact is nonlinear. Third, the returns to job training are also significant at about 4.5% and are remarkably similar across the whole different sectors at the bottom 75% of the wage distribution. Fourth, work experience as a migrant associated with substantial returns that, again, are higher for workers at the lower 10% of the distribution.

This finding alludes to considerable gains in earnings and productivity if China were to encourage migrant workers and their families to stay in big cities longer. To illustrate the impact of migrant-worker experience. The evidence presented provides several new insights on the labor market experience of migrant workers in China. We identify three key findings that have important policy implications for China and developing nations in general. First, education matters very much but it is more valuable for the lowest income group. Second, job training for people with low education such as migrant workers raises living standards considerably. When compared to non-migrant workers and their female counterparts, it seems that living standard of male migrant workers can benefit from more adequate training at the workplace. Third, work experience in big cities contributes significantly to labor income for migrant workers and their families.

The findings also emphasize the importance for policy given that migrant workers are severely disadvantaged in China due to institutional distortions and the rural-urban divide in educational endowments. Another source of disadvantage stems from uneven economic development and second-rate education in rural China. Migration provides an

escape from credit constraints but also raises the opportunity cost of education. This makes migrant workers vulnerable to poverty traps as they are deprived of personal development and further education.

The evidence in this study sheds new light on the effect of education and training on the incomes of migrant workers in China. It shows that the returns to education and job training for migrant worker are substantial. An important policy recommendation from this study is that, in addition to the exemption of fees and other expenses for schools in rural areas, the government should also consider strengthening technical education in rural China. Currently, technical schools provide 2-3 years technical training for middle school graduates (with nine years education). Parents are; however, required to pay high fees and board expenses in order to register their children with such schools, as they are beyond the compulsory education system. The training provided at these technical schools should be of high quality and market oriented. Equipped with the training received from technical schools, more rural labor can move directly into the industries that required more skills and so as to increase their incomes and improve their job security.

Another policy recommendation is that, given the high return of job training, extra public resources should be dedicated toward on-the-job training to complement the general training provided by local government agencies in the migrant source areas. Admittedly, it is difficult to find qualified managers and teachers to provide quality training to potential migrant workers in the poor and remote counties of China, and it is also challenging for local governments in poor and remote areas to understand the changing demand for the skills of migrant workers. Thus, the Central Government should

provide more incentives to employers in the destination areas to encourage greater participation in job training by migrant workers.

The effectiveness of worker training programs depends on the quality and the relevance of the training provided as well the motivations from the migrant workers to receive the training, and employer incentives to provide training. The new evidence here shows that, on average, a migrant worker reaches the peak of her income around 15-20 years of work experience and the returns to migrant work experience are considerable. Thus, the evidence suggests that both migrant worker and employer incentives to training ought to increase substantially if migrant workers are allowed to stay in urban areas longer, or even permanently. It follows that the removal of barriers to long-term residency in urban areas for migrant workers and their families would be a sensible policy initiative of high priority. Obviously, an improvement in the education and training system for migrant workers and the removal of the dual labor market will greatly assist China to develop more value-added industries in manufacturing and services so as to sustain China's high rate of growth. Finally, some of the above recommendations may be useful to other developing countries that rely on domestic migrant workers. Countries such as India can only benefit from China's experience.

In "Strategies for Managing Migrant Construction Workers from China, India, and the Philippines," authors Ling, Dulaimi and Chua, investigate why the Singapore construction industry employs migrant workers from other countries. The cultural differences between local project managers and foreign workers may give rise to communication problems and mismanagement, leading to low productivity. This study identified the similarities and differences in cultural traits among migrant workers from

China, India, and Thailand and recommended strategies to manage diversity among migrant construction workers. Workers from China have traits that are significantly different from Indian and Thai workers. The recommended management strategies to deal with cultural diversity are: engage highly skilled migrant workers; administer employment contracts closely; supervise strictly to lessen poor and passive-aggressive attitudes; reward workers who take initiative; and train workers to work safely and produce high quality workmanship. In addition to work-related strategies, project managers should also form concrete personal relationships with workers to create trust and organize social activities to engender team spirit (Ling et al, 2013.)

The aim of this research is to examine differences in traits among migrant construction workers in Singapore. The specific objectives are to: (1) identify the similarities and differences encountered by project managers when managing migrant construction workers from Mainland China (hereinafter referred to as China), the Indian subcontinent (India), and Thailand; and (2) recommend strategies for project managers to deal with national culture diversity among them. The purpose of the study is to inform project managers on the similarities and differences among construction workers of different nationalities so that they may become more sensitive to diversity and thereby communicate more effectively with migrant workers and manage them more effectively.

The research question is: What are the similarities and difference in traits and national cultures among the Chinese, Indian, and Thai operatives who are working on construction sites in Singapore? In managing a culturally diverse workforce, differences in traits among workers of different countries have to be recognized for their mindsets and behavior to be understood so that supervisors can manage migrant workers effectively. The

conceptual framework to explain cultural diversity among migrant operatives comprises six constructs: language differences, power distance, individualism, masculinity, uncertainty avoidance, and long-term orientation.

In conclusion, a typical construction site in Singapore comprises migrant workers from several countries. This study investigated, using a survey research design, the similarities and differences in traits among migrant workers from China, India, and Thailand working in Singapore's construction industry. As for Chinese workers, the main difficulties are their poor safety awareness and the difficulty in resolving disputes. The results suggest that project managers perceive that Thai workers do not appear to exhibit significant negative traits. Significant differences in traits were shown among the three nationalities. Compared with Indian and Thai workers, Chinese workers are perceived to have poorer attitudes, have poorer safety awareness, and give more difficulty when resolving disputes. In addition, compared with Thai workers, Chinese workers are perceived to be more likely to ignore employment obligations, have passive-aggressive temperaments, and be less trustworthy. Indian workers are perceived to exhibit significantly more negative traits than Thai workers.

Significant cultural diversity exists among workers from China, India, and Thailand, especially in working styles and attitude and methods of resolving disputes. Because of the differences among workers of different nationalities, there is a need to tailor appropriate management strategies to efficiently manage migrant workers. The findings contributed to practice by recommending strategies that managers could adopt in managing a culturally diverse workforce in a construction project. Recommended management strategies include the following: screen migrant workers by having them pass skills/trade

tests in the lingua franca; explain terms of employment clearly to migrant workers; administer employment contracts closely; supervise firmly to lessen poor and passive attitudes; reward workers based on their outputs that achieve preset quality targets; reward workers who take initiative; form concrete personal relationships with workers to create trust; train workers to work safely and produce high quality workmanship; organize social activities to engender inter team spirit; and eliminate root causes of disputes. Project managers may use the findings to help them overcome challenges that they may face in managing migrant workers.

These results have contributed to knowledge by showing that the Communicative Theory of Ethnic Identity (Hecht et al. 1993) does not feature strongly when Chinese, Indian, and Thai migrant workers are communicating with Singaporean project managers. It further contributed to knowledge, through the testing of hypotheses, that among Hofstede's (2001) six national cultural dimensions, individualism (IDV) does not play a significant role. China's individualism index (Hofstede 2001) may be too low; and thus, further research is needed to revise the index.

#### **4.1.4 Project Management in the Chinese Construction Industry**

Another key aspect of understanding the overall construction industry in China is project management. How project managers manage risk, organize their workforce, and respond to project challenges is critical. In "Risk Management in the Chinese Construction Industry," authors Tang, Qiang and Duffield, 2007 show there has been an increase in research on risk management practice in the construction industry. However, little research has been conducted to systematically investigate the overall aspects of risk management on the perspectives of various project participants. This paper reports the findings of an

empirical Chinese industry survey on the importance of project risks, application of risk management techniques, status of the risk management system, and the barriers to risk management, which were perceived by the main project participants.

The study reveals the following. First of all, most project risks are commonly of concern to project participants. Secondly, the industry has shifted from risk transfer to risk reduction. Next, current risk management systems are inadequate to manage project risks. Finally, lack of joint risk management mechanisms is the key barrier to adequate risk management. Future studies should be conducted to systematically improve the risk management in construction by different approaches that facilitate equitable sharing of rewards through effective risk management among participants. Such studies should also consider the establishment of an open communication risk management process to permit the corporate experience of all participants, as well as their personal knowledge and judgment, to be effectively utilized (Tang et al, 2007.)

It was decided to focus this study on a specific study area of China because the rapid economic expansion. This has resulted in many Chinese construction activities and has created the largest construction market in the world (Chen 1998), thus it provides a rich source of data for this study. The World Bank estimated that China's expenditure in infrastructure was highest among all East Asian countries and accounted for \$750 billion (United States) over the period 1995–2004 (Wang and Tiong 2000). It is expected that significant insights into risk management practice can be obtained through a deep understanding of the Chinese construction industry.

Based on the perceptions of the main project participants, the survey conducted in this study revealed the status of the risk management practice in the Chinese

construction industry. The major findings of this study include: The five most important project risks are “poor quality of work,” “premature failure of the facility,” “safety,” “inadequate or incorrect design,” and “financial risk.” Despite the different perceptions on some risks, all groups have a common view on the severities on most projects. The risk management systems applied in the industry tend to be informal, which are inadequate to manage project risks; “Lack of joint risk management mechanisms by parties” “shortage of knowledge/techniques on risk management,” and “different recognition of risk control strategies” are the top three barriers to risk management, with other barriers being also rated with moderate to high scores.

In “Project Management in the Chinese Construction Industry: Six-Case Study,” authors Chen, Qiang and Wang investigate how project management was introduced into China after the country’s economic reforms in the 1980’s and has since spread quickly throughout the whole country, particularly in the construction industry. However, despite the wide adoption of project management practices by construction organizations and the growing recognition of the importance of project management as an enabler of organizational success, empirical studies on project management in the context of the Chinese construction industry have been inadequate.

This paper presents the results of an empirical study of six Chinese construction organizations in order to come to a more comprehensive and sophisticated understanding of project management practices in the Chinese construction industry. The findings revealed: (1) a good appreciation of the role of projects and project management and satisfaction with current project management practices; (2) 11 key aspects of project management implementation; (3) 12 resultant value and benefits; and (4) five aspects of



the main challenges facing the organizations. Meanwhile, variations in project management practices and the resultant organizational value were identified, first between the three owner and the three contractor case study organizations, then between the two construction contractor organizations and the one design contractor organization (Chen, et al, 2009.)

This paper reports an empirical study of six Chinese project-based construction organizations in order to present a more comprehensive investigation of current project management practices in the Chinese construction industry and a sophisticated understanding of the resultant organizational value and benefits. More specifically, the aims of this paper are to identify (1) what are implemented in Chinese construction organizations in order to improve their organizational project management capabilities; (2) what important value and benefits project management implementation has created for these organizations; and (3) what challenges, if any, the organizations are facing.

As one of the oldest traditional industries that formed the back-bone in China's economy, the Chinese construction industry has developed rapidly since the country's economic reforms in the 1980s. It employed about 40 million people and contributed about 10% to GDP in 2006. With the progress of the economic reforms and the opening up policy since the 1980s, its management systems have changed tremendously toward a commercial approach and one major reform was the introduction of the Western originated project management concepts and practices. The World Bank also made a modest contribution to this process by introducing competitive bidding and international contractors for the first time in the Chinese construction industry on one of the bank's

early projects, which is well known in the industry as the “Lubuge impact” (Yang 1987).

The Lubuge Hydropower Plant is located in China’s Yun Nan province. In 1984, the Diversion Works of the hydropower development project obtained a loan from the World Bank. One of the World Bank’s conditions for providing the loan was that the main contractor for the Diversion Works must be selected by international competitive bidding (ICB), which was the first time that an ICB was made in the People’s Republic of China. Eight overseas and one Chinese state owned contractors submitted their tenders. Finally Japan’s Taisei Construction Corporation won the contract at a price 43% lower than the estimates made by the Chinese government.

For implementing the project, Taisei Construction Corporation sent a team of 30 to manage and control the project based on project management concepts and methods, and used the same Chinese contractor to undertake the construction works on site. The contract was completed 5 months ahead of schedule and to a good standard of quality (Lu 2004; Yang 1987). The Chinese government and the whole Chinese construction industry were astonished by the outcomes of the project, which demonstrated the advantages of ICB and the project management approaches for cost effectiveness, quality control, and early project completion. The Chinese State Council sent a team of officers and experts to go to investigate and conclude the “Lubuge experience” and to reform the construction administration and management systems. Since then, Chinese construction organizations have come a long way toward adopting a commercial approach. Project management concepts and practices, after being piloted and proved as effective, have been widely pursued in the Chinese construction industry (Chen and Partington 2004).

It is now mandatory and a common practice for all Chinese construction organizations to adopt project management practices. In order to guide and monitor construction project management practices, the Chinese government has developed and has been continuously updating its laws and regulations pertaining to issues such as project owner-responsible system, project contract systems, project bidding and tendering systems, project supervision systems and many other management issues such as health and safety, and environmental protection. Meanwhile, an overall construction project management standard was first published in 2002 and then revised in 2006 (MOC 2006). In accordance with these governmental regulations and standards, Chinese construction organizations have established their own management processes, guidelines, and tools, and taken measures to improve their project management practices and capabilities so as to ensure the organization's success.

However, despite the wide adoption of project management practices within construction organizations and the growing recognition of the importance of project management in the Chinese construction industry, empirical management studies in this context have been inadequate. In particular, the few studies in the context of the Chinese construction industry are largely single faceted. For example, focusing on safety management, a study by Fang identified the key factors that influence construction safety management in China and presented a safety assessment method (Fang et al, 2004.) Author investigated procurement management and identified the key assessment criteria for awarding construction contracts in China (Shen et al, 2004.) Another study by Shen examined Chinese contractor competitiveness indicators (Shen et al, 2006.) There are also several such studies with focus on risk management (Fang et al. 2004; Tang et al.

2007), partnering mechanism (Tang et al. 2006), construction project managers' competence (Chen et al. 2008.)

While these studies have investigated single-faceted aspects and different levels of the construction management activities in China, there is a need for a more comprehensive and sophisticated understanding of current project management practices in the Chinese construction industry and the resultant organizational value and benefits, which have implications for both practice and further in-depth research. Twenty years after the western originated project management practices were introduced into China, it is now mandatory and a common practice for all Chinese construction organizations to adopt project management practices. In order to present a more comprehensive and sophisticated understanding of current project management practices in the Chinese construction industry and the resultant organizational value and benefits, six Chinese construction organizations were studied.

From the examination and analysis of three main sources of data collected in the six case study organizations, namely, organizational background information, interviews, and surveys, 11 key aspects of project management implementation and twelve resultant organizational value and benefits were identified and ranked. While all the interview and survey respondents expressed a good appreciation of the role of projects and project management, and satisfaction with their organization's current project management practices, five aspects of the main challenges facing the organizations were also noted. Meanwhile, variations in project management practices and the resultant value and benefits between the six case study organizations were revealed.

The results of this research confirm the central role of projects and project management for Chinese construction organizational development and success, and have important implications for both management practice and future research. The identified variations in project management practices between the different types of case study organization, highlight the very important contextual implications for both management practice and academic research. Apart from its political and economic context, organizations must also understand its own nature, types of project, main challenges, and needs in order to establish the most effective management systems and improve its project management practices. Meanwhile, each type of construction organizations, such as the project owner, needs to understand the contexts and practices of other parties involved in the project, such as the construction and design contractors, so as to achieve effective communication and cooperation with each other. Moreover, the research results have presented the most important aspects of project management practices and the important value and benefits resulting from the project management implementation.

In “The State of Art of Risk Management Standards on Tunnels and Underground Works in China Vulnerability, Uncertainty, and Risk, authors Hu and Huang highlight the increasing attention of engineering risk management is paid more and more in China recent years. More than several ten years prior, risk assessment was only used for very large infrastructure projects and also focused on the project’s economic risk, such as Three Gorges Hydropower Station (1991) and Shanghai 1st Line Metro (1993). The designers would calculate the potential risk of economic loss during the large scale project construction, especially construction material price fluctuation. In 2002 quantitative risk assessment was firstly used for the project schemes comparison

among tunnel and bridge when crossing The Yangtze River from Pudong District to Chongming Island in Shanghai. The Yangtze River Tunnel of Shanghai is the biggest diameter in 2008 all around the world. The risk analysis of the project includes 17 special technology research topics, including environmental risk, river regime risk, hydrological risk, geotechnical risk, tunnel design risk and tunnel construction risk etc. It is a milestone for risk management of Chinese tunnel engineering which formed the compressive risk assessment for large scale tunneling engineering (Hu et al, 20114.)

Project Risk Management (project RM) is defined as all activities and measures for dealing with technical risks for managing a project, and widely used in all the project phases which include the preliminary, feasibility study, design and construction for all big projects from National level. The Chinese government and designers realized that project RM could be a good solution which can manage the engineering construction risks. The China Engineering Society organized experts from different companies, universities, and institutes to draw up some documents for risk management. Then, guidelines and standards were published for large scale projects like subway tunnel, railway and bridges.

The first Guideline for risk management for construction of tunnel and underground works edited by H. W. Huang and Q. F. Hu was issued in 2007 by Ministry of Housing and Urban-Rural Development of the People's Republic of China (MOHURD). Then it is updated as a National Code for risk management of underground works in urban rail transit in 2012. Some other ministries issued their own engineering risk management documents or code, like Provisional regulation of Risk Assessment and risk Management of Railway tunnels revised issued in 2007 by Ministry of Railways of the People's Republic of China (MOCR), Guideline of Safety Risk Management of

Highway Bridge and Tunnel Design issued in 2010 by Ministry of Transport of the People's republic of China (MOT) and Guideline of Safety Risk Management of Highway Bridge and Tunnel Construction issued in 2011 by Ministry of Transport of the People's republic of China (MOT). All the project RM guidelines or standards are used mainly in large infrastructure projects (like tunnels, roads, railways, bridges, and harbor works) to manage the technical risks during the Projects' feasibility study, design and construction phases. Furthermore, some large public clients required the application of project RM contractually. Projects' clients had accountability to politicians, by demonstrating that they applied project RM in order to minimize additional and unforeseen project costs, contractors might reduce their failure costs by applying project RM.

Tunneling and underground construction works impose many risks on all parties involved as well as on those not directly involved in the project. The very nature of tunnel projects implies that any potential tunnel owner is faced with considerable risks when building and developing such a project. Inherent uncertainties, including geology like ground and groundwater conditions, there might be significant cost overrun and delay risks are concerns as well as environmental risks. Also, as demonstrated by spectacular tunnel collapses and other disasters happened in the recent past, there is a potential for large scale accidents during tunneling work. Furthermore, for tunnels in urban areas there is a big risk of damage to a range of third party persons and property, which will be of particular concern where heritage designated buildings are involved. Finally, there is a risk that the problems which the tunneling

project cause to the public will give rise to public protests affecting the course of the project, even worse social instability. Figure 4.5 illustrates this model.

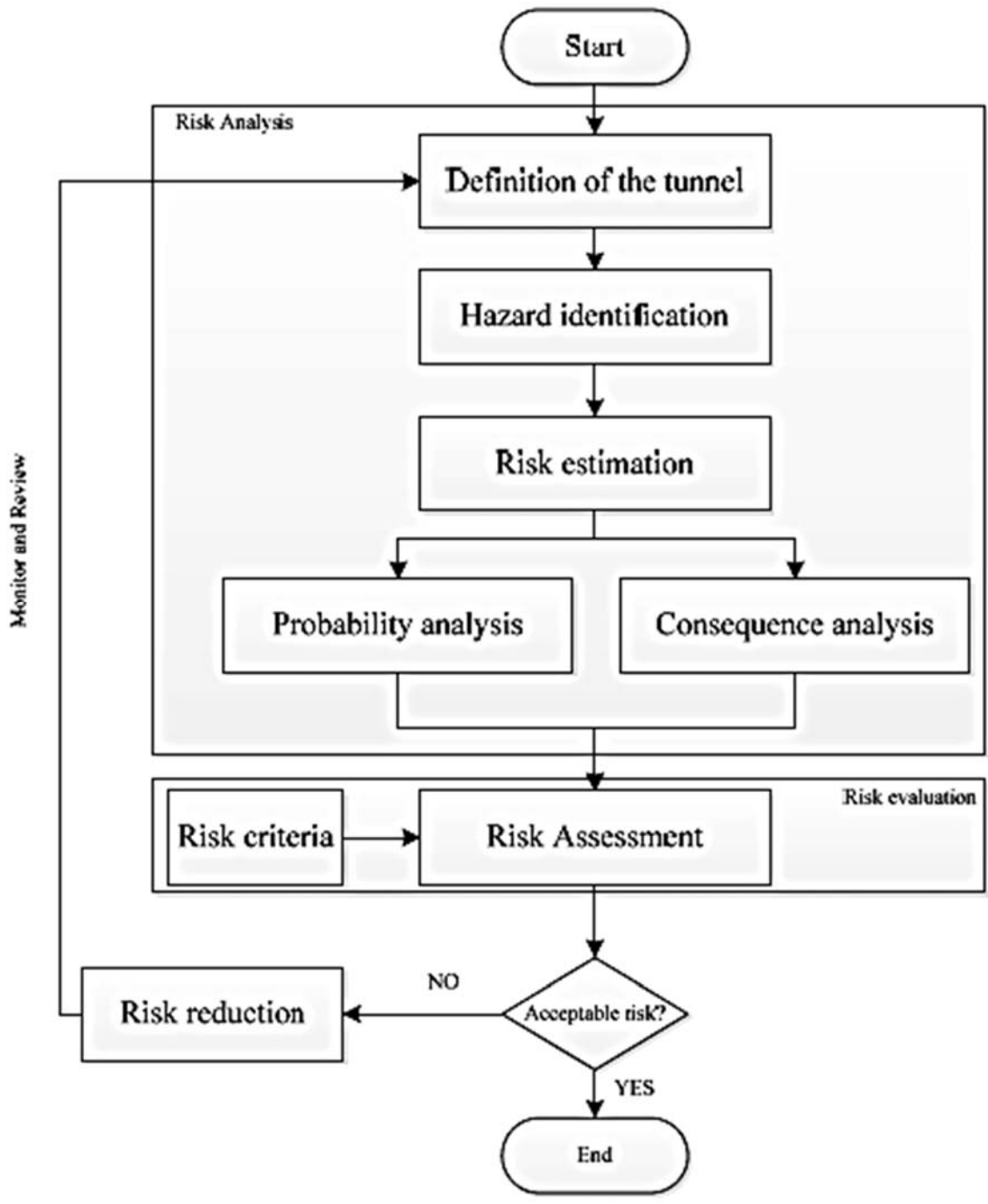


Figure 4.6: The Flowcharts of Risk Management of Tunnel and Underground Works. (Hu et al, 20114.)



Traditionally, risks have been managed indirectly through the engineering decisions taken during the project design and construction phase. There are many shortcomings that there is lack of a standard file to implement and check. Therefore, The International Tunneling Association (ITA) publishes a report to, in accordance with its statutes, facilitate the exchange of information, in order: to encourage planning of the subsurface for the benefit of the public, environment and sustainable development to promote advances in planning, design, construction, maintenance and safety of tunnels and underground space, by bringing together information thereon and by studying questions related thereto. The guideline of risk management for construction of tunnel and underground works is drawn up in 2005 after ITA's guideline is printed in 2004.

This article concludes that tunnel and underground work is a kind of high risk engineering which needs to strengthen risk management according to the engineering experiment and 2003- 2011 accident statistics in China. It is known that controlling tunnel risks is to rely on not only advanced technologies but also risk management. The guideline (2007) and code (2012) of tunnel and underground work were issued as a milestone for our engineering construction. They will improve the construction risk control ability and reduce the risk loss. The key point of the implementation of risk management in tunnel construction is to identify potential risk sources firstly, make the corresponding preventive measures and prepare the emergency rescue plan in advance. The dynamic risk management is established on an information based construction and site monitoring. The purpose of two documents is to indicate to owners the recommended industry best-practice for risk management and to present guidelines for code to designers as to the

preparation and implementation of a comprehensive tunnel risk management system in China.

## **4.2 Comparative Studies of Construction Practices in China**

Understanding the similarities and differences between Chinese practices and North American practices is the next step to understandings the benefits of each approach. Though there were no studies found that directly applied to pipeline construction nor trenchless technologies in China as compare to those in China, several studies did exist for vertical and transportation construction. The following articles were selected due to their comprehensive overviews in the areas of safety, labor, and legal conditions in the Chinese construction market.

### **4.2.1 Safety**

In “Comparative Study on the Perception of Construction Safety Risks in China and Australia,” authors Zou and Zhang discuss how safety is a major concern in the construction industry because fatalities and injuries from construction work bring great losses to individuals, organizations, and societies as a whole. This paper aims to understand how construction personnel perceive safety risks in China as compared with those in Australia. Postal questionnaire surveys were used to collect data on safety risk perceptions from the two nations. The safety risk factors were assessed using a risk significance index based on the likelihood of occurrences and the impacts on safety performance. The survey results revealed that in China the main perception of safety risks came from human- and/or procedure- related issues, with “low/no safety education” paramount, followed by “inadequate fire prevention and electrical prevention procedures,” etc. In contrast, the major safety risks perceived in Australia were related to the environment and physical site

conditions with “contamination of land, water and air” ranked first, followed by “unforeseen excavation of soil,” etc. To minimize construction safety risks in China, this paper suggests that the government should develop collective legislation and safety protection procedures, and enforce safety education and training to all site participants. Risks related to environmental and site conditions were generally realized by the Australia construction industry, which were not highly acknowledged in China. This may also bring imminent attention in this regard to the Chinese government (Zou et al, 2009.)

This article conservatively estimates that 3,000 construction workers are killed in work-related accidents per annum (Huang et al. 2000), and 1,174 deaths were related to construction accidents in 2003 as per the report by the Ministry of Construction, P.R. China (Table 4.1.) The Chinese government claimed the use of illegal and unsafe operations during construction was the driving factor of the high deaths toll. Similar situation existed in the Australian construction industry with its incidence rate of 28.6 per 1,000 employees in 2003–2004, which was almost twice of the overall industry average of 16.4 per 1,000 employees. It also experienced a high fatality rate of 4.7 fatalities per 100,000 employees in 2004–2005, which was almost twice the rate for the national average for all industries of 2.5 fatalities per 100,000 employees (ASCC 2006).

This paper aims to investigate and compare the perceptions of major safety risk factors in the Chinese and Australian construction industries. It will identify the major construction safety risk factors in China and Australia, and then analyze the reasons for and the resultant implications of the differences. Table 4.1 illustrates the trends of fatalities and safety risks in the Chinese construction industry.

Table 4.1: Trend of Fatalities and Safety Risks in the Chinese Construction Industry  
(Adapted From Tam et al. 2004)

Categories of Accidents	Fatalities (person, %)				
	1999	2004	2005	2006	2007
Falling from height	524 (48)	703 (53)	543 (46)	430 (41)	460 (45)
Electrocution	124 (11)	95 (7)	78 (7)	65 (6)	67 (7)
Hit by falling materials	116 (11)	140 (11)	141 (12)	134 (13)	117 (12)
Collapse of earthwork	148 (13)	191 (14)	222 (19)	216 (21)	206 (20)
Use of heavy machine	71 (6)	89 (7)	70 (6)	62 (5)	49 (5)
Lifting of weights	45 (4)	41 (3)	66 (6)	92 (9)	65 (6)
Other	69 (7)	65 (5)	73 (6)	49 (5)	48 (5)
Total	1097 (100)	1324 (100)	1193 (100)	1048 (100)	1012 (100)

This research methodology selected for this safety risk investigation comprised a comprehensive literature review, a survey to the Chinese and Australian construction industries, a statistical analysis of the survey data, and exploration of safety risk management in Australia and China. The survey questionnaire was designed to assess the perspectives which respondents held on various construction safety risk factors in China and Australia. Through literature reviews and understanding the problems, 50 questions reflecting safety risk factors were identified and classified into five aspects: ten questions related to legal and regulatory issues, seven related to safety education and training, six related to employee-related issues, ten related to technical issues, eight describing organizational management issues, and the last nine questions related to environmental- and site-condition-related issues.

The comparison of the level of education of the respondents in China and Australia. It shows that 73% of China's construction workforce did not complete high

school; this is significantly different when compared to Australia, where only 7% did not complete high school. The Chinese construction industry had an average low level of education, whereas in Australia the majority of its workforce received high school education or above. As a result, Chinese construction workers might have difficulty in understanding their responsibilities, rights, and the necessity of safety protection. They were not competent enough to maintain their safety rights and protect their benefits when working on construction sites. This would be one of the areas that needs to be built upon and improved for a proactive construction safety plan in China.

The respondents were practitioners in the construction industry. Respondents from both nations had almost equal lengths of experience in the construction industry, Chinese respondents had an average of 14 years of experience and Australian counterparts had an average of 15 years of experience. With respect to construction safety management, Australian respondents had an average of 11 years of experience, whereas Chinese respondents only had around 7 years of experience. It is astonishing that approximately a quarter of Chinese people had less than 2 years' experience in construction safety management.

Refer to Table 4.2 and Table 4.3. The results from China show that “inadequate fire and electrical prevention procedures” (0.43) is ranked as the highest risk followed by “lack of poor crisis preparedness (emergency plan)” (0.42), which are higher than those from the Australia survey results of 0.34 and 0.26, respectively. Kartam et al. (2000) described the “main concern of a contractor is how to save money and reduce costs. Safety is usually considered a waste of money by most contractors since they may be unaware of the effectiveness of safety prevention programs in reducing costs and

increasing productivity.” Thus, “inadequate safety programs” is ranked third and “not following safety checklist” ranked sixth. Although safety programs and safety checklists are emphasized to minimize potential hazards and dangers, it is up to the employers and employees to pay attention and follow these systems to maximize its functions. The Australia survey results show “inadequate safety programs” is scored 0.30, lower than the score in China; however, it is still classified as a high risk. On the other hand, “not following safety checklist” in Australia is below the high risk margin. The remaining high risk factors for China include “ignoring labor safety insurance” and “lack of union safety” with significance scores of 0.32 and 0.28. In comparison, the Australian construction industry only recognized them as medium risks.

Respondents in China ranked both “low/no safety education/ training” and “low level of formal education” as high risks, ranked first and fourth, respectively. In fact, the percentage of construction workers in China being trained in safety is very low. Statistics reveal that only 3% of workers have been trained and certified, 7% trained under short-term programs, whereas 90% received no training at all (Zhang 2001). This may provide some ideas for the Chinese government to develop a similar admittance policy to raise site workers’ safety consciousness, knowledge, and skills.

Personal stupidity” ranked first in both China and Australia with significance scores of 0.28 and 0.32. “Personal stupidity” can be classified into many situations such as people not understanding or following simple instructions, performing dangerous maneuvers, where they know they are taking a risk of injuring themselves, taking short cuts (wrong way) and ignoring the long way (right way). This is consistent with the

findings of Tam et al. (2004) that reckless operation is one of the top risks in the construction industry.

Table 4.2: Typical Safety Risk Factors for Construction Activities (Tam et al. 2004)

Rank	Factors affecting site safety	Relative important index
1	Poor safety awareness of firm's top leaders	0.93
2	Lack of training	0.90
3	Poor safety awareness of project managers	0.89
4	Reluctance to input resources for safety	0.86
5	Reckless operations	0.86
6	Lack of certified skill labor	0.84
7	Poor equipment	0.82
8	Lack of first aid measures	0.81
9	Lack of rigorous enforcement of safety regulations	0.74
10	Lack of organizational commitment	0.71
11	Low education level of workers	0.68
12	Poor safety conscientiousness of workers	0.65
13	Lack of personal protective equipment	0.62
14	Ineffective operation of safety regulation	0.59
15	Lack of technical guidance	0.55
16	Lack of strict operational procedures	0.55
17	Lack of experienced project managers	0.54
18	Shortfall of safety regulations	0.53
19	Lack of protection in materials transportation	0.53
20	Lack of protection in material storage	0.51
21	Lack of teamwork spirits	0.50
22	Excessive overtime work for labor	0.49
23	Shortage of safety management manual	0.48
24	Lack of innovation technology	0.43
25	Poor information flow	0.40

Table 4.3: Top Five Safety Risk Factors in China and Australia (Tam et al. 2004)

Country	Safety risk factors	Significant index score
China	Low/no safety education/training	0.46
	Inadequate fire and electrical prevention procedures	0.43
	Lack of poor crisis preparedness (Emergency plans)	0.42
	Hazardous materials	0.41
	Inadequate safety program	0.4
	Low hazard awareness from upper management	0.4
Australia	Contamination of land, water, and air	0.64
	Unforeseen ground conditions	0.51
	Poor precautions on working from height	0.47
	Asbestos contamination	0.44
	Poor electrical safety	0.42

“In reality, reckless operations largely occur during building demolition according to the China Statistical Yearbook of Construction. The number of fatalities resulting from reckless operations was 46 (4.19%) of the overall fatalities in 1999.

“Hazardous building materials” was ranked first by the Chinese respondents with a significance score of 0.41, and the Australian respondents also ranked it as a high risk with a score of 0.31. Not understanding material safety and its potential influences, handling hazardous materials without care, disturbing its internal membranes and causing them to spill out and contaminate surrounding area, etc., abound on the construction sites. Damage to the brain, nerve systems, and permanent damage to the human body are just some of the well-recognized impacts.

“Damaged equipment/inappropriate positioning of equipment” was ranked second by the Chinese construction industry with a significance score of 0.36, which is almost



identical to the result from the Australian construction industry. In 1999, 95 fatalities (8.66%) resulted from the problems of construction equipment in China. Construction equipment was well considered to be one of the weakest links in the China construction industry. As there were no plant-hiring services offered in China, the construction firms had to purchase their own construction equipment. Most equipment was not fully utilized, which placed a heavy financial burden on firms. Although around 30% of construction equipment is old and obsolete, it is still being used because most state-owned firms lack money to replace it (Chen 1997).

“Poor working from height precautions” has a significance score of 0.35 in China compared to a significance score of 0.47 in Australia. The China Statistical Yearbook on Construction (NBS 2000) reported that 50% of construction accidents in 1999 were related to falling from height, which is obviously higher than other accidents. With respect to fatalities, 524 construction workers (48%) lost their life due to falling from height. “Poor electrical safety” was ranked fourth in China with a significance score of 0.26, whereas the Australian construction industry scored it as high as 0.42. Electrocutions resulted in the second most fatalities in 1999 as per the China Statistical Yearbook on Construction (NBS 2000).

“Low hazard awareness from upper management,” “lack of management involvement in safety programs,” and “inadequate project planning” were ranked within the top three in China with significance scores of 0.40, 0.32, and 0.29, respectively, compared with the Australian results of 0.36, 0.26, and 0.23, respectively. It indicates that leaders play a very important role in construction safety management and project planning may influence the safety performance in a construction project. However, as contractors

have to finish the work within a specific period of time, at an agreed price, and at a certain standard of workmanship, they tend to focus on these immediate problems and give priorities to these objectives. In comparison, China's number one ranking is "natural forces (earthquake, tsunami, and flood)" with a significance score of 0.37. Earthquakes and floods, though large or small, do happen yearly in China. After each encounter the result is devastating, thus respondents in china have ranked it as a high risk factor.

Major differences in safety risk recognition exist between the two nations. Analyzing the differences will help the nations develop a better safety management system for the future. "Lack of poor crisis preparedness (emergency plans)" was found to be the biggest difference between the two nations in this section, with a significant index score difference of 0.15. It shows that the Chinese found the need for emergency planning very important, whereas the Australian saw it as less important. This might be due to the Australian respondents' relatively longer experience in construction safety management and as a result, they could foresee the crisis more competently and make appropriate preparation. Comparatively, more accidents and emergencies occur in the Chinese construction industry than in Australia, and this could be the reason leading to this major difference.

"Ignoring labor safety insurances" was scored the second highest difference at 0.13, with the Chinese seeing it as more risky than Australians. In Australia, it is illegal to work on a construction site without having the proper insurance, such as workers compensation and public liability. China has also developed regulations regarding insurance on construction sites; however, due to the lack of strict enforcement, such regulations have never been implemented well. Also, most labor forces and contractors

come from rural and country areas and are generally less educated, and they do not realize the importance of purchasing insurance and/or are not willing to purchase insurance in order to reduce their labor cost.

“Low/no safety education/training” was scored with the biggest differences in this section. As mentioned previously, Australia presents a higher level of safety education and training compared to China through regular site inductions, safety inductions (green card), and OH&S training. In China, construction workers live and work in a very poor conditions and they are often treated as third-class citizens. “No or little onsite training” was also found to have a significant difference between the two nations, with Australians being more conscious of this factor. This is an unexpected finding as site participants need to obtain green cards to be eligible to work on-site in Australia. This is not compulsory in China. This may deserve further research to determine what kind of on-site training is beneficial to construction site safety.

Furthermore, “low expectation in safety operation,” scored a difference of 0.09. Due to culture and education background, the Chinese people, particularly those less educated and from rural areas, may see their work as a way of making a living and hence not expect workplace safety to be of great importance. However, the Australian people regard a safe and healthy workplace environment as a fundamental work right.

Australian people’s view on “poor electrical safety” is largely different than the Chinese people. The Australian government has imposed strict regulations in managing safety when operating electrical equipment and dealing with live wires. As per the survey result, Chinese respondents fail to see electrical safety as high risk even though electrocution is the second most deadly cause of accidents in China. Hence, this issue

needs to be looked at in detail and discussed in the future planning of construction safety in China.

Another factor with a major difference is “inadequate safety precautions.” The Australians had a higher level of awareness on the importance of safety precautions, compared to their counter- parts in China. Implementing proactive safety actions can help minimize losses from injuries and fatalities. Accordingly, the Australian construction industry thought that more effort needs to be taken to better safety precautions. Given that Chinese labor forces are relatively less educated in terms of site skills and knowledge, Chinese safety policy makers should investigate how to improve construction safety proactively and in a more serious manner.

With respect to management-related issues, “communication barriers due to different languages” had the biggest difference. The Australian industry gave it a high rating as Australia is a multicultural nation and, as a result, the construction industry may present a language barrier. A large number of construction participants cannot communicate effectively because they may come from a non-English speaking background. In China, this problem is less likely as the majority of the labor forces is Chinese speaking.

The second major difference is the “inexperience of management teams.” The Australians realized that it was a critical issue related to construction safety. The Chinese, on the other hand, felt that this risk factor was not so important, which might be due to the lack of appropriate attitude toward management among industry practitioners. Practitioners in China should pay more attention to the development of competent

management teams and skills in industry, particularly in the area of construction safety management.

Environmental and site condition related issues including “contamination of land, water and air” had the paramount difference score among all the surveyed risk factors. It was highly regarded by the Australian industry practitioners. The much lower score does not mean contamination is not a concern in China. Rather, it reflects that the Australian construction industry cares more about the negative impacts of construction activities on their environment. The second major difference is “asbestos contamination.” Asbestos was found to be one of the most seriously contaminative products on construction sites and causes millions to suffer from long-term brain damage and respiratory illnesses. In China, people are still not fully aware of the impact and dangers of working with these products. Policies are urgently needed in China to regulate the construction site environment and minimize the contamination and pollution cases.

In conclusion, Australian respondents were generally more cautious about physical safety risks than the Chinese respondents. It is noted that “low or no safety education/training,” “inadequate safety programs,” “lack of fire and electrical prevention procedures,” “lack of poor crisis preparedness (emergency plans),” and “lack of upper management awareness” are all within the list raised by the Chinese respondents, whereas most risk factors faced by the Australians are related to site conditions and environments (rather than people). This indicates China should focus more on developing capability of its personnel such as safety knowledge and skills and standard operation and prevention procedures, to essentially improve construction safety performance. On the other hand, this also reflects that Australians have a relatively better way of managing

human-related construction safety risks and now has its effort focused more on minimizing impacts of construction activities on the environment. This finding also coincides with the relatively substantial experience concerning construction safety management that Australian industry practitioners had compared to their Chinese counterparts, as high- lighted earlier.

The comparison of the top five construction safety risks also shows that safety education and regulations were more of a concern at the moment in China, whereas environment contamination and unforeseen site conditions were highly recognized in Australia. The Chinese government should support safety management more by establishing safety legislation and procedures, and providing safety training and proper legal framework with stringent enforcement. The workers must be educated/trained about safety regulations, procedures, and skills. The Australian safety green card system might be referred to by the Chinese government in developing a similar admittance policy for construction participants. On the other hand, the study also found that environment issues have not been recognized yet by the Chinese people. Actually, the booming construction market along with the speedy development of the Chinese economy have resulted in a sacrifice of the environment in recent years. This may raise the government's attention to take actions and ensure sustainable construction and improve worker safety on construction sites.

#### **4.2.2 Productivity**

Productivity is a necessary consideration in industry comparison, particularly as it relates to project cost and schedule. In “Comparative Study of Activity-Based Construction Labor Productivity in the United States and China,” authors Shen, Jensen and Berryman

present research that compares construction labor productivity (CLP) of the United States with its Chinese counterpart at the activity level to evaluate productivity differences between the two countries from an operational perspective. Sampled activities included earthwork, concrete, masonry, structural steel, waterproofing, and interior of operational data in labor, equipment, and productivity, this research is intended for use as a pilot study. The selected representative activities include earthwork, concrete, masonry, structural steel, roof waterproofing, and interior finishes. The writers anticipated this study would prove helpful when comparing the competitiveness of construction industry of both the United States and China from a labor-productivity perspective (Shen et al, 2011)

The LIF, which describes the labor to equipment composition ratio of a construction crew, was found to be a significant contributing factor to the construction labor-productivity gap, which exists between the United States and China. The regression model and the empirical data indicated that the gap becomes wider as less labor is included in an activity and as the crew uses more equipment. The productivity of more labor-intensive activities is similar in both the United States and China. The efficiency and the effectiveness of construction equipment appears to be the main factor contributing to the productivity gap for equipment-intensive activities. The findings of this study provide quantitative evidence at the operational level to support the conclusions of other studies that identified the lack of adequate construction equipment as one of the major causes of low productivity in the Chinese construction industry (Shen et al. 2006; Chen 1998; Zhao et al. 2009).

Much smaller productivity gaps were found between the two countries in construction activities measured at the operational level times more productive (Zeng et al.

2003; Xu et al. 2005). The results of this study are similar to the observations in another comparative which measured the productivity by output value per employee with PPP adjustments. Because of the lack of detailed crew composition data, this study was unable to quantify precisely how the differences of equipment utilization between the two countries affected the productivity gaps despite the correlation has been identified between the CLP difference and LIF factor.

In “Comparison of Construction Labor Productivity between U.S. and China,” authors Chui and Bai investigate one of the main entry barriers faced by U.S. construction firms for entering the booming Chinese construction market is the acquisition of accurate labor productivity data in China. The accuracy of labor productivity data can mean the difference between the success and failure of the construction projects. Due to the sheer diversity and complexity of international construction practices, minimal research has been performed on comparative labor productivity between U.S. and China. Research is currently being conducted to assist U.S. construction firms in competing in the Chinese market. The U.S. labor productivity data is obtained from RS Means while the Chinese labor productivity data is collected on-site in Chongqing, China. Chongqing is the largest and most populated municipality of China’s four provincial-level municipalities. Comparative review of collected productivity data d will help enhance U.S. construction firms’ competitiveness in the Chinese market and improve their project management capabilities in China (Chui et al, 2010.)

This article describes how in both the developed and developing countries, with U.S. and China as specific examples, the construction industry has played a fundamental role in the process of economic development. As construction is a labor-intensive industry,



small and medium sized businesses are the mainstay of some segments of the construction sector in the countries' economy. Construction is also diverse with respect to matters relevant in competition policy. Competition in the construction sector is usually highly localized, but the competition for the award of some large projects can be national or even transnational in geographic scope. For U.S. construction firms entering the booming Chinese construction market, the entry barriers derive from the possibility of the U.S. construction firms having to acquire the technology, the accumulation of experiences from previous Chinese construction, and the achievements reached by research and development of Chinese constructors.

Minimal work has been done on the labor productivity comparisons between U.S. and China due to limitation of data and the complexity of international standards. As project particularity in the construction industry results in product heterogeneity, it is impossible to produce homogeneous products of construction works through mass manufacturing (OECD, 2008). Therefore, in large part due to its impact on competitiveness and its influence on the success of the project, construction firms in the U.S. and China need to take a detailed look at the productivity of its workers.

In China, the construction industry has played a powerful role in sustaining economic growth, in addition to producing structures that improves industrial productivity and quality of life over the recent years. According to the Engineering News-Record (ENR) Top 225 Global Contractors 2008, there are four Chinese construction firms are ranked in top ten and a total of fourteen Chinese construction firms are ranked in top one hundred in the world, compared to only nine were ranked in top one hundred in 2000. As for the ENR Top 225 International Contractors, China has become the country with the

highest number of contractors being ranked in 2007 with 51 firms, compared to only 34 in 2000. The difference between the ranking of the Top 225 Global Contractors and the Top 225 International Contractors is that the global contractors are ranked by its construction contracting revenue both at the home country and abroad, and the international contractors are ranked by the revenue generated only outside its own home country (Huang, 2009.)

In response to the industry needs, the primary goal of this research is to conduct an accurate measurement of on-site construction productivity in China for comparison of labor productivity in the U.S. at task level. It is widely accepted that productivity measurement plays an important role in the construction management process. Productivity measurement provides the necessary data to analyze factors for project owners, constructors, and management professionals to control construction progress, estimate the cost of future construction projects, and determine its competitiveness in the global market. In achieving these objectives, the researcher hopes that it could help the U.S. construction firms stay competitive and profitable in the Chinese and global markets.

Measurements of productivity are the prerequisite for improving the labor productivity in the construction industry by qualifying current performance. To achieve this goal, this research effort is being proceed to measure and document the record of and will help to understand the construction labor productivity at task level in Chongqing, China. This research is based in a collaborative arrangement between the University of Kansas and the Chongqing University in China for an in-depth examination of construction productivity measurement arrangement, advisement about Chinese ethical issues involved in conducting research, providing research assistants from the Chongqing University to

assist one of the researchers in conducting on-site measurements, and selecting multiple building construction sites in Chongqing area to collect labor productivity data. There are three frequently used techniques: time studies (stopwatch), work sampling, and foreman delay survey methods that are being used in this research.

This study concludes that because China is a socialist country with differences in the social political system and culture, as compared to other developed countries, its' differences are enshrined in its construction industry as well. The high labor productivity of masonry measured at one jobsite in China is a surprise. It provided an evidence of the fundamental changes in the Chinese construction industry since the economic reform. Dramatic progress has been made by the industry. Although the Chinese construction industry attracts international construction firms and is evolving towards a more mature industry based on developed nation models, the industry is unlikely to be the same as that of the U.S. in its industrial mechanism within the next 10 to 20 years. In this study, the researchers recognized many issues on the jobsite in relation to safety and quality. It indicates that the challenges ahead for the Chinese construction industry are serious and deeper reforms are required.

#### **4.2.3 Legal**

Lastly, the legal implications of the Chinese construction industry as compared to the United States are investigated as they apply to construction contracts. In “Comparison of Contract General Conditions between United States and China,” authors Chui and Bai discuss that in light of the fact that construction projects are expensive, complex, and time-consuming undertakings, a well-written contract that specifies each participant’s duties and obligations is required. Furthermore, a well-written contract with regard to business

practice differences between the United States and China is unquestionably needed by American owners, design firms, and construction companies conducting business in China.

In response to this industry need, general conditions of construction contracts commonly used in the United States (AIA-A201) and China (GF-1999-0201) have been analyzed and compared. The findings of this research reveal that the content of sub clauses in AIA-A201 and GF-1999-0201 is different in several ways. These differences may have been caused by cultural, historical, geographical, political, and language variations that exist between the American and Chinese construction markets. Understanding these differences could help U.S. companies stay competitive and profitable in China (Chui et al, 2010.)

A well-written construction contract that specifies each participant's duties and obligations is required. A construction contract contains many nontechnical provisions such as general conditions, supplementary conditions, and provisions of the agreement that pertain to the conduct of the work (Clough et al. 2005); these clauses provide a clear idea of each party's rights and obligations. An important, if not the most important, part of the construction contract is the general-conditions document (Fisk 2002). The general-conditions document, often referred to as the boilerplate, augments the construction contract, outlines the ground rules under which the project will be constructed, and spells out clearly and completely the rights, authority, and obligations of all the parties (Bockrath 2000; Hinze 2001). These rules are often lengthy and deal with subjects such as scope of contract documents and resolution of conflict between them, payments and completion, protection from and risk of loss to persons and property, disputes, etc. (Sweet 1999). Bubshait and Almohawis (1994) further identified that the

importance of these documents stems from their role in defining the relationships, rights, and responsibilities of the contracting parties in all the projects within an agency or a country. Furthermore, the general conditions document spells out the general project rules and relevant commercial terms.

Owing to the important role of the general conditions, coupled with their intended applicability in all the projects within an organization or even a country, general conditions are usually expressed in a standardized prepared printed contract form developed and published by different professional associations and bodies including the American Institute of Architects (AIA) and American Society of Civil Engineers (ASCE) and are in wide use throughout the construction industry. The wide usage reflects the recognition of the advantages of using standardized general conditions. One of the major advantages of standardized general conditions is familiarity. Such familiarity reduces the time and effort needed to prepare and review the contract documents and contributes to reducing the bid-price contingencies. Another major advantage of using standard general conditions is that these general conditions have often been court tested so that the legal interpretation is known (Hinze 2001). In brief, standard general conditions lessen the possibility of misunderstanding, undue compensation, the likelihood of change orders, and the occurrence of claims or litigation arising out of contractual performance. In the United States, the owners, contractors, architects, and engineers can select standardized forms of general conditions of construction contract from a variety of sources. Some common ones are listed as follows:

The most common source of the general-conditions documents used in the United States for building construction is AIA-A201 (2007 Edition) which is published by the

AIA. On the other hand, in China, Conditions of Contract for Works of Building Construction (GF-1999–0201) is the main source of the general-conditions documents. Despite the well-developed general conditions of construction contracts in the United States and China, respectively, there are a number of complex challenges due to culture differences that must be addressed when U.S. design firms and construction companies attempt to enter the Chinese market. Therefore, a well-written construction contract, specifically a general-conditions document, with particular regard to business practice differences between the United States and China is unquestionably needed by the U.S. owners, design firms, and construction companies that are conducting business in the Chinese market.

In response to this industry need, the purpose of this study was to analyze and compare general conditions of construction contracts that are commonly used in the United States (AIA-A201) and China (GF-1999-0201). The objectives of the research were as follows: (1) to identify appropriate contents in the GF-1999-0201 document that could be adopted by U.S. firms which conduct business in China, (2) To provide guidelines for future development of general conditions of construction contract in the Chinese market; and (3) To offer means of decision making for American companies on implementation of general conditions of contracts in China.

This study only examined AIA-A201 and GF-1999-0201 because these two standardized formats of general conditions are the most commonly used in building construction projects and on projects designed primarily by architects in the United States and China, respectively, despite the increasingly standardized formats published by different professional associations.

In conclusion, this study was an investigation of the differences in standardized general conditions between AIA-A201 and GF-1999-0201 that are used in the United States and China, respectively. This session offers a discussion on the major findings of the study and their applications to practice. In addition, recommendations for future research are proposed.

The content analysis revealed that the sub clauses being categorized into each of six categories were in similar proportions between both AIA-A201 and GF-1999-0201. In addition, the allocation of each category was correspondingly delineated. This finding suggests that in both standardized general conditions have the same value in terms of what are the important and critical issues that should be addressed and regulated in a general- conditions document.

The findings of this study confirm that the rights and obligations issues of each party involved under the agreement were the major component of the standardized general conditions in both AIA-A201 and GF-1999-0201. This finding is consistent with the statement of Sweet (1999) that general conditions provide clear and complete ground rules of the duties and rights of the parties. Furthermore, one can conclude that both AIA-A201 and GF-1999-0201 are used as contract documents to establish project relationships, specify each party's rights and obligations, define terms, and assign responsibilities.

The findings of the detailed examination reveal that the content of sub clauses in AIA-A201 and GF-1999-0201 is different in several ways. These differences may have been caused by cultural, historical, geographical, political, and language variations in the American and Chinese construction markets. In other words, although the sub clauses in

AIA-A201 and GF-1999-0201 function similarly in terms of establishing project relationships among parties, they are different by the nature of the market that they take on.

Based on the differences between AIA-A201 and GF-1999-0201 discussed above, the following recommendations were made for American companies (owners, architectural and engineering firms, and construction companies). First of all, American companies which use AIA-A201 as their general conditions of construction contract in China should add sub clauses that are important in the Chinese market but absent in AIA-A201, such as sub clauses that address each party's rights and obligations in handling ancient tombs, historical buildings or sites, fossils, or valuable items beneficial to the study of archeology and geology that are discovered at the site, sub clauses which regulate that the Contractor shall warrant to the Owner on the Work in accordance with the current laws, government standards, and related country's warranty policies, and so on. By adding and adapting sub clauses from GF-1999-0201, American companies will be able to possess and develop a more comprehensive format of standardized general conditions that can be used in the Chinese market without complications.

Next, when conducting business in China, American companies should be aware of the expectation of roles that each party takes may be different from that in the United States. For example, in China architects and engineers are required and expected to act as owner's authorized representatives. In addition, American companies should also be aware that those who are using GF-1999-0201 may have different presumption toward AIA-A201. Therefore, good communication with the cooperating Chinese construction companies or design firms is critical. It is also important for the U.S. design and



engineering firms or construction companies to understand the differences in their contract and make sure each party involved read through the overall general conditions before signing the contract that uses GF-1999- 0201.

Based on the results, two recommendations for future research are offered. This study merely investigated differences between two standardized formats of general conditions used in the United States and China. Therefore, comparisons among different types of standardized general conditions, such as those developed by the AGC and the ASCE, the U.S. government (federal acquisition regulations), the Engineers Joint Contract Documents Committee, and the International Federation of Consulting Engineers (FIDIC), are suggested for future studies. Moreover, a further investigation of the discrepancy between building construction and engineering construction is also recommended.

Finally, this study simply examined the content differences of AIA-A201 and GF-1999-0201 without taking considerations of finding and understanding the general challenges that already exist in practice. Qualitative studies that investigate the nature of problems and the assurance of compliance in the context of an actual or hypothetical construction project situation that American companies have encountered in applying AIA-A201 or other general- conditions documents in China are strongly recommended for future research. In addition to portraying challenges, the perceived causes of those challenges and American manufacturers' (owners), architectural and engineering firms', and construction companies' experiences in coping with their difficulties in the current Chinese market are valuable information for future development of standardized general conditions for construction contract in the Chinese market.

### **4.3 Infrastructure Construction and Trenchless Technologies in China**

While Horizontal Directional Drilling is the focus of this study, China's incorporation of all trenchless technologies is a critical aspect of the overall attitudes in China towards alternative pipeline construction methods. Including this topic in the literature review is necessary to learn when China first began adapting unconventional methods and how they are currently being utilized.

The first publication in North America highlighting the "Utilization of Trenchless Construction Methods in Mainland China to Sustain Urban Infrastructure" was not published by ASCE until 2006. In this article, authors Ariaratnam, Chan and Choi highlight the fact that China's Infrastructure-related issues have driven the government to seek out emerging methods such as trenchless technologies for installing and extending the useful life of existing underground utility networks. In response, professional trenchless societies were established including the China Shanghai Society for Trenchless Technology, the China Beijing Society for Trenchless Technology and the China Guangdong Society for Trenchless Technology. The role of these societies is to promote the adoption of trenchless construction methods through educational initiatives (Ariaratnam et al, 2006.)

A description of three trenchless construction methods were presented in this paper in the form of underground case studies of underground construction. Studies included one pipe bursting project in Chongqing, one pipe ramming in Shenyang, and two horizontal directional drilling (HDD) in Shanghai and Fuzhou. The purpose of these studies was to demonstrate applications of trenchless construction for sustaining

underground utility networks. For this purpose of this study, only a summary of the HDD projects were included.

In the first HDD study, a gas pipeline installation project, which is the main pipeline of the West-East Gas Pipeline Project entering the first section of Shanghai region, was installed using HDD. Two multiple installations of 28" and 12 3/4" diameter steel pipelines were installed distances of 1,168' and 1,184', respectively. A total of ten (10)-28" and eight (8)-12 3/4" diameter steel pipes were installed. Shanghai Win-Market Trenchless Technology Construction Company Ltd. utilized a Vermeer® D200 X 300 navigator directional drill rig to complete this project.

The project commenced on June 25, 2004 and was completed on July 27, 2004. A second HDD project in Shanghai involved the installation of ten (10)-8 5/8" diameter high density polyethylene electrical conduits over a distance of 2,625'. A Vermeer® D100 X 120 Navigator directional drill rig was used in this installation. The third HDD study described how HDD was used in Fuzhou to install two potable water lines. A 20" diameter steel pipeline and one (1)-2 1/2" diameter high density polyethylene line were both installed a distance of approximately 474' across a river. This challenging project was completed using a Vermeer® D33 X 44 Navigator directional drill rig.

In "The Emergence of the Horizontal Directional Drilling Industry in China," Ariaratnam, goes on to further describe the HDD industry in China in 2006. Ariaratnam describes how China was experiencing perhaps the fastest worldwide economic growth at the time. With numerous monumental construction projects underway and an ever increasing population growth, China was utilizing sustainable principles and methods for addressing their infrastructure needs. The article highlights the 2008 Summer Olympics

Games in Beijing, the 2010 World Expo in Shanghai, and the 2010 Asian Games in Guangzhou as catalysts for the rapid expansion of large scale pipeline projects and subsequent advancements in the area of Horizontal Directional Drilling (Ariaratnam, 2006.)

As an industry expert, Ariaratnam suggests that the future of HDD is abundant, as the country is facing major economic and population growth, exploring alternative construction methods for sustaining the vast underground utility network has been a priority. Minimally-disruptive and cost-effective trenchless technologies are now being employed in China to address their ageing and expanding infrastructure. The horizontal directional drilling market is growing by leaps and bounds in China, which is currently the fastest growing worldwide market for this technology. As more and more local Chinese equipment manufacturers enter the market, competition will grow exponentially. However, a major necessity is the proper training of drill rig operators on good drilling practices. This is imperative to minimize risks and ensure successful projects.

In “Experiences in Adopting Trenchless Methods in China,” Ariaratnam, Chan and Choi address ongoing challenges when promoting trenchless technologies in China including minimal local engineering knowledge, lack of trained contractors, lack of specifications, and system impact concerns raised by government owners. This paper provides a discussion of experiences in adopting trenchless technologies in China with recommendations obtained from lessons learned for individuals looking to initiate such future projects (Ariaratnam et al, 2006.)

Even with the current situation, trenchless technologies including horizontal directional drilling, pipe bursting, pipe ramming, microtunneling, cured-in-place lining,

fold-and-formed lining, and grouting are being used in China. As of 2006, local Chinese manufacturers were building trenchless equipment at a discounted rate in comparison to foreign-made equipment. For example, there are reported to be more than 1,500 HDD rigs currently in China and between 25 to 30 local manufacturers. It should be noted; however, that the top five Chinese manufacturers account for 80 percent of the locally made drill rigs. Foreign manufacturers such as Vermeer Corporation®, Ditch Witch®, American Augers®, Case, Robbins®, and TT Technologies® have had varying degrees of success in the Chinese drill market.

Ariaratnam suggests that perhaps the best way for foreign contractors to gain access to the Chinese construction market is through the formation of joint venture partnerships with local firms. U.S. contractor MRM Group created a joint venture with Taian-American Gas Services (TAGS) to form MRM/American Gas Services. Having success in China meant having a local partner and employing the local workforce, rather than bringing in foreign workers. Economically and culturally, utilizing the local workforce is the recommended way for foreign companies to be competitive. The company has had tremendous success employing horizontal directional drilling on major Chinese pipeline projects over the past decade.

This article concluded that domestic equipment manufacturers, making use of economic advantages, are beginning to capture more of the market from foreign entities. Subsequently, there has been an increase in domestic contractors employing trenchless technologies. Foreign companies interested in doing business in China must first understand the organizational structure of municipal governments. The lack of specialized engineering firms focusing on designing trenchless projects is an issue. Joint venture

relationships between Chinese and foreign companies are the best way for a foreign entity to enter the market. Employing a local labor force (and training them) is essential to remain competitive.

Nearly five years later, “A Parametric Study of Underground Utility Infrastructure in China” authors Cao, Ariaratnam and Lueke presented the analysis of 58 professionals who responded to a survey questionnaire regarding the underground utility infrastructure construction in China. The objective was to obtain knowledge about the current state of trenchless technology including distribution of trenchless projects; application area; operation methods; equipment aspects; solution to risk projects; and urgent issues facing construction. The results supported the rapid growth of commercial and residential construction due to urban development resulted in the need for installation of new water supply and sewer utilities in major cities. Additionally, oil and gas distribution systems were required to meet the demands of the urban growth, thereby requiring the transportation of these resources as part of the West-East Pipeline projects (Cao et al, 2011.)

In the next article “China's Municipal Pipelines: Today and Tomorrow” Professor Baosong Ma presents a comprehensive overview of the result of urbanization in the People's Republic of China and discussed how the country had increased in speed following the initiation of the reform and opening policy. These changing conditions brought to light the fact that China's municipal pipeline is facing a serious challenge and sees a great increase during the 12th Five-Year-Plan period (from 2011 to 2015). This paper presented the status of China’s municipal pipelines (including water, sewer, city gas, etc.) and the government’s plans to improve the municipal pipeline systems, such as new pipeline

construction and pipeline rehabilitation, which will bring great business opportunity for the pipeline suppliers and contractors. As well, the research and technical needs to meet the demand of China's municipal pipeline construction and rehabilitation were discussed in this paper (Ma et al, 2013.)

According to the 12th Five-Year-Plan Period, the new water supply network in urban areas will add 116,000 miles in length of new pipeline in addition to the renewal and reconstruction of 57,352 miles of pipeline. The new sewage pipe network will add 100,000 miles of pipeline and the and new gas pipeline network will add 156,000 miles. The total will be have 429,000 miles length, of which has not include urban rainwater network and central heating network. It is speculated that that the municipal pipeline of 500,000~560,000 miles length in the country is expected to be constructed. Huge municipal pipeline construction market will provides unique opportunities for new materials, new technology, and new methods in municipal pipeline network system. Because plastic pipe and trenchless technology have many advantages and superiority in competition, in urban municipal network system, which will be widely applied in 12th Five-Year-Plan Period.

#### **4.4 Chinese Investigations in Infrastructure Construction**

The next section included in this literary review is a comprehensive presentation of past and ongoing research in the area of infrastructure construction as performed by academic and industry leaders in China.

In “Yu-Ji Gas Pipeline Project Contractor HSE Management,” authors Sun, Wang and Wu introduce the HSE management system is constituted by organizations who implements safety, environment and health management, trade unions, practices, procedures, processes and resources etc. From the functional sense, HSE management

system is kind of risk analysis before accident to determine potential hazards and consequences due to their own activities, then take effective preventive and control measures to prevent its occurrence, which reduces potential personal injury, property loss and environment pollution. Thus, the HSE management system is a dynamic management process (Sun et al, 2009.)

The article discusses how as more and more gas pipeline construction, operations and services are provided by the contractor, contractor's HSE management level and performance in China is a direct impact on the company's overall HSE performance. How to control the project management system standards combining with the current situation and the specific circumstances of the contractor, and develop a realistic and feasible management procedures and requirements to regulate the contractor HSE management and improve the performance of all enterprises is of great practical significance.

Yulin-Jinan gas pipeline project is highlights as yet another important gas pipeline project China Petrochemical Corporation and also the state "Eleventh Five-Year" key projects, following the East Sichuan gas pipeline project. The completion of the pipeline will become an important component of national natural trunk pipeline network, it's also the first long-distance, large diameter, high pressure, integrated natural gas pipeline of construction and management since the establishment of branch offices. The gas source is located in the rich natural gas production Shaanxi Province, The pipeline's completion length was 649 miles as it passed through three (3) major mountains, eight Tunnels, 12 highways, 13 rails and across the Yellow River.

More than 80 contractors participated in Yulin-Jinan natural gas pipeline construction projects including exploration, blasting, the laying of pipelines, corrosion,



inspection testing, etc. Due to the huge difference in philosophy of contractors, heavy education and training work for HSE, many site safety monitoring matters, complex organizational structure of project management, a long construction period and local issues such as task co-ordination, Therefore during the construction period, the contractor's HSE management project is a prominent problems and priorities for project construction safety and environmental protection work.

Since the start, the Yulin-Jinan gas pipeline project has achieved gratifying results in the contractors' HSE management, but because of the current similar experience in the domestic long-distance pipeline construction is not rich enough, there are still some problems in the implementation process. This is shown in the following areas: There is a big gap among contractors in the on-site HSE dynamic evaluation in the HSE management system interface between the project department and the contractor; secondary contractor's HSE management is not regulate (this is also the focus of future management), inadequate training , poor quality of staff, "three against" phenomenon still exists. These issues need to be improved gradually in the future project constructions.

In “The Geohazards Features and Management of Zhongxian-Wuhan Gas Pipeline in Mountainous Areas,” authors Qinglu, Wang and Shen investigate the Zhongxian-Wuhan Gas Pipeline (ZWGP), which was put into operation at the end of 2004 as part of the West-East Gas Pipeline Project of China. Travelling from Zhongxian to Yichang and at about 249 miles in distance, the pipeline goes through the mountainous area where geological conditions are complicated. Zhongxian-Wuhan pipeline is one of the most outstanding pipelines facing the numerous geohazards that has ever been constructed in China. Thus,

geohazard investigation, risk evaluation and control engineering have been critical to ensure the pipeline construction was successful.

This paper summarizes the geohazard features and experiences of geohazards prevention and treatment. Based on 3 rounds of geohazards investigation along the pipeline, more than 183 geohazards sites were identified which included 96 landslides, 77 unstable rocks and 10 debris flow gullies. This article summaries the scale and distribution of geohazards along the pipeline, as well as the harm features of the pipeline. It is also introduced in this paper the geohazard management adopted by ZWGP, including the principles of geohazard prevention, running program, and frequently-used prevention methods (Qinglu et al, 2012.)

Nearly 400 km (249 miles) of the main pipeline passes through the mountainous areas located to the east of Chongqing City and to the west of Hubei Province where conditions include steep terrains, complex stratigraphic combinations and geological structures, changing weather conditions and recently intensified human engineering activities. (Refer to Figure 4.6) As for the significance of geohazards along ZWGP, the management department, Central China Gas Transporting Branch of Oil Pipeline Company, paid very high attention to the prevention of geohazards from beginning of its operation. Three rounds of field investigations on geohazards were made by the professional teams. The measures such as engineering treatments, professional monitoring or periodical inspection were taken to the geohazards based on their rank of risk classification. These investigations have largely contributed to the pipeline safe operation over 7 years.



Figure 4.7: ZWGP Pipeline Route Map (Qinglu et al, 2012.)

This series of scientific and feasible management systems was preliminarily setup as an application to this pipeline only. This milestone that the prevention of geohazards transformed from the traditionally scattered, attached and passive mode to currently well-organized, professional and predictable work. The managers gained a better understanding of basic situation and dynamics of geohazards based on the investigation. Further evaluation and special research work of geohazards along the pipeline were later performed by the academic professional as well as industry professional institutions. The prevention, treatment, monitoring and patrol can be made step by step according to characteristics, classes and risk levels of geohazards. In order to ensure the quality of projects, a series of strict bidding system for processes such as reconnaissance, design, implementation and completion and acceptance should be set up with the characteristics of geohazards prevention. This paper is just a preliminary summary of the team work of Petrochina

Pipeline Huazhong Gas Transportation Company for transporting gas. Therefore, any suggestions and criticisms are welcomed to improve the work.

In “Geological Hazard Assessment of Long-Distance Gas Pipelines,” authors Chen, Zhang and Ma describe how all over the world, geologic hazards have become primary threat to the natural gas pipelines. Almost all the long-distance gas pipelines pass through a diverse schematic geologic circumstances and encounter many sorts of geologic hazards such as sink holes, slope movement, mud/landslide and seismic threats. Because of the greatly sudden and destructive characters, the consequences of gas pipeline failure resulted from the geologic hazards are always grievous. Thus, it is an important task to predict and decrease the loss of the failure. Risk assessment can offer effective methods to managers to make preferable decisions to decrease the pipelines’ risk level due to geologic hazards. The mechanisms of threatens of geologic hazards to the gas pipeline are analyzed. Based on this, risk factors of natural gas pipeline due to geologic hazards are recognized, including the failure likelihood and failure consequences, and the five-grade factor system is set up. Furthermore, the geologic hazard risk assessment model is developed. (Figure 4.7.) The likelihood model is developed to account for factors that cause each threat. The consequence model is developed based on statistical analysis, industry practice, and engineering judgments subject matter experts (SME’s)) (Chen et al, 2009.)

Geologic hazards for long-distance gas pipelines are numerous. Slope movement is a primary concern as it can be caused by periodic wetting and drying of material, and development of a slip circle due to a weak soil layer. It is a very slow process but can cause significant structural damage and is often difficult to predict.

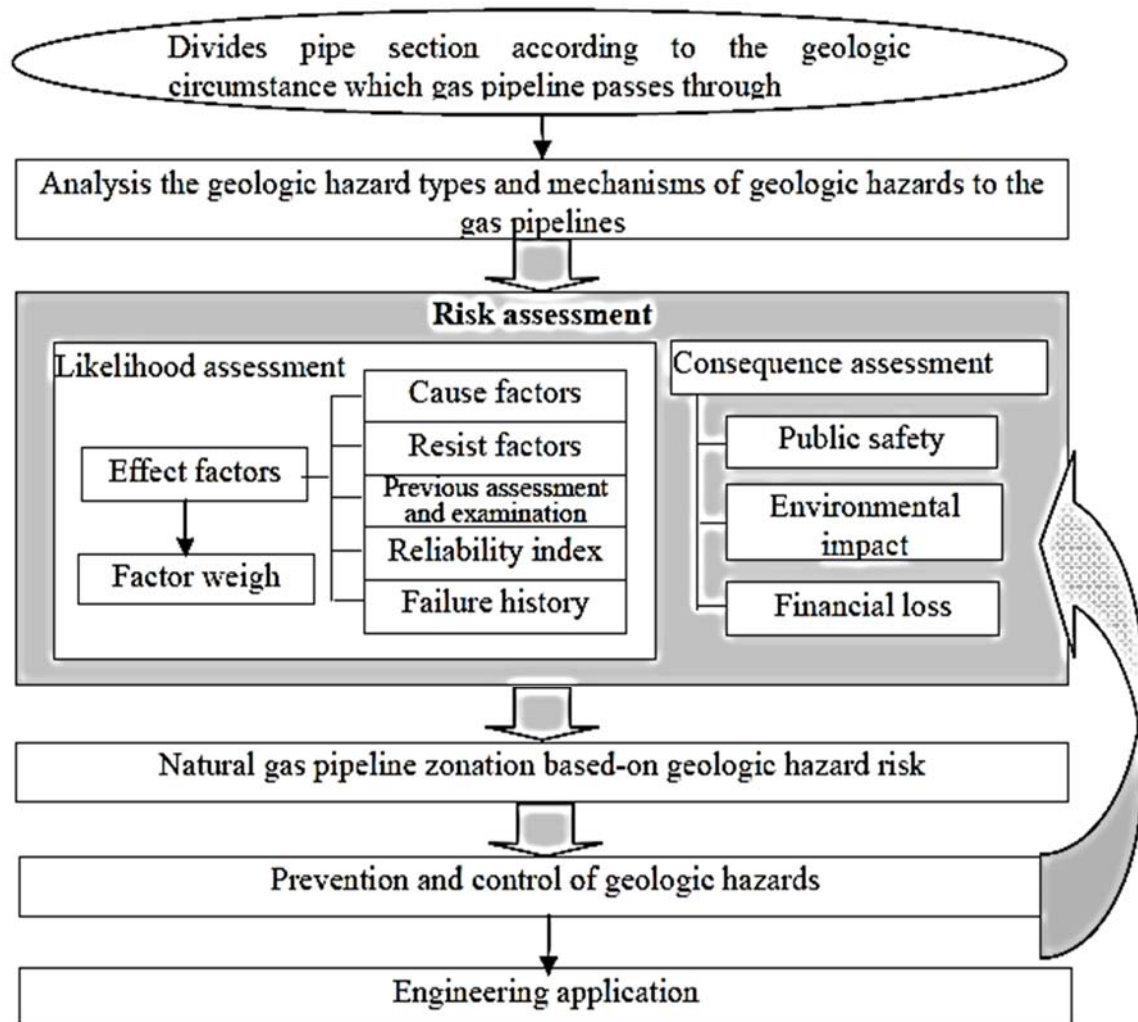


Figure 4.8: The Technical Frame and Process of The Geologic Hazard Risk Assessment of Natural Gas Pipeline (Chen et al, 2009)

Landslides are another concern. Landslides are considered mass movement of soil or rock along a flat surface or down steep slope due to weakening of soil through saturation of heavy rainfall, earthquake, soil instability and overloading. Landslides often occur with little to no warning and can be catastrophic. The next hazard investigated is settlement, which occurs as a result from compression of the soil due to nearby surface construction activities or other underground activities such as mining, ignition of coal beds or/and underground streams. Heave caused by frost heave in which ice layers are formed within

the soil that causes the ground to heave upward. Hydrological geotechnical threats when water flowing down a steep gradient may erode the riverbank, scouring on the bed of the river, cause flash flood when the river can no longer hold the excess water in the stream due to soil sediment and cause channel migration as the flow of the stream changes. Finally, seismic activities such as earthquake occur with very little warning and often result in project delay, increased cost, or even redesign.

In some sense, study on risk assessment of geologic hazard for long-distance natural gas pipelines has just started in the oil/gas storage and transportation field. Some groping research works were done in this paper based on actual practice and study, and there are many questions about this issue need to be solved. For example, the score and weigh of the effect factors, pipeline zonation based-on geologic hazard risk, and constituting and establishing pipeline risk assessment criterions and manuals adapt to the pipeline actual conditions are still difficult problems which are need to be studied farther.

#### **4.5 Chinese Investigations in Trenchless Technologies**

Chinese investigation in trenchless technologies build on the work done for general pipeline construction. This section investigated those studies being performed by Chinese researches in the area of trenchless technologies overall as well as those specific to the horizontal directional drilling method of construction.

In “Study on the Pipeline Crossing Methods and Suitability of Engineering Geological Conditions in the Middle Reaches of the Yangtze River,” authors Yin, Lv and Xie highlight methods adopted for pipeline crossings including HDD, microtunneling method, and so on. The engineering geological conditions have decisive impact on the pipeline crossing design and construction plan formulation. For this crossing of the

Yangtze River, first of all, the crossing point needed to be chosen based on the engineering geological conditions of the crossing Yangtze section, then the crossing method needed to be decided. To choose reasonable method, the pipeline crossing methods and suitability of engineering geological conditions needed to be fully studied (Yin et al, 2009.)

In recent years, with the successive development of West-To-East Gas Pipeline Project, Zhongxian-Wuhan Gas Pipeline Project, Yizheng-Changling Crude Oil Pipeline Project, oil and gas pipeline projects crossed the Yangtze River many times. Refer to Figure 4.8. Since the engineering geological conditions along the middle reaches of the Yangtze river are relatively complex, the application of suitable pipeline crossing method to the local engineering geological conditions were very significant to each pipeline crossing project.

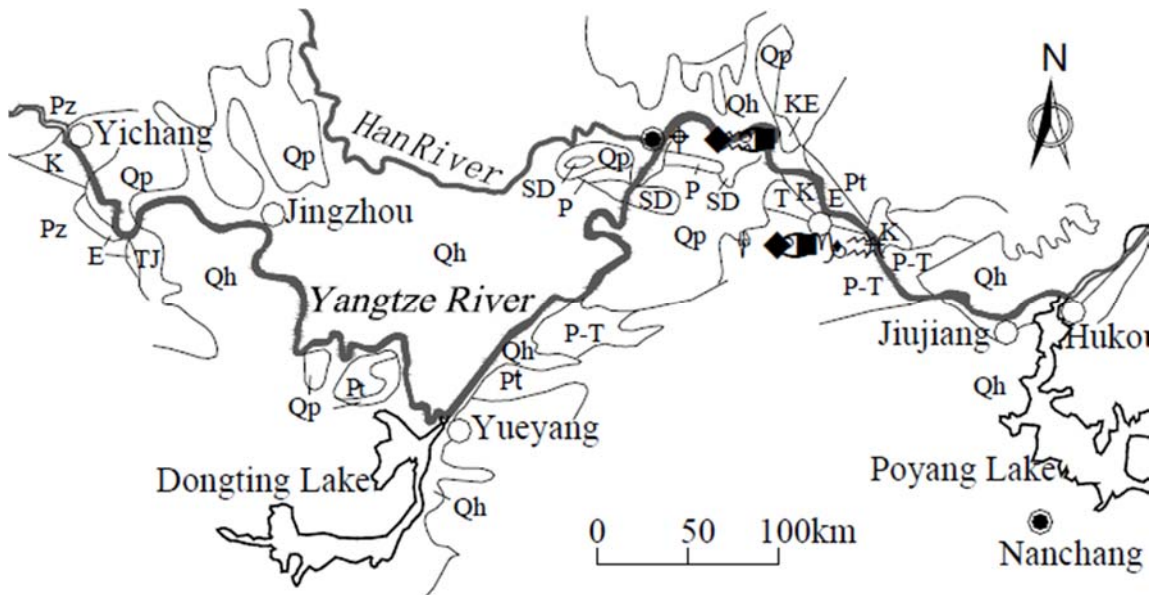


Figure 4.9: The Generalized Geologic Map (CWRC, 1999)

According to previous analysis, heavy water flow rates at the middle reaches of the Yangtze River made trenching-burying methods unsuitable for pipeline installation. This

paper presents the adopted suitability analysis for three trenchless pipeline crossing methods, directional drilling crossing method, shields tunneling method and mine tunneling method, to the engineering geological conditions in the middle reaches of the Yangtze River.

It was concluded that, according to the engineering geological conditions of crossing site and the suitability of each crossing method, more than one crossing methods used in combination would provide the best results. For example, when the engineering geological condition of one side of the crossing section is very complicated, but that of the other side is relatively simple, the combination of shields tunneling method and mine tunneling method can be applied together in the construction, which can effectively save the cost. The selection of crossing method should meet the demand of its engineering geological conditions. In addition, the engineering geological conditions should have a decisive impact on the pipeline crossing so that it is one of the most important evidences for construction organization design. Next of all, a detailed engineering geological investigation and comprehensive site evaluation needs to be conducted before construction. Finally, during actual construction of pipeline crossing project, the suitability of pipeline crossing method should be comprehensively analyzed based on the difficulty of construction, period, cost and maintenance and so on.

In “Risk Evaluation for Maxi Horizontal Directional Drilling Crossing Projects,” authors Ma, Najafi and Shen describe how Horizontal directional drilling HDD has become increasingly used for the construction of large diameter greater than 24” pipeline projects throughout China. Due to the large investment of capital and resources, it is important to conduct a risk evaluation prior to actual construction. However, there are relatively few



appropriate analyses or investigations available for such applications. This paper addresses the risk assessment for Maxi HDD projects. The combination of the fuzzy comprehensive evaluation method and analytical hierarchy process was adopted as the basic model. (Ma et al, 2010.)

The corresponding risk indices were constructed considering the factors affecting the projects and based on discussions with experts who have conducted HDD crossing projects. Structured judgment matrices and membership matrices were then directly developed from the index systems, and the weight vectors, subordinated vectors, and risk values determined by the use of Matlab software. Finally, the risk level of the projects was obtained by implementing the maximum membership degree law. The synthesis of the fuzzy comprehensive evaluation method and analytical hierarchy process has been demonstrated to provide a theoretical basis for the risk evaluation and establishment of risk control measures for Maxi HDD projects. The risk of Maxi HDD projects is evaluated using the combination of the fuzzy comprehensive evaluation method (FCEM) and the analytical hierarchy process (AHP). These methods have been widely used in risk evaluation for various applications.

The conclusion of this paper are that AHP is a combination of semi-quantitative and semi-qualitative methods, which can be used to determine the weight of various risk factors for the overall index system in HDD crossing projects. FCEM is also a combination of semi-quantitative and semi-qualitative methods, based mainly on fuzzy inferences, which can be used to obtain the total risk value of the system, which can then determine the risk of the project according to the maximum membership degree law. Finally, the two

methods are complementary to each other, and their combination provides an improved theoretical basis for the evaluation of the project risk.

In “Special Practices of Horizontal Directional Drilling in China,” authors Gao, Li and Ma, present eight horizontal directional drilling crossing cases and their problems and solutions. These crossings were conducted by horizontal directional drilling company of petroleum pipeline bureau in China, and to make it clear, these crossings are classified into three categories according to the major geological conditions (Gao et al, 2011.) These studies can be summarized as follows:

#### **Case Studies of HDD Crossings in Clay:**

*Qiantang River Crossing of Hong Yong Gas Pipeline:* The Qiantang River crossing of Hang Yong Gas Pipeline was conducted from September 2006 to March 2007. The crossing is located at Xinwei village, Hezhuang town, Xiaoshan district, Hang Zhou city. Project details included a pipe diameter of  $\Phi 32''$ , over a length of 8,038' with the deepest depth of drill reaching 103' beneath the lowest section of riverbed.

*Pengjiawan Waterlock Crossing of the West to East Gas Pipeline:* The crossing of Pengjiawan Water Lock in West to East Gas Pipeline project was conducted from November 2010 to January 2011 and made the domestic record of the longest HDD crossing for  $\Phi 48''$  pipeline. The crossing is located at Pengjiawan village, Gangkou town, Jiujiang county, Jiu Jiang city Jiang Xi province. Project details included a pipe diameter of  $\Phi 48''$ , over a length of 4,583' with the deepest depth of drill reaching 63'.

In summary of this section, although the suitable geological for HDD is clay, some problems are met in sticky clay, hard and soft soil (hardy clay and silt). The major problems of which are drilling pipe packed by stick clay, drilling operation can't move forward,

drilling pipe sink and can't move up. These impacts occur more often in large diameter pipeline crossing. The experience of HD crossing showed that, in hard clay operation, both suitable drilling tools and a large entrance angle should be selected, instead of that, in soft soil operation, rotating speed of prereaming should be slow, and pull force should be large.

### **Case Studies of HDD Crossings in Sand**

***Yellow River Crossing for Huiyin Pipeline:*** The Yellow River crossing of Huiyin pipeline project was conducted twice by both the Changqing Construction Company and HDD Company, respectively in November 2009 and then again in September 2010 and lasted more than eight months. The crossing is located at the north of Leitai village, Rencun town, Yongning county, Yincuan city. Project details included a pipe diameter of 18", over a length of 6,283' with the deepest depth of drill reaching 78'.

***Wei River Crossing in Second West to East Gas Pipeline:*** The Wei River crossing of Second West to East Gas Pipeline project was conducted by HDD Company in from March 2010 to January 2022 lasting more than ten months. The crossing is located at the Xingguang village, Xinyi Town, Weinan City, Shanxi Province, and also at the downstream of Wei River crossing of the Lanzhengchang Pipeline Project. Project details included a pipe diameter of  $\Phi 48''$ , over a length of 4,068' with the deepest depth of drill reaching 98'. This crossing was actually performed three times. The first attempt failed and the second one for temporary emergence usage was completed. The crossing was executed on the third and final attempt.

***Wei River Crossing of Lanzhengchang Product Pipeline:*** Wei River crossing of Lanzhengchang product pipeline was conducted by HDD Company in September 2008. The crossing is located at the Xingguang Village, Xinyi town, Weinan city, Shanxi

province. Project details included a pipe diameter of 26", over a length of 6,079' with the deepest depth of drill reaching 98'.

In summary of this section, sand with gravel and cobble is the normal geological condition for HDD crossing of large rivers. Sand under the river bed usually contains gravel, cobble and boulder, and their arrangement is without order. The density of the sand is from several sticks to over one hundred strikes in standard penetration test, and the lower dense sand may appear in dense sand layer. Impacts often met in pilot hole operation are those that a drilling pipe lost stability, drill tool is stuck, torque is very large and drill bit moves up difficulty at curvature section. And impacts occur in borehole reaming operation are such as borehole contracting and collapsing, drill tools stuck, large torque, moving up difficulty, drill tools sunk and worn severely, drill pipe broke and large pulling load, etc. The curvature section is difficult to pass through. The stability of drill pipe often lost in dense sand or in loose sand Drill pipe sink is because of the looser sand beneath and the heavier weight of the drilling tools. Moving up difficulty is because the sand layer overhead forward is denser than the ones passed through. The causes of the problems mentioned above are the stirring to the bore wall, cuttings maintaining in the bore, incorrect pulling way, etc. The practices mentioned above have given some solutions to the problems.

### **Case Studies of HDD Crossings in Rock**

*Heilongjiang River Crossing in China-Russia Pipeline:* Two parallel Heilongjiang River crossings of China-Russia Pipeline were conducted between September 2009 and April 2010. The crossings were located at the boundary of China and Russia near Xinan town, Mohe County, Heilongjiang province, China to the east of

Moheyite inland in Russia. Project details included a pipe diameter of 32”, over a length of 3,773’ with the deepest depth of drill reaching 180’.

***Jushui River Crossing in West-to-East Gas Pipeline:*** Jushui River HDD crossing of Second East to West Gas Pipeline was conducted by HDD company in 2010.1~2010.8 with eight months. The crossing construction has been conducted twice. The crossing was located at the Huren village, Xinchong town, Xinzhou district, Wuhan City, Hubei province. Project details included a pipe diameter of 48”, over a length of 3,130’ with the deepest depth of drill reaching 114’.

***Shahe River Crossing of the West-to-East Gas Pipeline:*** Shahe River crossing of West to East Pipeline was conducted by HDD Company in September 2010-January 2011 and lasted three months. This crossing is the longest rock crossing in Second West to East Pipeline, and made the record of 48” diameter pipe with the longest length of 3,497 in rock in China.

In summary of this section, rock is the normal soil for river crossing and is often covered by loose sand or soft soil layer. The integrating of the rock is different that some of them is with fracture and some of them is good but very hard. The primary problem for rock is drilling tools abrasion, large torque, drilling stuck, dog leg at rock and soft soil interface, large pulling force, etc. The solutions are as using wearable tools and preparing enough spare parts, selecting suitable mud system, cleaning the borehole more often. For the crossings with interface of soft soil and hard soil, exit point should be at the hard side. The operation process is like these, pullback the drilling pipe from exit point after the rock section has been reamed, and unload the rock used drilling tools, and load the soft soil used tools to ream the soft soil section. Another way is to improve the earth at soft and hard soil

interface, and then, work in the normal way. When construction in soft soil, drilling rotation should be slowly and pulling force should be great.

This article concludes by reinforcing the fact that the above mentioned cases are only a part of the crossings, and the problems and the solutions cannot cover all of the HDD crossings, but the situation is the primary and newly ones, and can be taken as for reference.

The next article could be considered the most significant and comprehensive publication prepared by Chinese investigators. In “Investigation of the Key Technology for Large-scale Directional Drilling Crossing for Oil and Gas Pipelines,” authors Yijie, Jiaqiang, and Lu present a paper that focuses on the discussion of the key technologies for large-scale directional drilling crossings of oil and gas pipeline as follows. Firstly, the components and construction process of large-scale directional drilling crossings are described. Then, the solutions to the key technological problems, such as drill path design, reaming process selection, mud formulation optimization, pull-back force estimation and drilling equipment allocation, etc., are investigated. Finally, a large-scale directional drilling crossing is illustrated to explain the concrete solutions corresponding to key technologies. The study results show that the reasonable technical support for direction, reaming, mud, equipment is the key to directional drilling crossings, which contributes to ensure the construction quality and progress of oil and gas pipelines (Yijie et al, 2011.)

This article discusses how the sequence of construction involves the geotechnical site investigation, the crossing curve design, the magnetic azimuth detection, the drilling rig set-up, the oriented hole construction, the bore expanding to different level, the borehole cleaning, the pipeline back-dragging, and the restoration of the site all contribute to the overall success of the project. As shown in Figure 4.9, the drill path is consisted by

five sections: the entry straight line (1-2), the entry arc line (2-3), the horizontal line (3-4), the exit arc line (4-5), the exit straight line (5-6). Thus, the drill path of pilot hole is determined by five key parameters, including entry angle ( $\alpha$ ), exit angle ( $\beta$ ), maximum depth of drill path ( $h$ ), radius ( $R$ ), length of drill path ( $L$ ). The length and depth of each section can be determined according to the trigonometric function equations.

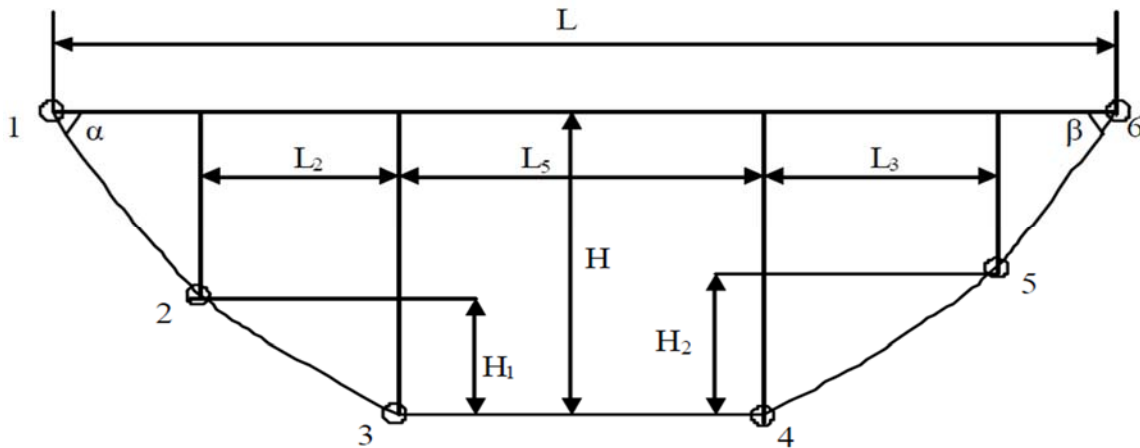


Figure 4.10: Elevation of the Drill Path (Yijie et al, 2011.)

The design of drill path is limited by various factors, but the primary limiting factor is the surface and underground condition of construction site. Thus, a detailed pre-geotechnical site investigation is required. Choose the proper routing based on the geological conditions, to keep away from the severe geological regions such as granite rock, pebble and quicksand, and reduce the risks of crossing construction. The appropriate geological conditions for directional drilling crossing mainly include cohesive soil, silty soil, sand-size soil and rock. Crossing of severe geological regions should be avoided.

The entry point and exit point of directional crossing is determined by the requirements of construction. The entry point should be fixed on the side having convenient traffic condition and gentle workspace. The exit point should be fixed on

the side having sufficient workspace to allow the pipelines assemble and pull back. The entry point is supposed to at equal or lower elevation than the exit point. These selections also actor into total depth of drill. The depth of cover is determined according to the scouring depth in flood control assessment system. The depth of cover should meet the requirements, 20' below the designed scouring line of flood water.

The entry angle of crossing pipeline shall between 8 and 18 degrees with an exit angle between 4 and 8 degrees. The design of entry angle is relative to the type of drill rig, and the exit angle is relative to the diameter of pipelines. The exit angle should be decreased with the increasing of the diameter of pipelines. If the workspace permits, the entry angle and exit angle should be as small as possible. Generally speaking, the entry angle should be smaller than 12 degrees and the exit angle should be smaller than 5 degrees in large-scale directional drilling crossing construction. The angle of entry angle and exit angle can be increased properly only when the drill path is limited by the condition of construction site, length of drill path is short and the depth of cover is great.

The radius of drill path should be enlarged as much as possible to decrease bending stress. Normally, the radius of large diameter pipelines should not be smaller than 1500 times of the diameter. When limited by the terrain condition, the radius of drill path should not be smaller than 1200 times of the pipeline.

The pilot hole being drilled smoothly is the key procedure of the directional crossing projects. The quality of the drilled pilot hole is the important principle to evaluate the crossing project. As the foundation of reaming of the pilot hole and pulling back of the pipeline, the pilot hole drilling influences on the pull-back force. Risk avoidance of the projects is reflected greatly on the construction of drilling of pilot hole.



The principle of evaluating the pilot hole includes the longitudinal and lateral deviation of the exit point, and the offset between the actual and theoretical drill path. The drilling direction should be controlled accurately along the designed drill path to ensure that the deviation is within the specified tolerance.

In the large-scale directional drilling crossings, the wired directional control system has higher precision than the wireless system. The wired directional control system should be given preference. The drilling parameters including position, depth and direction of drill bit, is detected by is detected by the directional tools. These parameters are used to estimate the deviation of the drilling direction. The deviation correction measures should be taken on time to adjust the drilling direction and ensure the precision of drilling.

As the critical point linking the drilling of pilot hole and the pulling back of the pipeline, the process of reaming is directly related to the pull-back construction. For the construction of lager diameter pipeline crossings, the diameter of the drill hole is enlarged to the proper size using several reaming operations. The drill hole has a serious trend of sinking in this construction. In addition, poor stability of pore wall increases the difficulty of construction.

The number of reaming operations is determined by the geological conditions and the diameter of pipeline. For the crossing project of large diameter pipeline, the number of reaming and flushing of holes should be reduced to decrease the descending distance. For the long distance crossing project, the number of reaming is closely associated with the geological conditions. With the increasing of hardness of the stratum and size of the product pipeline, the number of reaming operations should be increased.

The type of reamer is selected according to the geological conditions. Generally, the size of the maximum reamer should be 1.2 to 1.5 times of the pipeline's diameter to keep the mud flowing smoothly and ensure the pull back of pipelines safety. In order to reduce the descending tendency of drilling hole, the reamer and drill tools should be optimize to reduce the self-weight on the prerequisite of satisfying the reaming construction. Such measures include: piercing in the stiffeners of reamers to reduce the material of reamers, utilizing the buoyancy force to balance the self-weight by installing a cylinder in the end of reamers, adopting centering device to support the majority of reamer and reduce the offset. When reaming the pilot hole in a stratum with different hardness, slow down the reaming rate to avoid the sticking of the drill tools caused by the uneven rotation of the drill stem.

The mud should be of adequate quantity and proper property to take along the cuttings effectively, reduce the resistance force in the drilling hole and prevent the harmful abrasion in reamer and others drill tools. The ratio between the quantity of mud and the cuttings should be higher than 1:1. The mud is the main guarantee of a successful directional drilling project. No matter in the pilot hole drilling process the reaming period or the pullback operation, the mud usually plays a crucial role. Good performance mud can stabilize the hole, remove soil cuttings and lubricate the drill stem. The performance of the mud directly impacts the efficiency and benefits of the crossing. Optimize the mud formulations by taking into account the methods below. Appropriate amounts of chemical and materials should be added based on the engineering requirements.

Various chemical and materials are added to the drilling fluid to adjust its properties, ensuring that the mud has good rheological behavior, lubrication properties

and capabilities of removing fine gravels and stabilizing the borehole wall. The commonly used mud additives include viscosity increasing agent, stabilizing agent and lubricants. The ratio of mud components vary with different strata. Different strata conditions require different properties of mud. For non-cohesive soil strata (cobblestone strata), the drilling mud is required to remove and handle the soil cuttings, and prevent wastage in high permeability formations, which is especially important to prevent the hole collapse. For cohesive soil strata, the drilling mud is required to clean the drill head or the back reamer, and retard the expansion of the cohesive soil. In order to meet the above requirements, proper bentonite, certain polymers, additives are added to fresh water to produce a mud in fit condition.

In the slanted sections of the pilot hole, to ensure the bit cuttings are effectively removed and the borehole is clean, the water loss of the drilling mud should be controlled, and the hole collapse should be prevented. In this situation, the content of stabilizing agent and viscosity increasing agent should be increased. In the horizontal section of the pilot hole, increase the amount of lubricant promptly, reduce the viscosity and shear force appropriately to ensure the mud has better rheological properties, so that the cuttings can go back to the surface smoothly. As the lubricity of the mud is enhanced, the rotary torque and pull force of drilling can be reduced. In the reaming process, the amount of stabilizing agent, viscosity increasing agent should be increased in order to build up the properties of the drilling mud to prevent the hole from collapsing and shrinking. In the pull back process, in order to improve the lubricity of the mud and reduce friction and enhance the effect of cuttings removal, the amount of viscosity increasing agent and lubricants should be increased.

During the pull back process, pull back may fail in many situations, for instance, the quality of the hole wall is poor, the pilot hole collapses, failure of the universal joint and the clevis occurs, the equipment failure occurs, the anchoring of the drill rig is loose, and the lag phase in the pull back operation is too long for operation breakdown. Large-scale oil and gas pipelines have a longer length, higher self-weight and greater friction between the hole wall and the pipe wall, so the cracking and failure of the pipe will occur when the pilot hole has a large bending and a small diameter. The pull back operation should be determined by following the guidance as below. The pull back equipment should be selected according to the arrangement of the construction site.

The pull back operation should be a continuous operation to avoid collapse and shrinkage of hole which may increase the resistance in the operation or occur balling of drill bit. If the pull force increases rapidly and it is difficult to drag the drill rig back, the power boosters should be used to pull.

The pull-back pipeline should be arranged on the centerline of crossing path. Avoid forming an angle between the drill stem and the pipe in the exit point. If the terrain is relatively flat, dig a ditch for sending pipeline, pour water into the ditch and put the pipeline in the trench before the operation of pull back. When the diameter of the pipe is relatively small, the welded pipeline can be directly put on the roller frame to reduce the friction of pull back operation and protect outside anticorrosion layer of the pipeline. When the diameter of the pipe is relatively large, according to the exit angle, an exit slope should be excavated along the direction of the drill stem. The exit slope can ensure the pipeline is pulled back to the pilot hole precisely.

In general, the mud lost easily. If the leakage happens, the hole would be lack of mud, so the friction between the pipe and hole wall will increase. Finally, it pull-back force should be enhance. Make sure there is mud returning throughout the whole drilling process, which is particularly important for the reaming and pull back construction. The drill mud should be adjusted on time when the hard rock, mud limestone and gravel strata alternate in the same project.

Selection of drilling rig and drilling tool is the key technology of Horizontal direction drill project. The drilling rig and drilling tools should be selected appropriate to complete the crossing construction according to the geological conditions and specific project.

In the construction of the drilling pilot hole, the bottom-hole assembly (BHA) consists of the drill, elbow connection, a non-magnetic drill collar (containing a signal detection probe inside) and the drill stem. When drilling in the ordinary soft strata (soil, sand and silt layer), the common tri-cone drill bit is used. The power of drilling is directly provided by the thrust produced by rig pushing plate and the mud pressure. While drilling in rock formations, an inlay alloy drill bit is required. In this case, the drilling is completed mainly by the thrust produced by rig pushing plate, the torque produced by the rotary motor driven of drill rotation bit and the pressure coming from the drilling fluid. The most commonly used deflecting tools are mud motor and elbow connector. The building rate is determined by the radius of the elbow connector, the stiffness of motor and the hardness of the strata.

The assembly of the drilling tools in the pre-reaming operation consists of the drill stem and the reamers. The assembly of the drilling tools in pipeline pull back

operation consists of the drill stem, the reamers, the pullback universal joint and the product pipeline. The construction of the drilling is mainly completed by the thrust produced by the drilling rig, the rotating torque and the flow rate and pressure provided by the drilling fluid. The heavy weight of the pipeline and the drill stem result in large friction forces between drill stem and formation, therefore, the pull-back force and the torque of drilling rig must be large enough.

To ensure the success of projects, stopping during the drilling construction should be avoided. As the continuous operation time of drill rig is relatively long, good performance of the drill rig is required. Ordinary drill rig and deflecting drill bits can be used in the construction in loose soil. In the construction through hard rock or gravel stratum, drill rigs and drill bits having the capacity of rock-breaking should be chosen.

For large-scale crossing project, as the crossing distance is long, in the construction of the drilling the length and weight of drill stem is very great, and the friction between drill stem and hole wall increases, the required thrust to push the drill stem is large. Generally the diameter of drill stem is small. The stem easily becomes unstable and is damaged under pressure due to excessive bending. Thus, reasonable combination of drilling tool is essential.

In conclusion, the following aspects were highlighted to be paid attention to in order to solve this problem. Increase the diameter of drill stem. The larger the diameter of drill stem is, the greater the stability under pressure will be. The thrust is proportional to the moment of inertia of the drill stem cross section. Install stabilizer on the drill stem; Choose different drill bits for different stratum to prevent sticking of the drill tools.

In “Study on Influence Factors to Application of Large-Scale HDD to Oil and Gas, Pipe Installation,” authors Jiao, Zeng and Ma further discuss Horizontal directional Drilling (HDD) is widely used to install oil and natural gas pipes that have to below rivers and lake areas in China. With low-cost, environment friendly, high-efficiency, HDD is recommended as the first alternative of the West-to-East Natural Gas Transmission Project. However, there are still lots of technology obstacles around large-scale HDD crossing, especially in gravel-cobble strata, soft-hard combining strata, water sensitivity strata. In order to deal with these obstacles and find out the critical factors leading to troubles and failures during HDD crossing, this paper analyzes more than 12 mini cases of oil and gas pipe installation by HDD technology. Six normal troubles and seven potential factors are used to analyze the relationship between troubles and potential factors (Jiao et al, 2011.)

Survey results indicate there are twelve cases in all, seven (7) of them were finished at the first crossing without any failure and 5 of them suffered different failures; however, almost every project have suffered different troubles according to the construction logs. There are six normally directly troubles in HDD project as follow, abnormal torque, abnormal tensile, drill pipe broken, abnormal pressure, flurry leakage and slowly footage which can be obvious by works or manger. While there are some deep reasons that lead to these directly troubles which are considered as the seeds of failure.

In conclusion, this paper discusses twelve HDD crossing cases and analyzed the critical factors leading to the troubles and failures for HDD projects, particularly for large-scale diameter HDD. The two main conclusions can be summarized as follows. First, pipe broken is the major trouble leading to failure. Borehole destabilization, poor cutting transmission and path misalignment are considered as the critical factor of drill pipe

broken, while borehole deformation, disadvantage geological condition and poor design are secondary factors according to the survey and analysis above. Abnormal torque, pull/push force are the commonest troubles during HDD crossing, which may lead to other more severe troubles or failure. Borehole destabilization and deformation are critical factors leading to abnormal torque, while borehole destabilization, disadvantage geological condition and poor cutting transmission shows the critical factors of abnormal pull/push force. Secondly, disadvantage geological condition are considered as the critical factor of flurry leakage and slow footage. Likewise, it is also important factors relative to torque and pull/push force in HDD crossing. Thus, detailed geological survey has to be carried out before design and construction.

The next article discussed in this section presents a highly technical investigation of theoretical modeling for HDD. In “Theoretical Model to Predict Pulling Forces for Horizontal Directional Drilling Installation,” authors Cai, Xu and He present a model for predicting pulling force during pulling back phase in horizontal directional drilling. Comparison of HDD field data and predictions of pulling force indicates that the proposed method is rational. In the application of HDD technology, the prediction of pulling forces is an important research area which provides the basis for the design of crossing project, selection of drill rig, stability evaluation of pipeline during constructing process, and development of drag reduction technology. Supposing that pulling force is a linear function of the installation distance, an empiric coefficient is regressed to predict pulling forces according to field test data (Baumert, 2003). However, it is difficult to obtain resistance coefficients which can be used in wide scope since too many factors affect the pulling force and the cost of HDD experiments is high. In this study, components of the pulling force,



including weight and weight friction of pipe, friction due to directional changes of pilot bore, fluidic drag friction, were calculated separately and summed to get the total pulling force (Cai et al, 2013.)

Based on the theoretical model of pulling force prediction given by Cheng and Polak (2007) (Figure 4.10), this paper presents a new theoretical method to predict forces which develops in three aspects, including: (1) soil described by Winkler model is treated as an elastic body, (2) considering the nonlinear rheological properties of slurry, power law model is used, and (3) the resistance exerted on drill string is considered. A numerical program is coded using language C based on the new method and the accuracy of the model is evaluated by comparison of the pulling force predictions and field data.

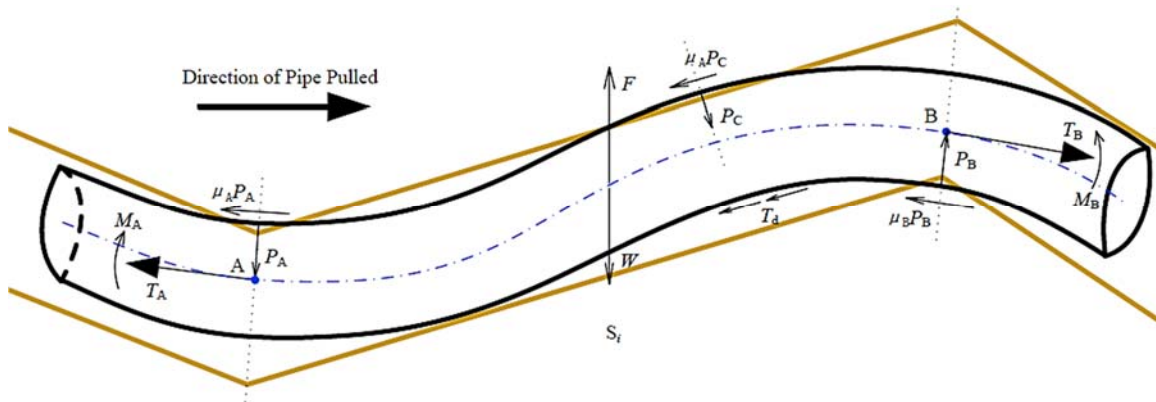


Figure 4.11: Interaction Analysis Between Drill Pipe and Soil (Cai et al, 2013)

The paper concludes that the theoretical model for predicting pulling forces during pulling back phase in horizontal directional drilling installations is built by analyzing four components of pulling force and creating physical models to calculate the corresponding component in the paper. The analytical method develops the method given by Polak et al. in three aspects: (1) the soil is described by Winkler model and it constitutes an elastic support for pipe during pullback, (2) considering the nonlinear rheological properties of

slurry, power law model is used in calculations, and (3) the resistance exerted on drill string is considered and pulling force at carriage is calculated. Except for the weight and weight friction of pipe outside pilot bore and fluidic drag friction, components of pulling force are calculated considering the effect of pipe-soil interaction by two parameters, namely pipe displacement and coefficient of chock effect which represent the displacement of pipe-soil contacting point and the clamping effect of soil on pipe in cross section during pulling back phase, respectively. Comparison of field test data and prediction results shows that the accuracy and reliability of the model is high.

The final article discussed in this section, “Case Studies of Microtunneling Used for Gas Pipeline Crossing in China,” authors Fu, Dong and Li discuss how, in recent years, as there is a large number of pipeline projects in China, microtunneling, as a kind of trenchless method, has been widely used. Although Microtunneling technology has certain advantages in dealing with complex geological and environmental conditions, there also appeared some failure cases due to certain reasons in the process of construction. This paper discusses some typical cases of Microtunneling in recent years in China, analyzes the reasons for the failure and summarizes the solution of the problems encountered in the construction, which can be used as engineering experiences in the future (Fu, Dong and Li, 2012.)

Microtunneling, as a kind of trenchless method, is an alternative of horizontal directional drilling method for pipeline trenchless construction. Compared to HDD, Microtunneling can be used in hard rock and soils with gravel and/or cobbles. For a short distance crossing project, its construction efficiency is higher than shield tunnel method, because it is no need to do segment transportation and installation in the ground. The

second west to east gas pipeline project is the longest pipeline in China at present, which use Microtunneling method several times to cross rock layer rivers in Jiangxi province of China. This paper describes the design and construction condition of these rivers, explains common problems and solutions about Microtunneling crossing.

At present, long distance rivers and rocks Microtunneling crossing project has high requirements of equipment matching and cutter tool applications, although Microtunneling works in good geological conditions has a high success rate in China, it does not indicate our Microtunneling construction technology, equipment and construction experience has been very perfect. Failures in rock Microtunneling project expose huge problems in Microtunneling construction in our country, we cannot take the experiences of ordinary Microtunneling projects directly to the use on the rivers and rocks Microtunneling projects, for the underground water level of rivers and rocks Microtunneling is high, geological conditions is complex, rock hardness is large, lithology characters change a lot, selection of cutter tools is not accurate and some other inherent characteristics, which is the bottleneck of further troubled development of rocks Microtunneling technology.

Therefore, we need to strengthen the equipment selection of the long distance pipe jacking, establishment of construction plan, correction the technique, research works about grouting friction reduction technology and so on, to ensure the success of long distance rivers and rocks Microtunneling in China.

#### **4.6 International Collaboration Efforts**

The final section discussed in this literature review overviews international collaboration efforts in the area of trenchless technologies. Efforts are in this area are relatively new; however, are building strength as general knowledge of trenchless

technologies expands to academics, industries, and the general public in China. In the ASCE publication “U.S.-China Collaborative Research Directions on Trenchless Technology and Critical Underground Infrastructure Issues,” authors Najafi and Iseley stress the importance of addressing the underground infrastructure challenges collectively among international researchers, specifically from the major countries and world powers, where the problems and possible solutions may be addressed. The article emphasized that the role of universities is to bring stakeholders together, provide insights, conduct research, disseminate research findings, facilitate cooperation and development and provide educational opportunities for current and future professionals (Najafi et al, 2008.) Figure 4.11 shows the first participants of the China-U.S. Joint Center for Trenchless Research and Development (CTRD.)



Figure 4.12: Participants of the “China-U.S. Joint Center for Trenchless Research and Development (CTRD)” (Najafi and Iseley, 2008)

This ongoing collaboration originated from combined efforts of the National Science Foundation, The University of Texas at Arlington and the China University of

Geosciences in the form of a workshop to bring together research expertise across various disciplines to utilize best resources relevant to solving underground infrastructure problems. The event provided an opportunity for researchers from both countries to target critical areas specific for each country, and capitalize on local resources. The critical technologies identified by researchers focused on trenchless methods, utility locating, freight pipelines, and asset management. This workshop was an excellent opportunity to address asset management and sustainability of lifeline systems and develop collaboration strategies and joint research programs.

In recent years, faced with the increasing demand for underground utility systems and population growth in urban areas, Chinese government and universities have started many research and development initiatives. The U.S. China Workshop on Trenchless Technologies and Critical Underground Infrastructure Issues was conducted to transfer lessons learned in U.S. and learn from recent Chinese activities. Discussions were broken into two broad areas of “asset management” and “trenchless technologies” and included specific topics such as Technology Transfer, Sustainable Practices, Research and Development Opportunities between China and U.S., Development of Standards and Specifications in U.S. and China, and Sustainable Growth in China and U.S.

Several relevant focus areas established at this conference. With regards to “Technology Transfer,” participants agreed that in both China and the U.S. asset management principles and practices are more mature in the transportation industry (bridges and roadways) than in the underground infrastructure industry especially with public owned facilities. Refer to Table 4.4. It was emphasized by the participants that much differences exist between applying asset management to above ground infrastructure rather

than underground infrastructure. Much of the progress made in the U.S. over the past five years is due to transferring technology from Australia, New Zealand, and other parts of the world. It is very important that programs be established for U.S. and China to work together in developing and applying asset management for water infrastructure. China has adopted many trenchless technology practices from the rest of the world and Chinese manufacturers are now making their own trenchless technology equipment, which is now starting to be exported to other parts of the world.

For “Sustainable Practices,” participants found the major driving force behind trenchless technology and asset management to be sustainability. This allows municipalities to accomplish underground infrastructure needs with minimum disruption and destruction to our society and the environment. This is a global issue and it will be important in future cooperative programs to make sure sustainability is emphasized. It is well understood that asset management involves maximizing the service life of assets. Trenchless technologies provide technical solutions to accomplish maximum service life. In addition, environmental cleanup and sustainability are being taken seriously in China despite the difficulties in balancing economic growth and the high levels of pollution that exist in some areas.

In the area of “Research and Development Opportunities between China and U.S.” it was agreed that there is much need and opportunity for China and the U.S. to establish and maintain a strong working relationship. This is largely due to the fact that much of the future challenges of applying trenchless solutions successfully to expand and maintain our underground infrastructure involve geological engineering, geosciences and geophysics.

Opportunities between China and U.S. Several universities in both China and North America have active research programs related to trenchless technology and many of them were represented in this workshop. A tangible outcome of the workshop was the creation of a China-U.S. Joint Center for Trenchless R&D, initially involving the China University of Geosciences, the University of Texas at Arlington and the Trenchless Technology Center at Louisiana Tech University. There are many opportunities for R&D collaboration based on different site conditions and technology needs and the different stages of development of various trenchless methods in the two countries.

Table 4.4: Workshop Topics (Najafi et al, 2008)

Technology Transfer	Excavation Damage Prevention
Sustainable Practices	Defect Remediation/Repair/Mitigation
Design and Construction for Natural Disasters and their Mitigation	Maintaining the Safety, Security and Reliability of Aging Pipeline Infrastructure
Innovative Materials and Technologies for Underground	Fostering Development of New Technologies and Strengthening Industry Consensus Standards
Policy/Regulatory/Finance/Consumer Aspects	Increasing R&D Funding and Leveraging R&D Resources while Improving R&D Performance
Comparing Urban Planning in China and the U.S.	Improving an Effective Technology Transfer Program Through Stakeholder Communication
Research and Development Opportunities between China and U.S.	The Value of Government/Industry Collaboration in China and U.S.
Key Challenges Facing Industry	Research and Development Success Stories
Damage Prevention in China and U.S.	Infrastructure Asset Inventory in China and U.S.

Direct Assessment/Pipeline Inspection	Development of Standards and Specifications in U.S. and China
Training and Certification of Operators, Engineers, Inspectors and Contractors	Plan for Sustainable Growth in China and U.S.

Finally, in the area of “Key Challenges Facing Industry,” key challenges facing the industry in China include developing the industry at a rapid rate while maintaining adequate quality control to avoid system failures. Damage to existing underground facilities while using HDD is also a significant issue in China. In the North America, key challenges involve improve inspection techniques to provide accurate and cost-effective information for asset management, extending rehabilitation approaches to water distribution systems and improving the ability to create trenchless reconnections for pressure pipe systems. Utility locating and see ahead technologies are also an issue in the U.S.

This article concluded that the workshop made a milestone and made the research directions and future efforts directions clear. After this workshop, China-U.S. Joint Center for Trenchless Research and Development (CTRD) was founded in order to foster continued dialogue and technology transfer between the two countries. Effective collaborations require significant efforts by both international parties to be fruitful and in the research arena are typically most effective with a small number of parties involved in the actual research.

As a follow up to this initiative, an “Update on the U.S.-China Collaborative Research Directions on Trenchless Technology and Critical Underground Infrastructure Issues” was published as part of the 2010 ASCE Annual Pipelines conference. Authors Stift, Najafi, and Ma describe discuss activities at the ASCE Pipeline Division sponsored



follow-up International Conference on Pipelines and Trenchless Technology (ICPTT 2009) in Shanghai. Between 2007 and 2009, several site visits by Chinese and U.S. industries and researchers were arranged. (Stift, Najafi, and Ma, 2010.) It was again emphasized by the participants that much differences exist between applying pipeline technologies in both countries. For example, due to some market entry barriers in the U.S., some materials and technologies may be used in China before they are used in the U.S. A comprehensive technology transfer program, through seminars and workshops, would be an ideal opportunity to address these issues. Technology transfer efforts plans expanded to workshops and seminars which are effective for transferring basic information; however, the process requires a much higher level of commitment from organizers. It would require a long-term mentoring program which must result in organizational developments. This program was accomplished through ASCE Pipeline Division, as described in the following sections.

The ASCE Pipeline Division's vision is to "become the organization that is the world leader for excellence in water, wastewater, oil, gas, and solid pipeline engineering." A summary of the Division's objectives in sponsoring ICPTT 2009 and benefits to the Division were:

- Informed a new international audience of the ASCE Pipeline Division's mission and organizational structure, as well as the work and products developed, including Manual of Practices and other technical publications of the Division's various technical committees
- Encouraged the ICPTT audience to become members of ASCE with focus in the Pipeline Division

- Promoted and solicited papers for the Division's new Journal of Pipeline Systems Engineering and Practices
- Provided a source of income for ASCE Publications in publishing the ICPTT 2009 Proceedings

It was concluded that the inter-connective relationships of the world's economies require collaboration and cooperation if the people of the world are to achieve a safe, reliable, and high quality of life. What started as a dialog between U.S. and Chinese researchers and industry, created the CTRD to collaborate with CURIE to foster continued dialog and technology transfer, and resulted in the highly successful ICPTT 2009 held in Shanghai, China and sponsorship by the ASCE Pipeline Division.

## 5. PROJECT CASE STUDIES

Data collection for this study came in several forms. First of all, a wide collection of existing case studies and technical publications in the area of Maxi-Rig Horizontal Directional Drilling practices both in North America and China were investigated. Significantly more studies dating significantly further back were found using North American sources. The purpose of this survey was to gather as much technical information possible that the HDD market had to offer in order to better compare North American and Chinese HDD construction practices. This data is considered mostly secondary and is used as support to the primary sources.

Two primary sources of data were used for this study and included project questionnaires and most importantly on-site visits to job sites both in China and North America. Two (2) research visits were made to Mainland China. The first visit occurred from May 2013 through June 2013 and totaled six (6) weeks. Figure 5.1 illustrates collaboration team located in Wuhan, China.



Figure 5.1: Research Team at China University of Geosciences -Wuhan

Most time was spent at the China University of Geosciences-Wuhan working with professor and Chinese industry expert Dr. Baosong Ma and his team of graduate students shown above. In addition, one onsite visit was made to the Vermeer Corporation®, an American drill manufacturer company with a manufacturing facility in Beijing. (Figure 5.2)



Figure 5.2: Vermeer® Manufacturing Facilities in Beijing, China

Site visits were made to three (3) large scale projects utilizing trenchless technology methods. The first project was a maxi-rig HDD river crossing located between the cities of Jingjiang and Jiangyin on the outskirts of the Shanghai metropolitan area. This project included installation of three (3) parallel pipelines installed beneath the Yangtze River. The Steel pipelines included one 18” diameter to be used for crude oil transmission) and two

28” diameter to be used for natural gas transmission. This project currently holds the world record large-diameter pipeline greater than 24” installation with an overall length of 10,807’.

The second project was another maxi-rig HDD river crossing located in the countryside outside Jiaozuo City in the Henan Province. This project included installation of two parallel pipelines spanning 6,050’ crossings beneath the Qin River. Each of the two steel pipes measured 40” in diameter to be used for seasonal irrigation to the river valley during the dry season. This project utilized a D-1000 drill rig manufactured by the Chinese manufacturer Lianyungang In-Rig. This one of a kind drill rig is currently the most powerful rig on earth with 2,000,000 lbs. of maximum thrust/pullback force.

The final project that was visited during this trip is not specifically included in the project case studies for this investigation; however, was yet another valuable exposure to Chinese construction projects utilizing trenchless technologies. This visit was to a tunnel project in the City of Zhuhai where CUG faculty and students had participated in the engineering and onsite quality control of an extensive pipe-roofing installation. The project required 32 individual pipes installed using the method of pipe jacking. This portion of the project is part of the overall Hong Kong–Zhuhai–Macau Bridge construction project. Upon completion, it will be the longest sea bridge in the world. Refer to Figure 5.3 and Figure 5.4.

The second visit to Mainland China occurred in October 2013 and totaled three (3) weeks. Time was spent at CUG gathering additional project data, comparing results from the previous visit, and finalizing project data surveys comparing maxi-rig HDD river crossings in china and North America.





Figure 5.3: Hong Kong–Zhuhai–Macau Bridge ([www.zs.gov.cn](http://www.zs.gov.cn))



Figure 5.4: Figure 5.4.: CUG Student Adjacent to Pipe Roofing System

During this visit, additional information was gathered while participating in the ASCE sponsored 4th International Conference on Pipelines and Trenchless Technology (ICPTT) held in Xi'an. Two additional site visits were made to large scale projects utilizing trenchless technology methods. This first visit was a return trip to the Qin River crossing project to witness final pullback operations and meet with the design engineer and construction team. The final trip made was to another maxi-rig HDD river crossing located in an area Northeast of Xi'an in the Shanxi Province. The total length along the drill path 9,688' crossing beneath the Weihe River. This crossing included one (P1)  $\phi$ 10.75" steel pipeline to be used for coal slurry transmission. This crossing was the longest HDD river crossing executed as part of the overall Shenmu-Weinan Coal Transmission Pipeline Project. The Shenmu-Weinan Coal Pipeline Project is of notable interest because it is China's first pipeline of its kind and will eventually be the world's longest coal transportation pipeline.

Upon return to the United States, project questionnaires were distributed to HDD contractors in the United States and completed for notable maxi-rig projects completed in North America. The focus was large scale projects involving projects for energy resource transmission (oil / natural gas / coal slurry) and involving large diameter pipelines. In addition, onsite visits were made to large scale maxi-rig projects in projects in Houston, TX.

The results from the project questionnaires as well as onsite visits comprise the majority of the information presented in the case studies below. The six case studies presented include a comprehensive overview of each of the three maxi-rig projects visited in China as well as three comparable projects that were performed in the United States.

While technical project data including path design, pressure analysis, and fluid composition are included in brevity, the focus of these case studies is on the actual construction methods utilized by the contractors performing the HDD crossings and presents technical information only as supporting information. Refer to Figure 5.5 for case study crossings located in China.



Figure 5.5: Map of Chinese Crossing Case Study Sites



## **5.1 Yangtze River Crossing, Jiangyin City, Jiangsu Province, CN**

### **5.1.1 Company Profile**

China National Petroleum Corporation (CNPC) is a Chinese state-owned oil and gas corporation and the largest integrated energy company in the People's Republic of China. CNPC is the parent of PetroChina, the fourth largest company in the world in terms of market capitalization as of July 2014.

CNPC is a world renowned multinational contractor in the survey, design, consultation, procurement, construction and management of long-distance pipelines and their auxiliaries, as well as medium-to-large storage tank works. CNPC provides Chinese and foreign customers with engineering services for pipelines used to transport different medium such as crude oil, natural gas, refined products, LPG, coal gas, nitrogen, oxygen, water, ethylene, coal and ore slurry, engineering services for oil and gas storage, and technical services for oil and gas storage and transportation, in compliance with Chinese and international standards.

Every year, CNPC constructs more than 3,500 km of pipelines including more than 20 km of crossing pipelines across 30 medium to large rivers using directional drilling. HDD has been utilized on numerous CNPC projects including the West-East Gas Pipeline, Shaan-Jing Gas Pipeline, and Western Crude Pipeline in China, Muglad Basin-Port Sudan Pipeline in Sudan, East-Wes Gas Pipeline in India, and the Far-East Oil Pipeline in Russia, as well as their auxiliary facilities.

### **5.1.2 Project Background**

In July 2013, CNPC successfully completed one crossing of the Yangtze River three parallel pipelines installed using the HDD method. The crossing included one (P1)

φ18” steel pipeline to be used for crude oil transmission and two (P2 & P3) φ28” steel pipelines to be used for natural gas transmission.

The total length for each of these crossings was nearly 11,000’ setting a world record length for a large-diameter pipeline, which is classified as greater than φ24” in diameter. This monumental crossing was one of several crossings of the Yangtze as part of the Jiangdu-Rudong Pipeline Branch of the West–East Gas Pipeline III (third phase) Natural Gas Pipeline Project. Upon completion, this section of natural gas pipeline will serve as the third major natural gas transmission source to the Shanghai metropolitan area.

### **5.1.3 Design and Construction**

Numerous independent subsidiaries CNPC’s division of “Oilfield Services, Engineering & Construction and Equipment Manufacturing” completed design, construction, and testing operations for the project. China Petroleum West-To-East Pipeline Company Pipeline Construction Project Department acted as the owner. China Petroleum Pipeline Engineering Corporation (CPPE) provided services of engineering design, survey, and overall contract management. Finally, China Petroleum Pipeline Bureau Horizontal Directional Drilling Company provided specialty construction services for specifically for Horizontal Directional Drilling (HDD) execution across the Yangtze River.

### **5.1.4 Crossing Details**

The direct path of the HDD crossing was located between the cities of Jingjiang and Jiangyin located Northwest of Shanghai in the Jiangsu Province. The distance between the entry and exit pits for each of the three segments was 10,778’ and the total length along the drill path was 10,807’. The river width at this location is 9,864’ with average depths of

water between 66' to 98' across the region. This specific drill path for this crossing was selected based on continuous silty clay soil conditions at a maximum total depth below the entry point of 141.8'. This depth was selected to ensure the lowest minimum buried depth to the top of the pipe to be 62' below the river bottom under normal conditions. Refer to Figure 5.6 and Table 5.1.

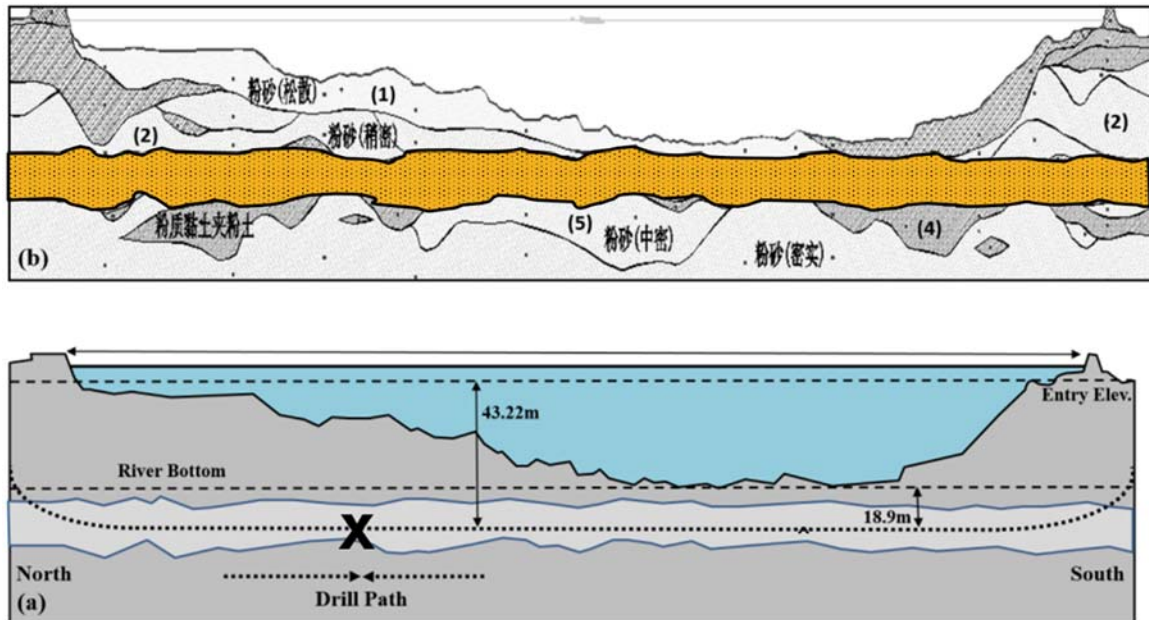


Figure 5.6: Profile View of Soil Conditions (Above) and Drill Path (Below)

Table 5.1: Yangtze River Crossing Project Parameters

Drill Soil Angle (Entry)	10 degrees
Drill Soil Angle (Exit)	8 degrees
Pipe Outer Diameter	(P1) 18", (P2 & P3) 28"
Pipe Wall Thickness	(P1, P2, & P3) 0.81"
Pipe Material	(P1, P2, & P3) L485 LSAW Steel Pipe
Pressure	10 MPa
Anti-Corrosion Protection	Factory Installed Epoxy Powder Coating
Additional Cathodic Protection	Epoxy Glass-Fiber Cloth at Each Weld

### **5.1.5 Safety and Quality Control**

The project foreman for each shift was responsible for the safety of his jobsite and crew. In addition, there is also a full time onsite CNPC safety representative that oversees all project operations. Each safety representative received formal safety training through the China National Petroleum and most often holds a degree from a university. It is unclear what specific training is provided for all other onsite workers. Daily safety meetings are held each at the beginning of each shift to discuss the tasks to be completed each day. For this project, there were particular safety concerns associated with flooding in the area due to recent inclement weather as well as ongoing awareness of project boundaries and access points located nearby swampy and marsh like areas.

CNPC Project supervisors are responsible for quality controlled (QA/QC) associated with HDD operations. Though they had no formal training, experience as well as company protocols were followed at all stages of the HDD operations. Examples of QA/QC for this project included survey monitoring of pilot hole location, depth, and azimuth during installation as well as drilling fluid management. Both the steering and mud records are kept by the driller and drill fluid team in increments of two hours as well as after each drill rod as completed its cycle. Drill performance was also critical and was constantly monitored for torque, pushing and pulling force readings, rotational speeds, and mud pressures. This information was recorded digitally through software and instrument display on the rig. Daily records are prepared by both CNPC Crossings as well as by the CNPC Construction Company. Figure 5.7 illustrates CNPC quality control and safety representatives.



Figure 5.7: CNPC Quality Control and Safety Representatives

### 5.1.6 Construction Approach

The Jiangyin City Planning Board approved a 164' wide pipeline path. The two (2)  $\Phi 28''$  natural gas pipelines were located downstream and the  $\Phi 18''$  crude oil pipeline was located upstream. The two (2) natural gas pipelines were spaced 82' and the crude oil pipeline was spaced 49' downstream of the closest natural gas pipeline. Refer to Figure 5.8 for schematic.

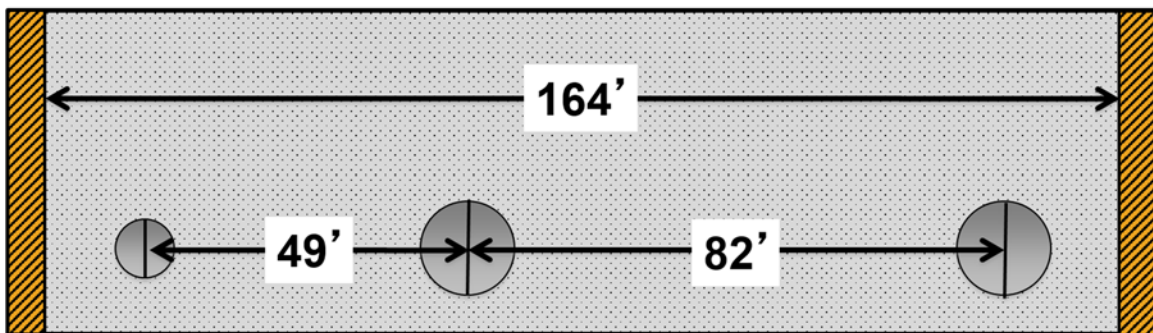


Figure 5.8: Spacing of Buried Pipelines Schematic

Because of the project length, the intersect method was selected as the best execution strategy for the project. Two (2) maxi-size drill rigs were selected. The main drill rig was an American Augers® DD-1100RS (500 Tonnes (1,100,000 lbs) of Maximum Thrust/Pullback Power) as shown in Figure 5.9. The auxiliary drill rig was a DW/TSX DDW-4000 (50 Tonnes (100,000 lbs.) of Maximum Thrust/Pullback Power). The Main Drill was located on the south bank of the river with the Auxiliary Rig located on the north bank of the river. This arrangement was selected due to the availability of the large rice fields on the north side needed for pipe fabrication and welding operations.



Figure 5.9: Main Rig - American Augers® DD-1100RS Drill Rig

The intersect method required extensive coordination between the DD-1100RS Main Rig and DDW-4000 Auxiliary Rig. Some projects that use the intersect method choose a “docking” location that is equal distance from each rig. For this project; however, the intersect location was selected to be 6,562’ away from the main rig along a potential docking area of 328’ long. Refer to Figure 5.10: Plan View of Project Site and Intersect Location. The ParaTrack 2® control system.

Each end of the magnetic signal was located at both the DDW-4000 and a DD-1100RS so that each operator could simultaneously track the drilling progress. Once the auxiliary rig drill reached the target area, it installed a short section of the axial magnet to guide the main DD-1100RS drill rig in order for the connecting of the drill path. Once they were connected, the DD-1100RS drill pipe pulled backed while the DDW-4000 drill rig propelled along the established drill path. Wire layout operations can be seen in Figure 5.11.

A mud recycling system was installed at each drill location. Each system required the construction of natural “mud ponds” and the installation of motorized “mud recovering” equipment. For each side, two (2) mud pits measuring 148’ x 148’ x 6.6’ were installed adjacent to one-another. A custom built German Kante Long Mud Recycling System with a Capacity of 3,785L/min was installed. The system utilized pumps and mud tanks manufactured by the Jiangnan Machinery Company. (Figure 5.12.) Clean water was taken from a well on the South bank of the river.

#### **5.1.6.1 Pilot Hole**

At each end of the drill path, approximately 525’ of  $\phi 14.84'' \times 0.472''$  casing was installed to secure the line of the path at each entry/exit location. (Note: This is much longer than is typically used in this application.) The main drilling rig utilized a  $\Phi 9-7/8''$  tricone bit with a  $\Phi 8''$  mud motor and the non-magnetic drill collar. The selection of drill rods was also unique as several sizes and lengths were combined including 3,281’ of  $\Phi 5-1/2''$  drill pipe, 4,921’ of  $\Phi 6-5/8''$  drill pipe and 2,625’ of  $7-5/8''$  drill pipe. (Note: When asked why a variety of rod sizes were utilized, the response was that the selection was based on what was available for such a long distance.)



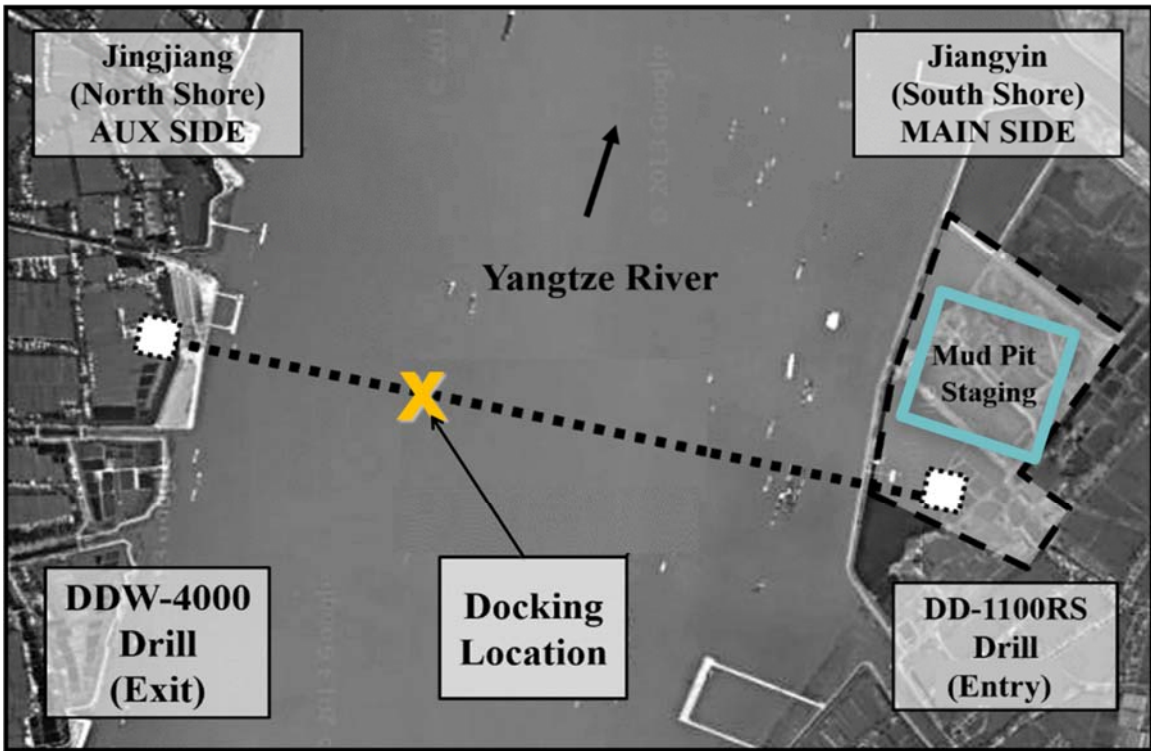


Figure 5.10: Plan View of Project Site and Intersect Location.



Figure 5.11: Onsite Workers Preparing ParaTrack 2<sup>®</sup> Tracing Lines





Figure 5.12: Onsite Mud Recycling System

The auxiliary drilling rig utilized the same  $\Phi 9-7/8$ " Tricone bit with a  $\Phi 8$ " mud motor and the non-magnetic drill collar. 3,281' of  $\Phi 5-1/2$ " drill pipe and 3,281' of  $\Phi 6-5/8$ " drill pipe was used from the north approach.

#### **5.1.6.2 Reaming Operations**

Once the pilot hole was successfully completed, the casing was removed and reaming operations began. For the  $\Phi 18$ " crude oil pipeline, the reaming operations were executed using new  $\Phi 6-5/8$ " S-135 drill pipe and a  $\Phi 26$ " barrel reamer.

For both  $\Phi 28$ " natural gas pipelines, the four levels of reaming operations were executed using new  $\Phi 6-5/8$ " S-135 drill pipe. The first operation utilized a  $\Phi 24$ " barrel reamer. This was followed by a second stage using a  $\Phi 30$ " barrel reamer and a third stage using a  $\Phi 36$ " barrel reamer. The fourth and final reaming stage was completed with a  $\Phi 44$ " barrel reamer and was followed by washing of the hole.

### 5.1.6.3 Pipeline Pullback

For the  $\Phi 18''$  crude oil pipeline, the pullback operation was executed using  $\Phi 6 \frac{5}{8}''$  S-135 drill pipe, a  $\Phi 27.17''$  barrel reamer, a 400 T gimbal, and 10,823' of  $\Phi 18''$  steel pipeline. For the 28'' natural gas pipelines, pullback was executed using  $\Phi 6 \frac{5}{8}''$  S-135 drill pipe, a  $\Phi 42''$  barrel reamer, a 600 T gimbal, and 10,823' of  $\Phi 18''$  steel pipeline. The pullback for all three (3) pipelines was performed as a continuous operation to avoid downtime resulting in increased resistance. Refer to Figure 5.13 for pipe stringing operations and Figure 5.14 for nighttime pullback operations.



Figure 5.13: Pipe Stringing Operations During Final Pullback



Figure 5.14: Nighttime Pullback Operations

#### **5.1.6.4 Post Construction**

Post construction operations were left to the responsibility of the CNPC Prime Contractor. Once the final pipeline testing was confirmed adequate, each of the two drill rigs was demobilized. After the HDD equipment and spare parts were removed, the set was left to be graded. Remaining drill fluid was disposed of according to local regulations.

#### **5.1.7 Worker Information**

Table 5.2 as shown above for crew breakdown. There were four crews total, one for each rig and for both the day and night shift. All crew members received wages in the magnitude of 12,000 RMB per month with the welding crew receiving 14,000 RMB per

month. Wages were paid on a monthly basis and hours typically ranged from 340-370 hours per month. This is based on workers working 12 hours per day seven hours per week.

Table 5.2: Onsite Worker Breakdown

Positions / jobs	#	Positions / jobs	#
Machine Leader	1	Operator	2
Steering	2	Rigger	2
Driller	3	Cook	1
Mud	4	Driver	3
Repair	2	Materials, staff	1
Electrician	2	Drill work	4
Electric welder	1	General workers	16
Crew Total			44
Machine Leader	1	Operator	2
Steering	2	Rigger	2
Driller	2	Cook	1
Mud	2	Driver	2
Repair	2	Materials, staff	1
Electrician	2	Drill work	3
Electric welder	1	General workers	18
Crew Total			41
Total Onsite Workers			85

All meals and board were provided to the workers. CNPC employed one full time cook per crew that was responsible for food preparation and clean-up for three meals per day. Housing for this project was acquired through the rental of local homes in the nearby area. In addition, each work was supplied with two changes of uniforms, a hard hat, and work boots as part of CNPS's standard required uniform.

### **5.1.8 Project Challenges**

The major challenge associated with this crossing was the length. Because the distance of the crossing was so long and deep below the river bottom, there was an increased risk of hydraulic fracture. The main steps used to avoid difficulties during the drilling of the pilot hole was the use of the intersect method which reduced pressure within the bore hole and the utilization of an extensive on-site fluid management system. CNPC employed a team of fluid engineers to monitor fluid returns at all times during crossing operations.

There was also risk associated with the pipe pullback. Because the product pipe was not able to be continuously welded, it required three welds to occur during product pullback. Once product pullback is started, it is ideal to perform the pullback continuously with no stoppage. This is due to the fact that there is a high risk for the pipeline to get “stuck” during times of welding during pullback. In this case, there were no issues due to again the close monitoring of the fluid properties.

### **5.1.9 Schedule and Results**

The original project schedule included 274 working days, which included all site preparation, pipe fabrication, drilling operations, and site restoration. The actual work was completed within this time frame. The construction of the third pipeline ( $\Phi 711$  (28”) natural gas) started on June 8, 2013 and was completed on July 27, 2013. The mobilization time for the drills rigs and pilot hole completion took a total of 23 days starting on June 9th, 2013 and completing on July 1st, 2013. Reaming operations started on July 4th, 2013 and were completed also 23 days later on July 26th, 2013. During this time, welding operations were completed starting on May 21, 2013 and were completing two (2) months

later on July 25, 2013. Pullback for the product pipe were started late in the day on July 26th, 2013 and took a total of 30 hours to complete. Pullback was completed with no issues. The average pullback force achieved during pullback was 120 Tons with a maximum pullback force of 160 Tons. Overall, the drilling operations were successful at steering along the design profile. Because of the structure of the stakeholders for this project, the initial design profile was adjusted to actual drill profile after completion.



## **5.2 Weihe River Crossing, Weinan, Shanxi Province, CN**

### **5.2.1 Company Profile**

China National Petroleum Corporation (CNPC) is a Chinese state-owned oil and gas corporation and the largest integrated energy company in the People's Republic of China. CNPC is the parent of PetroChina, the fourth largest company in the world in terms of market capitalization as of July 2014.

CNPC is a world renowned multinational contractor in the survey, design, consultation, procurement, construction and management of long-distance pipelines and their auxiliaries, as well as medium-to-large storage tank works. CNPC provides Chinese and foreign customers with engineering services for pipelines used to transport different medium such as crude oil, natural gas, refined products, LPG, coal gas, nitrogen, oxygen, water, ethylene, coal and ore slurry, engineering services for oil and gas storage, and technical services for oil and gas storage and transportation, in compliance with Chinese and international standards.

### **5.2.2 Project Background**

In December 2013, CNPC once again completed a remarkable HDD river crossing of the Weihe River in an area Northeast of Xi'an in the Shanxi Province. This crossing included one (P1)  $\phi 10.75''$  steel pipeline to be used for Coal Slurry transmission. Coal slurry is typically an equal part combination of fresh water and pulverized coal that allows effective transmission of coal over long distances. Coal slurry has been proven to be more economic for initial construction and operation when compared to railway transportation. In addition, pipeline transmission is more environmentally responsible method than above ground railway and trucking methods.

This crossing was the longest HDD river crossing executed as part of the overall Shenmu-Weinan Coal Transmission Pipeline Project. The Shenmu-Weinan Coal Pipeline Project is of notable interest because it is China's first pipeline of its kind and will eventually be the world's longest coal transportation pipeline. Upon completion, the 748Km (465Mi) pipeline will reach a coal handling capacity of 10 million tons annually. The pipeline originates in the Hong Liulin Mine located in the north area of Shanxi Province in the Guanzhong region. Thus, the project was also a key infrastructure construction project outlined by the "12th Five-Year Plan" in Shanxi province.

### **5.2.3 Design and Construction**

The overall stakeholder and contracting structure for this project differed from CNPC's internally based structure even though CPNC is the majority investor. In this case, the Shanxi Zhenwei Coal Pipeline Transportation Company, an independent contractor from CNPC acted as the owner. The Hubei-based Wuhan Institute of China Coal Science and Technology (Wuhan, Hubei, CN) was responsible for engineering, procurement and construction management. China Petroleum Pipeline Bureau (CPPB) again provided general contracting services for the overall length of the pipeline and China Petroleum Pipeline Bureau Horizontal Directional Drilling Company provided specialty construction services specifically for HDD execution across the Wei River crossing.

### **5.2.4 Crossing Details**

The crossing point is located at the Weihe River located within the city limits of Weinan, Shanxi. The distance between the entry pit and exit pit was 9,672' and the total length along the drill path was 9,688'. The maximum depth of the river is approximately 46'. The specific drill path for this crossing was selected at a maximum total depth below



the entry point of 105'. This depth was selected to ensure the lowest minimum buried depth to the top of the pipe to be 59' below the river bottom under normal conditions. In addition, favorable soil conditions at this depth included fine sand and clay. Additional Project Parameters are presented in Table 5.3.

Table 5.3: Weihe River Crossing Project Parameters

Drill Soil Angle (Entry)	10 degrees
Drill Soil Angle (Exit)	8 degrees
Pipe Outer Diameter	(P1) 6 1/4", (P2) 10 3/4"
Pipe Wall Thickness	.28"
Pipe Material	L450M PSL2 PIPE Steel Pipe
Pressure	1,291 PSI
Anti-Corrosion Protection	Factory Installed Epoxy Powder Coating
Additional Cathodic Protection	Epoxy Glass-Fiber Cloth at Weld Locations

### 5.2.5 Safety and Quality Control

The project foreman for each shift was responsible for the safety of his jobsite and crew. In addition, there is also a full time onsite CNPC safety representative that oversees all project operations. Each safety representative received formal safety training through the China National Petroleum and most often holds a degree from a university. It is unclear what specific training is provided for all other onsite workers. Daily safety meetings are held each at the beginning of each shift to discuss the tasks to be completed each day. For this project, there were particular safety concerns associated with wet conditions onsite and slippery platform areas.

CNPC Project supervisors are responsible for quality controlled (QA/QC) associated with HDD operations. Though they had no formal training, experience as well as company protocols were followed at all stages of the HDD operations. Examples of QA/QC for this project included survey monitoring of pilot hole location, depth, and azimuth during installation as well as drilling fluid management. Both the steering and mud records are kept by the driller and drill fluid team in increments of two hours as well as after each drill rod as completed its cycle. Drill performance was also critical and was constantly monitored for torque, pushing and pulling force readings, rotational speeds, and mud pressures. This information was recorded digitally through software and instrument display on the rig. Daily records are prepared by both CNPC Crossings as well as by the CNPC Construction Company. Figure 5.15 illustrates quality control testing equipment for drill fluid monitoring.



Figure 5.16: Quality Control Testing Equipment for Drill Fluid Monitoring

## **5.2.6 Construction Approach**

The  $\phi 10.75''$  coal transmission pipeline was located 49' downstream of a  $\phi 6.25''$  electrical casing that was installed consecutively. The intersect method was also selected for the project and utilized (2) two different maxi-size drill rigs than the Yangtze Crossing. The main drill rig was a Shanghai Goodeng GD5000-LL Drill Rig (550 Tonnes (1,146,500 lbs.) of Maximum Thrust/Pullback Power) as shown in Figure 5.16. The auxiliary drill rig was a Shanghai Goodeng GD3500D-L Drill Rig (365 Tonnes (805,000 lbs.) of Maximum Thrust/Pullback Power).

The Main Drill was located on the south bank of the river with the Auxiliary Rig located on the north bank of the river. For this project, the intersect location was selected to be 5,906' away from the main rig and 3,937' from the auxiliary rig. The ParaTrack 2<sup>®</sup> control system was again utilized for tracking for this crossing.

A mud recycling system was installed at each drill location and included natural "mud ponds" at each drill site. The ponds that were utilized for this project were much smaller than the ones used for the Yangtze crossing. The ponds acted as mud storage and recirculation to a custom built Linear Motion Shale Shaker Model-BWZS85-2P and silt removal system produced by Xi'an Brightway Energy Machinery Equipment Company which was located on the main drill side (Figure 5.17).

### **5.2.6.1 Pilot Hole**

Casing was installed to secure the line of the path at each entry/exit location. This included 230' at the Main Side and 164' at the Exit Side. The main drilling rig utilized a  $\Phi 9-7/8''$  tri-cone bit with a  $\Phi 6-3/4''$  mud motor and the non-magnetic drill collar.



Figure 5.17: Main Rig - Shanghai Goodeng GD5000-LL Drill Rig



Figure 5.18: Overhead View of Custom Fluid Recycling System

The selection of drill rods was also unique as several sizes and lengths were combined including 1,434' of  $\Phi 5\text{-}1/2$ " drill pipe and 5,784' of  $\Phi 6\text{-}5/8$ ". The auxiliary drilling rig utilized the same  $\Phi 9\text{-}7/8$ " tri-cone bit with a  $\Phi 6\text{-}3/4$ " mud motor and the non-

magnetic drill collar. Only 3,126' of  $\Phi 6\text{-}5/8$ " drill pipe was used from the north approach.

#### **5.2.6.2 Reaming Operations**

Once the pilot hole was successfully completed, the casing was removed and reaming operations began. Reaming operations were executed using  $\Phi 6\text{-}5/8$ " S-135 drill pipe and a  $\Phi 18$ " plate reamer.

#### **5.2.6.3 Pipeline Pullback**

The pullback operation was executed using  $\Phi 6\text{-}5/8$ " S-135 drill pipe, a  $\Phi 18$ " plate reamer, a 400 T gimbal, and 9,688' of  $\phi 10.75$ " steel pipeline.

#### **5.2.6.4 Post Construction**

Post construction operations were left to the responsibility of the CNPC Prime Contractor. Once the final pipeline testing was confirmed adequate, each of the two drill rigs was demobilized. After the HDD equipment and spare parts were removed, the set was left to be graded. Remaining drill fluid was disposed of according to local regulations.

#### **5.2.7 Worker Information**

All crew members received wages in the magnitude of 12,000 RMB per month with the welding crew receiving 14,000 RMB per month. Wages were paid on a monthly basis and hours typically ranged from 340-370 hours per month. This is based on workers working 12 hours per day seven hours per week.

All meals and board were provided to the workers. CNPC employed one full time cook per crew that was responsible for food preparation and clean-up for three meals per day. Housing for this project is unknown. In addition, each work was supplied with two changes of uniforms, a hard hat, and work boots as part of CNPS's standard required uniform.

### **5.2.8 Project Challenges**

The major challenge associated with this crossing was again the length. Because the distance of the crossing was so long and deep below the river bottom, there was an increased risk of hydraulic fracture. The main steps used to avoid difficulties during the drilling of the pilot hole was the use of the intersect method which reduced pressure within the bore hole and the utilization of an extensive on-site fluid management system. CNPC employed a team of fluid engineers to monitor fluid returns at all times during crossing operations.

### **5.2.9 Schedule and Results**

The execution of the Weihe River crossing section started on September 15<sup>th</sup>, 2013. Site preparation, rig mobilization, pipe pre-fabrication and welding, and the installation of the adjacent electrical casing lasted until November 6<sup>th</sup>, 2013. For the  $\phi 10.75''$  coal slurry pipeline, drilling of the pilot hole started on November 7<sup>th</sup>, 2013 and was completed 24 days later on December 2<sup>nd</sup>. Reaming operations started on November 21<sup>st</sup> and were completed 8 days later on November 28<sup>th</sup>, 2013. Pullback for the product pipe started on November 30<sup>th</sup>, 2013 and took a total of 28 hours to complete. Pullback was completed with no issues. The average pullback force achieved during pullback was 105 Tons with a maximum pullback force of 143 Tons. Overall, the drilling operations were successful at steering along the design profile. China Petroleum Pipeline Bureau Horizontal Directional Drilling Company began demobilization on December 2<sup>nd</sup>, 2013 and all remaining site restoration and pipeline tie-ins were taken over by the China Petroleum Pipeline Bureau (CPPB) construction team.



### **5.3 Qin River Crossing, Zhengzhou, Henan Province, CN**

#### **5.3.1 Company Profile**

Trenchless Mechanical Engineering Company Limited (Hebei Heng Shui Hong Tai, TME) was founded in 1998 and has a registered capital of 20 million Yuan. TMEC has built a professional team consisting of 68 senior managers, 26 senior professional technicians, more than 30 project managers, and more than 360 additional construction professionals.

TME's mission "focuses on contract, reputation, quality and safety," which has earned high praise from many project partners as the company as the company has gradually become a leader in Chinese trenchless construction enterprises. The company adheres to the concept of "elite worldwide equipment, first-class technology, top-notch quality, excellent management and rewarding honor."

#### **5.3.2 Project Background**

In October 2013, TME successfully completed one crossing of the Qin River with two parallel pipelines installed using the HDD method. The crossing included two (P1 & P2)  $\phi 40$ " steel pipelines to be used for irrigation to the riverbed during dry planting seasons.

The total length for each of these crossings was nearly 6,038'. This is a great distance for a large-diameter pipeline, which is classified as greater than  $\phi 24$ " in diameter. This project utilized a D-1000 drill rig manufactured by the Chinese manufacturer Lianyungang In-Rig. This one of a kind drill rig is currently the most powerful rig on earth with 2,000,000 lbs. of maximum thrust/pullback force. Specialized drill rods were required which were manufactured in the United States at a purchase cost of over \$5,000,000. Integrity in the drill rods was critical in order to meet the tensile capabilities of the drill rig.

### 5.3.3 Design and Construction

Trenchless Mechanical Engineering Company Limited was selected as the HDD contractor based on low bid. Jiaozuo City Water Conservancy Bureau was the project owner. Henan Water & Power Engineering Consulting Company acted as the design engineer and was contracted through Jiaozou City. (See Figure 5.18 for a photograph of onsite engineering discussions.) In addition, TMEC hired a third party consulting engineer that assisted with tooling design and fabrication, construction approach, and troubleshooting. Jiaozou City was responsible for final design signoff.

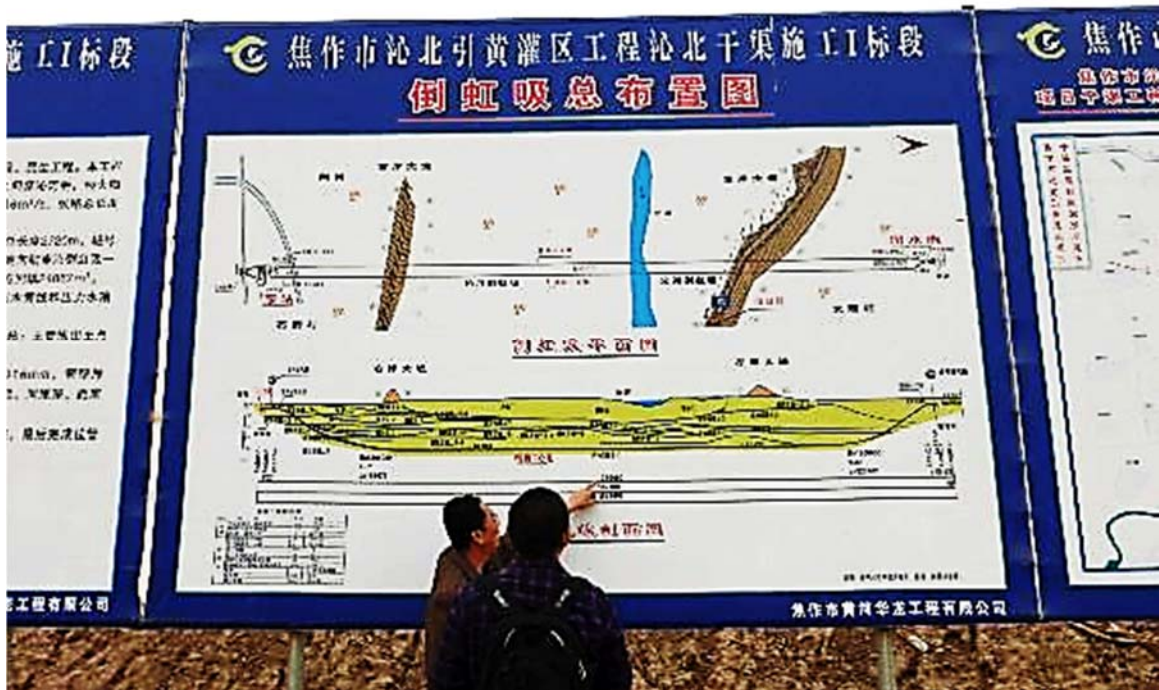


Figure 5.19: CUG Student and Engineering Consultant Reviewing Drill Path

### 5.3.4 Crossing Details

The direct path of the HDD crossing was located in the countryside outside of Jiaozuo City in Henan Province. The project site located in the Yellow River and Qin River alluvial plain. Qin River is a wide and shallow wandering river crossing this project area



from west to east. The major riverbed width is 426', and the riverbed elevation is 320.8'. During the flood season, water levels are elevated in part due to extensive levee systems that control the path of the river. During the dry season, the riverbed is virtually empty and is utilized for farmland. The construction stratum is Quaternary alluvial deposit. The geological survey report shows that the south bank of the river swing frequent, and the north shore of the river activity is weak. The soil conditions are comprised mostly of silt, sandy loam and silty loam. The groundwater is Quaternary loose bed pore water, mainly feed by rain and groundwater flow. The river water is a kind of brackish water, and the groundwater is a kind of fresh water. The groundwater has a slight corrosion on steel. Project parameters are presented below in Table 5.4.

Table 5.4: Qin River Crossing Project Parameters

Drill Soil Angle (Entry)	10 degrees
Drill Soil Angle (Exit)	8 degrees
Pipe Outer Diameter	(P1 & P2) 40"
Pipe Wall Thickness	(P1 & P2) 0.81"
Pipe Material	(P1 & P2) Unspecified Steel Pipe
Pressure	10 MPa
Anti-Corrosion Protection	Factory Installed Epoxy Powder Coating
Additional Cathodic Protection	Unknown

The distance between the entry and exit pits for P1 was 5,778' and P2 was 5,843' respectively. The total length along the drill path for each crossing was 6,370'. The total

depth below the entry point of 108.9'. This extreme depth was selected to ensure minimum buried depth to the top of the pipe to be fully covered under flood and scouring conditions.

### **5.3.5 Safety and Quality Control**

The TME project foreman for each shift was responsible for the safety of his jobsite and crew. As seen in Figure 5.19, there is also a full time onsite safety representative from the local city authority as well as the contractor that oversees all project operations. It is unclear what specific training is provided for all other onsite workers. Daily safety meetings are held each at the beginning of each shift to discuss the tasks to be completed each day. For this project, there were particular safety concerns associated with flooding in the area due to recent inclement weather as well as ongoing awareness of project boundaries and access points located nearby swampy and marsh like areas. In addition, the exit side of the crossing is located adjacent to the ongoing construction of a pump station requiring a small town crane. Workers are in close proximity to one another which presents possible challenges with workspace and equipment positioning.

Both the Jiaozuo City Water Conservancy Bureau and Henan Water & Power Engineering Consulting had full time quality controlled (QA/QC) present during HDD operations. Daily records were prepared by both Laney as well as by the third party drilling fluid engineer and submitted to both the owner and engineer.

### **5.3.6 Construction Approach**

The two (2)- $\Phi$ 40" water lines were spaced approximately 50' apart. The total jobsite work area is approximately 262' x 328'. See Figure 5.20 for illustration.



Figure 5.20: Onsite Safety/Inspection Professional

For this case, only one (1) maxi-size drill rig was initially were selected. The main drill rig was a D-1000 drill rig manufactured by the Chinese manufacturer Lianyungang In-Rig. This one of a kind drill rig is currently the most powerful rig on earth with 2,000,000 lbs. of maximum thrust/pullback force. (Figure 5.21.) The first pipe (P1) was installed successfully. The second pipe; however, had issues with the borehole collapsing. A second rig was brought in to intercept the original bore path beyond the point of collapse to perform final pullback. This secondary rig was D-280 also manufactured by the Chinese manufacturer Lianyungang In-Rig. This rig had approximately 280 tons of maximum thrust/pullback force. (Figure 5.22.)

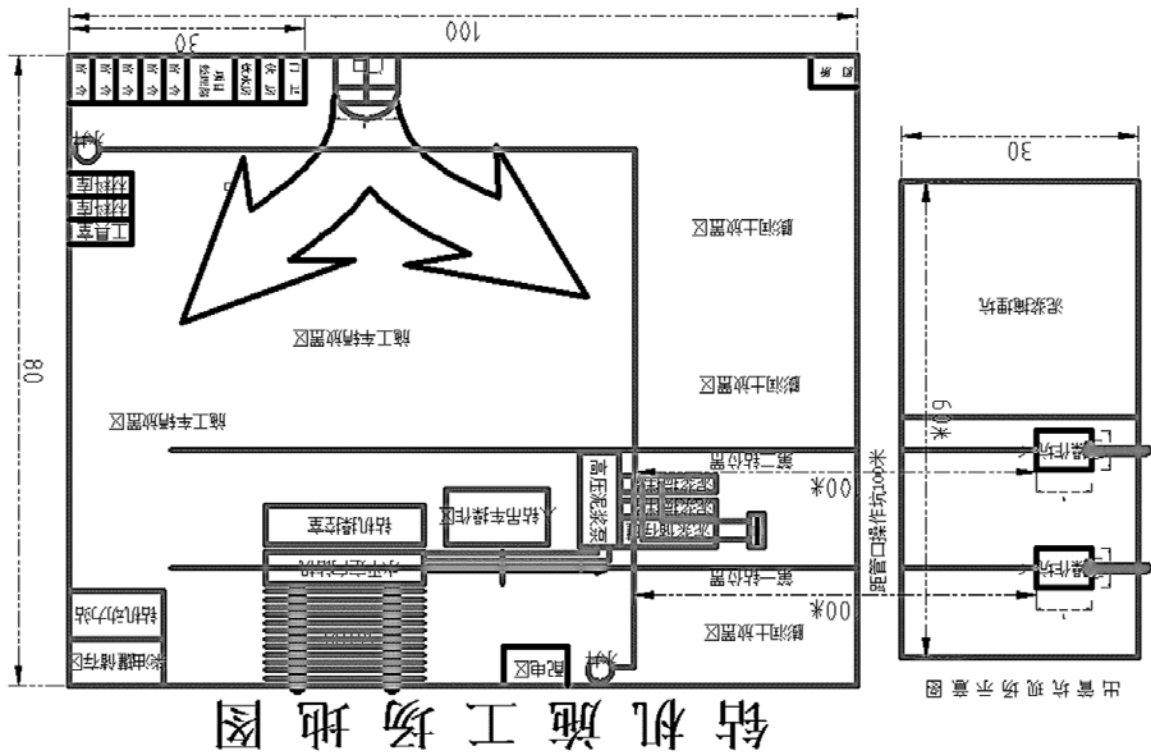


Figure 5.21: Jobsite Layout



Figure 5.22: Chinese Manufactured Lianyungang In-Rig Drill Rig





Figure 5.23: Auxiliary Drill Rig Located on Exit Side

The ParaTrack 2<sup>®</sup> control system and the magnetic signal were located at both the entry and exit to simultaneously track the drilling progress. Though this was not the first time the company had utilized the system, representatives from INROCK<sup>®</sup> performed onsite training for the workers. Refer to Figure 5.24 for steering unit.

A mud recycling system was installed at both the entry and exit sides. Each system required the construction of natural “mud ponds” and the installation of motorized “mud recovering” equipment. These ponds were located a distance away from the rig and mixing equipment, therefore, a sophisticated system of both pumping pipes as well as travel canals were built to maintain a complete fluid system. (Figure 5.23)

### 5.3.6.1 Pilot Hole

At the entry side, approximately 1,600' of  $\phi 12 \frac{7}{8}'' \times .472''$  casing was installed to secure the line of the path at each entry. (Note: This is much longer than is typically used in this application.)



Figure 5.24: Custom Built Fluid Mixing Tanks



Figure 5.25: Pilot Hole Steering Unit

The main drilling rig utilized a custom built  $\Phi 12\text{-}1/4$ " tricone bit with a  $\Phi 7$ " mud motor and the non-magnetic drill collar. The selection of drill rods included all custom built  $\Phi 6\text{-}5/8$ " drill pipe that was manufactured in this United States. This was done to ensure the tensile strength of the drill rods were of a high quality so that there was less risk associated with the possibilities of drill spin off during any off the HDD operations.

#### **5.3.6.2 Reaming Operations**

Once the pilot hole was successfully completed, the casing was removed and reaming operations began. Three levels of reaming were performed for each pipe. The first level was a 36" pass, followed by a 48" pass (Figure 5.25), and finally concluding with a 60" pass. The three reaming tools utilized were all custom carbide barrel reamers that were designed and built by the design team. In addition, a complete swab pass were performed at the end of each reaming operation to clean the hole and remove any remaining cuttings or debris that were not removed with the drilling fluid.

#### **5.3.6.3 Pipeline Pullback**

The pullback for both pipelines was performed as a continuous operation to avoid downtime resulting in increased resistance. The first pipeline was pulled successfully the first time. The second pipeline was also successfully pulled once the bore path was redefined using the secondary drill rig.

#### **5.3.6.4 Post Construction**

Upon completion of final pullback, final pipe testing was completed by the general contractor. Final pipe testing included use of a caliper pig and hydrostatic test. In addition, a hydrostatic test was performed which was completed successfully. Eventually, all site



conditions were restored to conditions similar to before construction began. Excess drilling fluid was disposed of using the land farming method to the river valley.



Figure 5.26: 48” Reaming Unit

### 5.3.7 Worker Information

All crew members received wages in the magnitude of 12,000 RMB per month. Wages were paid on a monthly basis and hours typically ranged from 340-370 hours per month. This is based on workers working 12 hours per day seven hours per week.

All meals and board were provided to the workers. TME employed one full time cook per crew that was responsible for food preparation and clean-up for three meals per day. Housing for this project was rented by the City of Jiaozou from local farms. In addition, each work was supplied with two changes of uniforms, a hard hat, and work boots



as part of CNPS’s standard required uniform. Figure 5.26 illustrates onsite crew wearing appropriate personal protective equipment.



Figure 5.27: Onsite Workers During Recovery Operations

### 5.3.8 Project Challenges

The Qin River Crossing, as do many large-scale HDD crossings, had its challenges. Because of the soil conditions, Liquefaction of saturated sand was an ongoing problem that contributed to the collapse during pipe 2 installation. In addition, drainage of foundation pit and seepage failure also contributed along with slope stabilization. These conditions combined contributed to fluid loss, bore hole collapse, and collapse pit. In addition, inclement weather played a part in onsite delays during all phases of the HDD execution.

### **5.3.9 Schedule and Results**

The original project schedule was delayed from the start due to extensive coordination effort delays as well as fluctuations in the wet and dry seasons. Once started, actual construction proceeded relatively quickly even with challenges associated with the completion of pipeline 2. For pipeline 2, pilot hole operations started on August 8<sup>th</sup> and completed on August 9<sup>th</sup>. Each of the three reaming passes was completed in three (3) days followed by one full day of hole cleaning. Finally, pipeline pullback started on September 1<sup>st</sup> 2013 and completed on September 3<sup>rd</sup> 2013. Overall, the drilling operations were successful at steering along the design profile. Because of the structure of the stakeholders for this project, the initial design profile was adjusted to actual drill profile after completion.

## **5.4 Yangtze River Crossing, Wuhan City, Hubei Province, CN**

### **5.4.1 Company Profile**

China National Petroleum Corporation (CNPC) is a Chinese state-owned oil and gas corporation and the largest integrated energy company in the People's Republic of China. CNPC is the parent of PetroChina, the fourth largest company in the world in terms of market capitalization as of July 2014.

### **5.4.2 Project Background**

*This project case summary has been adapted from the publication “High-Risk, 610mm Diameter, 2,090m HDD Project-A Case Study.” (Li et al, 2013)*

In September 2010, CNPC successfully completed one crossing of the Yangtze River which included one (P1)  $\phi 24$ ” steel pipeline to be used for crude oil transmission. The total length for this crossing of the Yangtze River near Wuhan, Hubei was nearly 11,000’. This crossing is part of the overall Lanzhou-Zhengzhou-Changsha Pipeline Project, which is a main transmission line to the Hubei and Hunan provinces.

For this project, the main geological formation encountered in the crossing section was cemented rock. Naturally, conglomerate is very hard, having a compression strength can be up to 8,600psi. On the contrary, glutenite is easily fractured, possessing a minimum compressive strength only is 20psi. Conditions along the drill path transmission from hard to soft frequently, therefore the geological investigation identified 12 potential fracture zones where the geology was extremely complicated and the risk during the construction was very high. Thus, this project is one of the most difficult HDD crossing projects in the world.

### **5.4.3 Design and Construction**

Numerous independent subsidiaries CNPC's division of "Oilfield Services, Engineering & Construction and Equipment Manufacturing" completed design, construction, and testing operations for the project. China Petroleum Pipeline Engineering Corporation (CPPE) provided services of engineering design, survey, and overall contract management. The China Petroleum Pipeline Bureau Horizontal Directional Drilling Company provided specialty construction services for specifically for Horizontal Directional Drilling (HDD) execution across the Yangtze River. Starting in January 2010, CPPE began engineering and CNPC required that the crossing should be completed at the end of December 2011. Thus, the total time for investigation, design and construction was 24 months.

### **5.4.4 Crossing Details**

The Yangtze River adjacent to the crossing section has a U shape bend with the riverbed higher at the South bank and lower at the North bank. The elevation of riverbed surface ranges from -14.1' to -19.7'. During initial site investigation, the water level was 34.2' and the depth ranged from 47' to 55'. The slope at the north side is gentle, decreasing at about 2 degree. The riverbed surface at the south side slopes to the north, decreasing at about 3 degrees. Figure 5.27 illustrates the design profile section of the crossing.

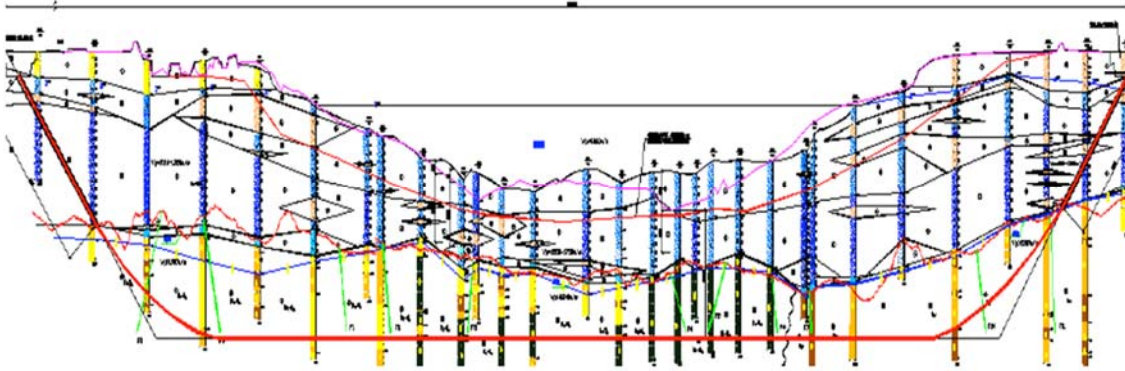


Figure 5.28: Profile Section of Crossing (Li et al, 2013)

The main exposed formation of the covering layer is silty sand and silty clay, distributing at both sides but discontinuous. The medium layer is silty fine sand and fine sand with the pebble bed in between. The under layer is argillaceous sandstone, glutenite and conglomerate, distributing discontinuously. Wherein, the cemented stone is massive structure and mainly is round in shape. The content of gravel is not even, normally from 40% to 60%. The main components of the hard conditions include limestone, sandstone and quartz etc. with the normal particle size ranging from .20” to .79” with larger particle sizes reaching 2.76”. The medium size of conglomerate is mainly composed of round gravel and pebble with the normal particle size from .20” to 1.57” with larger particle sizes reaching up to 3.94”. The particle shape is mainly angular and the content is about from 50% to 60% bound together by muddy cementation.

Because the boundary condition of the river section where the project located, the watercourse was generally controlled. The alternatively change of scouring and silting is obvious and the slope scouring is comparatively larger. For the beach, the maximum elevation change was about 9.8’ and for the main riverbed was is about 39.4’.

According to the geological datum, the maximum scouring depth at the crossing section is 39.4' while the crossing curve should be 19.69' below the scouring line. Land clearance is made for the site at south bank as the entry point of head rig while the entry point of auxiliary rig is selected at north bank. The selected entry angle was 16 degree and the exit angle was 14 degree. The radius of curvature for the elastic laying of this crossing is 36'' (1500D). The thickness of covering layer at north bank is about 131' and that at the south bank is about 121'. The path of the crossing selected had a maximum total depth below the entry point of 246'. Refer to Table 5.5.

Table 5.5: Yangtze River Crossing Project Parameters

Drill Soil Angle (Entry)	16 degrees
Drill Soil Angle (Exit)	14 degrees
Pipe Outer Diameter	(P1) 24''
Pipe Wall Thickness	(P1) Unknown
Pipe Material	(P1) API 5L X65
Pressure	8 MPa
Anti-Corrosion Protection	Likely
Additional Cathodic Protection	Unknown

#### 5.4.5 Safety and Quality Control

Based on previous case studies, it is assumed that the project foreman for each shift was responsible for the safety of his jobsite and crew. In addition, there was also a full time onsite CNPC safety representative that oversees all project operations. Based on company policies, each safety representative most likely received formal safety training through the China National Petroleum and most often holds a degree from a university.

Daily safety meetings are held each at the beginning of each shift to discuss the tasks to be completed each day.

CNPC Project supervisors were most likely responsible for quality controlled (QA/QC) associated with HDD operations. Industry standards examples of QA/QC for most likely included survey monitoring of pilot hole location, depth, and azimuth during installation as well as drilling fluid management. Both the steering and mud records are typically kept by the driller and drill fluid team in increments of two hours as well as after each drill rod as completed its cycle. Drill performance was also critical and was constantly monitored for torque, pushing and pulling force readings, rotational speeds, and mud pressures. This information is most often recorded digitally through software and instrument display on the rig. Daily records are prepared by both CNPC Crossings as well as by the CNPC Construction Company.

#### **5.4.6 Construction Approach**

Because of the project length, the intersect method was selected as the best execution strategy for the project. Two (2) maxi-size drill rigs were selected. The main drill rig was a 200 Ton Maximum Thrust/Pullback Power machine and the auxiliary drill rig was a 450 Ton Maximum Thrust/Pullback Power machine. The Main Drill was located on the south bank of the river with the Auxiliary Rig located on the north bank of the river. This arrangement was selected due to the availability of the large rice fields on the north side needed for pipe fabrication and welding operations.

The space required at the south side for placing all of the rig equipment, drill pipe, bentonite and mud tank resulted in an occupied site area is about 262' x 262'. Refer to Figure 5.28 for entry side set-up. The rig located at the South bank was a 200 ton piece of

equipment. The auxiliary rig site utilized a HK450 drill rig and also required a site area of approximately 262' x 262'. The site for assembling and welding of pipes located at the exit side occupied area of more than 6,561' x 66'. This space requirement suggests at the product pipe was able to be welded in full which is optimal.



Figure 5.29: Overview of Entry Side Construction Site (Li et al, 2013)

A mud recycling system was installed at each drill location. Each system required the construction of natural “mud ponds” and the installation of motorized “mud recovering” equipment.

#### **5.4.6.1 Pilot Hole**

Due to the project length, extreme entry and exit angles, and gravel conditions,  $\Phi 48'' \times 1.08''$  L415 SAWH steel pipe casing was installed at the entry side to a tampered length of 387'. The same casing was installed at the exit side to a tampered length of 515'. Refer to Figures 5.29 and 5.30 for casing set-up.





Figure 5.30: Casing Tamping Field on the South Bank (Li et al, 2013)



Figure 5.31: Casing Tamping Field on the North Bank (Li et al, 2013)

#### **5.4.6.2 Reaming Operations**

The efficiency of reaming is extremely low. During the first level of reaming (20in), it took about 150 min to drill one piece of drill pipe. After drilling 47 pieces of drill pipe in the second level of reaming (30in), the time consumed suddenly increased. It took about 600 min in drilling one drill pipe maximally.

While increasing the mud flow and times of hole-flushing at the site, the crossing axle was also analyzed to solve the problem of low efficiency in reaming. Because the entry angle was 2 degree larger than designed entry angle during casing tamping, the buried depth had to be increased in order to make sure the radius of curvature. However, it was low at the position from the 45th to 65th drill pipe with the lowest point being 49' below the designed axle because that in order to maintain the direction, the crossing curve was kept close to designed axle as much as possible and upward close to designed axle after getting horizontal. Because the curve got close to the designed curve gradually, every dog angle was 0.75. The drilling cuttings were accumulated at the low section, thus, it took long time when the reamer passing through this hole. Refer to Figure 5.32 and 5.33 for cuttings selection.

In addition, it was found that due to the excessive pursuit of ratio of dynamic shear force, the worker added too much MMH which caused the instability of mud performance. With the increment of MMH, the yield point and apparent viscosity was not infinitely increased but decreased after a peak appearing. However, the position of peak was related to the clay content. With the increment of clay content, the required quantity of MMH for peak appearing was also increased. It was a misunderstanding to increase the quantity of MMH to enhance the mud viscosity.

Thus, the construction team was recommended to control the ratio of dynamic shear force, but not increase MMH. After replacement of waste mud, hole-flushing was carried out again and the efficiency of reaming was improved. Please see Figure 5.31 for the time consuming situation of the 3rd level reaming.

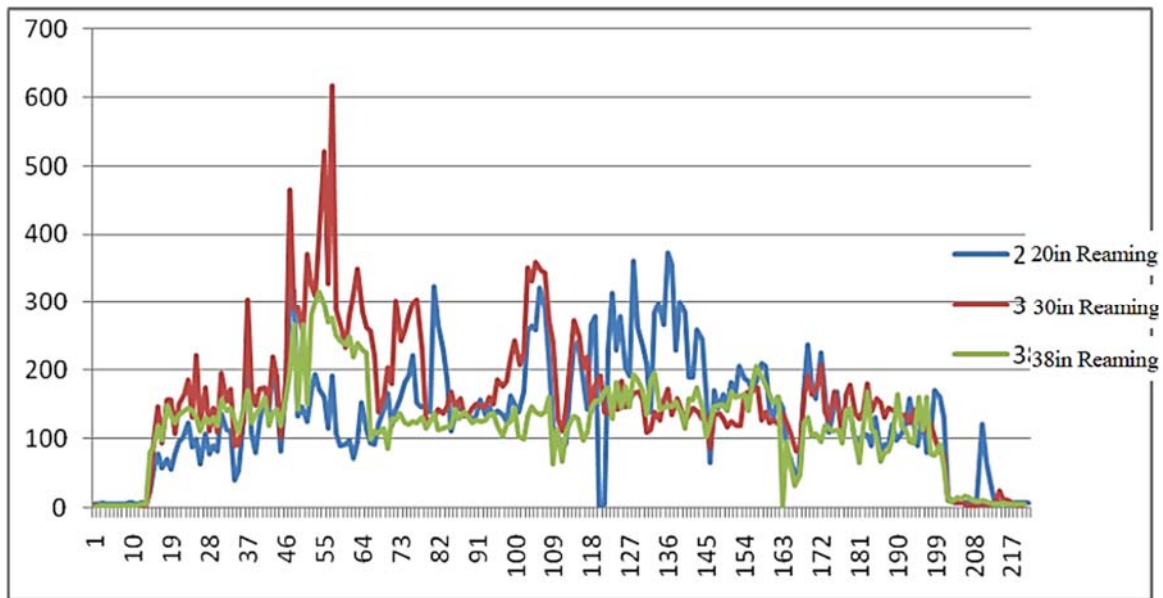


Figure 5.32: Time-Consuming Chart of Reaming (Li et al, 2013)

#### 5.4.6.3 Pipeline Pullback

The pull-back of pipeline was intended to be carried out utilizing a swing stage and turning rolls because Yangtze River was dry season in December, the ground water of land was connected with Yangtze River, the channels and fishponds along the precast pipeline were all dried-up and the discrepancy in elevation within the precast site of pipeline. The gap between turning rolls and swinging stage was not more than 66'. The crossing length of Yangtze River was about 6,857' and the distance between exit point and foot of levee was less than 1km. The elastic laying was adopted at the turning of pipeline. During pull-back stage, the lateral force produced by pipeline at the turning was large and the turning



rolls could not support, thus trench was considered to be excavated at the turning to give the side support to the pipeline.



Figure 5.33: Mud Jetting Nipple for Hole-Flushing (Li et al, 2013)



Figure 5.34: Carried Rock Debris During Excavation (Li et al, 2013)

The drilling tool used for pull-back is composed of 6-5/8in S-135 drilling pipe, 30in barrel reamer, 320T universal joint, 200T U-type ring and  $\Phi 610$  pipes. Such support devices as pulley block and hammer for emergency were equipped on the site. The pull-back was started at 3:20 p.m. on Dec.15, 2011 and in order to reduce the frictional resistance, the combination of turning rolls and trench for pull-back was adopted and the graphitic lubricant was added into mud. The lubrication result was ideal during the stage of pull-back with the force always less than 100t. It was completed at 1:50 p.m. on Dec.16, 2011, which took less than 23 hours. Figure 5.34 for photograph of successful pipeline pullback.



Figure 5.35: Successful Pipeline Pullback (Li et al, 2013)

#### **5.4.6.4 Post Construction**

It is assumed that post construction operations were left to the responsibility of the CNPC Prime Contractor. Once the final pipeline testing was confirmed adequate, each of the two drill rigs was demobilized. After the HDD equipment and spare parts were removed, the set was left to be graded. Remaining drill fluid was disposed of according to local regulations.

#### **5.4.7 Worker Information**

Though the specific crew sizes are unknown, it is assumed that all meals and board were provided to the workers. CNPC employed one full time cook per crew that was responsible for food preparation and clean-up for three meals per day. Housing for this project is unknown. In addition, each work was supplied with two changes of uniforms, a hard hat, and work boots as part of CNPS's standard required uniform.

#### **5.4.8 Project Challenges**

There were numerous challenges associated with this crossings. They included, but are not limited to, the following: Refer to Figures 5.35, 5.36, 5.37 and 5.38 for illustrations of project challenges.

***The Angle Of Casing Changed On The South Bank:*** The length of rammer casing was 410'. Though it reached the planned position, the angle of casing at the rock-soil border was 2 degree larger than entry angle because that the steering of rammer casing is not stable enough. In order to make the radius of curvature less than 1500D, the deflecting angle of every drill pipe was about 0.75 degree in curve and the low point of the actual drilled path is 49' lower than that of the designed drilled path.





Figure 5.36: Broken Drill Pipe (Li et al, 2013)



Figure 5.37: Stuck Reamer (Li et al, 2013)





Figure 5.38: Fractured Drill Pipe (Li et al, 2013)



Figure 5.39: Reinstall Center Locator inside Casing on the South Bank (Li et al, 2013)



***The Length Of Rammer Casing Is Not Enough On The North Bank:*** Casing was adopted to isolate the unconsolidated sands. Excavating pit of 16.4' depth at first, then ram the double casing. That is one casing is 60" diameter in the outer, which is of the length of 197'. And the other one is 60" in diameter inside the outer one, which is of the length of 394'. When the rammer casing length is 387', the trouble of underground water is uncontrollable. Thus, the rammer casing of north bank had to be cancelled.

***Stuck Pipe:*** .The first level reaming of 20" for the 3rd time crossing of Yangtze River was started on Feb. 13, 2011 and the applied drilling rig was the rock reamer produced by America INROCK®. When placing the 3rd set of reamer (the body is imported and the cone is domestic), it was found that the torque is big which would increase as long as the drilling depth is increasing. Upon the analysis and discussion on the site, it was decided to withdraw the 3rd set of reamer and increase hole-flushing. However, when withdraw the No.45 drill pipe, the rupture was occurred. It was analyzed that the rupture was occurred at the side of RP-5 (north bank, the side of designed exit point) according to the situation of mud return after grouting.

The machine for milling was installed at the entry point side (south bank of Yangtze River) to carry out hole-flushing for the section of hole from entry point to the reamer and to wash the area near the reamer. And then carried out the pull-back for the reamer on the south bank with 200 ton drilling rig but failed. Following 450 ton drilling rig was adopted for jam release. When the strength of ground anchor was up to more than 90% after re-pouring and such spare devices as pipe-rammer used for reverse tamping was got ready, the jam release was carried out again on March 17. The pull force of drilling rig started

decrease after being up to 280 ton and the jam release was succeed with the drill pipe starting to move slowly. It took three and half hours.

The length of crossing of Yangtze River was about 2km, the drill pipe was easily become buckling and collapse under pressure which would cause the drill pipe broken. One drilling rig was equipped for each bank, separately used for reaming and withdrawing the reamer. It was strictly prohibited to push back the drill pipe directly.

***The Drilling Path Was Lost:*** On March 19, the drill pipe were dragged from the exit point side on the north bank with RP-5 drilling rig, totally 16 pieces and the distance from the fracture to the joint of drill pipe was about 4.9'. On the north bank, RP-5 drill rig was adopted to find hole, but after drilling about 20 pieces of drill pipe still cannot coincide with the original hole. Later tried again but still failed.

After failing, HK 450 drilling rig was adopted to drill the pilot hole and kept moving backwards and forwards while drilling every drill pipe so as to carry out hole-flushing. On Apr. 1st, the mud flow was about from 14 to 18 ft<sup>3</sup>/min, the rotate speed was about 2rpm and the penetration rate is approximately from 3.3' to 5' after the crossing of sand layer. Basically there was no pushing force and the drill pipe was driven by the drill bit. Because of the disturbance by former two times of finding hole, the incline angle was downward. For long-distance pipeline with large moment of torsion, the pushing force cannot be applied to drill pipe, otherwise, it will make the drill pipe broken under combined stress. In the night, the drill bit was found below RP-5 drilling rig on the north bank. Compared with original position, the drill bit was deviated to left in 3.3' and forward 55.8'.

The moment of torsion is oversized. During the stage of finding hole, the moment of torsion for drill rig was about 40,000 Nm. Even after increasing the mud flow more than 529,720ft<sup>3</sup>, the moment of torsion was still above 28,000Nm. The result was not ideal.

Two sets of mud pump were in parallel connection, but the mud flow only can be 71ft<sup>3</sup>. Since long time of high-load operating, the mud pumps always broke down. Limited by the performance of mud equipment, the moment of torsion of drill rig still cannot be effectively reduced after increasing the mud flow. After finding hole, the hole-flushing was started immediately and one mud jetting nipple was installed every 1,640'. In view of moment of torsion, when the speed of hole-flushing was 5ft/s, the moment of torsion was up to 38,000 to 40,000 Nm; when the speed of hole-flushing was 20ft/s, the moment of torsion was down to 32,000 to 35,000 Nm.

Since the function of increasing the mud flow on reducing the moment of torsion for drill rig is very limited, it was considered to optimize the mud performance. Based on the requirement of that to reduce the yield point, structural viscosity and filter loss of mud, to increase the plastic viscosity and to keep the stability of entire mud system, the technician considered increasing soda ash, caustic soda and CMC into the original mud system to support the positive electricity system.

After several days' continuously adjustment during the stage of hole-flushing, the ratio of dynamic shear force was maintained above 1, the filter loss was about 8ml/30min and the PH value was about 11. Thus, the mud system was comparatively stable. The particle size of carried rock debris excavated from entry point was about the same as fingernail, which accounts for that the ratio of dynamic shear force was basically meet the requirement on rock debris carrying.

#### 5.4.9 Schedule and Results

In Sep. 24, 2010, the trail crossing of silicon casing started to be carried out for the 3rd time crossing of Yangtze River and in Nov.20 the pull-back of this silicon casing was succeed in one time. Based on the successful experience in crossing of silicon casing and upon sufficient preparation, the product oil main pipeline started drilling on Dec.24, 2010 and the pilot hole accurately come up out of the ground on Jan. 27, 2011 (actually crossing length is 6,857' and the exit angle is 10 degree). Through almost one year's construction, three times reaming had been completed, successively 20in (totally taking 117 days), 30in (taking 87days) and 38in (taking 81 days), and also several times of hole-flushing. The pull-back of pipeline was finished successfully at 13:50 on Dec.16, 2011, which totally took almost one year. Refer to Table 5.6 for operation breakdown.

Table 5.6: Results of Yangtze River HDD Crossing

No.	Construction	Start Time	Duration
1	Silicon Casing	Sep.24, 2010	56 days
2	Pilot Hole of Main Pipeline	Dec.24, 2010	34 days
3	20in Reaming	Feb.13, 2011	76 days
4	30in Reaming	Jun.10, 2011	87 days
5	38in Reaming	Sep.4, 2011	81 days
6	Pull-back	Dec.15, 2011	23 hours

The maximum pull-back force is 350t and the maximum torque of pilot hole during drilling and reaming stages is 80,000 N.m. This successful crossing of Yangtze River through rock mass established the record of longest length in crossing of rock mass

domestically, and also provided a new idea in crossing Yangtze River for the pipeline both at upstream and downstream of Yangtze River.

## 5.5 Lake Houston Crossing, Houston, TX, USA

### 5.5.1 Company Profile

Laney Directional Drilling Co. (Laney), a leading provider of horizontal directional drilling services to the energy, telecommunications and infrastructure sectors. Laney had been in business for 23 years and had completed over 2000 projects at the time of award.

### 5.5.2 Project Background

In February 2012, Laney Directional Drilling completed a record breaking HDD crossing below Lake Houston in northeast Harris County, TX. This crossing included one (p1)  $\phi 6'' \times 0.432''$  steel pipeline to be used for natural gas transmission. This project was a Kinder Morgan replacement of existing pipeline that parallels the FM 1960 bridge crossing Lake Houston. The pipeline was needed to be deeper in the lake, as it was becoming exposed and boats were scrapping it. Refer to Figure 5.39 for plan view of crossing location.

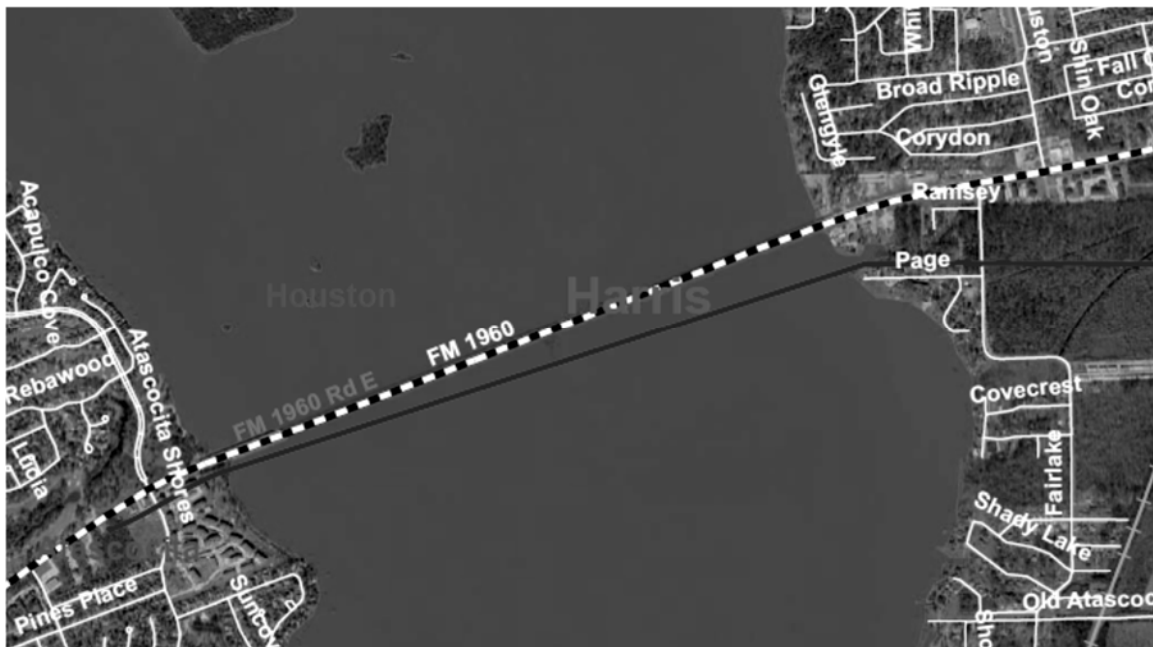


Figure 5.40: Plan View of Crossing Plan (Laney 2013)

At the time of completion, this crossing was the longest HDD crossing executed on record with a total installation length of nearly 11,000'. The prime pipe contractor was Sunland Construction of Eunice, Louisiana.

### **5.5.3 Design and Construction**

The project delivery method for this project was Design-Build. The HDD portion of the project was originally low-bid; however, the contract was originally awarded to another HDD contractor who was unable to successfully install the crossing. Laney then negotiated with the prime contractor, Sunland Construction, to come in a redesign and complete the crossing. Laney was able to complete the project for the company's original bid price.

The governing local authority for the Corps of Engineers who acted on behalf of the pipeline owner who was Kinder Morgan Pipeline. Laney acted as the design engineer of record as well as the HDD contractor. Initially, the both the HDD contractor and Designer were selected using the Low-Bid process; however, difficulties with the initially selected companies required a change in contractors. Laney was selected due to prior success with Kinder Morgan, familiarity with the conditions of south Texas, and knowledge of complex and lengthy drills. To add strength the HDD team, Laney Directional Drilling subcontracted HDD Survey specialists' In-Rock to aid in the pilot hole surveying and GHG Corp to perform drilling fluid management

### **5.5.4 Crossing Details**

Refer to Figure 5.40 for overview of crossing path and figures 5.41 and 5.42 for arial views of each drill site. The crossing point is located at Lake Houston located within the county limits of Harris County, TX. The total elevation difference was 7.5' higher at

the exit side. The distance between the entry pit and exit pit was 10,936' and the total length along the drill path was 10,971'.

The maximum depth of crossing was approximately 70.2' at the deepest part of the lake. The specific drill path for this crossing was selected at a maximum total depth below the entry point of 143' with an average total depth at the bottom most tangent point between 125' and 130'. Unlike large rivers with fluctuating flows, Lake Houston is located very near sea level and has limited concern with scouring of the bottom. This allows minimum cover to be less than under river conditions. The drill path was selected at a distance near the adjacent bridge for access purposes but an efficient distance away to reduce chances of underground conflicts or magnetic interference with tracking. Project parameters are presented in Table 5.7.

Table 5.7: Lake Houston Crossing Project Parameters

Drill soil angle (entry)	12 degrees
Drill soil angle (exit)	12 degrees
Pipe outer diameter	(p1) 6"
Pipe wall thickness	0.432"
Pipe material	API- 5L-ERW X-52
Operating Pressure	1032 psi
Anti-corrosion protection	Factory installed 14-16 mils fusion-bonded epoxy coating and an 20 mil abrasion resistant overlay
Additional Cathodic Protection	Epoxy glass-fiber cloth at weld locations

In addition, favorable soil conditions at this depth included dense sand and clays. Laney picked the dense sand to reduce the potential for inadvertent returns and hydraulic



fracture. It also wanted to be above the lost downhole tooling to reduce the interference and pilot hole surveying issues its drillers might have encountered from these undesirable obstacles.



Figure 5.41: Alignment of Drill Path Across River (Laney 2013)





Figure 5.42: Aerial View of Entry Side (Laney 2013)



Figure 5.43: Aerial View of Exit Side (Laney 2013)

### **5.5.5 Safety and Quality Control**

The project superintendent for each shift was responsible for the safety of his jobsite and crew. Each superintendent received formal safety training through the City of Houston Area Safety Council. In this case, each of Laney's superintendents had over 10 years of experience working on HDD jobsites. Each onsite worker must be up-to-date on general safety courses required by the Houston Area Safety Council as well as receiving typical on-site training. In addition, daily safety meetings are held each morning to discuss the tasks to be completed each day. For this project, there were particular safety concerns associated with the existing pipelines on either side of the proposed alignment near both entry locations.

Laney Directional Drilling Superintendent and Project Managers were also responsible for quality controlled (QA/QC) associated with HDD operations. Though they had no formal training, experience as well as company protocols were followed at all stages of the HDD operations. Examples of QA/QC for this project included survey monitoring of pilot hole location, depth, and azimuth during installation as well as drilling fluid management. Daily records were prepared by both Laney as well as by the third party drilling fluid engineer and submitted to the home office as well as to Kinder Morgan. Drill performance was also critical and was constantly monitored for torque, pushing and pulling force readings, rotational speeds, and mud pressures. This information was recorded digitally through software and then tabulated in excel by the drill operator and onsite surveyor to monitor progress.

### **5.5.6 Construction Approach**

The intersect method was selected for the project and utilized (2) two different maxi-size 750 Class drill rigs (Figure 5.43.) Both drill rigs were Laney Directional Drill custom built LLD 750 lb. machines. Entry side was located at the west bank of the river and exit side was located at the east bank. This was based on the available work area along the owners existing easement.

The rigs were positioned on both the entry and exit sides of the alignment until pullback was started at which point the drill on the east side was removed to allow for the product to enter the exit pit location. Each drill was located on the centerline of the design path. The west rig was located approximately 1,430' and the east rig was located approximately 1,565' from the edge of the lake. For this project, the intersect location was selected to be 5,906' away from the main rig and 3,937' from the auxiliary rig. Both drill rigs drilled from the east side and west side of the lake simultaneously until both pilot bits were in the same hole. The pilot hole assemblies were then tripped out to the west side of the lake, making one continuous drill pipe string in the hole.

The ParaTrack 2<sup>®</sup> control system was utilized for tracking for this crossing which is considered to be a wireline system, the coil was laid on the ground surface in coordination with the Highway 1960 bridge. A second check coil was established in a shallow section of the lake to further verify the drill location along the required path. Both of the surveyors making the intersect were trained by INROCK<sup>®</sup>, the equipment manufacturer.





Figure 5.44: LDD 750 Drill Rig (Laney 2013)

Onsite water was sourced from a fire hydrant located adjacent to the jobsite. A mud recycling system was installed at each drill location; however, the available jobsite space did not allow for any retention ponds. Fracture tanks were used instead to store water and extra drilling fluids. Small pits were constructed at the entry point which was used to store drilling returns temporarily until they were pumped into the cleaning system the returns were then pumped from the cleaning system to the mixing tank before pumping back downhole. Two (2) custom built Laney mud recycling systems that were designed with Derrick or Mi Swaco. There was one Derrick system positioned on the West side and one Mi-Swaco system positioned on the East side.

The drilling fluid is was a combination primarily of water and bentonite with small amounts of soda ash, and additives. A third party fluid engineer was on-site at all times

taking tests on the drilling fluid pumped downhole as well as the returns. The purpose of this was to ensure that the cleaning system was acting properly. Laney Prepared a Fluid Management Plan based on the subsurface conditions which was managed by the GHG Corp to ensure an impartial third party. By following the drilling fluid plan, Laney was able to experience very little torque on the entire length of the drill pipe which was attributed to the engineering design component, operational efficiencies, and drilling fluids plan.

#### **5.5.6.1 Pilot Hole**

At each end of the drill path, approximately  $\phi 14''$  casing was installed to secure the line of the path at each entry/exit location. This included 400' at the main side and 1,000' at the exit side.

Initially, the main drilling rig utilized a  $\phi 11''$  tri-cone bit with a mud displacement motor and the non-magnetic drill collar. It was then switched to a  $\phi 9-7/8''$  tri-cone bit on a jetting assembly due to more favorable soil conditions than anticipated. The auxiliary drilling rig utilized initially used the same  $\phi 11''$  tri-cone bit with a mud displacement motor and the non-magnetic drill collar; however, later switched to the same  $\phi 9-7/8''$  tri-cone bit on a jetting assembly. The entire selection of drill rods was made of 31' rod sections of  $\phi 6-5/8''$  drill pipe with each s-135 drill pipe section having 961,000 lbs. of tensile capacity.

After Laney adjusted to site conditions, a crew from each side drilled toward the middle of Lake Houston. A mile and a half of the crossing was under water. Laney superintendents worked from the exit side because that is where the 17.5-degree bend was designed. After the drill pipes intercepted, efforts switched to the entry side to help push the drill pipe out all the way to the exit side of the crossing. Having the second half of the

crossing already drilled via the pilot hole intersect method made it possible to push the drill pipe successfully for such a long length.

#### **5.5.6.2 Reaming Operations**

No reaming pass was required for this crossing as the pilot hole was large enough to accommodate pipe pullback.

#### **5.5.6.3 Pipeline Pullback**

The pullback operation was executed using  $\phi 6-5/8''$  s-135 drill pipe fixed with a stabilizing swivel. The product pipe was pulled in from the east side in four sections, requiring three welds to be made during the pullback process. Limited space on the exit side of the crossing the pipe contractor required Sunland to make three tie-in welds in the rain as pipe pullback was completed. Each of the four (4) section was approximately 2750' each and was comprised of approximately 40' steel pipe sections. Refer to Figure 5.44 for pullback operations.

#### **5.5.6.4 Postconstruction**

Upon completion of final pullback, final pipe testing was completed by the general contractor Sunland. Final pipe testing included use of a caliper pig and hydrostatic test. In addition, Sunland performed a hydrostatic test of the pipeline for 8 hours which was completed successfully and accepted by Kinder Morgan. Laney provided a one (1) year warranty after pullback is complete. Sunland was responsible for returning all work areas back to their original condition as well as removing all remaining mud from the jobsite and taking it to the local disposal facility.



Figure 5.45: Product Pipe during Pullback (Laney 2013)

### **5.5.7 Worker Information**

Each drill crew had a superintendent, driller, surveyor, 3 operators, 2 laborers and a parts runner. There were four crews total, one for each rig and for both the day and night shift. All crew members were union workers and received wages in accordance with the pipeline contractor's agreement. All were paid hourly and got paid each Friday.

### **5.5.8 Project Challenges**

The Lake Houston HDD crossing had logistical challenges at both the entry and the exit side as Laney had to set up its rig between two existing, in-service pipelines. A normal dead man setup is 16' wide; however, Laney only had 1' to work with between the two "hot" pipelines. The dead man and LDD-750 rig on the exit side also had to be modified to fit in the space available. Alterations to the drilling equipment were made on the spot as they didn't know the full extent of the space restrictions until they arrived onsite.

Other obstacles acting as work site constraints included railroad tracks, a gas station



and apartment complexes to name a few. There were several abandoned attempts, which added to the complexity of the operation because not only was Laney for the project re-design, the engineer also had to accommodate for a new profile and alignment associated with just subsurface conditions. Site preparation did include removal of one existing pipeline.

Design conditions were equally challenges as the final HDD design also included a side bend of 17.5 degrees, which normally is not a challenge on shorter crossings. The horizontal curve was a left-hand turn and we needed to stay in the Kinder Morgan right of way. It was very challenging, especially because this was done below the lake in which there is no wire coil to track. John Odom, one of Laney's field superintendents on the record-breaking project, says, "It takes a lot of torque to turn that much drill pipe. We just had to take the side bend gradually and make sure we had really good drilling fluid in the hole at all times."

#### **5.5.9 Schedule and Results**

Site preparation and rig mobilization took approximately two days for each drill rig which occurred simultaneously. The execution of drilling operations started on February 22nd, 2012 and was completed 18 days later on March 10<sup>th</sup>, 2012. This was accomplished by working two (12) twelve hour shifts seven (7) days per week at each rig location. Pullback for the product pipe started late in the day on March 10<sup>th</sup> and took just under two (2) days completing on March 11<sup>th</sup>, 2012.

Pullback was completed with minor issues. Hydraulic fractures, though minor, occurred near adjacent houses, a gas station, and apartments. In response, Laney ran small diameter casing until they reached a formation which helped reduce the potential for

inadvertent returns. It was also difficult to push almost 11,000' of drill pipe all of the way across the crossing in the softer soils. This challenge was overcome by accurately managing the drilling fluid. Laney hired a specialized third party drilling fluid engineer to be present onsite during construction. With this length, (Laney) needed to carefully consider things like the viscosity, gel strengths, yield point and plastic viscosity of the mud and PH of the make-up water.

The average pullback force achieved during pullback was 150,000lbs with a maximum pullback force of 200,000. Overall, the drilling operations were successful at steering along the design profile. Laney Directional Drilling began demobilization on March 13th, 2012 and all remaining site restoration and pipeline tie-ins were taken over by the Sunland Construction team.

## **5.6 Sabine River Crossing, Liberty, TX USA**

### **5.6.1 Company Profile**

Ranger Directional, Inc. (Ranger) performs the underground installation of product pipelines and conduits, including horizontal directional drilling ("HDD") installations beneath waterways, congested areas, highways, and other environmentally sensitive areas. Our offering of turnkey design, construction, and HDD installations for the telecommunication, pipeline, gas, water, electric, and cable TV industries has positioned Ranger Directional, Inc. at the forefront of domestic U.S. utility infrastructure construction. Since 1993, Ranger Directional, Inc. has successfully completed projects in some of the most difficult geological conditions in the U.S. RDI's construction management team has nearly 60 years of combined experience and its key field management personnel possess over 50 years of experience in all aspects of project operations.

### **5.6.2 Project Background**

In May 2013, Ranger Directional, Inc. completed yet another record breaking HDD crossing below the Sabine River and nearby swamplands. This crossing included one (p1)  $\phi 12''$  steel natural gas transmission pipeline drilled a horizontal length of nearly 2.1 miles under the Sabine River and across the Texas-Louisiana border. At the time of completion, this crossing was the longest HDD crossing executed on record in North America with a total installation length over 11,000'. This crossing is part of the larger natural gas transmission project running 139-miles from Liberty, TX, to Eunice, LA.

### **5.6.3 Design and Construction**

This project owner for this pipeline was Crosstex Energy Services. Crosstex awarded the prime pipeline installation contract WCH Inc. based on combination of a low

bid proposal and best qualified contractor. Ranger was then contractor to Sunland to perform the specific HDD operations associated with the Sabine River Crossing.

The specific pipeline spread spanning under the Sabine River was governed by the federal regulators as they did not give the owner, Crosstex Energy, permission to build it over the region's wetlands 115 miles east of Houston. This resulted in extensive permitting and coordination with environmental specialists in the region.

#### **5.6.4 Crossing Details**

The project crossing spanned from Starks, LA to Deweyville, TX and crossed under the Sabine River. The total elevation difference was minimal between the entry and exit sides of the drill. The distance between the entry pit and exit pit was 11,049' and the total length along the drill path was 11,065'. The maximum depth of crossing was approximately 92' from the entry location and 71' below the deepest section of the river bottom. The increased coverage of 71' was selected to ensure appropriate pipe coverage during scouring conditions. Surface conditions consisted of mostly sandy ground on the exit side and swampy/soft ground on entry side. Conditions along the drill path were good and considered of soft clays and sands. Refer to Table 5.8 for additional project parameters.

#### **5.6.5 Safety and Quality Control**

As for most crossings, the project superintendent for each shift was responsible for the safety of his jobsite and crew. Each superintendent received formal safety training through the National Pipeline Council. In addition, daily safety meetings are held each morning to discuss the tasks to be completed each day. Ranger's superintendent and Project Managers were also responsible for quality controlled (QA/QC) associated with HDD operations. All onsite workers were required to attend a formal safety training provided by

Crosstex Energy that covered both general and project specific safety training. Figure 5.45 for onsite project supervision. WHC Construction also provided project supervision during all HDD operations and contributed to the Safety and QA/QC process.

Table 5.8: Sabine River Crossing Project Parameters

Drill soil angle (entry)	Unknown
Drill soil angle (exit)	Unknown
Pipe outer diameter	(p1) 12”
Pipe wall thickness	0.432”
Pipe material	Unspecified Steel Pipe
Operating Pressure	Standard Operating Pressure
Anti-corrosion protection	Factory installed fusion-bonded epoxy coating with an abrasion resistant overlay
Additional Cathodic Protection	Epoxy glass-fiber cloth at weld locations

### 5.6.6 Construction Approach

The intersect method was selected for the project and utilized (2) two different maxi-size drill rigs. The main drill rig was a Mears 1.2 million pound pullback machine (Figure 5.46) and the auxiliary drill rig was a Vermeer® D330x500 with 330,000 pounds of maximum Thrust/Pullback Power. Entry side was located at the west bank of the river and exit side was located at the east bank. This was based on the available work area along the owners existing easement. The rigs were positioned on both the entry and exit sides of the alignment until pullback was started at which point the drill on the east side was removed to allow for the product to enter the exit pit location.



Figure 5.46: Ranger Onsite Management (Ranger)

Each drill was located on the centerline of the design path. For this project, the intersect location was selected to be 6,308' away from the main rig and 4,757' from the auxiliary rig. Both drill rigs drilled from the east side and west side of the lake simultaneously until both pilot bits were in the same hole. The pilot hole assemblies were then tripped out to the west side of the river, making one continuous drill pipe string in the hole. Intersection was completed on the first attempt. Ranger project management contributed key factors to making the successful intersect to “careful planning, including taking the initiative of performing soil sample investigations to determine the best soil layer for the intersect point, and being able to have several check coils throughout the drill path. Ranger maintained very good hole conditions. We had a mud program designed by DCS



for this drill and used two of DCS Fluid Solutions' mud engineers during the entire project.”



Figure 5.47: Main Drill Rig



Contractors cleared wooded areas and constructed 200-by-200-foot pads at entry and exit locations. Mats were necessary for a board road at the entry location due to the long distance to the nearest roadway

The ParaTrack 2<sup>®</sup> control system was utilized for tracking for this crossing which is considered to be a wireline system, the coil was laid on the ground surface in coordination with a secondary check coil. Both of the surveyors making the intersect were trained by INROCK<sup>®</sup>, the equipment manufacturer. Figure 5.47 illustrates driller performing pilot hole operations.

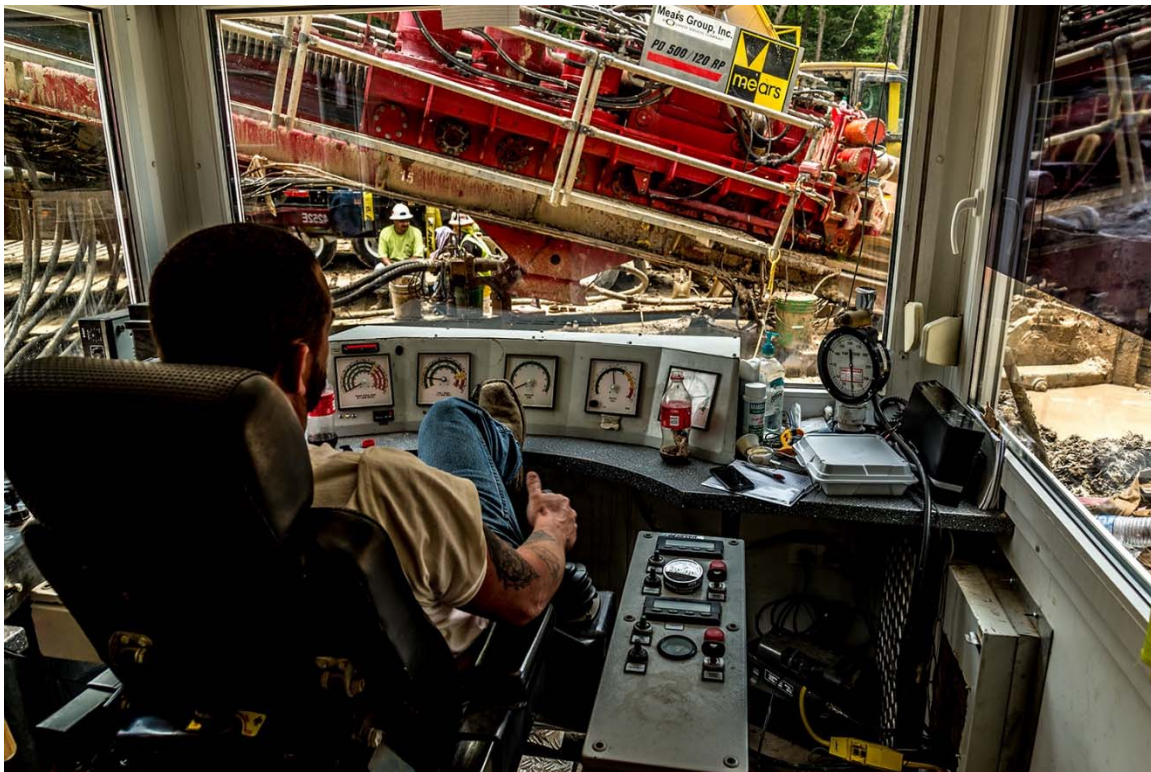


Figure 5.48: Steering Operations (Ranger)

Onsite water was sourced from a fire hydrant located adjacent to the jobsite. A mud recycling system was installed at each drill location; however, the available jobsite space did not allow for any retention ponds. Fracture tanks were used instead to store water and



extra drilling fluids. Small pits were constructed at the entry point which was used to store drilling returns temporarily until they were pumped into the cleaning system the returns were then pumped from the cleaning system to the mixing tank before pumping back downhole.

A third party fluid engineer was on-site at all times taking tests on the drilling fluid pumped downhole as well as the returns. The purpose of this was to ensure that the cleaning system was acting properly.

#### **5.6.6.1 Pilot Hole**

At each end of the drill path, casing was installed to secure the line of the path at each entry/exit location. Pilot holes were drilled with 1 1/4" bits and Adtech 8" mud motors were used. Ranger crews drilled from each side of the River to achieve the intersect. Ranger Superintendents worked from the entry side. After the drill pipes intercepted, efforts switched to the exit side to help pull the drill pipe out all the way to the exit side of the crossing.

#### **5.6.6.2 Reaming Operations**

Reaming operations were completed with a 22" split-bit hole openers made one pass followed by one 18" swab pass.

#### **5.6.6.3 Pipeline Pullback**

Pipeline pullback was complete successfully with no issues. Refer to Figure 5.48 and Figure 5, 49 for photographs taken during pullback operations.



Figure 5.49: Product Pipe During Pullback (Ranger)



Figure 5.50: Successful Pipeline Pullback (Ranger)

#### **5.6.6.4 Post Construction**

Upon completion of final pullback, final pipe testing was completed by the general contractor WHC. Final pipe testing included use of a caliper pig and hydrostatic test. In addition, Sunland performed a hydrostatic test of the pipeline for 8 hours which was completed successfully and accepted by Crosstex Energy. Ranger provided a one (1) year warranty after pullback is complete. WHC was responsible for returning all work areas back to their original condition as well as removing all remaining mud from the jobsite and taking it to the local disposal facility.

#### **5.6.7 Worker Information**

There were four crews total, one for each rig and for both the day and night shift. Specific man counts for each crew were not provided. All crew members were union workers and received wages in accordance with the pipeline contractor's agreement. All were paid hourly and got paid each Friday.

#### **5.6.8 Project Challenges**

The geography of the location contributed to difficulties during the course of the project. Rig areas on both sides had very soft and muddy conditions. This made it difficult to back trailers and vacuum trucks down the long, narrow board road constructed on the entry side. At the exit point, there were problems pushing out the last 120' of drill pipe and bit due to the very soft ground conditions on the surface. A large exit pit had to be dug with sheet pilings in order to finally get our drill bit out of the ground. Although the project has roadside access, it was near only rural roadways, so traffic control was needed due to the quantity of vacuum trucks and pipe trailers that were required.

Surveying was challenging due to site conditions combined with the use of two rigs for the intersect method. Ranger laid out 1,500' of coil. Surveying was time consuming and at times difficult due to the heavily-wooded lands and swampy areas. To be safe, Ranger laid out five coils.

Finally, although there was space to lay out and weld the entire section of pipe for pullback, it could not be laid out straight because of large trees and swampy areas.

#### **5.6.9 Schedule and Results**

Site preparation and rig mobilization took approximately four (4) days for each drill rig which occurred simultaneously. Pilot holes and the intersect were completed in 12 days, plus four days for the entry-side rig to push. Reaming was completed in seven days operating both drill rigs 24 hours a day with two crews on each rig, working 12-hour shifts. To install casing, complete, the intersect and remove the drill bit from the ground required 19 days. Pullback took 25 hours, including two hours to make pipe repairs. The average pullback force achieved during pullback and maximum pullback force are unknown; however, overall, the drilling operations were successful at steering along the design profile.

## **5.7 Walnut Grove Crossing, Walnut Grove, CA, USA**

### **5.7.1 Company Profile**

Gabe's Construction Company, Inc. has offered Horizontal Directional Drilling services since 1989. Using this drilling method we can install products under rivers, streams, roads or environmentally sensitive areas. Gabe's has successfully placed over three million feet of product for various public and private clients

Gabe's Construction Company, Inc. was founded by Jacob Gabrielse and his sons John, George and Edwin in 1942. This Wisconsin corporation, in its fourth generation, has served the Pipeline, Telecommunications, Utility, and DAS industry with hard work and determination. Jacob's commitment to quality, integrity and service to the customer has been continued by his successors.

Over the years, Gabe's has installed thousands of miles of fiber optics, underground pipes and cables for various telephone companies, gas utilities, electric companies, municipalities, cable TV, and private industries using the horizontal drilling method.

### **5.7.2 Project Background**

In November 2008, Gabe's completed yet another maxi-rig HDD crossing in Walnut Grove, California. This crossing included one (p1) (24") × 0.500" steel casing with (2) 10" SDR 7 HDPE carriers to be used as a dual sewer foreman. The total drill length was approximately 5,900' and cost approximately \$1,200,000. This project was completed for the Sacramento Sewer District. Refer to Figure 5.50 for approximate crossing location and site map.

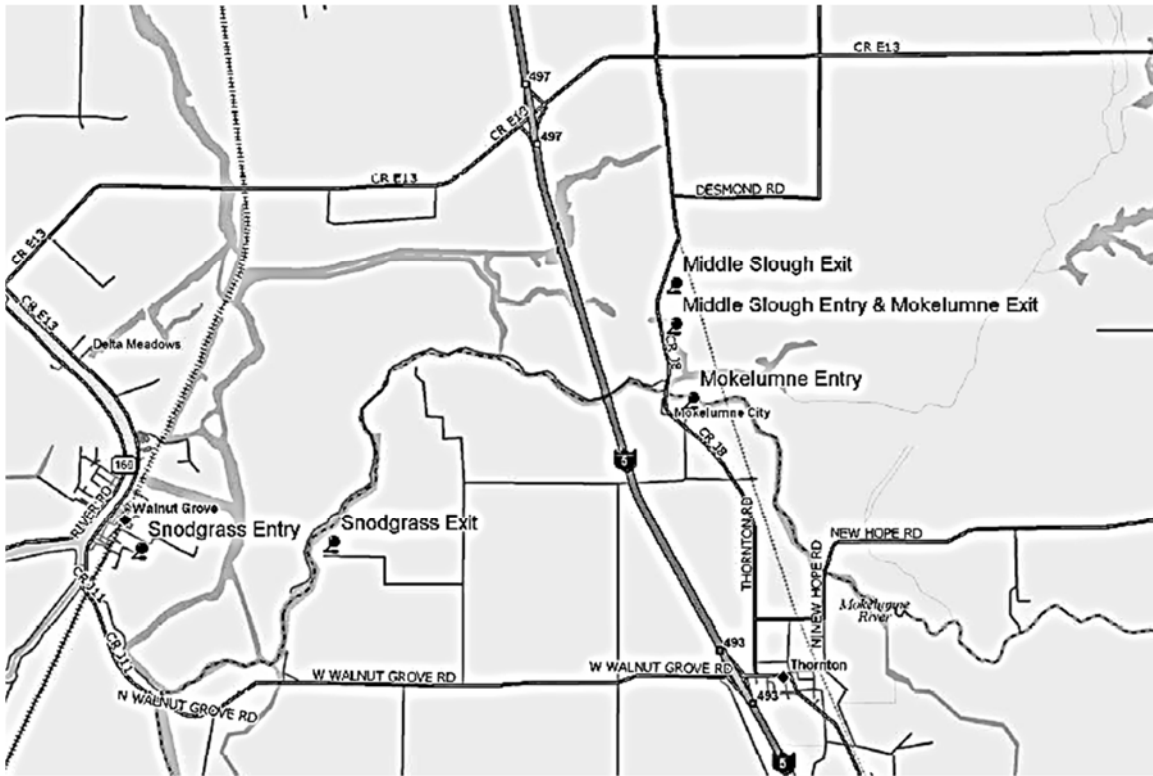


Figure 5.51: Site Map

### 5.7.3 Design and Construction

Because this was a publicly funded infrastructure project, the project delivery method was advertised low bid. Mountain Cascade was selected as the prime contractor. Gabe's was included as major subcontractor during the bid process and later negotiated the contract based on a combination of best qualified and low bid. As a part of the contractor's requirements, a bond was acquired.

The governing local authority was the City of Sacramento and the Sacramento Sewer District. To add strength the HDD team, Gabe's subcontracted HDD survey specialists Rockwell to aid in the pilot hole surveying. Permitting was required for numerous entities involved with the HDD crossing. Because the project was completed in



California, extensive environmental permits were coordinated with local regulating authorities and environmental specialties. Figure 5.51 illustrates the overall site.



Figure 5.52: Site Overview

#### **5.7.4 Crossing Details**

The crossing point is located at Snodgrass Slough and Mokellmne River located within the county limits of Yuba County, CA. The Main drill of bore was 5,835' over the path of the drill and the distance between the entry and exit side was 5,566'. Refer to Table 5.9 for additional project parameters.

#### **5.7.5 Safety and Quality Control**

The project superintendent for each shift was responsible for the safety of his jobsite and crew. Each superintendent received formal safety training through the national Pipeline Association. In addition, daily safety meetings are held each morning to discuss the tasks to be completed each day. Safety includes inspection of rigging and grease equipment, checking of fluids, and warming of equipment.

Sacramento Sewer District and Gabe’s Superintendent and Project Managers were also responsible for quality controlled (QA/QC) associated with HDD operations. Daily records were prepared by Gabe’s and submitted to Sacramento Sewer District. In addition, Gabe’s provided random X-Ray of pipeline weld as well as pull head well testing.

Table 5.9: Walnut Grove Crossing Project Parameters

Drill soil angle (entry)	12 Degrees
Drill soil angle (exit)	12 Degrees
Pipe outer diameter	(p1) 24”, (p2 & p3) 10”
Pipe wall thickness	.500”
Pipe material	(1) Steel Casing, (p2 & p3) HDPE Carriers
Operating Pressure	Unknown
Anti-corrosion protection	Unknown
Additional Cathodic Protection	Unknown

### 5.7.6 Construction Approach

The intersect method was not utilized selected for the project. Only one (1) maxi-size 625 American Augers® drill rig (Figure 5.53) was utilized. Entry side was located at the west bank of the river and exit side was located at the east bank. This was based on the available work area along the owners existing easement.





Figure 5.53: Main Drill Rig

The APS® steering tool and TruTracker® System were used for tracking. The Truegyde Software® control system was utilized for tracking for this crossing which is considered to be a wireline system, the coil was laid on the ground surface. Surveyors and drillers were both trained by Sharewell® representative Richard Bond. Figure 5.52 illustrates the tracking survey of the exit path.

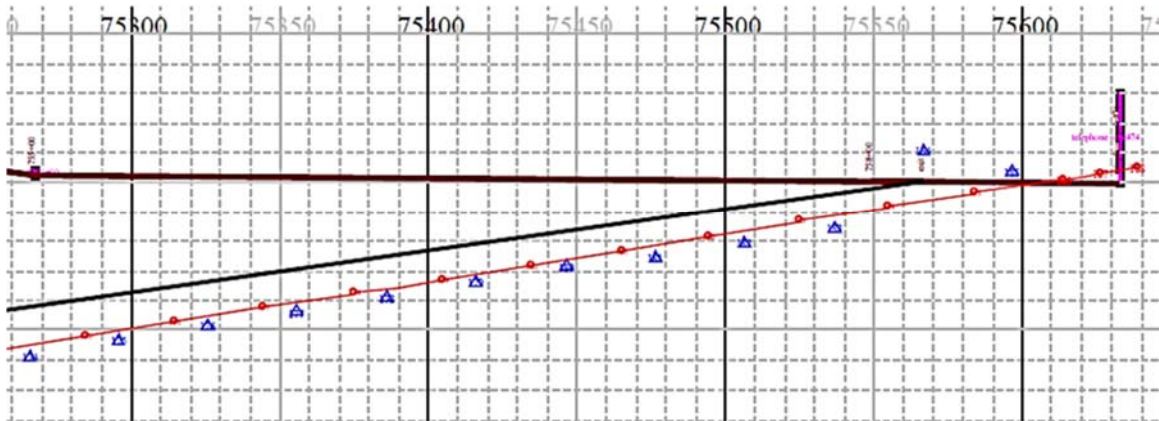


Figure 5.54: Tracking Survey of Exit Path

Onsite water was sourced and hauled from a fire hydrant located adjacent to the jobsite. A mud recycling system was installed at each drill location; however, the available jobsite space did not allow for any retention ponds. Fracture tanks were used instead to store water and extra drilling fluids. Small pits were constructed at the entry point which was used to store drilling returns temporarily until they were pumped into the cleaning system the returns were then pumped from the cleaning system to the mixing tank before pumping back downhole. The mud recycling system utilized was a combination of a Mud Tech MCT 1000 / Tulsa 600 GPM System,

The drilling fluid is was a high yield bentonite Barakade 225 mix combination primarily of water and bentonite with small amounts of soda ash, and additives. The primary testing procedure was the Marsh Funnel test

#### 5.7.6.1 Pilot Hole

The drill rig utilized a  $\phi 12 \frac{1}{4}$ " sub bit with an APS probe. The entire selection of drill rods was made of 30' rod sections of  $\phi 6\text{-}5/8$ " drill pipe. No casing was installed to secure the line of the path at each entry/exit location.

### **5.7.6.2 Reaming Operations**

Reaming operations utilized one pas with a 36” fly cut reamer that was a specialty design and constructed by Gabe’s.

### **5.7.6.3 Pipeline Pullback**

The pullback operation was executed using  $\phi 6-5/8$ " s-135 drill pipe fixed with a 24” fly cutter with a ball reamer and stabilizing swivel. The product pipe was pulled in from the in four sections, requiring three welds to be made during the pullback process. Limited space on the exit side of the crossing the pipe contractor required three tie-in welds as pipe pullback was completed. Each of the four (4) section was approximately 1,500’ each and was comprised of approximately (38)–40’ steel pipe sections.

### **5.7.6.4 Post Construction**

Upon completion of final pullback, final pipe testing was completed by the general contractor. Final pipe testing included use of a caliper pig and hydrostatic test. In addition, hydro testing of the pipeline for 8 hours which was completed successfully and accepted by the Sacramento Sewer District. Gabe’s provided a one (1) year warranty after pullback is complete. The general contractor was responsible for returning all work areas back to their original condition as well as removing all remaining mud from the jobsite and taking it to the local disposal facility. In the state of California, disposal practices are monitored and require extensive procedures.

### **5.7.7 Worker Information**

All crew members were union workers and received wages in accordance with the pipeline contractor’s agreement. All were paid hourly and got paid each Friday.

### **5.7.8 Project Challenges**

Site conditions were problematic and condensed a pond located at the front of the rig combined with fluid returns contributed to soft soil conditions. Operations were ongoing to keep drill solid when pulling pipe. In addition, pullback required mid welds which slowed down pullback and resulted in stalling of the pipe during pullback. This was overcome by hammering and overcoming hydro lock.

### **5.7.9 Schedule and Results**

Figure 5.54 illustrates an example project completion report. Site preparation and rig mobilization began on October 8<sup>th</sup>, 2008 and the date of completion was November 25<sup>th</sup>, 2008. Approximately 100,000 pounds of pullback pressure was achieved towards the end of the pull. When stopped during midwelds. 450,000 pounds of pullback force. HDPE pulled in at approximately 25,000 lbs. Overall, the drilling operations were successful at steering along the design profile. Gabe's began demobilization on March 13<sup>th</sup>, 2012 and all remaining site restoration and pipeline tie-ins were taken over by the general construction team.

Project Start Date: 10-8-08  
Date of Pipe Pull: 11-25-08

Entry Station: 700+00 Exit Station: 756+26  
Entry Elevation: -1.94' Exit Elevation: +4.86'  
Horizontal Distance: 5,626 (5,897' MO)  
Line Azimuth: 82

Bench Mark Data: C/o of Tower Anchor B-3 (Figure 1-A)  
Utility Pole #74 (Sta# 75+ 655)

Actual Horizontal Drill Alignment: Based off offset from line  
Azimuth of 82 degrees

Method of Horizontal Alignment:  
Azimuth: Sta# 71 + 683 thru 72 + 556 TruTracker: Sta# 70 + 051 thru 75 + 596  
Straight N/A Side Curve: N/A

Clearance or Cover required at Control Points: \_\_\_\_\_  
- 102 at Sta# 70 + 572 thru Sta# 74 + 835

Figure 5.55: Project Completion Report

## **6. COMPARATIVE ANALYSIS**

The following section discusses the complete horizontal directional drilling process and highlights standard practices as observed in Mainland China as compared to standard those practices observed in North America. This section reflects all aspects of the HDD process from initial design to final inspection. The Horizontal Directional Drilling Best Practices (Bennett and Ariaratnam, 2008) as well as sample specifications from both North America and China were used as a framework for this comparison.

### **6.1.1 Geotechnical Site Investigation**

In both North America and China, it was found that extensive geotechnical investigations were performed prior to design and construction. The major difference found between the Chinese method and the North American method is who performs the initial investigation. In China, it appears that most often the investigation is the responsibility of the owners and results are provided to the design engineer and contractor for evaluation. In North America; however, this is not the case. In most cases, the geotechnical investigation is the responsibility of the design engineer who is most often an independent party from the owner. In other cases, particularly for design-build crossings, the HDD contractor is responsible for both the design and geotechnical investigation. Thus, all responsibility associated with designing a profile to the appropriate geotechnical conditions is born to the HDD contractor.

## **6.2 Introduction**

The Chinese government plays a dominant role in the development of its construction industry. Thus, changes in political and economic policies by the Chinese government directly affect the way horizontal directional drilling contractors do business.

Since 1979, the country has undergone what is considered a “cultural revolution” which has had a direct impact to HDD contractors in China as the Chinese government has drastically changes policies in order to reform the overall construction industry. The development of the Chinese construction industry since this time can be divided into three stages.

During the first stage from 1979 to 1992, the Chinese construction industry was largely controlled by the government under an assignment system. Shortly after the Cultural Revolution in 1979, China adopted an open-door policy in order to attract foreign investments. State-Owned Enterprises (SOEs) were the backbone in the domestic market, while Rural Construction Teams (RCTs) were declining under the reform. In October 1992, construction industry reform was announced at the Chinese Party Congress Convention. This marked the start of the second stage which lasted from 1993 to 2001. After the unified construction laws were issued in 1992, the Chinese construction industry developed at a higher speed. While SOEs and Urban and Rural Collectives (URCs) lost half of their market share, the number and gross output value of other types of domestic firms (OTDFs) grew by 35 and 40%, respectively, by 2001, become the major contributor to the growth of the domestic market. The third and current stage began in 2002, and was triggered by China’s formal admission to the World Trade Organization (WTO). After the WTO accession in 2001, the domestic market became more liberalized to foreign companies, and more Foreign Funded Firms (FFFs) started doing business in the Chinese market. During this time the market share of SOEs and URCs continued to decrease, while OTDFs had gained more than 70% of the domestic market.

Like North American, Chinese HDD construction enterprises have two kinds of ownership: public and private. Public ownership enterprises include state-owned, state-holding, and collective enterprises. Ongoing Chinese economic reform has allowed Chinese private enterprises to continuously expand over the past 12 years.

In the North America, HDD construction enterprises are primarily privately owned firms. In China; however, while there are privately owned HDD firms, for example Yellow River, the vast majority of major HDD crossings are performed by SOE's such as the CNPC Crossing Company. Thus, the large-rig HDD market, particularly for energy infrastructure, is dominated by public firms that serve as subsidiaries to the Chinese government. This is due to the fact that nearly all of the buried pipeline energy infrastructure in China is designed, constructed, and operated by other government owned and regulated agencies on a national scale. Privately owned firms; however, are large contributors to local markets, and perform many small scale and large scale buried utility construction projects for services maintained on a providential level.

### **6.3 Design**

#### **6.3.1 Design Analysis and Calculations**

In general, design considerations between Chinese contractors and North American Contractors are similar; however, theoretical testing of potential stresses are more thoroughly analyzed by Chinese engineers. It was found that both Chinese and North American project's design are carried out in accordance with national standards of each country as well as the Pipeline Research Council International (PRCI) standards (<http://prci.org/index.php/about/>). PRCI is the preeminent global collaborative research



development organization of, by, and for the energy pipeline industry. PRCI was founded in North America and has world headquarters located in Virginia, USA.

A major difference; however, was the extent to which these calculations were carried out and presented. In North America, designs are most often based on meeting minimum design parameters. The first step is meeting the requirements of the free stress pipe bending including calculation of the minimum radius of pipeline, hoop stress, longitude stress, bending stress, and shear stress. Operating stresses of the pipeline itself are calculated for maximum shear stress and net longitude stress as well as the combined stress of these factors. Finally, installation stresses are computed at each step of the pipeline path to ensure that there will be no issues while actually installing the pipeline. This calculation is particularly valuable for determining the most appropriate pipe effect and pull force achieved during at different levels of water fill as well selection of the appropriate size drill rig or rigs.

In China, this analysis is taken one step further and includes advanced simulation models and graphing of all stages of all operating. Examples of these can be shown below in Figures 6.1, 6.2, and 6.3. The example figures reflect specific tool types and sizes which will be required by the contractor to use for actual construction. This design and modelling analysis is performed for each step of the drilling process and for each size pass that will be required by the HDD contractor to perform.

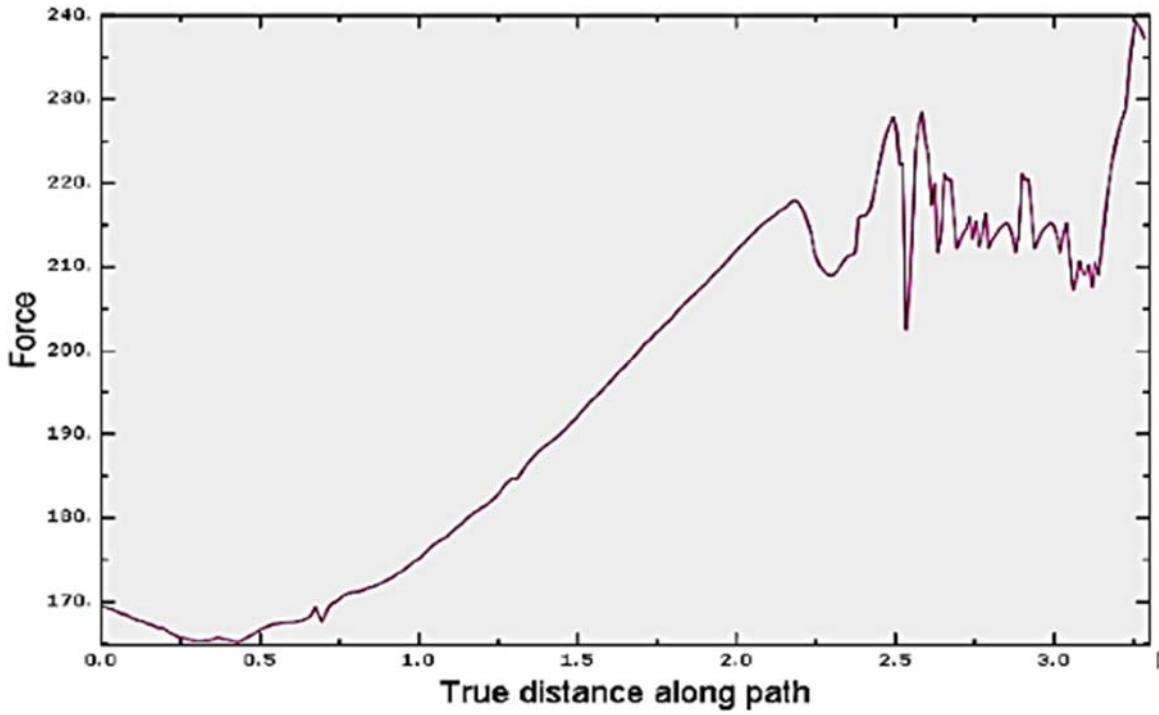


Figure 6.1: Force Analysis Along Drill Path (CNPC)

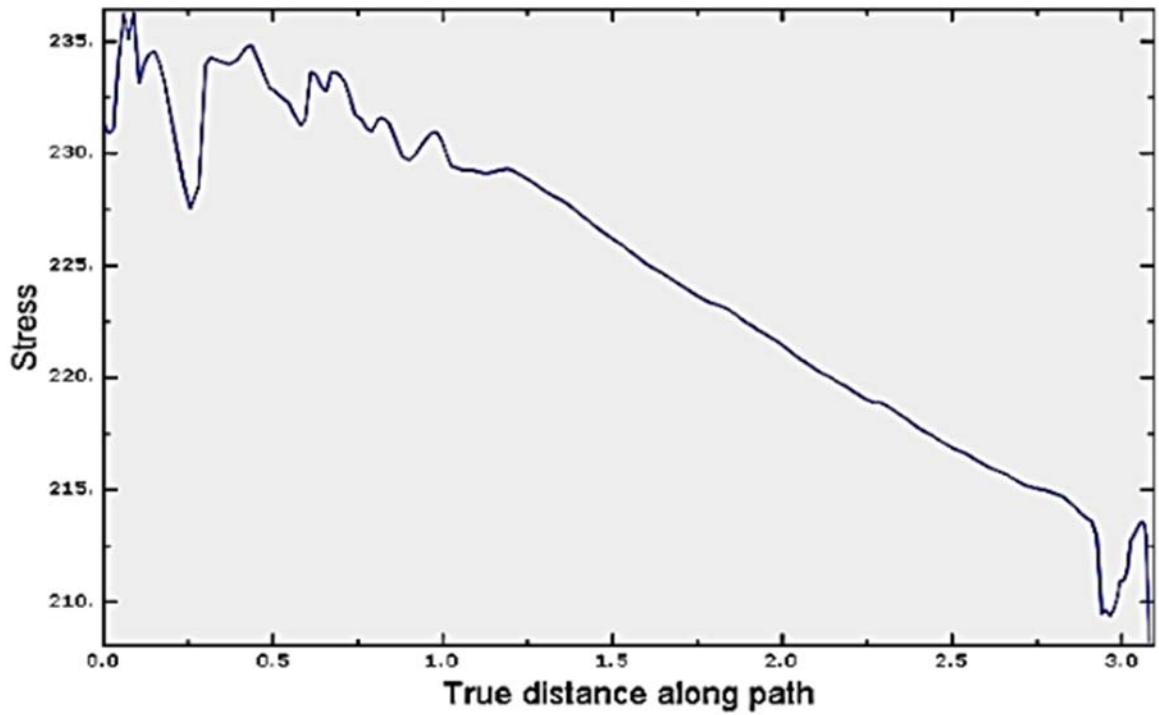


Figure 6.2: Stress Analysis Along Drill Path (CNPC)

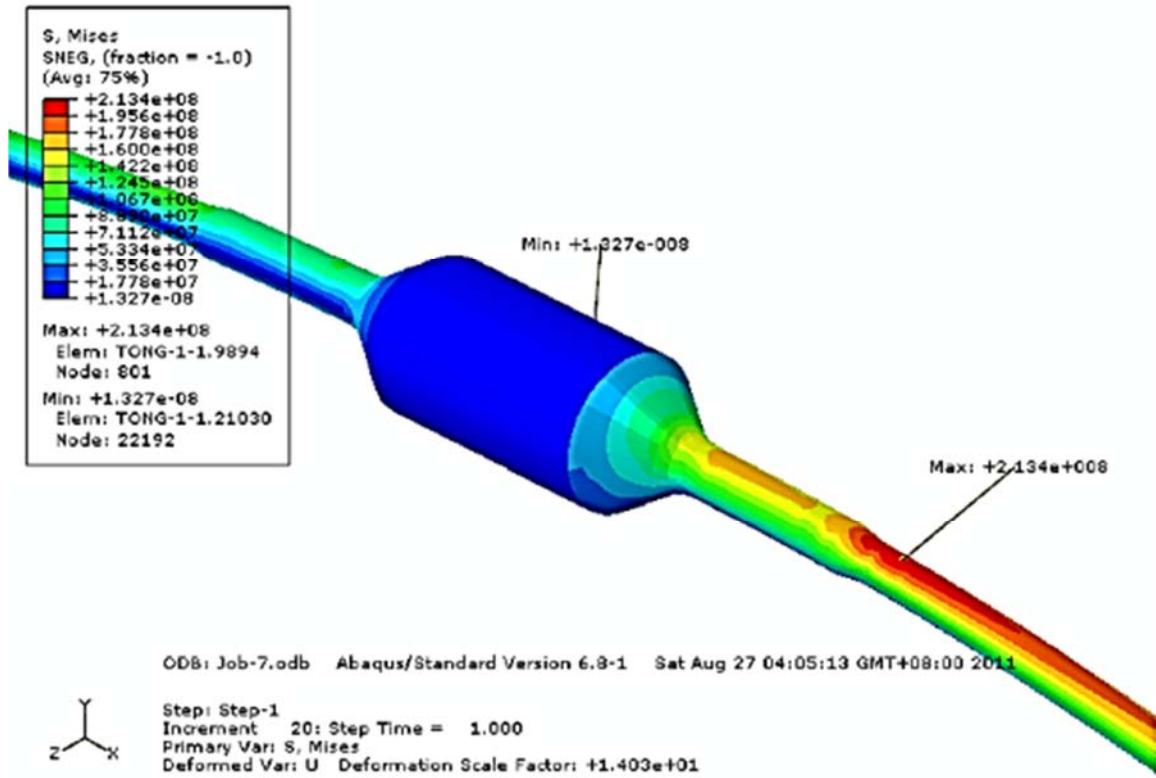


Figure 6.3: Model Analysis of Pipe String Operations (CNPC)

One area that North America appears to be more advanced in is the completion of detailed hydraulic fracturing reports for project owners. These reports have become more common especially for critical crossings and crossings located in environmentally susceptible areas. Analysis of hydraulic fracture potential consists of two steps. The first step is the estimation of annular drilling fluid pressure and the second step is the estimation of pressure at which shear failure of soil occurs (limiting annular drilling fluid pressure). Provided that the drilled hole has not collapsed, maximum drilling fluid pressure occurs during the pilot hole process. This is because frictional head loss is reduced in larger hole diameter. Also, in granular soil formations (angle of friction greater than zero), the shear failure pressure or limiting pressure increases with increase in drilled hole diameter. The hydraulic fracture potential analysis is performed for pilot hole process only and is used as

a tool to identify potential risk areas along the path of the pipeline (Laney, 2014.) Refer to Figures 6.4 and 6.5.

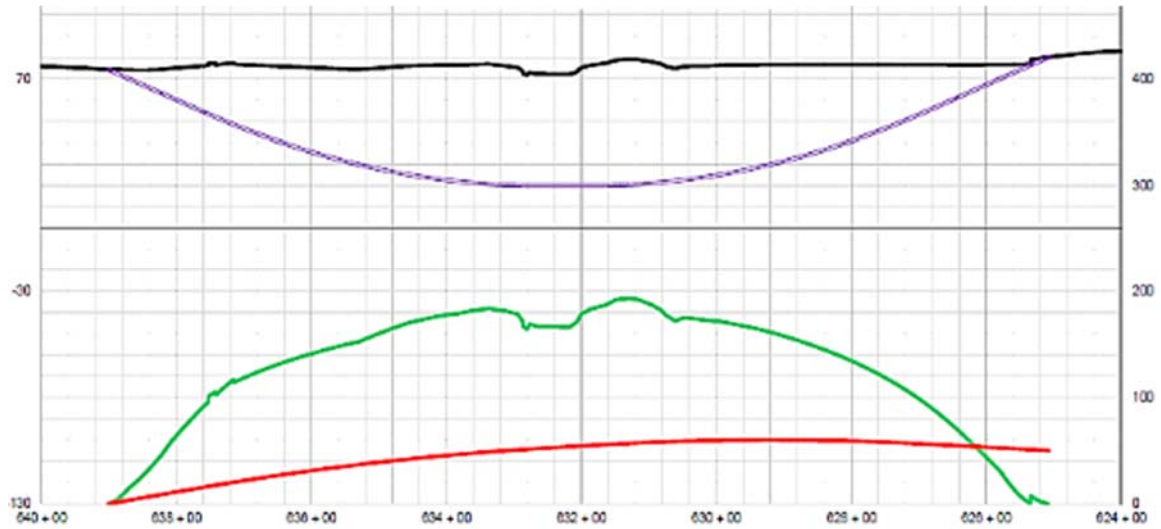


Figure 6.4: Annular and Limit Pressure Chart (Laney)

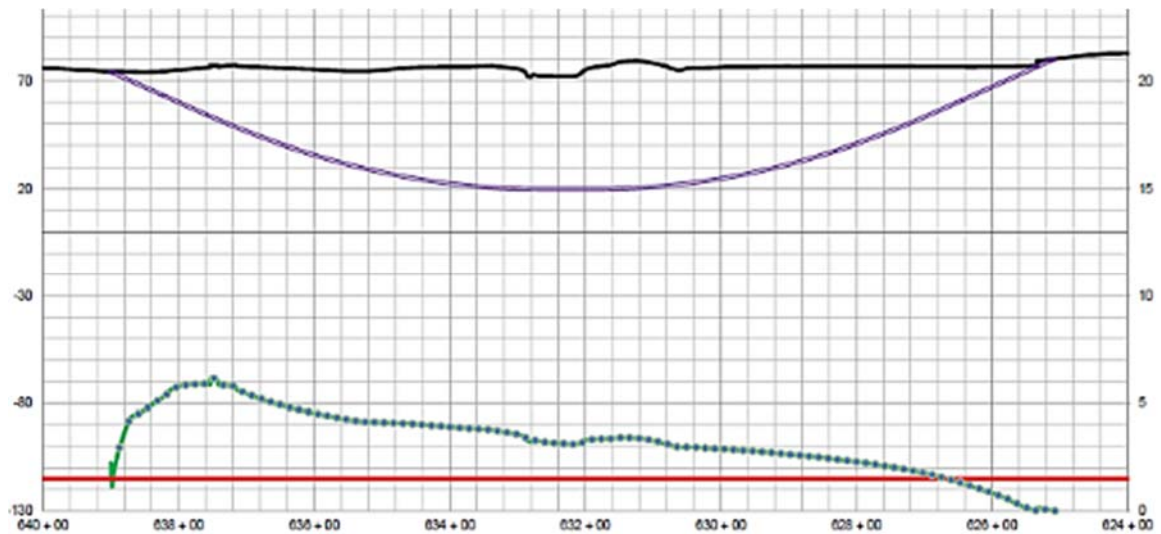


Figure 6.5: Example Factor of Safety Chart (Laney)

#### 6.4 HDD Application and Process

Typically, in North America, the HDD contractor furnishes all supervision, labor, equipment, materials and supplies to perform the work necessary to install pipe by

horizontal directional drilling (HDD) in accordance with project Drawings, Specifications, Contract Documents. In most cases, those documents are prepared by third parties being either the owner direct, the local authority over the project, or a designated design engineer. In some cases, the contractor is contracted to provide both design and construction services under design-build contracts. This is similar in China; however, as shown in the CNPC case studies, the owner and engineer are often subsidiaries of the same parent agency. This is a highly uncommon ownership structure as compared to projects in North America.

The HDD contractor does not typically proceed with work before the owner approves its supervisor, personnel, subcontractors, vendors, drilling plan and schedule. Typically this information is provided during the bid process. This is especially true for projects utilizing alternative project delivery methods where company qualifications is just as, if not more, important than actual bid price. For most Chinese projects; however, this information is not found to be necessary.

In both China and North American, all parties are still required to comply with all requirements of permits obtained by the owner for construction of the pipeline facilities and drilling operations. In the US, more than in China, the HDD contractor must identify water sources and obtain any required permits for water withdrawal. This is not the case in China. In addition, American HDD contractors are typically responsible for all work necessary for withdrawing and transporting water to the job site, including all costs associated with the water usage. This discrepancy is huge in terms of total project cost between China and North America, as depending on the specific project conditions, can result in high water costs for both acquisition and hauling.

In North America, it is not uncommon for the owner to require the HDD contractor to provide personnel with radios to monitor water bodies and ground surface for drilling fluid release or surface settlement along the full length of the drill corridor at all times during drilling operation. This was not witnessed to be the case on any of the jobsites visited in China. In addition, the HDD contractor typically monitors facilities and other sensitive areas within 500' of the drill path for drilling fluid migration and release. Inspections are typically performed daily or more often if fluid migration is detected. Sometimes, when working next to highways, streams or sensitive natural areas, a full time monitoring crew will may be required if specified in the contract. These costs are also the responsibilities of the HDD contractor and typically included at the time of bidding.

In North America, the HDD contractor typically submits a drilling schedule with its bid for owner approval. The schedule is typically job specific and complies with the schedule specified in the in the contract documents. This plan addresses continuity of supervision, quality management, and communication between shifts to address completion of tasks and processes begun in previous shifts or to be undertaken in subsequent shifts. In the case of Chinese projects, this schedule is given to the HDD contractor by the designer / owner. The HDD contractor is required to meet those dates set forth as part of the project documents. The following items are examples of just some of the activities found to be included in the both North American and Chinese schedules:

- Dates for move in, drill start, pullback completion, move out
- Dates for fabrication and hydrostatic pre-testing of pullback pipe
- Mobilization and set up durations
- Pilot drill duration

- Reaming steps with duration for each ream pass
- Final hole preparation and pullback duration
- Dates for final hydrostatic testing and internal inspection
- Clean up, restoration and move out duration

The HDD contractor also often submits a drilling plan with its bid for owner approval. In all cases, the drilling plan cannot override or change requirements of Drawings, Specifications, Contract Documents or this specification without written approval from owner. This plan does not relieve the HDD contractor of any responsibility or liability for safety, damages, compliance with permits and regulations, accuracy, adequacy of the plan for execution of the project. In the case of Chinese projects, this drilling plan is given to the HDD contractor by the designer / owner. The HDD contractor is required to meet those dates set forth as part of the project documents. The following items were found to be included in the both North American and Chinese plans:

- Size of drilling rig, including torque and pulling capacities
- Type of rig, including size of motors
- Type of tracking equipment to be utilized and its stated accuracy
- Pilot survey equipment with sketch of tracking cable layout
- Pilot hole size, each reaming step size, and final hole size
- Diameter, type, grade of drill pipe
- Type of pilot hole bits (include diameter and type)
- Type of hole opening tools (include diameter and type)
- Equipment (pumps, etc.) required to obtain water
- Drilling fluid system, including recycle plans (if applicable)

- Drilling fluid and hole cuttings disposal method and location
- Spare equipment and parts inventory

#### **6.4.1 Site Preparation**

Typically, project workspace for drilling sites is limited to that space shown on the contract documents in addition to pipeline right of way (ROW) as shown on the project drawings. Typically, HDD contractors in North America may not occupy, cross or utilize any areas outside provided workspace. In China; however, the local government has access to nearly all areas within its jurisdiction, including private land, and thus this is respected but not strictly enforced.

In both China and North American, it was found that all work associated with the preparation of the drilling sites (entry / exit points) and pullback area, including clearing, vegetation removal, top soil segregation, access road construction, etc. was the responsibility of the general, or prime, contractor. In China, it was observed that the overall sites were much more spread out than those in North America and therefore spanned larger overall footprints than similarly sized projects in North America.

For most HDD construction sites in North America, the HDD contractor is required to install either safety fence or another adequate barrier to prevent equipment, vehicle or pedestrian traffic from crossing over drill path in areas subject to surface collapse or bore hole collapse per the contract documents. In North America; however, fencing is almost never shown on any drawings and is therefore not installed unless the site is located in an urban area. Lack of fencing is particular in remote areas that have limited site access. In China; however, all jobsites witnessed had a system of safety fencing in place even in the most remote areas. This fencing encompassed the entire drill site on both the entry and exit



sides in many cases and sometimes surrounded acres of land including all equipment, onsite trailers, material staging areas, and fluid management systems. Figures 6.6 and 6.7 illustrate typical fencing arrangements on Chinese jobsites.



Figure 6.6: Fencing and Designated Entry for Chinese Site (Chain Link Example)



Figure 6.7: Safety Fencing for Chinese Site (Metal Pile Example)

Signage is another aspect of Chinese jobsites that was found to be much more complex than those sites in the North America. In North America, very little signage is located on site. With the exception of required OSHA signage and governmental hiring

practices posters, almost no additional signage is located on the jobsite. In china; however, signage is an abundant feature of any jobsite. Signage includes directional signage for jobsite entry, onsite labeling of all individual staging areas including material and equipment areas, and fluid testing areas. Safety signage is also abundant onsite and can be seen located in numerous areas.

In addition, all onsite HDD sites posted a large schematic of the HDD design path and plan view of the project jobsite. These drawings are used for onsite coordination with engineers and contractors as well as daily coordination with onsite workers discussing the current status of the project and anticipated activities for that day of work. Refer to Figures 6.8, 6.9, and 6.10 for examples of signage on Chinese jobsites.

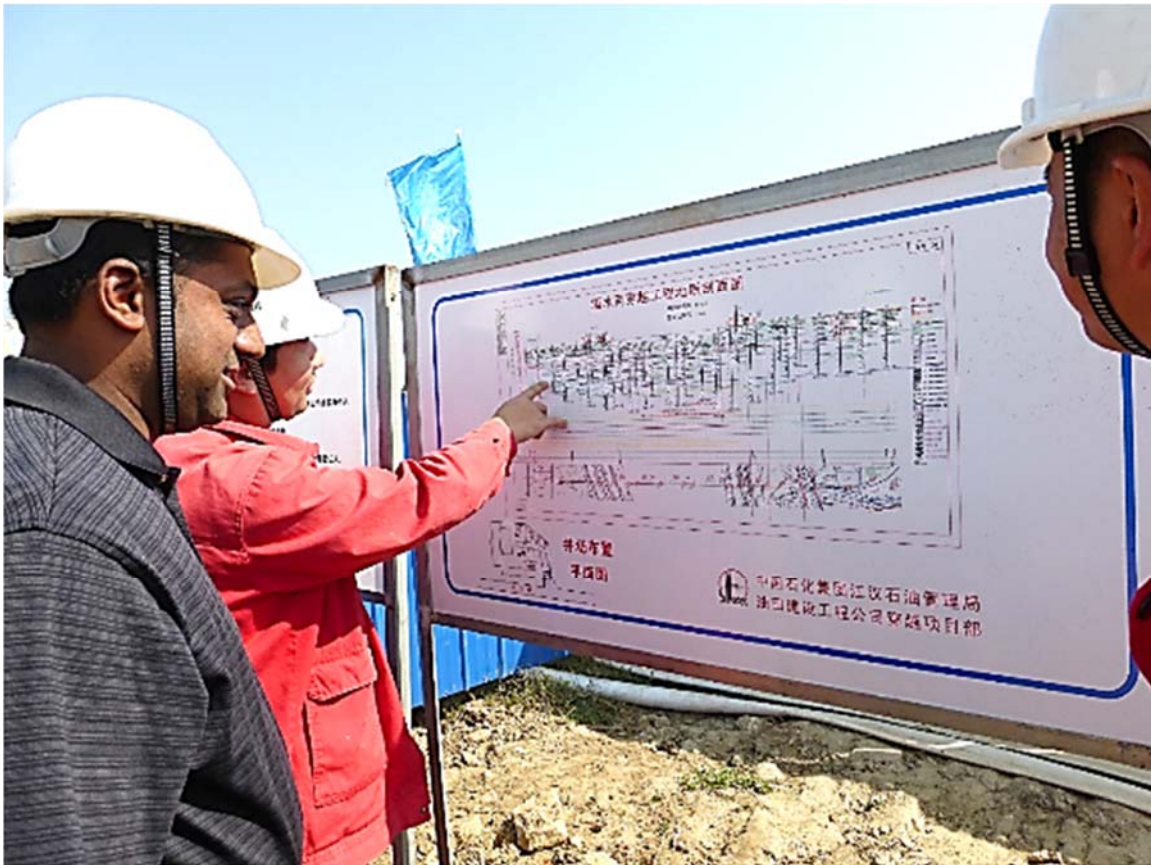


Figure 6.8: Onsite Logistics Planning Board



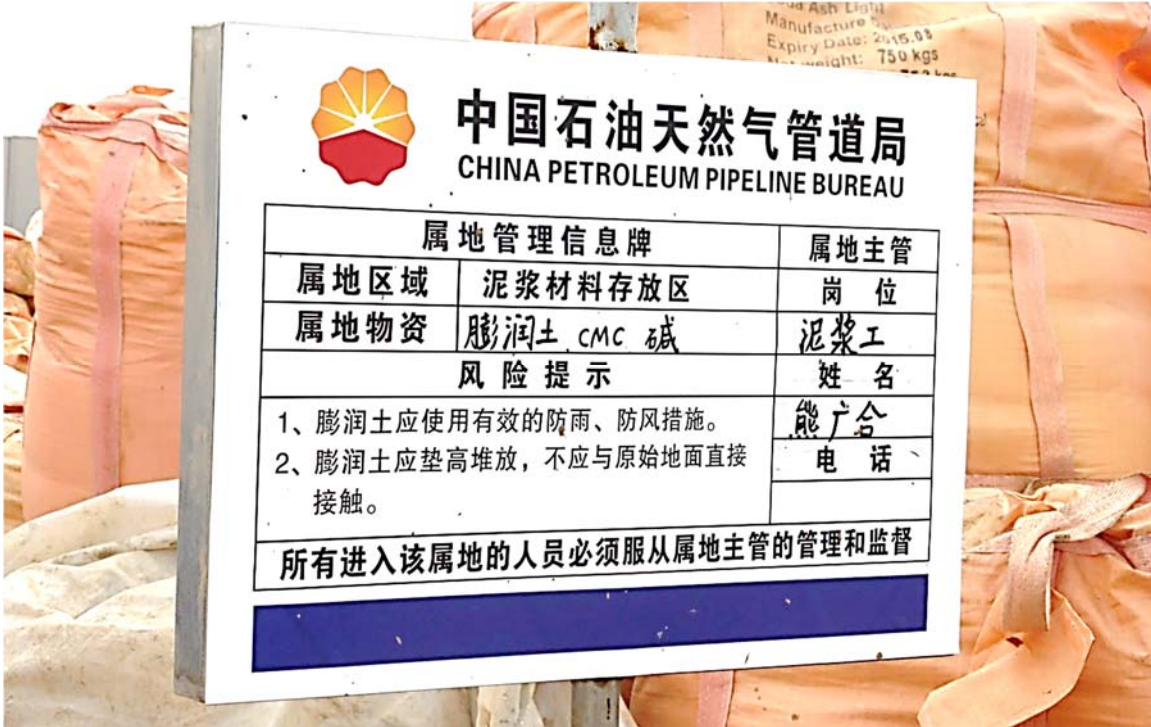


Figure 6.9: Onsite Signage – Material Storage Area



Figure 6.10: Onsite Signage – Additional Storage Area

Another aspect of Chinese jobsites that differed significantly from North American jobsites, particularly for maxi-rig jobsites, was onsite access and worker area platforms. Because many large rig crossings are located in remote areas, jobsite areas are typically remote and difficult to access. Access can be particularly difficult in times with inclement weather causing flooding or muddy conditions. In North America, the typical approach to jobsite access is to install sophisticated systems of timber matting to elevate work equipment and provide a sound platform for the general drill area. Refer to Figures 6.11 and 6.12 for typical timber matting. Timber matting also provides a working area that is elevated, and therefore drains easily during raining weather. Figure 6.13 illustrates flooded Chinese jobsite without timber matting. Jobsite matting can span hundreds of feet by hundreds of feet and also serves the safety of onsite workers who are travelling between onsite operations. Access roads into jobsites can span thousands of feet up to miles and allow onsite workers and visitors to travel to the jobsite safely.



Figure 6.11: Typical Timber Matting for Site Access





Figure 6.12: Application of Timber Matting for Total Project Drill Area



Figure 6.13: Flooded Jobsite Without Timber Matting in China

In China; however, this was not the case. Timber matting did not appear to be a method utilized by Chinese contractors. This often resulted in extremely muddy jobsites and difficulty accessing the site for normal site access. In extreme cases, it was noted that total jobsite access was unavailable and operations were delayed. Onsite working platforms were also significantly different onsite in China. Precast concrete spans were seen to be laid between major operations during heavy foot traffic areas to assist in construction workers traveling between main areas on the jobsite. Hand laid brick pathways were also witnessed. Based on the layout of the brick pathways, they appeared to have been labor intensive to install. Refer to Figures 6.14 and 6.15 for photographs of access paths installed on HDD jobsites in China.



Figure 6.14: Preformed Concrete Panels Used for Walking Paths





Figure 6.15: Hand Laid Walking Path

#### **6.4.2 Pilot Bore and Tracking**

In both the United States and China, the pilot hole is along the path shown on the plan and profile drawing as prepared by the design engineer. During pilot hole drilling, the position of the drill string is monitored at all times with precise downhole survey instruments and verified with surface locating system. While it is ideal that the pilot hole is drilled according to the path shown on the approved on the engineering profile, several factors such as human error, slight differences in tracking, and unexpected soil conditions result in differences from the design path and actual path. This is industry wide and accepted as long as the drill is maintained within certain tolerances. In addition, right-of-way restrictions, foreign lines, utility crossings and/or structures take precedence. Typical

tolerances for construction path parameters are generalized as shown in Table 6.1 and are main considerations for both North American and Chinese contractors.

Table 6.1: Approved Path Parameters

Item	Tolerance
Pilot Entry Angle	Increase (deepen) or decrease (shallow) accordingly.
Pilot Entry Location	Typically unchanged due to tie in locations off major pipeline. Only minor adjustments, typically forward or back along path of drill.
Pilot Exit Angle	Increase (higher) or decrease (flatten) accordingly.
Drill Radius	Must remain at a radius equal to or greater than that shown on the plan and profile drawing. Pilot drill deviations and corrections made along the drill path may not exceed the absolute minimum radius, over a three joint range (PCRI).
Pilot Exit Location	Extend longer or make shorter than exit stake. Slight adjustments can be made left or right of survey centerline.
Pilot Depth	Minimal decrease in pipe design depth allowed. Major foot increase in depth allowed.
Pilot Alignment	Typically should remain within 5' left or right of the centerline survey.

### 6.4.3 Reaming/Hole Enlargement

Another difference that was found between the case studies investigated and general HDD practices between China and North America was reaming operations. In China, significantly more reaming passes were made on the investigated projects than



would have been made under similar soil conditions in the United States. Refer to Table 6.2 which identifies reaming passes for Case Study #1: Yangtze River Crossing.

Table 6.2: Case Study 1 Reaming Summary (Actual)

	(P1) 18" Crude Oil	(P2) 28" Natural Gas	(P3) 28" Natural Gas
9 7/8" Pilot Hole	X	X	X
24" Barrel Reaming	X	X	X
26" Barrel Reaming		X	X
30" Barrel Reaming		X	X
36" Barrel Reaming		X	X
42" Barrel Reaming		X	X
Pull-Back	X	X	X

According to the Horizontal Directional Drilling Good Practices Guideline (Bennett and Ariaratnam, 2008,) the recommended relationship between product diameter and reamed diameter for a product diameter greater than 24" is equal to the product diameter plus 12". So, for a 28" pipeline the appropriate enlargement size would be 40". Because 28" is not a typical pipe size, 42" is adequate for hole enlargement as shown above.

Per industry accepted standards in North America, a rule of thumb for reamer increases is approximately 600in<sup>2</sup> per pass. For example, an increase in reamer sized 24" to 26" is only 79in<sup>2</sup>. An increase of 36" to 42" is 368in<sup>2</sup> which is more in line with standard practices in North America but still not optimal. Assuming that the drill string was 9 7/8" as shown above, an aggressive but performable reaming sequences could be reduced to the following as shown in Table 6.3.

Table 6.3: Case Study 1 Reaming Summary (Theoretical US Approach)

	(P1) 18" Crude Oil	(P2) 28" Natural Gas	(P3) 28" Natural Gas
9 7/8" Pilot Hole	X	X	X
24" Barrel Reaming	X	✗	✗
26" Barrel Reaming		✗	✗
30" Barrel Reaming		X	X
36" Barrel Reaming		X	X
42" Barrel Reaming		X	X
Pull-Back	X	X	X

After the 9 7/8" pilot hole, under good soil conditions, it is not unlikely that the next pass could be as aggressive as going straight to a 30" reaming pass, which is an increase in 630in<sup>2</sup>. A final reaming pass could then be made from 30" to 42", which is an increase in 649in<sup>2</sup>. This large increase could be accommodated utilizing larger fluid pumps to ensure proper fluid circulation.

Explanations for the difference is reaming aggressiveness between Chinese contractors and those in North American are unknown; however several possibilities include a conservative approach to ensure bore hole stability and reduced need for cost savings on labor. Fluid management equipment sizing and availability may also play a part of the extended construction approach. Finally, lack of experience may also play a part in this decision by Chinese contractors.

#### **6.4.3.1 Pipe Layout, Fabrication, and Testing**

One major difference that was observed between Chinese HDD practices and North American HDD practices is the responsibility of the welding activities of pipeline used for the HDD crossing. In both regions, the pipeline material itself was furnished by the owner and provided to the prime pipeline contractor. In North America, it is standard practice for the HDD contractor to have no responsibility for welding, testing, or tying in the pipeline used for the crossing to the main pipeline. This is the responsibility of the prime contractor as well. The same applies to all required equipment and material needed to apply external coatings to field joints on the pipe section fabricated for pullback including repairs. In China; however, this operation seems to be blurred. In the case of the CNPC crossings, project questionnaires as well as onsite visits indicate that the welding operations and testing of the crossing pipeline is performed by the HDD contractor. Figure 6.16 illustrates onsite CNPC welding operations. Tie-ins to the main line are still performed by the prime contractor. This difference is substantial because it represents a significant risk to the Chinese contractors over the length of the crossing as compared to North American contractors who differ this risk to the prime contractor.



Figure 6.16: Onsite Welding Operations

In both North American and China, internal corrosion resistant coating is applied to all field joints to bridge the internal corrosion resistant coating that was factory applied. This activity is contracted out in both North American and China to a specialty contractor to specifically perform that operation. As discussed above, surface preparation and coating application for the internal corrosion resistant coating is the responsibility of the HDD contractor in China and the prime contractor in North American. Inspection of this coating is performed during installation and immediately prior to pipe being pulled back into the drill hole by both the prime contractor and the owner.

Finally, the prime contractor hydrostatically tests each fabricated pipe section at pressures and duration as specified by the owner and design engineer. In North America, it

was found that this duration was a 4 hour pre-test is required on all pipe segments used for the pullback section. In China, this was specified to be an 8 hour pre-test. This is discussed in further detail in the safety, quality control and reporting section of this analysis.

In North America, pipes may be hydrostatically pre-tested on skids or rollers as illustrated in Figures 6.17 and 6.18. Thus, in North America, roller supports are the selected method for pipeline staging. Roller supports provide incremental support for the pipeline at an elevated position that is minimally destructive to the natural ground. Supports are arranged such that they are loaded approximately equally, typically every 40' to 60' in length. Supports in low areas are raised to keep the drill section as straight as possible additional supports are used to provide firm support so that sinkage is minimized in areas where the ground is soft. During pullback, the exposed pipe is supported on rollers. And elevated to the correct angle using large booms or cranes.



Figure 6.17: Low Profile Pipe Rollers (www.mcelroy.com)





Figure 6.18: Plated Pipe Roller ([www.trenchless.in/pipe-roller.html](http://www.trenchless.in/pipe-roller.html))

In China; however, the use of support rollers is not always common. In many cases, no rollers are used at all. Instead, extensive mounds are built from the natural terrain to support the pipeline as illustrated in Figure 6.19 and 6.20. This requires significant change to ground conditions as well as labor necessary to create the natural support systems. While this seems logical, the result is increased labor cost as well as extensive site remediation post construction. In addition, additional booms and cranes are needed to lift longer sections of pipeline during the pullback operations.



Figure 6.19: Product Staging During Welding Operations (Example 1)



Figure 6.20: Product Staging During Welding Operations (Example 2)

#### **6.4.4 Pullback**

Pullback operation start immediately after the final swab pass has been completed. Once pullback operations begin, pullback operations continue until they are completed. This requires multiple shifts for this jobsites that are not already scheduled that way. In both China and North America, the HDD contractor provides and maintains all instrumentation necessary to accurately measure drill string axial and torsional loads. While the owner has access to these instruments and their readings at all times, it is the sole responsibility of the HDD contractor to monitor pullback progress and ensure the pipeline is progressing appropriately. Monitoring of the maximum permissible tensile load imposed on the pull section in continuously monitored and calculated along the drill path to ensure the pipeline does not fatigue and break as well as the drill string. In addition, this measurement is critical to ensuring the drill rig is operating correctly and under design conditions as well as fluid management is controlled correctly. In both China and North America, the pullback operation is considered to be the most crucial step in the HDD process.

It was also witnessed that both North American and Chinese contractors used a swivel assembly to connect the pull section in order to minimize torsional stress imposed on the pull section. It is ideal that the pipeline is installed in one continuous string with no tie-in welds. This; however, is not always the case as multiple sections of product pipeline are often required due to spacing limitations. This requires tie-in welds to be completed during pullback operations. This situation can be especially challenging as stoppage in pipeline progress can result in stuck pipe conditions and in worse case scenarios



abandonment of the pipeline completely. Thus, extreme caution is taken in both China and in North America while performing such tie-ins.

As previously stated, during the pullback operation, side booms and/or cranes to assist movement of the pipe both in North America and in China. The equipment is used to lift the pullback section up to reach the proper entry angle and safely support the pipeline in the break over area. In some cases, where the exit angle is deeper, larger equipment is required. This operation appeared similar in all regions.

#### **6.4.5 Demobilization, Site Cleanup, and Restoration**

In North America, it is common for The HDD contractor to inject cement grout into annulus at entry and exit of completed HDD. The minimum extent of the grouting will be to completely seal and fill the upper portion (typically 30' of hole entirely with grout with the top 5' filled) with soil compacted to match surrounding soil conditions. In North America, the HDD contractor is responsible for checking for voids along all attempted drills and final drill corridor. If present, the HDD contractor fills voids and compact subsoil along installed pipeline and along any abandoned drill path. It is unknown if these are standard practice in China.

Typically the prime contractor is responsible for restoring the ground above drill corridor to original contours and condition including furnishing and installing approved fill material, topsoil or pavements. The HDD contractor is responsible for the removal of all equipment, materials, debris and trash and then perform final clean up and restore all work areas. Restoration includes temporary and permanent vegetation as specified in the Drawings and Contract Documents. This seems to be the same both in China and North America.

## **6.5 Equipment and Materials**

For any HDD crossing, particularly large-rig crossings, the equipment and tooling selection can be critical to the success of the project.

### **6.5.1 Rig Selection**

Rig Selection is first and foremost decision made for a HDD crossing. It was found that North American contractors only utilized North American manufactured drill rigs for the large rig projects. In China; however, Chinese contractors utilized both North American and Chinese Manufactured drill rigs. In recent years, the expansion of the Chinese rig manufacturing market has grown, making large rig production in China financially beneficial to Chinese contractors. Based on the Chinese case studies, the selected rigs utilized for all three of the CNPC projects as well as the Qin River crossing were more than enough force to complete the installation. Selection of these rigs was likely due to the availability of the rig as well as the reduced risk for hydraulic fracture drilling pilot hole operations

### **6.5.2 Drill Pipe**

One unique detail that was found on more than one Chinese project was the utilization of several sizes and lengths of drill pipe as shown in Figure 6.21. In Case Study 1: Yangtze River Crossing, the entire 11,000' drill string consisted of 4,101' of  $\Phi 5$ " drill pipe, 1,280' of  $\Phi 5\text{-}1/2$ " drill pipe, 3,084' of  $\Phi 6\text{-}5/8$ " drill pipe and 2,362' of  $7\text{-}5/8$ " drill pipe. When asked why a variety of rod sizes were utilized the response was that the selection was based on what was available for such a long distance. In North America, this was not found to be the case on any of the large scale projects investigated. In cases that

additional drill pipe would be required, it is likely that at least some, if not all, of the cost of additional drill pipe would be included the bid cost for the job.



Figure 6.21: Drill Pipe – China

### 6.5.3 Drill Bits and Downhole Tools

Tooling selection between Chinese and North American contractors seem relatively similar. In general, Chinese contractors made selections that were similar to those in the United States with respect to mud motors, drill bits, and reamers. Sizes also seemed to be somewhat standard with respect to typical pipe sizes. A major difference between drill bit and downhole tool selection between Chinese contractors and North American contractors is who actually makes the selection of the tools. As discussed in the design section of this investigation, in China, specific tools are modelled and forces are calculated for those

specific tools. Thus, the HDD contractor is required to utilize the types of tool specified by the engineer. In North America; however, the specific schematic of pilot, reaming, and pullback operations is left to the discretion of the HDD contractor.

Another difference that was quality of the tooling. In most cases, tools are manufactured by companies specialized in manufacturing those parts. In some cases in North America, mostly when abnormal tooling sizes are required, North American contractors will fabricate custom tools; however, it is not common practice. Tools are also purchased with the expectation that they can be used for more than one project if possible, and, if needed, can be refurbished after usage. The quality of the tools are critical to ensure the tools do not fail or become dislodged from the drill pipe. In China; however, it is very common for custom tools to be built specifically for one job and then abandoned afterwards. Thus, the quality of the tools only needs to be high enough to complete the job the tools were built for. Equipment witnessed on Chinese jobsites can be seen in Figures 6.22 and 6.24. Figure 6.23 illustrates a newly galvanized unit utilized on a North American project.





Figure 6.22: Rusted Barrel Reamer – China



Figure 6.23: Refurbished Galvanized Mill-Tooth Reamer (Laney, 2014)



Figure 6.24: Galvanized Barrel Reamer – China

#### 6.5.4 Drilling Fluid Delivery, Recovery, and Containment Systems

Fluid management, particularly for large rig, large diameter, and long crossings, is critical. While both North American and Chinese contractors agree to this fact, the system implemented by each region has both similarities and great differences. In both North America and China, the HDD contractor provides and maintains all instrumentation necessary to accurately measure drilling fluid discharge rate and pressure. In both cases, the HDD contractor takes all necessary precautions to insure the drilling fluid pressure in the drilled hole does not exceed what can be contained by the overburden soil to prevent any migration into water bodies, wetlands, utilities, foundations, structures, road/railroad right of ways, or any other facilities. In North America, hydraulic fracture and inadvertent returns, particularly unfavorable in environmental susceptible areas. In china; however, this is not

as large of a concern due to less stringent environmental regulations and lack of urbanization in many locations. In both cases; however, contractors seem to make every effort to maintain circulation and recycle the drilling fluid throughout the drilling process. Not only is it an asset to continuous progress on a drill site, recycling of mud reduces the cost of raw bentonite.

In North American, the HDD contractor is most often require submit, and follow, a job specific plan of the proposed drilling fluid mixing system, cleaning system, and drilling fluid pumping capabilities and shall provide the plan with its bid. In China, a similar plan is developed but it is provided by the owner / design engineer with the expectation that the contractor will abide. The following items were found to be included in the both North American and Chinese plans:

- Total volume of mixing tank – (BBLS)
- Total volume of cleaning tank – (BBLS)
- Scalping shakers – quantity
- Desander cones – quantity
- Desander shakers – mesh size
- Desilter cones – quantity
- Desilter shakers – mesh size
- Centrifuge(s) – quantity
- Drilling fluid pump(s) capabilities:

In both regions, the HDD contractor is responsible for providing metal fluid tanks on both sides of the crossing sufficient to contain all drilling fluids resulting from the drilling operation. It is also the responsibility of the HDD contractor to insure that all drilling fluids

are contained within the drilled hole, the drill pit or the fluid tanks. The containment scenario; however, is drastically different between China and North America. In North America, fluid return pits are small, measuring less than 15' by 15' in most cases. Also, there is typically only one pit that stores all returns prior to entering fracture tanks and the overall recycling system. Material is minimized and regenerated only according to what is needed to complete the hole plus a small reserve to assist in pressurizing the fluid through the bore hole.

In China; however, this system is significantly different. Chinese contractors utilize what could be a two-stage recycling system which uses both extensive storage pits and standard equipment. The natural settling tank pit system can be huge, as witnessed on the Qin, Yangtze, and Weihe River crossings. In the case of the first Yangtze River crossing, the pits measured over 150' by 150' and 6.5' deep which required a significant amount more land as well as drilling fluid to use. The system works by allowing the natural flow of the water as well as gravity to allow cuttings to settle in the ponds prior being recycled. After some time in the ponds, the water is then pumped from the top of the second pit back through the recycling system as it is needed. The location of these pits can also be located a great distance away from the equipment. In those cases, the water is initially diverted to the pits through a system of onsite channels and then pumps a great distance back to the equipment using large pumps and tubing. Figures 6.25, 6.26, 6.27 and 6.28 illustrate various Chinese fluid return systems witnessed in Mainland China.





Figure 6.25: Cuttings Canal Path System



Figure 6.26: Cuttings Retention Ponding Systems (Example 1)

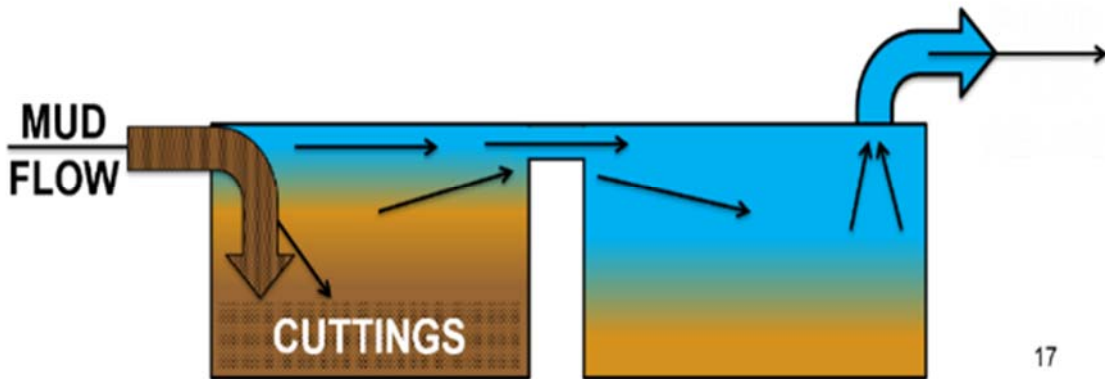


Figure 6.27: Schematic of Cuttings Path





Figure 6.28: Cuttings Retention Ponding Systems (Example 2)

Another vast difference between China and North America is the location which they acquire fresh water for the drilling fluid. In North America, water is rarely permitted to be taken from the local stream, river, or lake that the pipeline is crossing. In these cases, water is transported via haul truck from a local source to the jobsite. This can be a particularly expensive portion of crossing costs in North America depending on how much water is required and how far it is being shipped from. In China; however, regulations are relaxed in this area and allow contractors to pump water from the nearby water body in most cases. In other cases, onsite wells are dug and water is sourced from underground aquifers and groundwater as shown in figure 6.29.



Figure 6.29: Onsite Water Well

With regards to fluid removal, North American HDD contractors are responsible for promptly removing all drilling fluids and associated cuttings from job site and hauling to an approved facility for proper disposal. All costs of disposal of both drilling fluids and associated cuttings, including hauling, are typically the responsibility of the HDD contractor and are included in the bid. In the case of Chinese contractors, no such plan identified. In North America, the HDD contractor often prepares a disposal management plan that may include the following considerations:

- Description of the plan for disposal of the drilling fluid and cuttings
- Anticipated drilling fluid composition (MSDS sheets in North America)
- Anticipated additives (MSDS sheets in North America)
- Anticipated intervals of disposing of the drilling fluid
- Disposal hauler
- Estimated quantities to be disposed

In both North America and China, remaining drilling fluids and cuttings are removed from the jobsite upon completion. In the case of North America, typically the HDD contractor, but in some cases the owner, is responsible for hauling all drilling fluids and associated cuttings from job site to a locally approved facility for proper disposal. The costs of disposal of both drilling fluids and associated cuttings, including hauling, can be a significant expense especially in rural areas that require long distance cutting as well as in more strict environmental areas including the state of California. In rare cases, owners are able to use private property, upon the landowner's approval, to land farm drilling fluid and associated cuttings. Land farming can have some cost savings; however, the HDD Contractor/Owner is still responsible for all work necessary for land farming, as well as any improvements to the property and including improvements necessary for ingress and egress to the site. In addition, there are stringent environmental protocols that are necessary in certain regions.

Land farming is most often the selected method of spoil removal in China and is most often the responsibility of the owner, not the HDD contractor. As discussed, there is a significant amount more of both cuttings and drilling fluid to dispose of for Chinese HDD sites. In all cases visited, the method of disposal for at least some of the cuttings was land farming in very close proximity to the jobsite. In some cases, some of the water that had been separated from the cuttings was released back into the adjacent water body. In no case was the fluid hauled offsite via truck to a facility specifically used for disposal.

#### **6.5.5 Drilling Fluid and Additives**

In both North America and China, the mud composition is determined by the HDD contractor. Though water and bentonite are the main components of drilling fluid, additional

additives are sometimes used in different soil conditions. Viscosity of the fluid is also critical depending on the type of soils encountered such as sand, silt, clay, rock and gravel. In North America, MSDS sheets for all mud components are required to be onsite at all times by the project owner as well as OSHA. Any changes to the drilling fluid composition or use of additives during construction are most often submitted to the owner for approval. In China; however, this is not a requirement as MSDS sheets are not always available.

In both China and North America, HDD contractors check drilling fluid properties at least four times per shift during drilling operations. Tests performed by both Chinese and North American contractors include the following:

- Density (Per API RP 13B-1)
- Viscosity (Apparent, Plastic, Viscosity and Yield Point Per API RP 13B-1)
- Funnel Viscosity (Using Marsh funnel, Per API RP 13B-1)
- Gel Strength (per API RP 13B-1)
- Solids and Sand Content (Per API RP 13B-1)
- Water loss (Filtration, Per API RP 13B-1)
- Chemical Quality (PH, Chlorides, Hardness, Per API RP 13B-1)

For complex crossings, the HDD contractors in North America most often provide a certified mud engineer/technician on-site during all phases of the drilling process whether or not it is specifically specified by the owner. Though it is not often required, HDD contractors in North America find value in having a third party mud engineer onsite to monitor complex crossings they are not capable to handle in house. This is not always the case. In the case of Chinese contractors, both scenarios were witnessed. For Case Study 3: Qin River Crossing, no outside mud engineer was provided. For all CNPC



projects; however, it is standard for a full time CNPC employed mud team, typically consisting of 2-3 engineers, is onsite at all times as seen in Figures 6.30 and 6.31.



Figure 6.30: CNPC Fluid Quality Control Team Members



Figure 6.31: Sinopec Fluid Quality Control Team Members

### **6.5.6 Bore Tracking Equipment**

It was found that the TruTracker<sup>®</sup> and ParaTrack 2<sup>®</sup> were the selected method of tracking both in China and in North America. Unlike the drill rig market that has expanded to China, North America remains the leading manufacturer of onsite tracking equipment. While drilling, the HDD contractor computes the position in the X, Y and Z-axis relative to ground surface from down-hole survey data. This was found to be completed at once per drill in both North American and China. Once the pilot hole has “punched out”, or resurfaced on the exit side, the final survey with the survey probe at the ground elevation which was tied back into the entry location to complete a total survey of the complete path profile. This information is covered in the reporting section of this analysis.

## **6.6 Jobsite Safety and Quality Control**

### **6.6.1 Safety**

The United States Occupational Safety and Health Administration (OSHA) is the agency of the United States Department of Labor that’s mission is to "assure safe and healthful working conditions for working men and women by setting and enforcing standards and by providing training, outreach, education and assistance" OSHA is responsible for enforcing its standards on regulated entities. The agency sends Compliance Safety and Health Officers to work sites, where they carry out inspections and assess fines for regulatory violations. Inspections are planned for work sites in particularly hazardous industries.

In China, the comparable agency is the State Administration of Work Safety (SAWS). Like OSHA, SAWS is directly under the State Council run by the Chinese government. Its responsibilities include: to guide and coordinate the examination and



inspection of national work safety; to qualify and supervise the social agencies that provide tests and examinations, safety appraisals, safety training, safety consulting for industrial, mining, and commercial enterprises; to organize and guide education on national work safety, and take charge of safety training and assessment for work safety supervisors and coal mine safety supervisors; to organize, guide and supervise, in accordance with the law, the assessment of workers from specially identified industries (excluding the operators of special equipment) and for the safety qualification of enterprises' chief administrators and safety supervisors; to supervise and inspect enterprises' work safety training; to supervise the work safety of the industrial, mining, commercial enterprises that are under the charge of the central government, and supervise the performance of such enterprises in implementing related work safety laws and regulations; to organize and carry out international exchange and cooperation with foreign governments, international organizations and NGOs in respect of work safety.

While SAWS is the safety regulator at a national level, HDD contractors in China also implement internal safety programs to ensure the health of their employees. As a SOE, CNPC has developed a comprehensive health, safety and environment management system (HSE) committed to the principle of “putting people, the environment, safety and quality first” and the goal of “zero injuries, zero pollution and zero accidents”. CNPC’s HSE management system is an integration of various elements such as organizational structures, mandates, practices, procedures, processes and resources used for health, safety and environment management. In 2013, CNPC continued to improve its HSE management system and standardized its implementation, as part of the 12th Five-Year Plan. The HSE system was reviewed twice throughout the company, and the system’s defects were

identified and rectified. In accordance with the HSE system standard framework, more than 20 regulations and standards relating to operational safety, environmental protection health management and performance examination were formulated and revised.

Source control and project supervision are key to CNPC's safety management, particularly on large scale HDD crossing project sites. For contractors, CNPC issued the Implementation Rules on Annual Evaluation of Construction Contractors, in order to further standardize contractor management. The company also implemented whole-process safety supervision, to ensure that the operation of contractors complies with our HSE standards. In addition, some projects are specifically certified by the ISO 9001:2008 quality management system, the OHSAS 18001:2007 occupational health and safety management system and the ISO 14001:2004 environmental management system issued by the British Standards Institute (BSI).

Though measures are in place to protect the health and safety of onsite HDD workers, China's enforcement of these regulations; however, is somewhat less stringent than the US. Thus, several unsafe situations were witnessed on Chinese jobsites in comparison to those safety standards accepted in North America. In addition, in the case of the Qin River crossing, the safety measures employed by the Yellow River Crossing company, a private construction enterprise, were insufficient compared to those practices witnessed on the SOE jobsites. In general, basic differences in construction techniques utilized in China as compared to those in North American inherently create less safe environments for HDD workers in China as compared to those in the United States. For example, the utilization of extensive drainage ditches and diversion channels for fluid management creates a higher opportunity for worker accidents in China than comparable

operations in North America. Figures 6.32, 6.33, and 6.34 illustrate safety challenges witnessed on Chinese jobsites.

Chinese contractors were; however, witnessed to be more advanced in the implementation of safety uniforms to all onsite workers with delineation of job requirement visible as seen in Figure 6.35. In North America; however, uniforms are not standard for the HDD industry.



Figure 6.32: Onsite Temporary Facility Construction



Figure 6.33: Site Overview with Safety Taping at Trench Locations



Figure 6.34: Trenching Adjacent to Tower Crane





Figure 6.35: Standard Sinopec Uniform

### **6.6.2 Hydrostatic Testing, Inspections and Acceptance**

Figure 6.36 shows onsite continuous welding inspections during the Yangtze River Crossing. In North America, it is common for the HDD contractor inspect the pipeline sections at the entry and exit points for visual damage. X-Rays are commonly performed on all exposed girth welds to demonstrate that no weld cracking has occurred in the rammed or pulled sections of the carrier pipe. This process is typically performed by the owner or contracted third party of the owner. In some cases, test coupons are performed for material inspection of the pipe itself. While this is not directly related to the HDD operations, it can affect the crossing process if the pipeline itself is compromised causing project delays and additional cost to both the HDD contractor and the owner.



Figure 6.37: Onsite Continuous Welding Inspections

Ultimate approval; however, is almost always based on the successful hydrostatic test, gauging tool survey, shape checks and material inspections as they comply with all applicable regulations. The same was found for the final testing requirements for Chinese jobsites. At the end of product pullback, there is typically an 8-hour hydrostatic test performed of the installed pipe at test pressures and procedures as specified. This hydrostatic test is required for owner approval and acceptance of HDD installation.

Though the HDD contractor is not directly responsible for this testing, there are typically costs included for assistance and time in the costs to install the pipeline crossing. Final approval of the crossing appears to be similar in both North American and China and includes the review and approval of the results of the drill profile survey information,

hydrostatic test data, sizing plate run data (if required), internal pipeline inspection report, and any material inspection data. It is not until all factors have been deemed passing that the acceptability of installed HDD is given and the HDD contractor is granted permission to demobilize.

### **6.6.3 Reporting**

In both China and North American, the HDD contractors almost always submit daily reports to the owner at end of each work shift. The following items are examples of items recorded by the both North American and Chinese on a daily (or per shift) basis:

- Supervisor on site, crew members on site, shifts/time worked
- Description of work, tools in use, footage completed
- Daily total of Bentonite used and total to date
- Drilling fluid additives in use
- Maximum torque values on each pilot or reaming joint
- Penetration rates for each pilot or reaming joint

In addition to those items listed above, the HDD contractor often includes the maximum torque values read on each pilot joint or reaming joint run to confirm no excessive torque was encountered beyond normal operating conditions as well as survey information on the calculated radius of each three (3) joint segment of the pilot hole. Figure 6.38 shows hand written quality control reports utilized in China.





Figure 6.39: Hand Written Quality Control Report

In both North America and in China the HDD contractor provides an as-built drawing to the owner, ideally within 15 days after completion of the pilot hole. In North America, this document is an accurate document of the actual as-built path profile as compared to the original design profile. In China; however, this is different. It was found that in China, the as-built drawing is indeed provided according to what was actually constructed. However, it was found that is likely that on some Chinese projects, the original design drawing is sometimes changed after construction to match the true conditions. Thus, the result is a near perfect execution of the intended design as it is presented to the owner.



## **6.7 Worker Considerations**

### **6.7.1 General**

In China, the labor demographic is unique as compared to North America and labor sourcing somewhat more complicated. China is characterized by a dual economy due to striking regional disparity in income levels along with a huge income gap between rural and urban areas. The eastern region is more developed and has the highest income per capita, while the western region is at the bottom in terms of economic and social development. Thus, there is a distinct difference in China between what are considered “rural workers” as compared to “urban workers.” During the 1950’s, the Chinese government implemented the household registration system (*hukou*) to classify households as rural or urban, became an instrument to identify who came from rural areas. Once a household is classified, it is extremely difficult to change a rural *hukou* to an urban one. In fact, even today there are laws prohibiting migrant rural workers from moving to cities to find employment opportunities.

Due to the remote areas that many large scale crossings are performed in, it was found that many of the management roles and engineering rolls were filled by what could be considered to be “urban” workers working directly for CNPC. Field labor; however, is most likely composed of a composite crew of both workers who travel from crossing to crossing as well as local rural workers. This is partially the result that no matter the location, some government regulations specify that certain jobs are to be closed to rural migrant workers and filled by urban workers only. In the case of private construction enterprises, there is more allowance for the hiring of rural migrant workers. Specific benefits will be further discussed in the wages section of this analysis.

### **6.7.2 Crew Sizing**

The labor allotment, particularly in rural areas, is significantly higher in number in China. The main factor for this is the significant increase in wage for North American workers. Another factor for smaller HDD crews in North America is the workers in the North America are typically sourced directly by the HDD contractor. Many projects are governed by union regulations, for which the requirements are different than those that are non-union. Projects on the East Coast, in particular, have significant worker expectations for hiring more workers than would be required in southern states due to labor matching regulations. Workers are typically sourced directly by the HDD contractor as well as from local union halls in the governing region where the crossing project occurs. In China, unions are not present and therefore not a consideration for HDD contractors. However, it is a common practice to employ many more workers than is actually required. This is a standard of practice that is recognized on a national level in order to employ more people of China's 1.3 billion person population. Figures 6.38 and 6.39 illustrate onsite field crews and onsite engineering teams on Chinese HDD projects.



Figure 6.40: Onsite Workers During Drilling Operations



Figure 6.41: Sinopec Drill / Engineering Team

### 6.7.3 Pay Wages and Benefits

In North America, the vast majority of HDD crews are paid based on the number of hours worked per week. Typically, it is standard practice for workers to work a standard 40 hour work week. Anything over this number of hours is paid at least 150% and up to 200% depending on the total amount of hours worked per week and hours worked per day. Wages are paid to workers on a weekly basis. In the case of many HDD projects, typical work hours are 12 hours per day, six days per week. The following Tables 6.4, 6.5 and 6.6 illustrate the average wages paid in North America to the three most prominent trades in the HDD industry: laborers, drivers (teamsters) and operators.

Table 6.4: Quick Facts: Construction Equipment Operators ([www.bls.gov](http://www.bls.gov))

Statistic	Value
2012 Median Pay (Per Year)	\$40,980 per year
2012 Median Pay (Per Hour)	\$19.70 per hour
Entry-Level Education	High school diploma or equivalent
Work Experience in a Related Occupation	None
On-the-job Training	Moderate-term on-the-job training
Number of Jobs, 2012	409,700
Job Outlook, 2012-22	19% (Faster than average)
Employment Change, 2012-22	78,200

Table 6.5: Quick Facts: Construction Laborers and Helpers (www.bls.gov)

Statistic	Value
2012 Median Pay (Per Year)	\$29,160 per year
2012 Median Pay (Per Hour)	\$14.02 per hour
Entry-Level Education	Training
Work Experience in a Related Occupation	None
On-the-job Training	Short-term on-the-job training
Number of Jobs, 2012	1,284,600
Job Outlook, 2012-22	25% (Much Faster than average)
Employment Change, 2012-22	325,200

Table 6.6: Quick Facts: Heavy and Tractor-Trailer Truck Drivers (www.bls.gov)

Statistic	Value
2012 Median Pay (Per Year)	\$38,200 per year
2012 Median Pay (Per Hour)	\$18.37 per hour
Entry-Level Education	Postsecondary non-degree award
Work Experience in a Related Occupation	None
On-the-job Training	Short-term on-the-job training
Number of Jobs, 2012	1,701,500
Job Outlook, 2012-22	11% (As fast as average)
Employment Change, 2012-22	192,600

While the above statistics represent the median wages paid out industry wide, actual wages earned by HDD crews are significantly higher when factoring in per diem wages, travel premiums, and overtime increases. Wages are particularly higher for union projects that carry higher base wages and significant benefits.

In China, wages are paid to the workers in two ways. Each non-salaried worker is paid a monthly stipend of approximately 12,000 RMB (approx. US\$1,967) plus room and board. For this particular project workers are housed at a local hotel and provided with three (3) meals per day, which is prepared by an onsite cook employed by CNPC. The second form of payment is given in the form of end of job “bonuses.” Additional wages are given based on both overall job performance as well as each individual worker's performance as determined by the project manager. Specific amounts are unknown but can vary between zero (0) and one-hundred (100) percent. This results in an annual base salary of approximately US\$23,606/yr., \$US5.39/hr. at 4,368 hrs./yr.

While these wages appear to be extremely low as compared to North American HDD workers, they are much higher than other industries in China employing migrant workers as well as compared to minimum wage standards country wide. Refer to figure 6.40. As shown, the median pay of 12,000 RMB is nearly 10 times higher than that of the minimum wage in many western areas. Thus, for that reason alone, these jobs are highly coveted and difficult to get with connections.

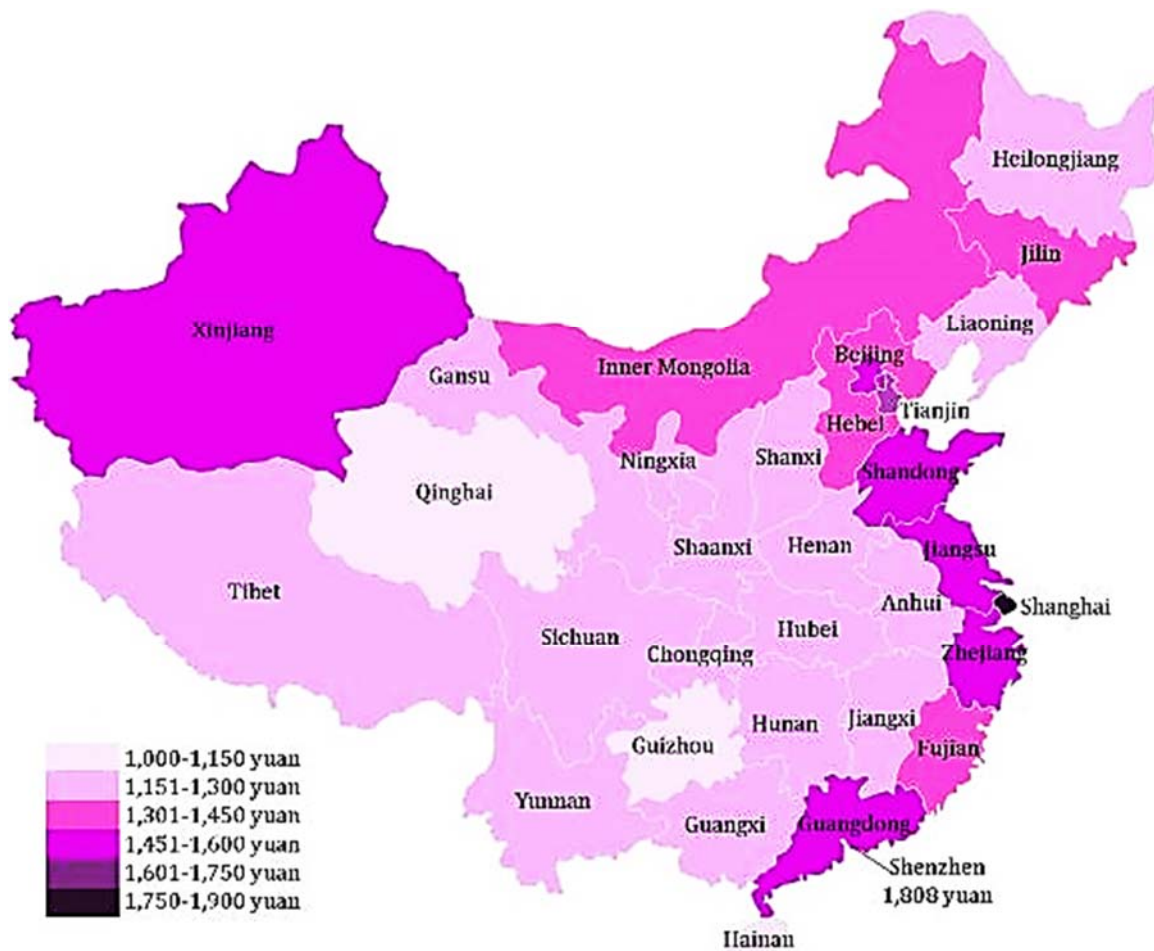


Figure 6.42: Average Minimum Wage in Earnings Per Month (www.clb.org)

Regarding benefits, urban workers are typically entitled to social security coverage such as a pension, unemployment insurance, medical insurance and subsidized public housing. Rural workers; however, do not always receive the same benefits. The data indicate that only 5 per cent of migrant workers were covered by a pension scheme, less than 2 per cent by unemployment insurance, 3 per cent by medical insurance and that less than 10 per cent were living in public housing. Another survey conducted by the Ministry of Agriculture in 2005 showed that only 13 per cent of rural migrant workers had insurance coverage for occupational injuries and diseases, 10 per cent by medical insurance and 15 per cent by a pension scheme.

#### **6.7.4 Working Hours**

Working hours in China were found to be twenty-four (24) hours per day seven (7) days per week. Shifts are broken into two (2) twelve-hour shifts per day. The day shift starts at 7:00 AM and ends at 7:00 PM. The night shift starts at 7:00 PM and ends at 7:00 AM. Monthly wages are based on workers completing the entire daily twelve (12) hour shift all seven days per week. In China, workers were not given overtime premium. This is not an uncommon practice in North America, particularly for fast-tracked projects; however, double shifts are more common only during pullback period.

These hours are in accordance with similar studies involving rural worker hours. The majority of migrant workers have longer working hours than local urban workers, and more working days per week. This can be seen from 6.41 and 6.42. The 2002 CHIPS data show that over 80 per cent of rural migrant workers worked seven days per week, and only 7 per cent worked five days in accordance with the officially mandated number of working days for local urban workers. One third of migrant workers had to work 9 to 10 hours per working day, almost one quarter 11 to 12 hours, and 12 per cent 13 or more hours per day.



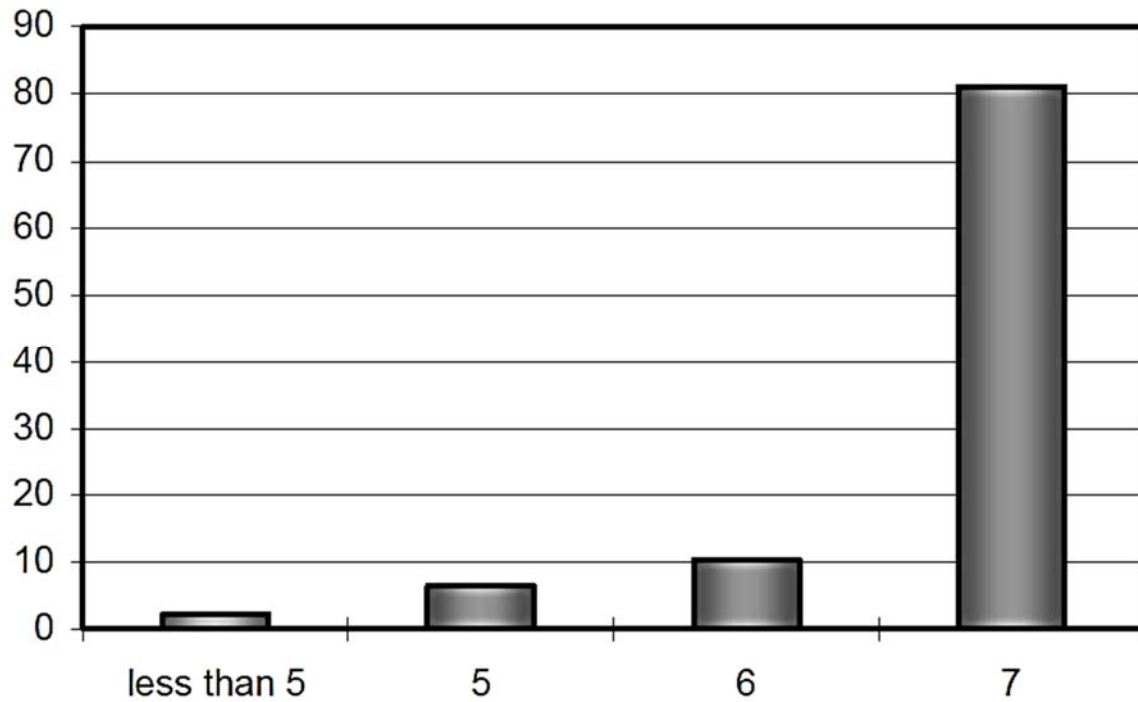


Figure 6.43: Working Days Per Week For Rural Migrant Workers, 2002 (%) (Shi, 2008)

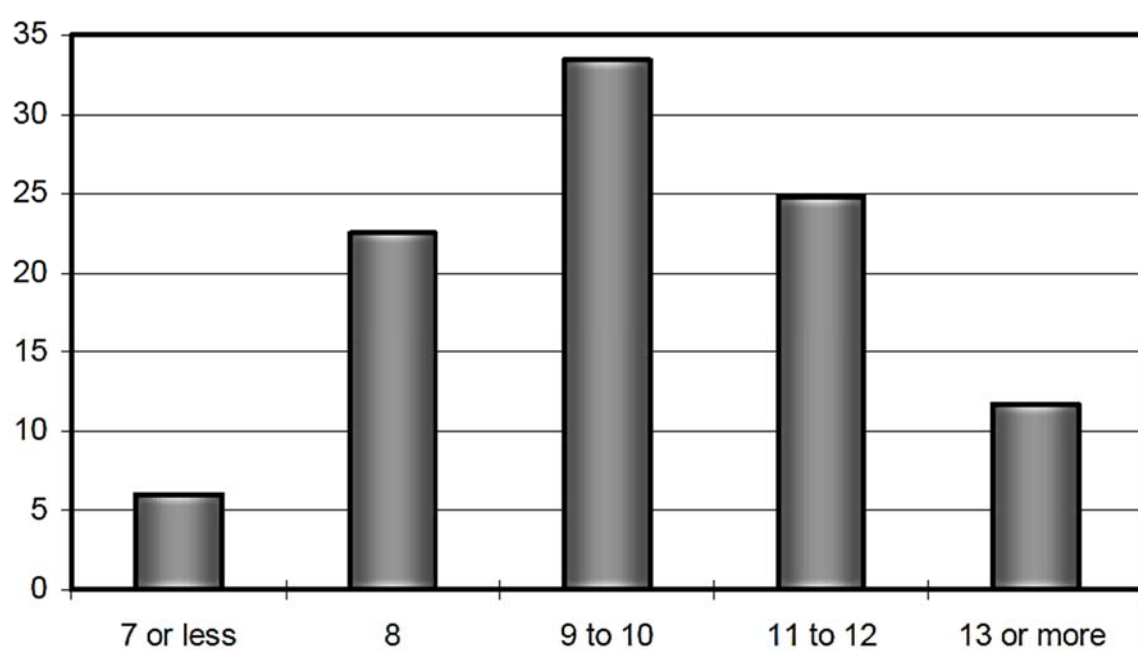


Figure 6.44: Daily Working Hours Per Week For Rural Migrant Workers, 2002 (Shi, 2008)

### **6.7.5 Living Conditions**

In North America, HDD crews are often compensated for room and board in the form of a per diem rate allotted to each worker. The minimum amount of this per diem is set by the national pipeline contractors associated and is dependent on distance from the workers home office, the region the project is occurring in, and the size of the pipeline installation. Additional funds can be provided at the discretion of the HDD contractor. Per Diem rates typically range from 45USD to 110USD.

In China, room and board is also provided; however, directly to the worker and as no per diem monetary rate is given. The majority of workers live in jobsite dormitories that are provided by their employers for large construction sites. These dormitories are crowded and lack basic furniture, sanitation facilities, heating and air-conditioning (Xu, 2007). For the projects investigated for this study, the HDD crossing durations were relatively short, and housing was acquired by the contractor through nearby residential rentals or local hotels. In all cases, workers shared accommodations, sometimes 4 or more to a room. According to CHIPS data, the average living area per migrant worker in 2002 was minimal as compared to those standards in North America. Approximately 22 per cent of migrant workers had a living area of less than 5 square meters per capita and 28 per cent between 5 and 8 square meters.

Another major difference in housing conditions between Chinese and North American HDD crews was the presence of basic sanitation facilities. In North America, it is standard practice to provide standard sanitation including toilets and showers either privately per room or shared among several rooms. In China; however, one study found

that 45 per cent of migrant workers lived in housing without a bathroom or toilet, 22 per cent in housing with only a toilet and 17 per cent in housing with a shared public toilet. However, even given the limited living space and poor housing conditions, housing costs are still considered to be a privilege among Chinese workers.

It was found that the average time which migrant workers stayed outside their village was 9.4 months in 2006. For construction workers, and in particular HDD workers with ever changing jobsites, it is unlikely that the workers families joined them. Housing was only provided to the worker and not the family. In addition, traditional Chinese values place a women's role to carry more responsibility for work in the home, including with respect to the care of children and aging parents. In addition, migrant children face many difficulties in obtaining access to public schools in urban areas.

#### **6.7.6 Education**

Many onsite workers in China are highly educated & often possess advanced academic degrees in engineering and science based disciplines. This mostly applies to management and supervision positions onsite performing rolls of engineers, project managers, inspectors, field supervisors, safety professions, and even specific trade positions such as surveyors, drillers, and welders. This is different than in North America as many of these positions do not require any higher education.

General field workers; however, were found to have lower levels of education in China than in North America. Rural migrant workers in general have low educational attainment. As shown in Figure 6.43, data indicate that in 2004, 65 per cent were lower-middle school graduates, while 18 per cent had an educational level of primary school or below. This means that at that point, 83 per cent of migrant workers had completed no

more than nine years of schooling. In rural China, compulsory education is nine years and the enrolment rate in upper middle school (school years 10 to 12) is relatively low, although it has been increasing slightly. This is partially due to education up to middle school (eight to nine years of education) becoming mandatory only in 1986. It was also found that increases in school fees, poverty and poor educational quality in rural areas were major contributors to the low levels of education achieved in rural China. The low educational attainment of rural migrant workers indicates that they enter the labor market as unskilled workers, in need of training.

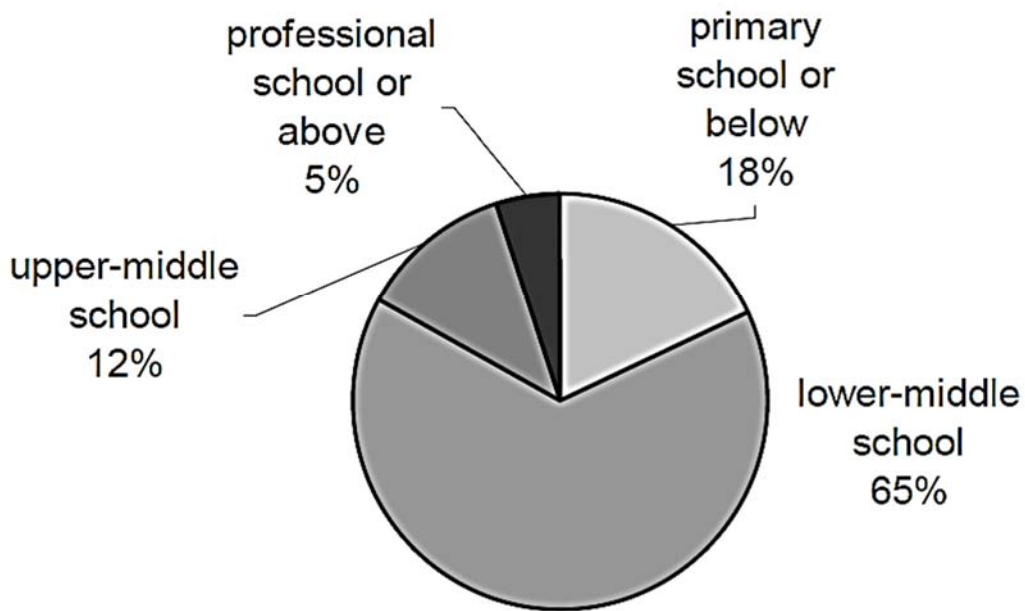


Figure 6.45: Educational Attainment of Rural Migrant Workers, 2004 (Shi, 2008)

## 7. CONCLUSIONS AND RECOMENNDATIONS

### 7.1 Analytical Conclusion Summary

Based on the comparative analysis performed between Chinese HDD construction methods and those utilized in North America, the following overall conclusions were found:

**With regards to *General HDD Market Considerations*, major findings include:**

- The Chinese government plays a dominant role in the development of its construction industry. Thus, changes in political and economic policies by the Chinese government directly affect the way horizontal directional drilling contractors do business.
- Nearly all of the buried pipeline energy infrastructure in China, including major HDD crossings, are designed, constructed, and operated on a national scale by the Chinese government. Thus, the large-rig HDD market, particularly for energy infrastructure, is dominated by State Owned Enterprise's such as the CNPC Crossing Company.
- Privately owned firms; however, are large contributors to local markets, and perform many small scale and large scale buried utility construction projects for services maintained on a providential level.

**With regards to *Design*, major findings include:**

- With regards to design, in both North America and China, it was found that extensive geotechnical investigations were performed prior to design and construction. The major difference found between the Chinese method and the North American method I who performs the initial investigation.

- It was found that both Chinese and North American project's design are carried out in accordance with national standards of each country as well as the Pipeline Research Council International (PRCI) standards.
- In China, analysis includes advanced simulation models and graphing of all stages of all operation and reflects specific tool types and sizes which will be required by the contractor to use for actual construction
- North America appears to be more advanced in is the completion of detailed hydraulic fracturing reports for project owners. These reports have become more common for critical crossings and crossings located in environmentally susceptible areas.

**With regards to *HDD Application and Process*, major findings include:**

- In the case of Chinese projects, the overall project schedule, drill plan and reporting requirements are given to the HDD contractor by the designer / owner. In North America, these items are generated by the HDD contractor.
- In China, the local government has access to nearly all lands, including private land, and thus easements, right-of-ways, and private land boundaries do not limit the size of Chinese project sites. Thus, in China, it was observed that the overall jobsites are more spread out than those in North America and therefore spanned larger overall footprints than similarly sized projects in North America.
- For most HDD construction sites in North America, the HDD contractor is required to install either safety fence or another adequate barrier to prevent equipment, vehicle or pedestrian traffic from crossing over drill path in areas subject to surface collapse or bore hole collapse per the contract documents. In North America; however, fencing is almost never shown on any drawings and is therefore not installed unless the site is located in an

urban area. In China; however, all jobsites witnessed had a system of safety fencing in place even in the most remote areas. This fencing encompassed the entire drill site on both the entry and exit sides in many cases and sometimes surrounded acres of land including all equipment, onsite trailers, material staging areas, and fluid management systems.

- In North America, the typical approach to jobsite access is to install systems of timber matting to elevate work equipment and provide a sound platform for the general drill area. In China; however, this was not the case. Timber matting did not appear to be a method utilized by Chinese contractors. This often resulted in extremely muddy jobsites and difficulty accessing the site for normal site access.
- In China, precast concrete spans were seen to be laid between major operations during heavy foot traffic areas to assist in construction workers traveling between main areas on the jobsite. Hand laid brick pathways were also witnessed. Based on the layout of the brick pathways, they appeared to have been labor intensive to install.
- In both the United States and China, the pilot hole is along the path shown on the plan and profile drawing as prepared by the design engineer.
- It was determined that in China, significantly more reaming passes were made on the investigated projects than would have been made under similar soil conditions in the United States. The result was an increase in overall work-hours, total project duration, and additional tooling requirements.
- In North America, roller supports are the selected method for pipeline fabrication and staging. In China, extensive dirt mounds are built from the natural terrain to support the pipeline. This requires significant change to ground conditions as well as labor necessary to create the natural support systems.

- In both China and North America, the pullback operation is considered to be the most crucial step in the HDD process.
- Restoration includes temporary and permanent vegetation as specified in the Drawings and Contract Documents is performed by the prime contractor, not the HD contractor, in both China and North America.

**With regards to *Equipment and Materials*, major findings include:**

- Rig Selection is first and foremost decision made for a HDD crossing. It was found that North American contractors only utilized North American manufactured drill rigs for the large rig projects. In China; however, Chinese contractors utilized both North American and Chinese Manufactured drill rigs. Based on the Chinese case studies, the selected rigs utilized for all three of the CNPC projects as well as the Qin River crossing were more than enough force to complete the installation.
- One unique detail that was found on more than one Chinese project was the utilization of several sizes and lengths of drill pipe.
- Chinese contractors made selections that were similar to those in the Unites states with respect to mud motors, drill bits, and reamers. A major difference between drill bit and downhole tool selection between Chinese contractors and North American contractors is who actually makes the selection of the tools. In China, specific tools are modelled and forces are calculated for those specific tools. Thus, the HDD contractor is required to utilize the types of tool specified by the engineer. In North America; however, the specific schematic of pilot, reaming, and pullback operations is left to the discretion of the HDD contractor.



- In some cases in North America, mostly when abnormal tooling sizes are required, North American contractors will fabricate custom tools; however, it is not common practice. Tools in North America are also purchased with the expectation that they can be used for more than one project if possible, and, if needed, can be refurbished after usage.
- In China; however, it is common practice for HDD contractors to manufacture tools that are job specific that will be abandoned afterwards. Thus, the quality of the tools only needs to be high enough to complete the job the tools were built for.
- In North America, hydraulic fracture and inadvertent returns, particularly unfavorable in environmental susceptible areas. In china; however, this is not as large of concern due to less stringent environmental regulations and lack of urbanization in many locations.
- The drilling fluid delivery, recovery, and containment systems have similarities and great differences between North American and China. In North America, fluid return pits are small, measuring less than 15' by 15' in most cases. Also, there is typically only one pit that stores all returns prior to entering fracture tanks and the overall recycling system. In China, the natural settling tanks utilized are significantly larger than those in the United States and therefore result in increased material usage and disposal as well as an over increase in project footprint.
- Another vast difference between China and North America is the location which they acquire fresh water for the drilling fluid. In North America, water is rarely permitted to be taken from the local stream, river, or lake that the pipeline is crossing. In these cases, water is transported via haul truck from a local source to the jobsite. In China; however, regulations are relaxed in this area and allow contractors to pump water from the nearby

water body in most cases. In other cases, onsite wells are dug and water is sourced from underground aquifers and groundwater.

- North American HDD contractors are responsible for promptly removing all drilling fluids and associated cuttings from job site and hauling to an approved facility for proper disposal. Land farming is most often the selected method of spoil removal in China and is most often the responsibility of the owner, not the HDD contractor. In some cases, some of the water that had been separated from the cuttings was released back into the adjacent water body.

- In both North America and China, the mud composition is determined by the HDD contractor. Though water and bentonite are the main components of drilling fluid, additional additives are sometimes used in different soil conditions. In both China and North America, HDD contractors check drilling fluid properties at least four times per shift during drilling operations. Tests performed by both Chinese and North American contractors include density, viscosity, strength water and sand content, water loss, PH, and hardness.

- For complex crossings, the HDD contractors in North America most often provide a certified mud engineer/technician on-site during all phases of the drilling process whether or not it is specifically specified by the owner. For all CNPC projects; however, it is standard for a full time CNPC employed mud team, typically consisting of 2-3 engineers, to be onsite at all times for all major crossings.

- It was found that the TruTracker<sup>®</sup> and ParaTrack 2<sup>®</sup> were the selected method of tracking both in China and in North America. With regards to *Jobsite Safety and Quality Control*, major findings include:

- The United States Occupational Safety and Health Administration (OSHA) is the governing agency responsible for safe and healthful working conditions on HDD projects. In China, the comparable agency is the State Administration of Work Safety (SAWS.) SAWS safety standards are modelled closely after the British Standards Institute (BSI).
- Though measures are in place to protect the health and safety of onsite HDD workers, China's federal enforcement of these regulations; however, is somewhat less stringent than the US.
- The majority of jobsite safety is managed at the jobsite level by field supervision. In the case of Chinese projects, there is at least one full time safety personnel onsite at all times.
- Chinese contractors were witnessed to be more advanced in the implementation of safety uniforms to all onsite workers with delineation of job requirement visible. In North America; however, uniforms are not standard for the HDD industry.
- Final approval of the crossing appears to be similar in both North American and China and includes the review and approval of the results of the drill profile survey information, hydrostatic test data, sizing plate run data (if required), internal pipeline inspection report, and any material inspection data. It is not until all factors have been deemed passing that the acceptability of installed HDD is given and the HDD contractor is granted permission to demobilize.
- In North America, as-built drawings typically represent an accurate document of the actual as-built path profile as compared to the original design profile. However, it was found that is likely that on some Chinese projects, the original design drawing is sometimes

changed after construction to match the true “as-built” conditions. Thus, the result is a near perfect execution of the intended design as it is presented to the owner.

**With regards to *Worker Considerations*, major findings include:**

- In China, there is a distinct difference between what are considered “rural workers” as compared to “urban workers.” Due to the remote areas that many large scale crossing are performed in, it was found that many of the management roles and engineering rolls were filled by what could be considered to be “urban” workers working directly for CNPC.
- Field labor; however, is most likely composed of a composite crew of both workers who travel from crossing to crossing as well as local “rural” workers
- The labor allotment, particularly in rural areas, is significantly higher in number in China. However, it is a common practice to employ many more workers than is actually required. This is a standard of practice that is recognized on a national level in order to employ more people of China’s 1.3 billion person population.
- In North America, the vast majority of HDD crews are paid based on the number of hours worked per week. Typically, it is standard practice for workers to work a standard 40 hour work week. China, wages are paid to the workers in two ways. Each non-salaried worker is paid a monthly stipend of approximately 12,000 RMB (approx. US\$1,967) plus room and board. As shown, the median pay of 12,000 RMB is nearly 10 times higher than that of the minimum wage in many western areas. Thus, for that reason alone, these jobs are highly coveted and difficult to get with connections.
- Regarding benefits, urban workers are typically entitled to social security coverage such as a pension, unemployment insurance, medical insurance and subsidized public housing. Rural workers; however, do not always receive the same benefits.

- Working hours in China were found to be twenty-four (24) hours per day seven (7) days per week. Monthly wages are based on workers completing the entire daily twelve (12) hour shift all seven days per week. In China, workers were not given overtime premium.
- In North America, HDD crews are often compensated for room and board in the form of a per diem rate allotted to each worker. In China, room and board is also provided; however, directly to the worker and as no per diem monetary rate is given. The majority of workers live in jobsite dormitories that are provided by their employers for large construction sites. These dormitories often lack basic furniture, sanitation facilities, heating and air-conditioning.
- Many onsite workers in China are highly educated and often possess advanced academic degrees in engineering and science based disciplines. This mostly applies to management and supervision positions onsite performing rolls of engineers, project managers, inspectors, field supervisors, safety professions, and even specific trade positions such as surveyors, drillers, and welders. This is different than in North America as many of these positions do not require any higher education. General field workers; however, were found to have lower levels of education in China than in North America.
- Rural migrant workers in general have low educational attainment.

## **7.2 Contribution to Body of Knowledge and Practical Significance**

Contribution to both body of knowledge and standard of practice is critical for this study as it is important to see both the scientific contribution and practical significance of any research. This research has resulted in the following outcomes with respect to both considerations:

- An Increase in basic understanding of HDD construction methods being used in china.
- Creation of baseline model of comparison between new Chinese methods of HDD construction as compared to those long established practices in North America.
- Creation of an opportunity for Chinese HDD methods to contribute to the world's knowledge for global best practices for the horizontal directional drilling method.
- Promotion of both domestic & international competitiveness among North American contractors.
- Strengthening of international partnership between the North America & China in the area of trenchless research & development towards directions on critical underground infrastructure.

### **7.3 Directions for Future Research**

#### **7.3.1 Energy Outlook for China**

In the future, rising energy demands in China will most certainly have a direct effect on buried pipeline construction as well as the HDD industry in China. The data used to

generate the following projection Figures 7.1-7.7 was obtained from the International Energy Outlook 2013 prepared by the United States Government.

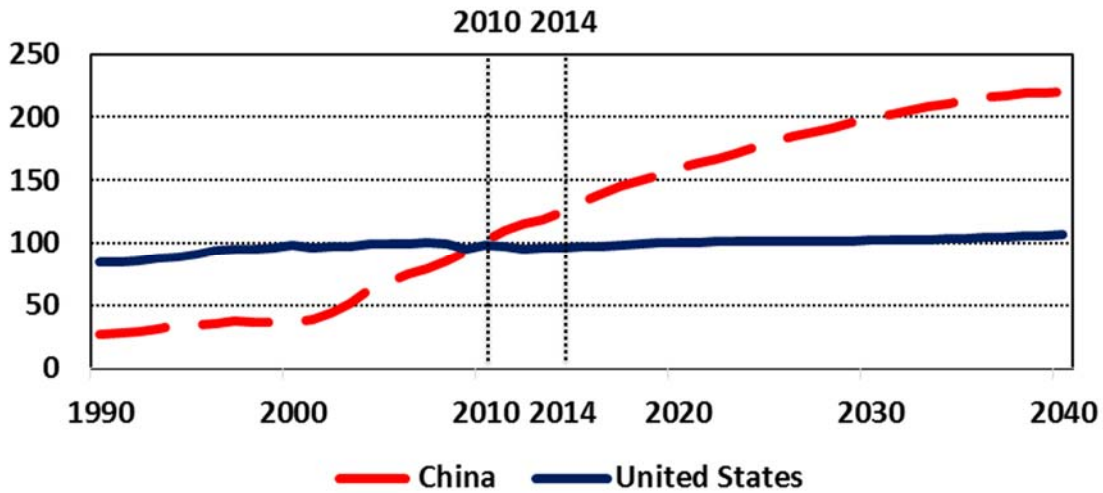


Figure 7.1: China and United States Energy Consumption 1990-2040 (Quadrabillion Btus) (Adapted from the International Energy Outlook, 2013)

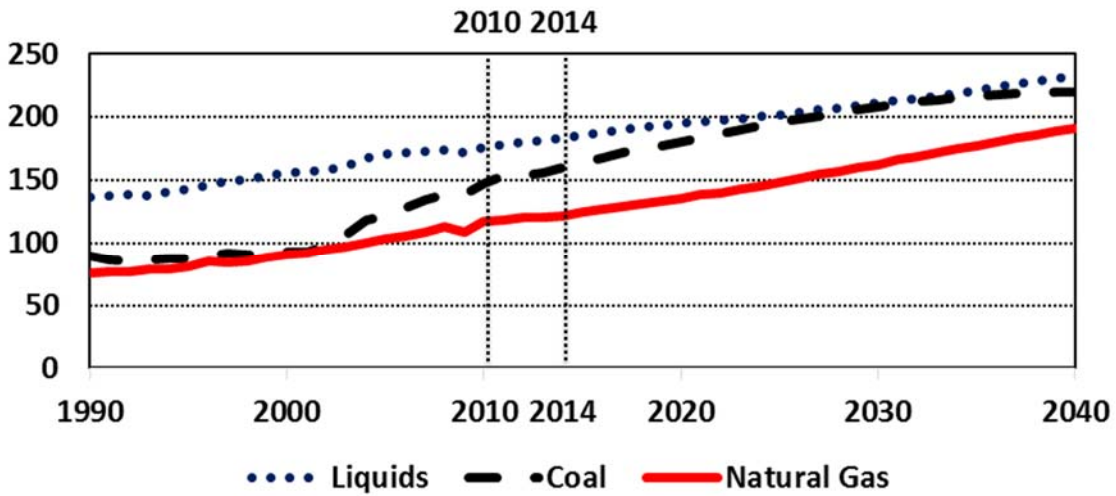


Figure 7.2: World Energy Consumption by Fuel Type 1990-2040 (Quadrabillion Btus) (Adapted from the International Energy Outlook, 2013)

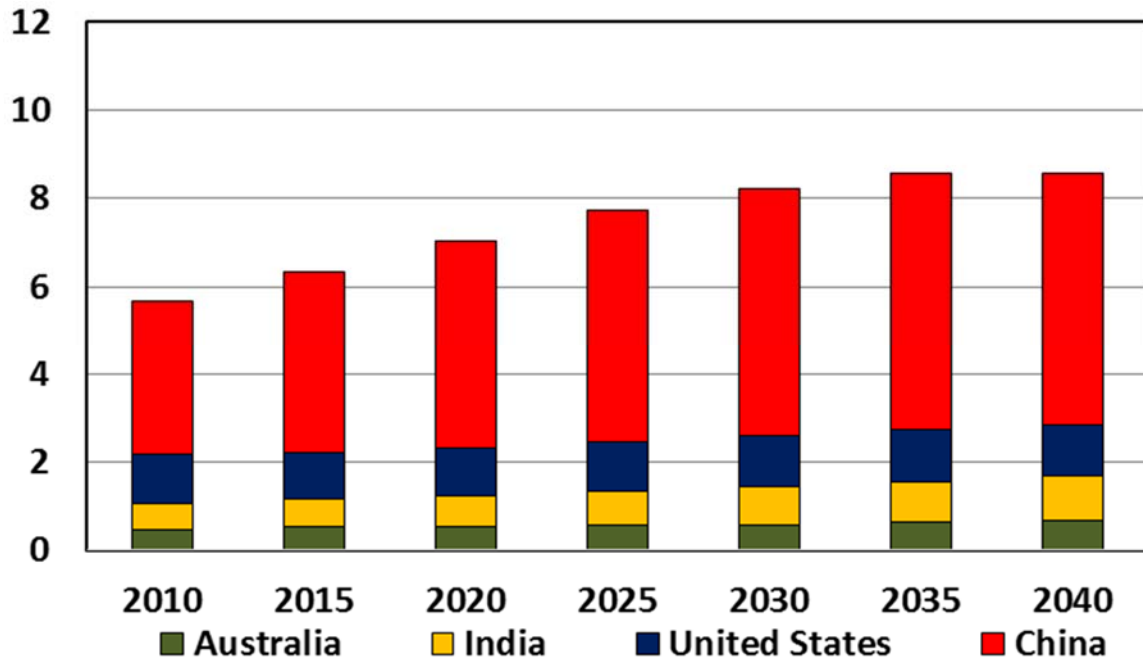


Figure 7.3: World Coal Production, 2010-2040  
 (Quadrabillion Btus) (Adapted from the International Energy Outlook, 2013)



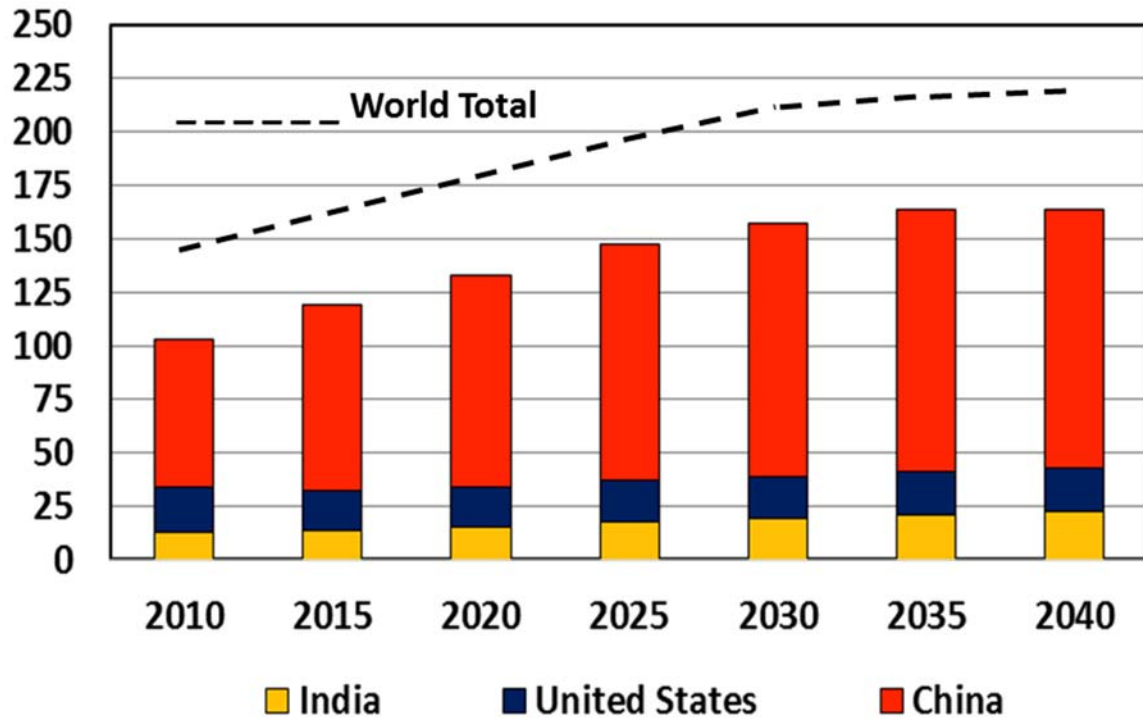


Figure 7.4: World Coal Consumption by Leading Consuming Countries 2010-2040 (Quadrabillion Btus) (Adapted from the International Energy Outlook, 2013)

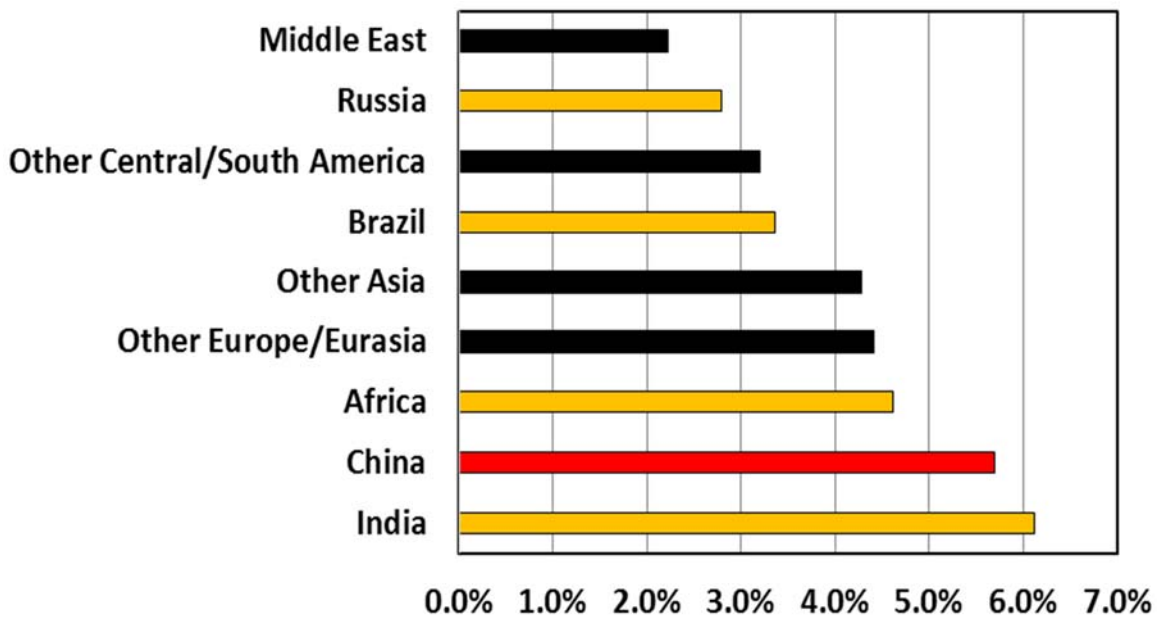


Figure 7.5: Non-OECD Real Gross Domestic Product Growth Rates, 2010-2040 (Adapted from the International Energy Outlook, 2013)

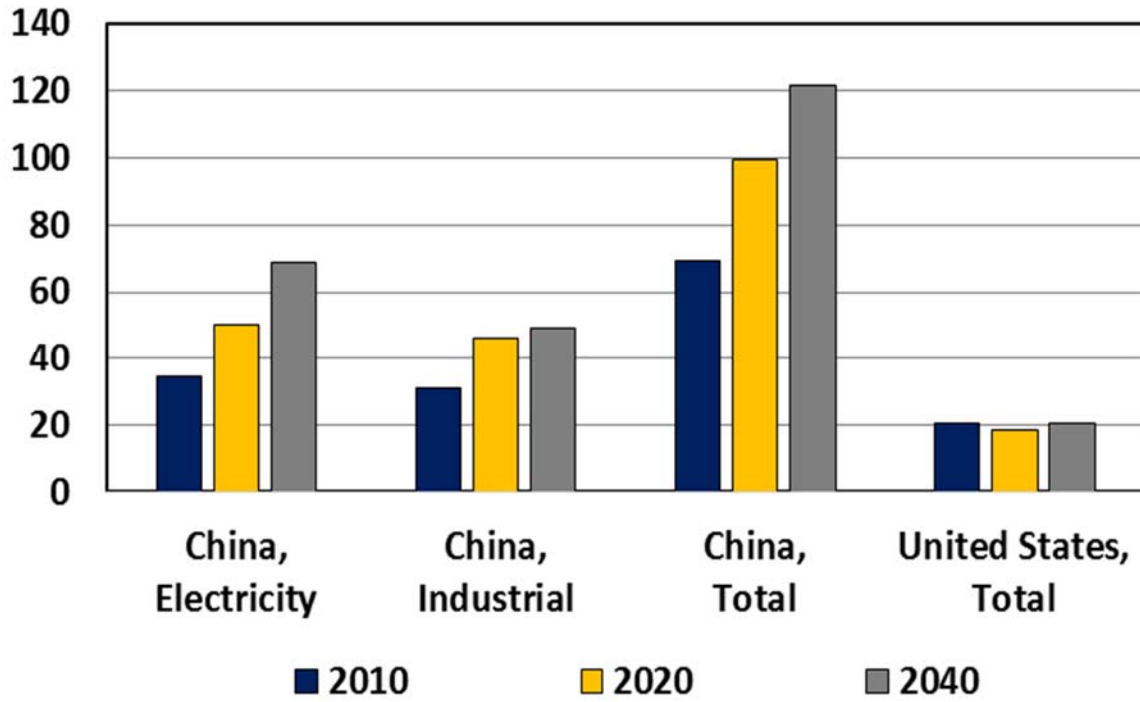


Figure 7.6: China Coal Consumption by Sector and Total Compared with U.S. Total Coal Consumption, 2010-2040 (Quadrabillion Btus) (Adapted from the International Energy Outlook, 2013)

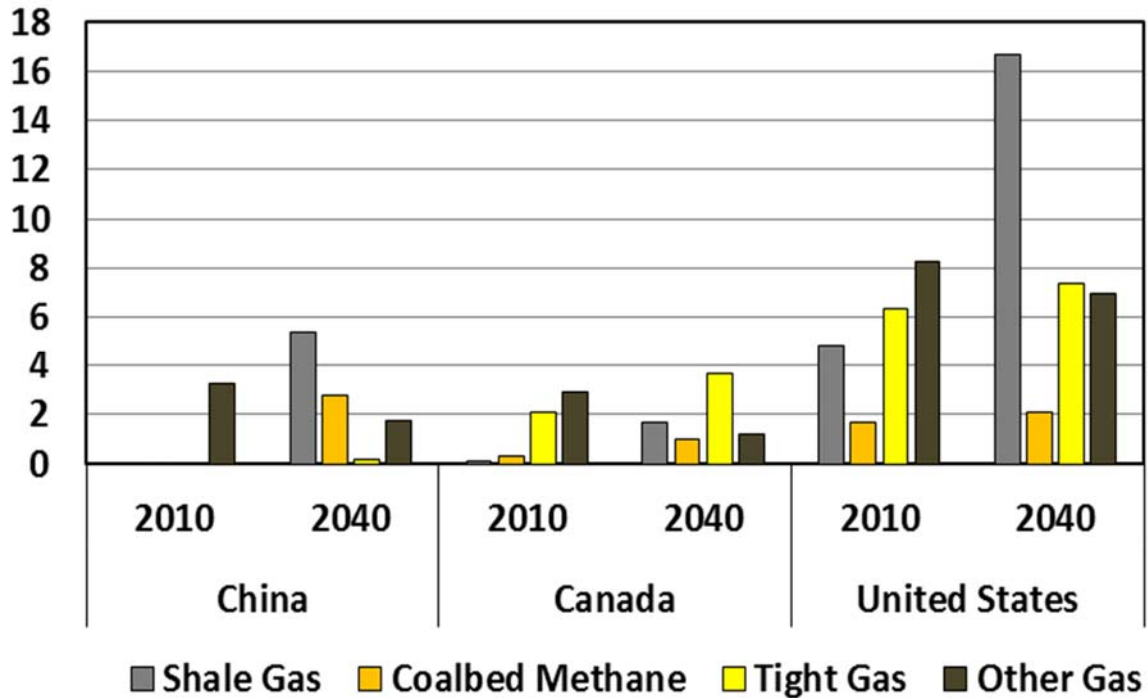


Figure 7.7: Natural Gas Production in China, Canada, and the US, 2010 and 2040 (Trillion Cubic Feet) (Adapted from the International Energy Outlook, 2013)

Based on Figures 7.1 through 7.7, the following predictions can be made with regards to the growth of the HDD market in China:

- The Chinese government will continue to fund large-scale pipeline construction projects and will continue to tighten energy efficiency requirements for all parties. Thus HDD will be utilized more than ever before.
- Chinese manufacturers of maxi-rig equipment will continue to test the boundaries of how “large” future drill rigs can be produced.
- An increase demand for natural gas and oil resources will contribute to increased international pipeline projects and trade agreements. .
- Coal slurry pipeline will further contribute to energy transmission as a new and emerging market.

- Domestic pipeline installation will grow in response to efforts to develop rural areas located inland.

### **7.1.1 International Significance**

The People's Republic of China has international borders with 14 countries, more than any other, country. The Chinese government has taken diplomatic action to improve their relationship with ASEAN states to secure good relationships with its neighbors. Currently, China has International Pipeline Agreements in Place with the following neighboring countries to design, build, and operate international oil and gas transmission pipelines. Total border mileage is listed:

- Russia (3,605 Miles)
- India (3,380 Miles)
- Burma (2,185 Miles)
- Kazakhstan (1,533 Miles)
- Kyrgyzstan (858 Miles)
- Pakistan (523 Miles)
- Tajikistan (414 Miles)

Additionally, China is in talks with the resource rich nations of Iran, Malaysia and Syria to develop international pipeline transmission networks to the region. In the future, there is a foreseeable increase in large diameter pipeline projects and HDD crossings with international contributions. Refer to Figure 7.9 and Figure 7.10 for applicable maps of China and pipeline partnerships.

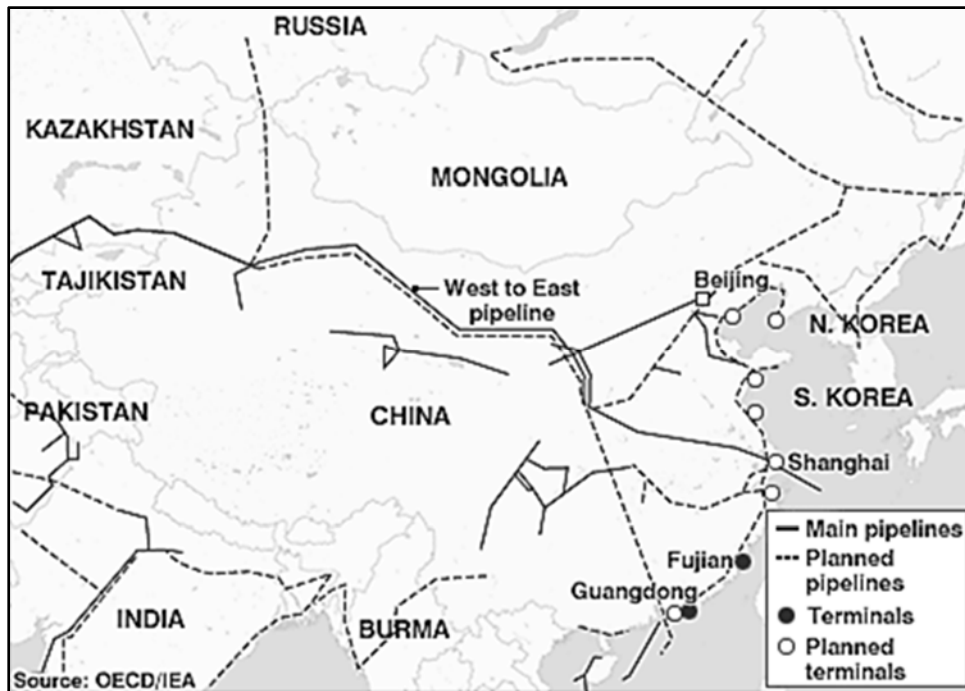


Figure 7.8: International Russia / China Pipeline (CNPC, 2014)



Figure 7.9 Potential Pipeline Route for International Pipeline to China (CNPC, 2014)

### **7.1.2 Opportunities for Continued International Collaboration**

Globalization and world economy has produced new opportunities and challenges both for developed and developing countries. Underground infrastructure and pipelines are lifelines of this global economy, and require a great deal of planning, education, research and development. It is obvious that developing countries can learn from mistakes of industrialized nations, by not repeating same mistakes. Therefore, technology transfer and research collaboration between countries is one of the important issues in today's economy and globalization. Academic researchers, with industry partners, government agencies, have a major role in the development and dissemination of technology between countries (Najafi et al, 2008.)

### **7.1.3 Future of HDD in China**

As of 2010, China was estimated to have approximately 36,000km (22,400 miles) of natural gas pipeline. By the end of 2015, and as part of the country's Twelfth "Five-Year" Plan (2010-2015), the Chinese government plans to nearly triple the country's natural gas pipeline network to 100,000km (62,100 miles.) In order to accomplish this paramount goal and expand its national energy infrastructure, China has become the fastest growing country utilizing Horizontal Directional Drilling (HDD). The Plan Outlines Efforts To Rebalance Its Economy, Shifting Emphasis From Investment Towards Consumption And Development From Urban And Coastal Areas Toward Rural And Inland Areas.

China's rapid adoption and advancement in large diameter natural gas pipeline installation has resulted in numerous successful pipeline projects which include a series of recently executed record-breaking HDD installations. It is expected that records will

continue to be broken as large-scale pipeline installations continue and competition between China National Petroleum Corporation, Sinopec (China Petroleum & Chemical Corporation), and China National Offshore Oil Corporation increase. In addition, Chinese manufacturers of maxi-rig equipment will continue to test the boundaries of how “large” future drill rigs can be produced. Thus, China’s role as the global leader in large-scale horizontal directional drilling will not only continue, but will grow in the foreseeable future.

As China’s economy expands over the foreseeable future, rising personal incomes will lead to rapid urbanization, higher demand for personal vehicles, and higher demand for quality of life enhancers such as air conditioners and appliances. These factors contribute to the International Energy Outlook 2013 (IEO2013) projection that world energy consumption will grow by 56 percent between 2010 and 2040. Much of this growth in energy consumption occurs in China where demand is driven by the country’s long-term economic growth. Figures 4 and 5 illustrate future energy consumption through 2040.

By the end of 2015, and as part of the country’s Twelfth “Five-Year” Plan (2010-2015), the Chinese government plans to nearly triple the country’s natural gas pipeline network to 62,100 miles (100,000 KM). Figure 7.10: shows closing ceremonies for the completion of a pipeline project. In addition, China plans to add 6,000 miles of crude oil pipelines and at least 6,000 miles of oil product pipelines to the system as part of this plan. Coal slurry pipeline is also expected to further contribute to energy transmission as a new and emerging market.



Figure 7.10: Closing Ceremonies at Pipeline Project Completion ([www.cnpc.com.cn/en](http://www.cnpc.com.cn/en))

With this said, it can be expected that there are vast opportunities for Chinese HDD contractors to continue to test the limits of the HDD technologies through equipment advancement, record setting executions, and number of crossings attempted. Chinese manufacturers of maxi-rig equipment will continue to test the boundaries of how “large” future drill rigs can be produced. HDD contractors will attempt crossings that are larger and further than ever before attempted. Finally, the Chinese government will continue to fund large-scale pipeline construction projects and will continue to tighten energy efficiency requirements for all parties. These factors combined further solidify China’s role as the global leader in trenchless technology methods and provide the opportunity for Chinese HDD contractors to contribute to the world’s knowledge for best practices



## REFERENCES

- Ariaratnam, S.T., Chan, W., and Choi, D. (2006). "Experiences in Adopting Trenchless Methods in China." *Proceedings of the Pipeline Division Specialty 2006 Conference*, American Society of Civil Engineers, Chicago, Illinois, on CD.
- Allouche, E. N., and Como, C. (1997). "Horizontal Directional Drilling Technology, Techniques and Applications." *Proceedings of the 1997 NASTT/University of Alberta Technology Seminar*, North American Society for Trenchless Technologies. Alberta, Canada, 18–26.
- Allouche, E., Ariaratnam, S., and Lueke, J. (2000). "Horizontal Directional Drilling: Profile of an Emerging Industry." *Journal of Construction Engineering and Management*, American Society of Civil Engineers, 126(1), 68–76.
- Applegate, D., Cronberg, A., and White, T. (2011). "Challenges of Large Diameter Horizontal Directional Drills." *Proceedings of the Pipeline Division Specialty 2011 Conference*, American Society of Civil Engineers, Seattle, WA, 596-606.
- Ariaratnam, S., Chan, W., and Choi, D. (2006). "Utilization of Trenchless Construction Methods in Mainland China to Sustain Urban Infrastructure." *Practice Periodical of Structural Design and Construction*. American Society of Civil Engineers, 11(3), 134–141.
- Bajaj, D., and Zhang, R. (2003). "Managing Construction Industry Development in China." 2003 AACE International Transactions, AACE International, Morgantown, West Virginia. On CD.
- Baumert, M.E., 2003. "Experimental Investigation of Pulling Loads and Mud Pressures during Horizontal Directional Drilling Installations." Ph.D. Thesis, University of Western Ontario, London, Ontario.
- Bennett, R.D., and Ariaratnam, S.T. (2008). "Horizontal Directional Drilling Good Practices Guidelines, 3rd Edition." HDD Consortium. Arlington, Virginia.
- Bennett, R.D., and Wallin, S. (2003). "American River Crossings Now and Then." *2013 International No-Dig Conference*. International Society for Trenchless Technologies, Las Vegas, Nevada, On CD.
- Bo, X. and Chan, A. (2012). "Investigation of Barriers to Entry into the Design-Build Market in the People's Republic of China." *Journal of Construction Engineering and Management*, American Society of Civil Engineers, 138(1), 120–127.
- Bockrath, J. T. (2000). *Contracts and the Legal Environment for Engineers and Architect*. 6th Edition. McGraw-Hill, New York.

- Bubshait, A. A., and Almohawis, S. A. (1994). "Evaluation the General Conditions of a Construction Contract." *International Journal of Project Management*, Elsevier BV, 12(3), 133–136.
- Cao, H., Ariaratnam, S., Lueke, J., Wei, H., Sun, P., and He, R. (2011). "A Parametric Study of Underground Utility Infrastructure in China." *Proceedings of the International Conference on Pipelines and Trenchless Technologies 2011 Conference*, American Society of Civil Engineers, Beijing, China, 2199-2208.
- Cao, H., Sun, P., Wu, X., Zhong, S., and Zheng, M. (2012). "Analysis of Influence Factors on Borehole Path Control Associated with Horizontal Directional Drilling." *Proceedings of the International Conference on Pipelines and Trenchless Technologies 2012 Conference*, American Society of Civil Engineers, Wuhan, China, 1890-1897.
- Carpenter, R. (2008). "Large Rig Market Speeds Ahead." *Underground Construction Magazine*. Houston, TX, June 2008.
- Carpenter, Robert. (2008). "The China Syndrome." *Underground Construction Magazine*. Houston, TX, June 2008.
- Changjiang Water Resources Committee (CWRC). (1999). "Atlas of Yangtze River basin." M.SinoMaps Press, Beijing, China, 32-33.
- Chen, J. and Chen, C. (2008). "The Yangtze River Transportation-Economic Belt." *Transportation and Development Innovative Best Practices 2008*. American Society of Civil Engineers. 87-92.
- Chen, L., Zhang, P., Ma, J., Feng, B., and Zhao, J. (2009). "Geological Hazard Assessment of Long-Distance Gas Pipelines." *Proceedings of the International Conference on Pipelines and Trenchless Technologies 2009 Conference*, American Society of Civil Engineers, Shanghai, China, 1774-1782.
- Chen, P., and Partington, D. (2004) "An Interpretive Comparison of Chinese and Western Conceptions of Relationships in Construction Project Management Work." *International Journal of Project Management*, Elsevier BV, 22, 397–406.
- Chen, P., Partington, D., and Wang, J. N. (2008). "Conceptual Determinants of Construction Project Management Competence: A Chinese Perspective." *International Journal of Project Management*, Elsevier BV, 26, 655–664.
- Chen, P., Qiang, M., and Wang, J. (2009). "Project Management in the Chinese Construction Industry: Six-Case Study." *Journal of Construction Engineering and Management*, American Society of Civil Engineers, 135(10), 1016–1026.
- Chen, Z. and Li, H. (2006). "Discussion of "Risks in Chinese Construction Market—Contractors' Perspective" by Dongping Fang, Mingen Li, Patrick Sik-wah Fong,

- and Liyin Shen.” *Journal of Construction Engineering and Management*, American Society of Civil Engineers, 132(3), 327–328.
- Cheng, E., Polak, M.A., (2007). “Theoretical Model For Calculating Pulling Loads For Pipes in Horizontal Directional Drilling.” *Tunneling and Underground Space Technology*, Elsevier Limited, 130(3), 424–432.
- China National Petroleum Corporation. (2012). “2012 Corporate Social Responsibility Report.” China National Petroleum, Beijing, China, 2012.
- China National Petroleum Corporation. (2012). “East-West Natural Gas Pipeline: Taxing-Hibiscus Segment. Yangtze River Directional Drilling Construction Program.” China National Petroleum, Beijing, China, 2012.
- China National Petroleum Corporation. (2012). “Engineering Statement for the Taxing-Hibiscus Segment of the East-West Natural Gas Pipeline.” China National Petroleum, Beijing, China, 2012.
- China National Petroleum Corporation. (2010). “Facts and Figures Report: 2010.” China National Petroleum, Beijing, China, 2012.
- Chui, K. and Bai, Y. (2010). ”Comparison of Contract General Conditions between United States and China.” *Journal of Architectural Engineering*, American Society of Civil Engineers, 16(4), 119–125.
- Chui, K. W., and Bai, Y. (2010). “Comparison of contract General Conditions Between the U.S. and China.” *Journal of Architectural Engineering*, American Society of Civil Engineers, 16(4), 119–125.
- Clough, R. H., Sears, G. A., and Sears, S. K. (2005). *Construction Contracting: A Practical Guide to Company Management*, 7th Ed., Wiley, Hoboken, N.J.
- Communist Party’s School (2005). “A Survey of Nine Years Compulsory Education in Rural China. In: Yang, D.P., ed., *The Development Report of China’s Education*.” Social Sciences Academic Press China, Beijing, China, 297-305.
- Deng, Q., Wang, X., Shen, F., and Li, H. (2012). “The Geohazards Features and Management of Zhongxian-Wuhan Gas Pipeline in Mountainous Areas.” *Proceedings of the International Conference on Pipelines and Trenchless Technologies 2012 Conference*, American Society of Civil Engineers, Wuhan, China, 1240
- Fang, D. P., Li, M., Fong, P. S., and Shen, L. Y. (2004). “Risks in Chinese construction market—Contractor’s perspective.” *Journal of Construction Engineering and Management*, American Society of Civil Engineers., 130(6), 853–861.
- Fisk, E. R. (2002). *Construction Project Administration*. 7th Ed., Wiley, Hoboken, N.J.

- Fu, G., Dong, P., Li, G., Liu, G., and Liu, Y. (2012). "Case Studies of Microtunneling Used for Gas Pipeline Crossing in China." *Proceedings of the International Conference on Pipelines and Trenchless Technologies 2012 Conference*, American Society of Civil Engineers, Wuhan, China, 1898-1904.
- Gao, H., Li, G., Ma, X., Guo, J., and Ma, J. (2011). "Special Practices of Horizontal Directional Drilling in China." *Proceedings of the International Conference on Pipelines and Trenchless Technologies 2011 Conference*, American Society of Civil Engineers, Beijing, China, pp. 2216-2224.
- Hinze, J. (2001). *Construction Contracts, 2nd Ed.*, McGraw-Hill, New York.
- Hofstede, G. H. (2001). *Culture Consequences: Comparing Values, Behaviors Institutions, and Organizations Across Nations, 2nd Ed.*, Sage, Thousand Oaks, CA.
- Huang, X., Fang, D., and Li, X. (2000). "Construction Accident Losses: How Much an Accident Costs." *Proceedings from the 2000 International Symposium on Safety Science and Technology*, Chemical Industry Press, Beijing, 320–325.
- Huang, Y. (2009). "The Growth Trend of the Chinese Construction Industry: When It Will Surpass the U.S. Construction Industry." M.S. Thesis. Department of Civil, Environmental, and Architectural Engineering, University of Kansas, Lawrence, Kansas, December 2009.
- Huang, Y., Lan, Y., and Bai, Y. (2013). "Development of the Chinese Construction Industry after the Cultural Revolution: Administration Framework, Economic Growth, and Market Structure." *Journal of Architectural Engineering*, American Society of Civil Engineers, 19(1), 41–50.
- Jiao, R., Zeng, C., and Ma, B. (2011). "Study on Influence Factors to Application of Large-Scale HDD to Oil and Gas Pipe Installation." *Proceedings of the International Conference on Pipelines and Trenchless Technologies 2011 Conference*, American Society of Civil Engineers, Beijing, China, 2254-2262.
- Ling, F., Dulaimi, M., and Chua, M. (2013). "Strategies for Managing Migrant Construction Workers from China, India, and the Philippines" *Journal of Professional Issues in Engineering Education and Practice*, American Society of Civil Engineers, 139(1), 19–26.
- Ling, F., Dulaimi, M., and Chua, M. (2013). "Strategies for Managing Migrant Construction Workers from China, India, and the Philippines." *Journal of Professional Issues in Engineering Education and Practice*, American Society of Civil Engineers, 139(1), 19–26.
- Liu, Y., Zhao, X., and Liao, Y. (2013). "Market Structure, Ownership Structure, and Performance of China's Construction Industry." *Journal of Construction*

- Engineering and Management, American Society of Civil Engineers, 139(7), 852–857.
- Low, S. P., and Jiang, H. (2003). “Internationalization of Chinese Construction Enterprises.” *Journal of Construction Engineering and Management*, American Society of Civil Engineers, 129(6), 589–598.
- Lu, W., Ye, K., Flanagan, R., and Jewell, C. (2013). ”Developing Construction Professional Services in the International Market: SWOT Analysis of China.” *Journal of Management in Engineering*, American Society of Civil Engineers, 29(3), 302–313.
- Ma, B. and Zhou, W. (2013). “China's Municipal Pipelines: Today and Tomorrow.” *Proceedings of the Pipeline Division Specialty 2013 Conference*, American Society of Civil Engineers, Fort Worth, TX. 10-18.
- Ma, B., Najafi, M., Shen, H., and Wu, L. (2010). ”Risk Evaluation for Maxi Horizontal Directional Drilling Crossing Projects.” *Journal of Pipeline Systems Engineering and Practice*, American Society of Civil Engineers, 1(2), 91–97.
- Ma, B., Zeng, C., and Yang, C. (2008). “The Present Conditions and Sustainability of Underground Infrastructure Asset Management in Mainland China.” *Proceedings of the Pipeline Division Specialty 2008 Conference*, American Society of Civil Engineers, Atlanta, GA, 1-8.
- Ma, B.S., and Najafi, M. (2008). “Development and Applications of Trenchless Technology in China.” *Tunneling and Underground Space Technology*, Elsevier Limited, 476–480.
- Mastny, L. “Renewable Energy and Energy Efficiency in China: Current Status and Prospects for 2020.” REEP Renewable Energy and Energy Efficiency Partnership (REEP). Worldwatch Institute, 2010
- Mayo, R. E., and Liu, G. (1995). “Reform agenda of Chinese construction industry.” *Journal of Construction Engineering and Management*, American Society of Civil Engineers, 121(1), 80–85.
- Najafi, M., Iseley, T., Ma, B., and Gokhale, S. (2008). “U.S. – China Collaborative Research Directions on Trenchless Technology and Critical Underground Infrastructure Issues.” *Proceedings of the Pipeline Division Specialty 2008 Conference*, American Society of Civil Engineers, Atlanta, GA. 1-11.
- National Bureau of Statistics (NBS). (2000). “China Statistical Yearbook on Construction 1999.” *Investment in Fixed Assets Statistics Division*, China Statistical Press, Beijing, China.

- National Bureau of Statistics (NBS). (2005). "China Statistical Yearbook on Construction 2004." *Investment in Fixed Assets Statistics Division*, China Statistical Press, Beijing, China.
- National Bureau of Statistics (NBS). (2006). "China Statistical Yearbook on Construction 2005." *Investment in Fixed Assets Statistics Division*, China Statistical Press, Beijing, China.
- National Bureau of Statistics (NBS). (2007). "China Statistical Yearbook on Construction 2006." *Investment in Fixed Assets Statistics Division*, China Statistical Press, Beijing, China.
- National Bureau of Statistics (NBS). (2008). "China Statistical Yearbook on Construction 2007." *Investment in Fixed Assets Statistics Division*, China Statistical Press, Beijing, China.
- Shen, L. Y., Li, Q. M., Drew, D., and Shen, Q. P. (2009). "Awarding Construction Contracts on Multicriteria Basis in China." *Journal of Construction Engineering and Management*, American Society of Civil Engineers, 130(3), 385–393.
- Shen, L. Y., Lu, W., and Yam, M. C. H. (2006). "Contractor Key Competitiveness Indicators: A China Study." *Journal of Construction Engineering and Management*, American Society of Civil Engineers, 132(4), 416–424.
- Shen, L. Y., Zhao, Z. Y., and Drew, D. (2006). "Strengths, Weaknesses, Opportunities, and Threats for Foreign-Invested Construction Enterprise: A China Study." *Journal of Construction Engineering and Management*, American Society of Civil Engineers, 132(9), 966–975.
- Shen, L., and Song, W. (1998). "Competitive Tendering Practice in Chinese Construction." *Journal of Construction Engineering and Management*, American Society of Civil Engineers, 124(2), 155–161.
- Stift, M., Najafi, M., Ma, B., and Kanchwala, M. (2010). "Update on the U.S.-China Collaborative Research Directions on Trenchless Technology and Critical Underground Infrastructure Issues." *Proceedings of the Pipeline Division Specialty 2010 Conference*, American Society of Civil Engineers, Keystone, CO, 775-792.
- Sun, D., Wang, T., and Wu, Y. (2009). "Yu-Ji Gas Pipeline Project Contractor HSE Management." *Proceedings of the International Conference on Pipelines and Trenchless Technologies 2009 Conference*, American Society of Civil Engineers, Shanghai, China, 765-1773.
- Sweet, J. (1999). *Legal Aspects of Architecture, Engineering, and the Construction Process, 6th Ed.*, Brooks/Cole Publishing Company, Pacific Grove, CA.

- Tam, C. M., Zeng, S. X., and Deng, Z. M. (2004). "Identifying Elements of Poor Construction Safety Management in China." *Safety Science*, Elsevier, 42(2),569–586.
- Tang, W., Duffield, C. F., and Young, D. M. (2006). "Partnering Mechanism in Construction: An Empirical Study on the Chinese Construction Industry." *Journal of Construction Engineering and Management*, American Society of Civil Engineers, 132(3), 217–229.
- Tang, W., Qiang, M., Duffield, C., Young, D., and Lu, Y. (2007). "Risk Management in the Chinese Construction Industry." *Journal of Construction Engineering and Management*, American Society of Civil Engineers, 133(12), 944–956.
- United States Department of Energy. (2013). "International Energy Outlook 2013." DOE/EIA-0484 (3013). July 2013
- Wang, S. Q., and Tiong, L. K. (2000). "Case Study of Government Initiatives for PRC's BOT Power Plant Project." *International Journal of Project Management*, Elsevier BV,18, 69–78.
- Wang, V., (2011). "China to Build World's Longest Coal Pipeline." September 9, 2011. [www.en.sxcoal.com](http://www.en.sxcoal.com).
- Lu, W., Li, H., Shen,L., Huang, T, Xu, T., Greenwood, D. (2006). "Using Design-And-Build as an Entry Strategy to the Chinese Construction Market." *International Journal of Project Management*, Elsevier BV, 24, 438–445.
- Xiao, S., Ning, G., and Li, R. (2012). "Study on Geological Hazard Risk Assessment and Risk Management of Oil and Gas Pipeline Projects." *Proceedings of the International Conference on Pipelines and Trenchless Technologies 2012 Conference*, American Society of Civil Engineers, Wuhan, China, 378-388.
- Xinhua. (2011). "Key Targets of China's 12th Five-Year Plan." *China Daily*. March 5, 2011.
- Xu, T., Tiong, R. L. K., Chew, D. A. S., and Smith, N. J. (2005). "Development Model For Competitive Construction Industry in the People's Republic of China." *Journal of Construction Engineering and Management*, American Society of Civil Engineers, 131(7), 844–853.
- Yijie, Q., Jiaqiang, J., Lu, Y., Dailu, Q., Xiangwei, K., and Liang, M. (2011). "Investigation of the Key Technology for Large-Scale Directional Drilling Crossing for Oil and Gas Pipelines." *Proceedings of the International Conference on Pipelines and Trenchless Technologies 2011 Conference*, American Society of Civil Engineers, Beijing, China, 2298-2308.

- Yin, X., Lv, W., Xie, L., Li, S., and Zhang, S. (2009). "Study on the Pipeline Crossing Methods and Suitability of Engineering Geological Conditions in the Middle Reaches of the Yangtze River." *Proceedings of the International Conference on Pipelines and Trenchless Technologies 2009 Conference*, American Society of Civil Engineers, Shanghai, China, 1047-1055.
- Yin, X., Xie, L., and Li, S. (2011). "The Main Environmental Geological Problems Caused by Directional Drilling Crossing in the Middle Yangtze River." *Proceedings of the International Conference on Pipelines and Trenchless Technologies 2011 Conference*, American Society of Civil Engineers, Beijing, China, 1968-1976
- Zeng, S. X., Chen, H. M., and Tam, C. M. (2005). "Market Structure of the Construction Industry of China." *Architectural Science Review*, Earthscan, 48(4), 367–375.
- Zeng, S. X., Tam, C. M., Wang, H. C., and Deng, Z. M. (2003). "Overcoming Problems Associated With Sustainable Development of the Construction Industry in China." *Architectural Science Review*, Earthscan, 46, 353–361 (in Chinese).
- Zhang, P., Luo, P., Wu, Y., and Huang, Y. (2011). "The Status, Development, and Key Technologies of Pipeline Directional Drill Project." *Proceedings of the International Conference on Pipelines and Trenchless Technologies 2011 Conference*, American Society of Civil Engineers, Beijing, China, 2338-2349.
- Zhao, Z. Y., Shen, L. Y., and Zuo, J. (2009). "Performance and Strategy of Chinese Contractors in the International Market." *Journal of Construction Engineering and Management*, American Society of Civil Engineers, 135(2), 108–118.
- Zou, P. and Zhang, G. (2009). "Comparative Study on the Perception of Construction Safety Risks in China and Australia." *Journal of Construction Engineering and Management*, American Society of Civil Engineers., 135(7), 620–627.