

Organizational Results Research Report

October 2005

RI02.003

Trenchless Construction Methods, and Implementation Support

Prepared by University of
Missouri-Columbia and
Missouri Department of
Transportation

FINAL REPORT

RI02-003

**Preparation of Construction Specifications,
Contract Documents, Field Testing,
Educational Materials, and Course Offerings
for Trenchless Construction**

Prepared for the
Missouri Department of Transportation
Organizational Results Division

By:

Mohammad Najafi, P.E.
Director, Center for Underground Infrastructure Research and Education,
Construction Management Program
Michigan State University, 205 Farrall Hall, East Lansing, MI 48824

Brett Gunnink, P.E.
Department Chairman, Department of Civil Engineering
Montana State University – Bozeman
205 Cobleigh Hall, P.O. Box 173900, Bozeman, MT 59717

George Davis, R.G.
Geotechnical Liaison, Missouri Department of Transportation (MoDOT)
1617 Missouri Blvd., P.O. Box 270, Jefferson City, MO 65102
and
Adjunct Faculty, Missouri State University Department of Geology, Geography, and Planning
901 S. National Avenue, Springfield, MO 65804

October 2005

The opinions, findings and conclusions expressed in this report are those of the principal investigator and the Missouri Department of Transportation. They are not necessarily those of the U.S. Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. OR06-007	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Preparation of Construction Specifications, Contract Documents, Field Testing, Educational Materials, and Course Offerings for Trenchless Construction		5. Report Date October 2005	
		6. Performing Organization Code University of Missouri-Columbia	
7. Author(s) Mohammad Najafi, P.E., Brett Gunnick, P.E., George Davis, R.G.		8. Performing Organization Report No. OR06-007/RI02-003	
9. Performing Organization Name and Address University of Missouri-Columbia 310 Jesse Hall Columbia, MO 65211		10. Work Unit No.	
		11. Contract or Grant No. RI02-003	
12. Sponsoring Agency Name and Address Missouri Department of Transportation Organizational Results P. O. Box 270-Jefferson City, MO 65102		13. Type of Report and Period Covered Final Report	
		14. Sponsoring Agency Code MoDOT	
15. Supplementary Notes The investigation was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration.			
16. Abstract Trenchless technology offers methods by which underground utilities may be installed without damage to overlying pavement, if proper precautions are observed. In the past ten years, repeated improvements in technology, materials, and methods have advanced faster than the guidelines and specifications for use of the technology. In addition, training in the technology for designers, engineers, and inspectors has not kept pace with developments. Field observation and testing of four different types of horizontal boring and four different pipe types installed for these borings has led to the successful development of a new performance specification for Pipe Installation by Horizontal Boring, Section 734 of the <u>Missouri Standard Specifications for Highway Construction</u> . In addition, a new material specification has also been added to the Standard Specifications as a result – Section 1075 – Centrifugally-cast Fiberglass Reinforced Polymer Mortar Pipe. Observation of an actual MoDOT construction pipe jacking installation was followed by three separate horizontal bore installations on property of the University of Missouri-Columbia.			
17. Key Words Pipe jacking, pipe ramming, horizontal boring, horizontal directional drilling (HDD), trenchless construction, guided boring		18. Distribution Statement No restrictions. This document is available to the public through National Technical Information Center, Springfield, Virginia 22161	
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 55	22. Price

Form DOT F 1700.7 (06/98)

Acknowledgements

The authors would like to recognize substantial and valuable contributions made by persons from academia, the Missouri Department of Transportation (MoDOT), and within the trenchless technology industry of time, materials, and effort towards the completion of these projects. Within the Engineering Department of the University of Missouri we would like to thank Dr. Sam Kiger for his arrangements in coordination of the use of equipment at the Capsule Pipeline Field Station, and Mr. C.H. Cassil for his work in securing necessary equipment for completion of the guided boring test and the pipe ramming test. Students Rui Xu and Russell Humphrys provided valuable assistance during these tests and at the pipe jacking job site by acting as surveyors and general labor throughout. Student Bhavani Gangavarapu from Michigan State University aided during both the set-up and execution of the ArrowBore_{TM} installation.

For their timely assistance with the pipe jacking field evaluation in Macon, we wish to thank the staff of MoDOT's North-Central District (District 2), in particular Macon Project Office Resident Engineer Jeff Gander. We also wish to thank Casey Jones and the staff of Keith Contracting, L.L.C. of Jefferson City for their cooperation.

Thanks are also due to the following equipment manufacturers and pipe supplier who supplied equipment, pipe, and expertise for the test borings: Akkerman, Inc., of Brownsdale, Minnesota for guided boring equipment; TT Technologies of Aurora, Illinois for pipe ramming equipment; Pittsburg Pipe of St. Louis, Missouri for steel pipe, Mission Clay Pipe of Pittsburg, Kansas for clay jacking pipe, and Hobas Pipe, USA of Houston, Texas for their CCFRPM pipe. Particular individuals who contributed to the progress of this study include: Rick Melvin of TT Technologies, Terry Fisher of Akkerman, Inc., Ted Dimitroff of Trenchless Flowline of Columbia, Missouri, and Gene Kaiser, of Kaiser Cable of Jefferson City, Missouri.

Thanks are also expressed to the presenters at the workshop seminars: Carl Neagoy of Herrenknecht, Inc., Terry Fisher of Akkerman, Inc., Frank Canon of Baroid IDP, and Ted Dimitroff of Trenchless Flowline, and Mickey Austin and John Rowdy of TT Technologies.

Executive Summary

Trenchless technology offers methods by which underground utilities may be installed without damage to overlying pavement, if proper precautions are observed. In the past ten years, repeated improvements in technology, materials, and methods have advanced faster than the guidelines and specifications for use of the technology. In addition, training in the technology for designers, engineers, and inspectors has not kept pace with developments.

Field observation and testing of four different types of horizontal boring and four different pipe types installed for these borings has led to the successful development of a new performance specification for Pipe Installation by Horizontal Boring, Section 734 of the Missouri Standard Specifications for Highway Construction. In addition, a new material specification has also been added to the Standard Specifications as a result – Section 1075 – Centrifugally-cast Fiberglass Reinforced Polymer Mortar Pipe. Observation of an actual MoDOT construction pipe jacking installation was followed by three separate horizontal bore installations on property of the University of Missouri-Columbia. Comparison of the four types of horizontal boring has led to a better overall understanding of the processes involved, and how to prevent settlement and heave during highway construction in the future for maintaining pavement integrity. One of the horizontal bores installed centrifugally cast fiberglass reinforced polymer mortar pipe for the very first time in the world using horizontal directional drilling.

In May 2003, three training workshops were also held for MoDOT engineers and inspectors in Kansas City, Jefferson City, and St. Louis. One hundred and fourteen MoDOT employees from all 10 Districts and from the Central Office attended the workshops, and were certified to a basic understanding of trenchless technology by Michigan State University.

Table of Contents

Executive Summary.....	iii
Chapter 1. Project Introduction.....	1
Chapter 2. Goal and Objectives	3
Chapter 3. Pipe Jacking Field Evaluation of Active Construction Project J2P0701.....	4
3.1. Introduction to Pipe Jacking.....	4
3.2. Description of Pipe Jacking Method	4
3.3 Description of Route 63 Site in City of Macon, Missouri	5
3.4 Pipe Jacking Job J2P0701 Progress, Completion, and Aftermath	6
Chapter 4. Pipe Ramming Field Evaluation	12
4.1 Introduction to Pipe Ramming	12
4.2 Description of Pipe Ramming Method.....	12
4.3 Pipe Ramming Field Evaluation.....	13
Chapter 5. Guided Boring Field Evaluation	21
5.1 Introduction to and Description of Guided Boring Method	21
5.2 Guided Boring Field Evaluation.....	21
Chapter 6. Horizontal Directional Drilling Field Evaluation.....	27
6.1 Introduction to Horizontal Directional Drilling (HDD)	27
6.2 Description of Horizontal Directional Drilling Method	27
6.3 Description of Arrowbore™ method.....	28
6.4 Horizontally Directionally Drilled ArrowBore™ Field Evaluation.....	29
Chapter 7. Discussion of Results	32
7.1 Types of Horizontal Boring Compared	32
7.2 Development of Performance Specifications	34
Chapter 8. Trenchless Technology Training Workshops for MoDOT Engineers and Permit Inspectors.....	35
Chapter 9. Conclusions and Recommendations.....	37
9.1 Conclusions	37
9.2 Recommendations	38
References	39
Appendix A. Preconstruction Meeting Minutes from Job J2P0701	40
Appendix B. Narrative Report Upon Project Completion prepared by Macon Project Office Resident Engineer Jeff Gander.....	41
Appendix C. MoDOT Plan Sheets from Pipe Jacking Installation, Job J2P0701.....	42
Appendix D. Logs of Borings Completed at Capsule Pipeline Field Station	45
Appendix E. Specifications	47
Appendix F. Questionnaire for Experience in Trenchless Road Crossing Methods.....	49

Chapter 1

Project Introduction

Demand for installation of new underground utility systems in congested areas with existing utility lines has increased the necessity for innovative and economical systems to go underneath and alongside in-place facilities. Environmental concerns, social (indirect) costs, new and more stringent safety regulations, difficult underground conditions (containing natural or artificial obstructions, high water table, etc.) and new developments in equipment have increased demand for trenchless technology. Trenchless technology methods include all methods of installing or renewing underground utility systems with minimum disruption of the surface or subsurface.

Trenchless technology has become popular for underground utility construction road crossings. In recent years, there has been remarkable progress in development of new trenchless technology equipment and methods. These developments have produced improvement in jacking force capacity and increased drive length, improvements in steering and tracking systems, availability of new and different types of pipe and other advancements. Preparation of design guidelines, construction specifications, process inspection, materials testing, and the training of engineers, construction and permit inspectors in contracts and bid documents, has not kept pace with new developments. Most all governmental agencies, with a few notable exceptions, are not current with capabilities and limitations of the new methods, materials, and equipment.

To better protect pavement integrity, experimental research on ground movement during and after various trenchless constructions becomes vital. Such research may prove or deny the hypothesis that trenchless technologies are the preferred minimum-damage methods for utility installation. This can aid Departments of Transportation (DOTs) in making better-informed decisions regarding trenchless construction. Through quantitative measurements and analysis, if ground movements are discovered, comparing pre-construction ground conditions to these movements establishes a baseline for quantification of possible movement and damages. Analysis of the movements provides valuable input for DOT construction guidelines and specifications for controlling the use and implementation of trenchless technology in DOT right-of-way.

Beginning in September 2002, The Missouri Department of Transportation (MoDOT), The University of Missouri-Columbia, and Michigan State University cooperated in a study of major trenchless road crossing methods and their effects in order to maintain pavement integrity. The scope of work for this project included engineering analyses of trenchless construction methods (TCMs), method evaluation of specific applications, review and completion of the then-developing MoDOT construction guidelines and performance specifications, development of course offerings and course materials for MoDOT engineers, inspectors, and special technical personnel. For the purpose of this project, an active construction installation of two 60- inch reinforced concrete pipe (RCP) culverts, each eighty feet long, was observed and monitored on Highway US 63 in the City of Macon, Macon County, Missouri. Results of this installation were evaluated for possible future improvement. In addition, a field experiment was conducted at a controlled location to evaluate and compare capabilities of three generally-accepted trenchless installation method types of horizontal boring, namely: auger boring, horizontal directional drilling, and pipe ramming. These methods have been used or are known to have future potential for use under MoDOT roadways and/or right-of-way.

In April 2002, a site owned by the University of Missouri-Columbia was selected for test installations. This site is part of the Capsule Pipeline Field Station west of Columbia, and where field-testing of methods other than pipe jacking took place. A geotechnical investigation was conducted to determine the nature of the soil at this location. Two areas were excavated for launch and reception pits in this area. A boring length of 120 feet, simulating the approximate width of a highway right-of-way for a two-lane road, was selected. A boring depth of approximately 14 feet was used for all borings.

The pipe jacking observation on US Highway 63 took place beginning in April 2002, associated with job number J2P0701, administered by MoDOT's District 2 Macon Construction project office and Resident Engineer Jeff Gander. The contractor for this installation was Keith Contracting, L.L.C. of Jefferson City, Missouri. The two RCP culverts were installed without incident. Progress was observed and measured for possible heave and/or settlement by students from the University of Missouri-Columbia.

Beginning in July 2002, a series of three borings were completed at the Capsule Pipeline Field Station test site. Three different methods of horizontal boring installation different from pipe jacking were used, and three different types of pipe were compared for their utility in these installations. The three types of horizontal borings completed were horizontal directional drilling (HDD), pipe ramming, and guided boring, using centrifugally cast fiberglass reinforced polymer mortar (CCFRPM) pipe, steel pipe, and vitrified clay pipe (VCP).

MoDOT specifications were reviewed during 2002. Standard Specification 734, formerly named "Pipe Jacking", was rewritten and expanded to include other possible types of horizontal boring that might be undertaken within State of Missouri right-of-way. It was formatted as a performance specification, and retitled "Installation of Pipe by Horizontal Boring Methods". It was included in the 2004 Missouri Standard Specifications for Highway Construction. The need for an additional specification addressing CCFRPM pipe was also identified, and was written as Standard Specification 1075, "Centrifugally Cast, Fiberglass Reinforced, Polymer Mortar Pipe".

One hundred fourteen MoDOT engineers, inspectors, designers, and permit inspectors were trained in 2003 during a series of three one-day workshops held in St. Louis, Kansas City, and Jefferson City. The attendees were certified to possess a basic level of understanding in the field of trenchless technology by Michigan State University's Center for Underground Infrastructure Research and Education (CUIRE) in East Lansing, Michigan. Subjects covered in the one-day seminars included the importance of trenchless technology in highway engineering and construction, MoDOT's new standards and specifications that were developed for use (as well as others that pertain to pipe types and materials involved in trenchless installations), horizontal directional drilling, drilling fluids, pipe ramming and pipe bursting, microtunneling, pipe jacking, and geology/ geotechnique pertaining to installations.

Chapter 2

Goals and Objectives

The original goals for this research study included six primary goals. These goals were:

- (1) Observation of construction operations at the City of Macon pipe jacking installation associated with MoDOT job number J2P0701,
- (2) Measurement of settlements and heave on the road surface and changes to the characteristics of the subgrade for the aforementioned project,
- (3) Studying possible improvements to methods used for the aforementioned project,
- (4) Comparison of the selected method for this project with other available techniques suitable for similar applications with recommendations for use of the selected method or other technologies in future applications,
- (5) Review of current MoDOT guidelines and specifications and the preparation of specifications for trenchless construction methods (TCM) as identified above, including the quantification of advantages, capabilities, and limitations of TCMs for different applications under the roadway and right-of-way,
- (6) Field testing and observation of three major trenchless construction methods (namely, guided boring, pipe ramming, and horizontal directional drilling) with evaluation of the following parameters:
 - a. Effects of drilling fluids used during boring,
 - b. Accuracy,
 - c. Identifying possible effects on embankments and road structures,
 - d. Identifying possible soil deformations and effects on adjacent structures and utilities,
 - e. Suggesting possible improvements in safety and productivity,
 - f. Determining potential pitfalls for individual methods, and
 - g. Use of different types of pipe materials.

To accomplish these tasks, cooperation between all parties involved proved to be critical.

Prior to the field evaluations, geotechnical information was obtained for both the City of Macon pipe jacking job location and for the Capsule Pipeline Field Station location. Accurate and complete geotechnical information serves as a necessary first step towards the evaluation of possible methods that may be used. In the case of the Macon site, determination of possible boulders in the highway fill through which the bore was planned influenced the selection of possible methods. If boulders or used pavement slabs had been found in the fill, pipe jacking would have been extremely difficult or impossible, leaving only the possible options of utility tunneling or pipe ramming.

The Geotechnical Section of the Construction and Materials Division investigated both locations prior to all of the horizontal borings. These borings were made available to our research team.

Materials and boring equipment with personnel were made available at reduced cost or no cost by equipment and pipe manufacturers. The University of Missouri-Columbia also provided personnel and a forklift for use in the off-loading of pipe and equipment. A portion of the University's Capsule Pipeline Field Station was also made available for use in test installations, and University personnel constructed and later filled in a launch pit and reception pit which simulated two sides of a highway embankment or two excavations adjacent to a roadway.

Chapter 3

Pipe Jacking Field Evaluation of Active Construction Project J2P0701

3.1 Introduction to Pipejacking

The term *pipejacking* can be used to describe a specific installation technique as well as a process applicable to other trenchless technology methods. When referred to as a process, it implies a tunneling operation with the use of thrust boring and pushing pipes with hydraulic jacking force. This concept of a jacking system is adopted by many trenchless technologies, including auger boring and microtunneling. However, for the purposes of this research report, pipe jacking is regarded as an installation technique.

Pipe jacking is a trenchless technology method for the installation of a prefabricated pipe through the ground from a drive shaft or trench to a reception shaft or trench. The first use of pipe jacking was at the end of the 19th century. In the 1950s and 1960s, new capabilities were added to pipe jacking by European and Japanese companies, including extended drive length, upgraded line and grade accuracy, enhanced joint mechanisms, and improved excavation and face-stabilizing shields. These developments, improved operator skills and experience, and better quality pipe materials have enabled pipe jacking to be accepted as a popular trenchless technology.

3.2 Description of Pipejacking method

In a pipe jacking operation, jacks located in the drive shaft propel the pipe. The jacking force is transmitted through pipe-to-pipe interaction to the excavating face. When excavation is accomplished, spoil is transported through the jacking pipe to the drive shaft by manual or mechanical means. Both excavation and spoil removal processes require workers to be inside the pipe during the jacking operation. Usually, the minimum recommended diameter for pipe installed by pipe jacking is 42 inches.

Figure 3.1 illustrates the typical components of a pipe-jacking operation. The cyclic procedure uses thrust power of the hydraulic jacks to force the pipe forward through the ground as the pipe jacking face is excavated. The spoil is transported through the inside of the pipe to the drive shaft or trench, where it is removed and disposed of. After each pipe segment has been installed, the rams of the jack are retracted so that another pipe segment can be placed in position for the jacking cycle to begin again.

Excavation is accomplished by hand mining or mechanical excavation within a shield or by an auger boring machine. Excavation method selection is based on an assessment of the subsurface for instability. If there is any possibility of excavation face collapse, soil stabilization techniques, such as dewatering or grouting, must be considered.

Pipe jacking is capable of a high degree of accuracy, as a laser is used to control line and grade. Installations to an accuracy within an inch are common, with reasonable anticipated tolerances of between ± 3 inches for alignment and ± 2 inches for grade.

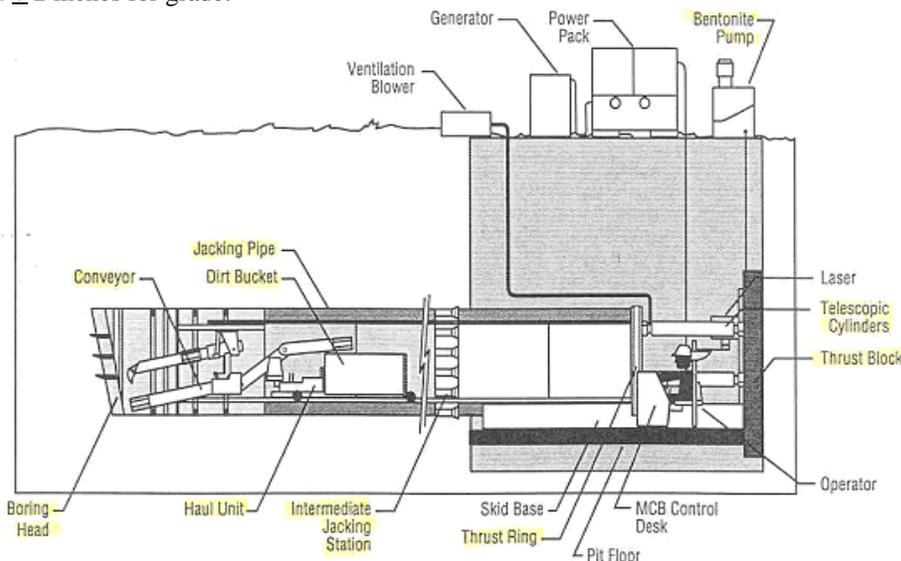


Figure 3.1 Typical components of a pipe jacking operation (Iseley and Gokhale, 1997)

3.3 Description of Route 63 Site in City of Macon, Missouri

The need for this installation was deemed necessary in calendar year 2000. Upstream flooding was caused by an increase in impervious drainage surface from urbanization within the city of Macon that did not drain effectively during a storm event. MoDOT District 2 staff determined that two additional 60-inch culvert pipes needed to be added to existing drainage through the embankment on Route 63. Traffic demands and lack of an effective alternate detour route through the City of Macon indicated that open cutting was impractical, and an alternative method of installation was deemed necessary.

In January 2001, a geotechnical investigation was conducted into the nature of the fill materials that were associated with the embankment to determine the best possible method for the installation. Initially it was thought that either pipe jacking or pipe ramming would be the best option to use for such an installation. If boulders or large obstructions were found in the fill materials, then pipe ramming would be the only alternative available.

Two borings were completed to a depth 10 feet below the flow line of the culvert that already existed in the embankment. Both borings were completed at, or in close proximity to, the location of the culvert pipe additions.

No boulders or waste slab materials were found in the embankment fill. The soils encountered at the site consisted primarily of lean clays with scattered sand and gravel. The top eleven feet of the embankment consists of lean clay fill material, which overlies lean clay with traces of sand and gravel. From the geotechnical investigation, it was determined that resistance to the process of pipe jacking would be minimal, and that water table level would not be a concern during installation, which might have necessitated use of dewatering procedures. Geotechnical investigation also determined that a standard water and bentonite drill mud mixture would be sufficient to decrease frictional forces on the pipe during its advance, since no swelling, high plastic index, or fat clays were found during borings. These would have necessitated the need for a polymeric drilling mud additive to prevent clays from swelling during boring operations.

Due to the short overall length of the proposed drive/bore, the need for intermediate jacking stations was not anticipated nor recommended. However, additional needs were outlined in the initial geotechnical report. These included a minimum 200' by 200' construction easement adjacent to the fill for a launch pit, pipe storage, and all necessary equipment for the pipe jack; resilient joint cushioning material for the pipe to be jacked (the report recommended plywood) to prevent pipe deflection and edge loading at each jacked pipe joint; and that pipe excavation should not exceed 24" ahead of the pipe being jacked, with no more than 1.2" of overcut. In the event of inadvertent over-excavation or void development, external grouting of the pipe with a suitable cementitious grout was also recommended.

The use of a modified Design Special Provision for jacking pipe, modified from DSP 93-21B, was also recommended. The modified provision is listed below in its entirety:

Jacking Pipe DSP-93-21B

1.0 Description

At locations shown on the plans, reinforced concrete pipe culvert (gasket type) shall be jacked into place underneath the existing pavement in accordance with the following requirements:

2.0 Materials

When jacked pipe is specified, the class of pipe specified in the contract item will be determined for vertical load only. Additional reinforcement or strength of pipe required to withstand jacking pressure shall be determined and furnished by the contractor at his own expense.

3.0 Construction Requirements

- 3.1 Variations from theoretical alignment and grade for the completed jacked pipe shall not exceed 1.2" for each 20' of pipe.
- 3.2 The excavated hole shall not be more than 1.2" greater than the outside diameter of the pipe. When material tends to cave in from outside these limits, a metal shield shall be used ahead of the first section of pipe when jacking or pushing.
- 3.3 The jacking equipment shall be operated by experienced workers and in a manner meeting the approval of the engineer..
- 3.4 Any areas resulting from caving or excavation outside of the above specified limits shall be backfilled with cementitious grout which will fill the voids and any annular space surrounding the pipe.

4.0 Method of Measurement

Measurement of jacked pipe, complete in place, will be made in accordance with Section 726.8.1 of the Standard Specifications.

5.0 Basis of Payment

The accepted quantities of jacked pipe, complete in place will be paid for at the contract unit price for the pay items included in the contract. Payment will be considered full compensation for excavation from jacking or boring operations, grout for filling voids, and any other incidental items or equipment necessary to complete the installation.

Finally, it was recommended that the jacking process should only be approved following inspection by a qualified inspector, and that a survey grid should be established to provide detection of settlement or heaving.

By conducting a geotechnical investigation to determine the best possible method for the installation, carefully crafting a design special provision to guide work on the job, and recommending an experienced and qualified contractor and experienced inspector from MoDOT, it was hoped that the success of the job would be insured.

3.4. Pipe Jacking Job J2P0701 Progress, Completion, and Aftermath

The contract to complete this job was awarded to Keith Contracting, L.L.C. of Jefferson City, Missouri. This company is an experienced contractor in pipe jacking installation. A preconstruction meeting was held at the District 2 office in Macon, Missouri on March 5, 2002 at which additional information was shared between all parties. Included among those present were: the MoDOT Resident Engineer for the Project, Jeff Gander, MoDOT Project Manager, Ron Perkins, the owner of Keith Contracting, Casey Jones, his Project Manager for this project, Mike Mulligan, and his Boring Superintendent, Donny Licktige. Curtis Elam, a Senior Construction Technician with MoDOT who had previous experience in inspection of pipe jacking, was named the construction inspector for the job. A variety of information was shared during the meeting that further insured the success of the project.

No utility relocations were found to be necessary for completion of the job, and this information was reported to the contractor. The contractor also informed MoDOT representatives during the progress of the meeting that the pipe jacking equipment to be used by Akkerman would be a 500,000-pound thrust capacity machine. This was deemed to be more than adequate for the purpose intended. A copy of the meeting minutes for the pre-construction conference is attached as Appendix A.

Prior to the project contract date, University of Missouri personnel installed four subsurface ground movement indicators (pressure plates) above the centerline of the planned drainage pipes. A MoDOT crew from the Macon project office measured ground movements for these indicators as well as several surface points before, during, and after construction. University of Missouri civil engineering students also visited the site during and after construction to take photographs, interview key personnel, and monitor progress of the pipe jacking. Later, a follow-up to these activities took place during June 2002, where survey data was collected and analyzed by the students for post-construction analysis of the installation.

The two reinforced concrete culvert pipes were to be installed at right angles to centerline Route 63 at Station 1201 +70 and Station 1201 +80. Beginning on April 11, 2002, a boring launch pit was constructed on the east side of Route 63. Setup of the pipe jacking equipment required a relatively level surface that was gravel-covered, so that the thrust block could be installed. Once the launch area was level, on April 16 the boring equipment was set up for use. The 16-foot length of the machine allowed individual concrete pipe sections to be added from storage immediately adjacent to the boring machine. Figures 3.2 to 3.10 are photographs that illustrate important features of the installation process that took place. Appendix C contains pertinent plan sheets from the bid documents that illustrate the location, alignment, cross sectional data, and other information.

Installation of the first pipe was completed on April 18. Work resumed on April 22 to install the second pipe. Installation of the second pipe was completed the following day. During the pipe jacking process, the set survey points and settlement gauges were monitored for changes in elevation. Of the 33 survey points set, 5 exhibited no change, and 25 exhibited less than 0.1' change. The remaining 5 points all exhibited less than 0.2' change in elevation. This was consistent with the minimal amounts of settlement to be expected with a new pipe jacking installation.

The following year, a concerned citizen reported a bump at this location, indicating that the pavement had settled further. Further investigation led to the conclusion that the flared end of the northern pipe had experienced piping due to incomplete compaction around the pipe. The defect was repaired, and the pipe continues to function normally.

The successful installation of these pipes was reported in two national magazines, the April 2003 issue of *Trenchless Technology* and the April 2003 issue of *Underground Construction*.

Figures 3.2 through 3.10 illustrate important characteristics of the pipe jacking process and the installation that was completed for MoDOT.



Figure 3.2. Cutterhead on Akkerman pipe jack apparatus. Note thrust block for jacking at left of photo. Photo taken by District 2 Macon office Resident Engineer Jeff Gander.

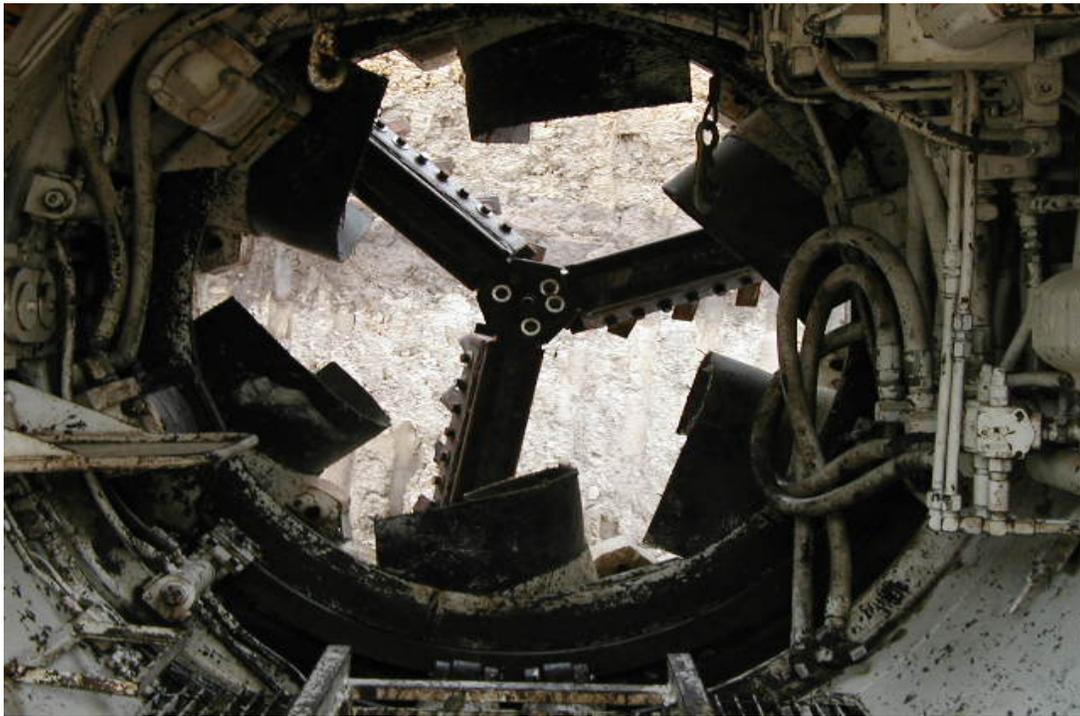


Figure 3.3. View of cutterhead assembly from inside of pipe jacking equipment. Photo by Jeff Gander.



Figure 3.4. Spoil bucket inside jacking frame assembly. Spoil bucket is filled with dirt which is removed by cutterhead before pipe is jacked into place. Photo by Jeff Gander.



Figure 3.5. View of complete pipe jacking equipment and job layout. Crane in background will be used to add additional pipe segments as needed when jacking is underway. Photo by Jeff Gander.



Figure 3.6. Conveyor belt removes spoil from cutterhead face area and transports the dirt to the spoil bucket for removal from the pipe jack area. Photo by Jeff Gander.



Figure 3.7. Concrete pipe being jacked into place behind cutterhead assembly. Note track leading out of pipe for spoil bucket removal. Photo by Jeff Gander.



Figure 3.8. Cutterhead assembly emerging from west side of embankment. Photo by Jeff Gander.



Figure 3.9. Emerged cutterhead assembly. After jacked concrete pipe emerges from the reception pit, the pipe jacking operation is complete. Note minimal amount of overcut by excavated cutterhead around circumference of assembly. Photo by Jeff Gander.



Figure 3.10. Completed installation. Photograph was taken immediately following a storm event that would have overwhelmed the single box culvert already in place. The photo illustrates the ability of the new culverts to function as designed. Photo by Jeff Gander.

Chapter 4

Pipe Ramming Field Evaluation

4.1 Introduction to Pipe Ramming

Pipe ramming involves the use of the dynamic force and energy transmitted by a percussion hammer attached to the end of a pipe. The basic procedure generally comprises ramming a steel pipe through the soil by using an air compressor. Pipe ramming permits the installation of large steel casings in a wide range of soil conditions. It provides continuous casing support during the drive with no overexcavation, and it does not require the jetting action of water or the use of drilling fluids. However, longer drives may require the use of small amounts of drilling fluids for pipe lubrication as the percussive thrust force of the hammer diminishes over distance.

Pipe ramming is most valuable for installing larger pipes over shorter distances and for installations at shallower depths. It is suitable for all ground conditions except solid rock, and is often safe where some other trenchless methods can lead to unacceptable surface settlement (e.g., open face auger boring in loose or granular soils). Pipe ramming is typically used for horizontal installations, but can also be applied to vertical projects, such as driving pile and the installation of micropilings.

4.2 Description of Pipe Ramming Method

Two major categories of pipe ramming are closed-face and open-faced pipe ramming. With the closed-face ramming technique, a cone-shaped head is welded to the leading end of the first segment of the pipe to be rammed. This head penetrates and compresses the surrounding soil as the casing is rammed forward. The soil-pipe installation interaction that results when this method is used is similar to the interaction that takes place when soil compaction (also known as “impact moling”, or “missile moling”) methods are used. This method is employed for pipes up to 8 inches in diameter. A “rule of thumb” used by many contractors states that for each inch of outer diameter of the pipe rammed with the closed-face ramming method, one foot of cover over the pipe should be present to avoid upward soil heave.

With the open-faced ramming technique, the front of the leading end of the steel casing or conduit remains open so that a borehole the same size as the outer diameter of the casing is cut. This allows most of the in-line soil particles to remain in place, with only a small amount of soil compaction occurring during the ramming process. This technique is employed for pipes larger than eight inches in diameter, and may be used for either carrier pipe or casing pipe in a normal road crossing.

To facilitate the pipe ramming process, the leading edge of the first segment of pipe or casing is usually reinforced by welding a steel band from 6 to 24 inches in width around the exterior of the lead end of the pipe. This banding provides two distinct advantages: (1) it reinforces the leading edge of the pipe, and (2) it decreases the amount of friction around the casing as the pipe is advanced. This band may also be added on the inside of the pipe if desired, or if the outer casing band is insufficient reinforcement in difficult soil conditions. This interior band, like the outer casing band, also reduces the soil friction inside of the casing.

After the casing process is complete, the soil that has entered the casing during the ramming process is removed by the addition of compressed air or water from either end of the casing if small-diameter casing is used. For larger and oversized casings, augers similar to those used in auger boring may be used to remove spoil from the casing. In the largest casings, where man-entry is possible, the casing may be cleaned out by hand or by the use of a skid-steer loader.

An open-ended pipe ramming procedure normally consists of eight steps:

1. A shaft or pit is constructed as a launch pit.
2. A steel leading-edge band for reinforcement is welded on the leading edge of the first segment of casing.
3. Casing is placed in the drive shaft or pit, and is adjusted to achieve the desired line and grade. Where line and grade are not critical, the pipe can be supported by construction equipment such as backhoes, cranes, side-boom tractors, wood or block supports, or directly on the pit floor. In cases where the achievement of line and grade are critical, the pipe is supported by adjustable bearing stands, launch cradles, platforms, I-beams, or pipe jacking/ auger boring machine tracks (The final item has the added advantage of being able to support augers during the cleanout process, possibly decreasing time spent on the job.)
4. The pneumatic hammer or pipe ram device is attached to the casing, and is connected to an air compressor or other pneumatic or hydraulic power source. This may be accomplished by the use of special adapters for

particular sizes of pipe, known as “collets”. For larger pipes, specially designed “ramming cones” are used to enhance the energy force transfer between the pneumatic hammer and the pipe.

5. The drive is initiated and continued until installation is complete. If multiple pipe segments are being used, after each segment the pneumatic hammer is removed from the launch area so that additional pipe segments can be welded into place.
6. The casing is cleaned out as required.
7. Equipment is removed from the launch pit
8. The area is restored as required.

Typical diameters of pipe installed by pipe ramming range from 6 to 60 inches, though pipe ramming has been used to install pipe as large as 147” in diameter. Drive lengths can be up to 200 feet in length, though longer crossings have been completed.

Though this method is limited to steel pipe only, its versatility over a wide range of soil conditions gives it favor among many contractors who also use it in horizontal directional drilling (HDD) for drill pipe assists, for drill stem recovery, and for casing in gravelly conditions (the ‘conductor barrel’ method). A significant disadvantage to this method is that steel casing will require welding, which increases overall job time spent. This disadvantage has been addressed in the last 10 years by an interlocking steel pipe joining system developed by Permalok Corporation of St. Louis, Missouri. This preinstalled precision joint connection provides for rapid joining of steel pipe, many times eliminating the need for in-field welding and associated down time, which increases productivity. This technology becomes even more economical if the need for a certified welder on a job site is eliminated, added to the increase in productivity.

4.3 Pipe Ramming Field Evaluation

The first horizontal boring type chosen for method evaluation at the Capsule Pipeline Field Station was pipe ramming, due to its relative simplicity and the minimal amount of training needed for on-site personnel. Prior to this installation and two other field tests at the Field Station, a survey datum was established and a survey grid was laid out on the embankment between the designated launch pit and the designated reception pit. The embankment was meant to simulate a road crossing, and was 80 feet wide, from edge of launch pit to edge of reception pit. The survey grid established for all three test borings is depicted as Figure 4.1. Launch and reception pits were approximately 90 by 35 feet, allowing for multiple installations.

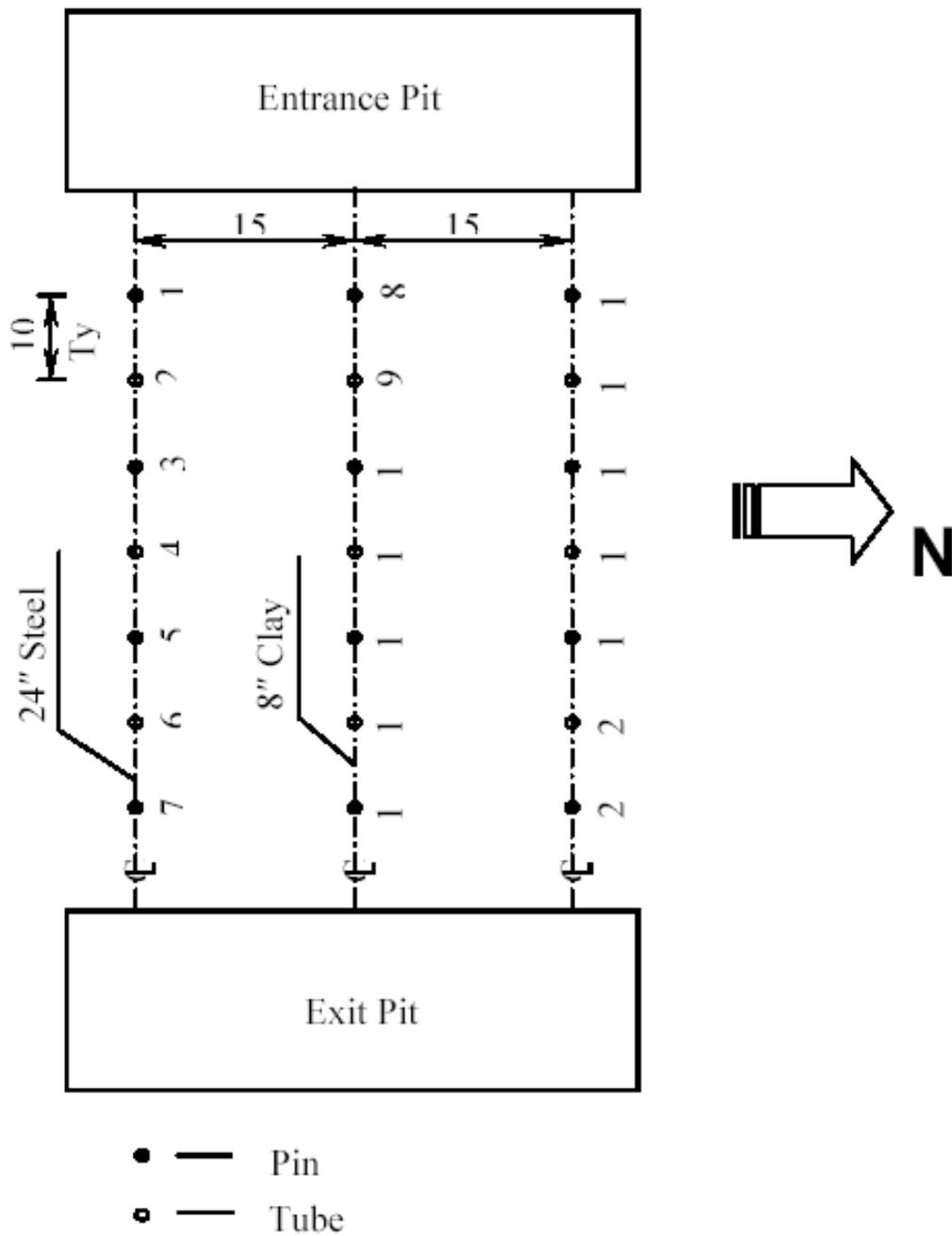


Figure 4.1 Survey grid established over centerline of the three horizontal bores used in test activities. Each location marked as a 'tube' is in actuality a settlement plate, installed by University of Missouri-Columbia personnel.

Prior to beginning the bores, a geotechnical investigation was undertaken by MoDOT personnel to determine soil types and engineering soils data. A CME-850 geotechnical drill rig was used to obtain laboratory samples using both 3-inch and 5-inch Shelby tubes, as well as a split-spoon sampler. Saturated unit weight for the soil ranged from 124.5 to 131.9 pounds per cubic foot. The soil is identifiable as fat clay (CH) by ASTM Classification, with liquid limits ranging from 27 to 65, and plastic indices ranging from 6 to 46. Slickensides were found in samples taken from some of the Shelby tubes, indicating a high shrink-swell potential, and indicating the need for a polymeric mud additive that would function as an anionic surfactant. This would prevent the clay from sticking to steel drilling tools, pipe, and other items during boring. Logs of the borings completed are attached in Appendix D.

TT Technologies of Aurora, Illinois supplied the pipe ram and a field technician to train personnel on site, along with a Grundomudd™ bentonite mud mixing unit and a plastic pipe pig for use in cleaning the pipe if necessary. The Missouri Department of Transportation supplied a boom truck and operator for handling five 20-foot sections of 24-inch steel pipe, and also supplied a 15 foot length of steel I-beam for a pipe guide. 750 cubic feet per minute air compressor was also supplied by MoDOT. The University of Missouri-Columbia supplied an engineering technician and several graduate students to aid in completion of the installation, as well as welding equipment.

First, the steel I-beam was placed on the ground in the direction in which the pipe was to be rammed. A steel leading edge band was welded into place on the end of the pipe which would be driven into the embankment. This was followed by two pieces of angular steel that were also welded onto the pipe. Immediately behind the first angular steel piece a bentonite drip fitting was also welded into place. A long flexible plastic line to the Grundomudd bentonite mix tank led from this drip fitting. The second piece of angular steel was not used for any fittings, but was there to balance the movement of the pipe through the embankment. The pipe was lowered onto the I-beam using the boom truck, and the pneumatically powered pipe ram was attached to the pipe using canvas strap webbing that was tightened into place. The pipe ram was then attached by a hydraulic hose to the air compressor. When the air compressor was turned on, the reciprocating action of the hammer inside the pipe ram began to move it into the embankment.

Since the pit was sloped adequately to comply with OSHA safety regulations, it was necessary to have several people stand on the end of the pipe until it was seated properly into the soil by the pipe ram. One day was required to set up the pit for installation. Two additional days were required to ram the lengths of pipe to completion. The majority of the time used in the installation was for welding additional pipe segments together. It took nearly an hour for two experienced welders to weld the pipe together, but only took 15 to 20 minutes to ram each additional 20-foot segment of pipe.

As the pipe was being rammed, vibrations from the pneumatic hammer impact could be felt on top of the embankment. The location of the leading edge of the pipe could be found by finding the point with the most evident ground vibration. However, there was no displacement of the soil as indicated by the monitoring of survey points established along the centerline of the pipe.

Upon completion of the installation, the pipe was cleaned out, simulating a planned future use. This was accomplished by hooking a pressure plate welded onto the end of the pipe to the air compressor. The force of compressed air pushed the displaced soil out the other end of the pipe. Under normal circumstances, cleaning out the pipe with a plastic pig under air pressure would follow this compressed air cleaning. We had a pig available at the site, but decided not to use it for safety reasons. If we had used the pig to clean out the pipe, the slope of the reception pit might have acted as a launch ramp, and pitched it many feet into the air.

Measurements taken at the survey locations along the pipe centerline before, during, and after the installation revealed no movement, or negligible movement. Pipe ramming could thus be verified as a minimal effect technology for the installation of utility product pipe under roadways in this type of soil.

Figures 4.2 through 4.11 illustrate important characteristics of the pipe ramming process and the installation that was completed for MoDOT.



Figure 4.2. Basic set-up of pipe ramming operation in launch pit at Capsule Pipeline Field Station. Photo taken by University of Missouri student Russ Humphrys.



Figure 4.3. Pipe ram attached to end of steel pipe using canvas straps. Note holes in soil removal cone attached to pipe between pipe and pipe ram. This soil removal cone is a patented device of TT Technologies, and allows excess spoil displaced by the ramming process to drop away from the pipe as it is advanced. Photo by Russ Humphrys



Figure 4.4. Reinforced steel leading edge band on front of first section of pipe that was rammed. Steel band is 6 inches in width. Photo by Russell Humphrys.



Figure 4.5. Hydraulic hose connection on end of pipe ram. Note that pipe and ram are on a steel I-beam to establish line of ramming. Photo by Russ Humphrys.



Figure 4.6. Lifting pipe ram into place with boom truck. This process was repeated for each advance of the steel pipe. Photo by Russ Humphrys.



Figure 4.7. Welding steel pipe. More time was spent welding than ramming pipe. Each additional weld took 1 ½ to 2 hours, where each segment of pipe only took 15 to 20 minutes to ram. Photo by Russ Humphrys.



Figure 4.8. Leading edge of pipe emerging in reception pit. Photo by Russ Humphrys.



Figure 4.9. Emerged pipe upon completion of pipe ram. Note bentonite feed line on top of pipe. A bentonite, water and anionic surfactant mixture was pumped continuously into the pipe and on top of the pipe to lubricate soil within and outside of the pipe and decrease frictional resistance to the ramming process. Photo by Russ Humphrys.



Figure 4.10. Air pressure plate to be inserted inside pipe prior to spoil removal. Rubber gasket prevents air leakage as air pressure is increased inside pipe to push lubricated soil materials out. Photo by Russ Humphrys.



Figure 4.11. Air pressure plate installed in place. Photo by Russ Humphrys.

Chapter 5

Guided Boring Field Evaluation

5.1. Introduction to and Description of Guided Boring Method

The guided boring method, also known as the pilot tube method, is used in conjunction with horizontal auger boring to install small diameter pipe with greater grade and alignment precision than normal auger boring. The guided boring machine (GBM) contains a specially designed theodolite guidance system to guide the installation of pipes. Accurate pipeline installation is achieved through continuous video monitor surveillance of a laser illuminated target via the theodolite. Steering of the pilot head is accomplished by aligning an angled pilot head to the desired course and thrusting forward. After the steering head has reached the reception shaft or pit, a reaming head and auger tubes with flighting are installed behind the initial pilot tubes. With the addition of each section of auger tube in the launch shaft or pit, a section of pilot tube is removed in the reception shaft. The process is repeated until all of the pilot tube sections have been removed. A pipe section is then installed on the final section of auger casing and the subsequent pipes are thrust into place while the auger tubes are removed from the reception shaft.

The success of this method depends upon the ground conditions. If soils with boulders are encountered, the auger tubes might be deflected, which will eliminate the precision capacity of the equipment to remain on line and on grade.

5.2 Guided Boring Field Evaluation

The second evaluation boring used guided boring to install 8" vitrified clay pipe. This pipe was donated and manufactured by the No-Dig division of Mission Clay Pipe. An Akkerman guided boring machine was used for this installation. The setup of the equipment was complicated, and required two technicians from Akkerman to facilitate. Since the pit was sized and sloped to meet OSHA specifications, additional bracing was needed to enable the guided boring machine to have sufficient thrust to install the pipe used. Under normal conditions, the GBM would be positioned so that the rear of the machine would be facing the opposite wall, which would be protected by a trench box. Instead, an elaborate setup of three concrete blocks, a steel I-beam girder, and two additional I-beams were used to transfer the force to the opposite wall. It took an entire day to set up the machine and align it with the survey points that were set up for the installation (See Figure 4.1), and establish the bracing for the GBM.

On the second day, the GBM unit was connected to an external Akkerman power unit. A combination theodolite and video camera was sighted down the centerline of the hollow pilot tubes. This arrangement was linked to an external video monitor that enabled the operators to determine the precise direction in which the steering head of the GBM unit was pointed. The pilot tubes were installed precisely, followed by the flighted augers and steel casing. As the augers were pushed through the pilot hole with their surrounding steel casing, the pilot tubes were removed from the reception pit.

The GBM was then modified to install the clay pipe. Each segment had steel joint sleeves and resilient cushioning material (precut particle board) to insure against pipe damage during the installation. The resilient cushioning material, similar to the cushioning materials used in pipe jacking, insured that the thrust load placed upon the pipe by the GBM would be distributed evenly around the circumference of the pipe joint. The pipe was installed along the same line as the steel casings, and as the steel casings emerged from the reception pit, they were removed and returned to their original containers with an Akkerman A-frame. The pipe was jacked in using a constant pressure of 500 to 600 pounds per square inch. No lubricating drill fluid (such as bentonite slurry) was deemed necessary due to the soil type.

Similar to the pipe ram operation the hole was never left unsupported during installation, as the pilot hole was enlarged by the continuous flight augers it was kept open by the segments of steel casing. This allowed the clay pipe to be installed with a minimum of force.

Figures 5.1 through 5.10 illustrate the progress of the guided boring method, and the field evaluation that took place.



Figure 5.1. Akkerman Guided Boring Machine (GBM). Photo by Russ Humphrys.



Figure 5.2. Akkerman Power Unit, Augers in casing, and clay pipe. Photo by Russ Humphrys.



Figure 5.3. Lead segment of pilot boring string. Photo by Russ Humphrys.



Figure 5.4. Video monitor used for continuous targeting of theodolite/laser guidance. This is continuously referred to by the operators to maintain line and grade to exact tolerances. Photo by Russ Humphrys.



Figure 5.5. Advancing the first segment of the pilot boring string with GBM. Photo by Russ Humphrys.



Figure 5.6. Target that will be continuously monitored on the video display terminal is inside the boring string. This insures continuous real-time monitoring of line and grade. Photo by Russ Humphrys.



Figure 5.7. Addition of steel casing with nested auger flights along the bore path of the pilot hole. Once the pilot hole is established, this further insures maintenance of line and grade such that utility product pipe can be installed along the same path. Photo by Russ Humphrys.



Figure 5.8. Emergence of steel casing in reception pit area. This will be followed by installation of utility product pipe. Photo by Russ Humphrys.



Figure 5.9. Eight-inch vitrified clay pipe to be installed by guided boring method. Note the steel retaining ring and particleboard resilient modulus cushioning to prevent pipe damage. Photo by Russ Humphrys.



Figure 5.10. Clay pipe installation with GBM. Photo by Russ Humphrys.

Chapter 6

Horizontal Directional Drilling (HDD) Field Evaluation

6.1 Horizontal Directional Drilling Introduction

Horizontal Directional Drilling (HDD) technology originated in the petroleum industry during the 1970s and has evolved with additional technology that was developed in water well installation and in the utility industry. Much of modern HDD technology evolved from boring techniques employed in the 1960s for the underground installation of cables and conduits in urban areas. Trenching or open-cut methods were commonly used at that time to install a variety of utilities. Over time, the method has matured from relatively simple utility borings to installation of large diameter pipes (50 inch diameter and larger) for as far as 4000 to 5000 feet. These methods allow the installation of both small and large diameter ducts, pipes, and conduits without the risk of environmental damage often associated with trenching operations.

HDD is defined as a steerable system for the installation of pipes and conduits and cables using a surface-launched drilling rig. It can be characterized as a two-stage process. First, a pilot bore is created along a planned path using both thrust of the drilling rig for changing direction, and rotation of the drill rods and bit to advance in that direction. In the second stage of the process after the pilot bore is completed, a backreamer is attached to the end of the drill string, followed by the desired flexible or semi-flexible utility product pipe. The pipe is installed along a bentonite mud slurry pathway that is created when the backreaming is complete. Tracking of the pilot bore and backreaming process is enabled by a radio sonde that is contained within a housing that is within the drill bit. Accuracies of installation within one inch are possible using the HDD process.

6.2 Description of Horizontal Directional Drilling (HDD) method

Directional drilling methods utilize steerable drilling systems to install both small and large diameter lines. The pilot hole is drilled with a diameter of 1 inch to 5 inches along the proposed design centerline. Then, the pilot hole is enlarged by backreaming to the desired diameter, sometimes by successive passes of different-sized backreamers, to install the desired utility product pipe. The product pipe is connected to the end of the drilling rod and backreamer assembly by a swivel and pulled through the enlarged pilot hole. The pilot hole is normally drilled by a surface launched rig with an inclined carriage, that is typically adjusted at an angle of 8 to 18 degrees from the surface of the ground for entrance and between 8 and 12 degrees at the exit.

Rotating the drill bit, assisted by the thrust force transferred from the drill string, performs soil cutting in the mechanical drilling process. The mechanical drill bits may vary from a slim cutting head with a slanted face for small and short bore applications to a diamond mounted roller cutter used with mud motors for large and long crossings. For small systems utilizing mini-HDD, directional steering control is accomplished mainly by the bias created by the slanted cutter head face. For large systems used for maxi-HDD, a bent housing (a slightly bent section between 0.5 and 1.5 degrees of the drill rod) is used to deflect the cutter head axis from the following drill string. In both small and large systems, pushing the drill head without rotating can follow a curved path, and a straight path can be drilled by applying simultaneous thrust and torque to the drill head.

High-pressure jetting is used in utility boring applications (a technique that is seldom used today). It is an effective method for cutting through soft formations and lends itself to directionally controlling the course of the borehole through the unique shape of the jet bit. The utility boring method utilizes high pressure, low-volume drilling fluid, usually bentonite mud, to jet through shallow, soft soil formations to ensure the surrounding formation will not become saturated and unstable. HDD, on the other hand, uses mechanical cutting and high-volume and high-pressure fluid through soft formations with a bentonite or polymer-based mud as the bit advances. High volume and velocity in HDD are necessary to carry cuttings back to the surface through the bore annulus. It should be emphasized that utility boring is mechanically-assisted fluid cutting of formations, while HDD is fluid-assisted mechanical cutting of formations. This difference is important in preventing settlement under structures and roads.

Table 6.1 compares the main features of typical HDD methods.

Type	Diameter	Depth	Drive Length	Torque	Thrust/Pullback	Machine weight	Typical Applications
Maxi	24 to 48 inches	≤ 200 feet	≤ 6000 feet	≤ 80,000 ft-lbs.	≤ 100,000 pounds	≤ 30 tons	River, major highway crossings
Midi	12 to 24 inches	≤ 75 feet	≤ 1000 feet	900 to 7000 ft-lbs.	20,000 to 100,000 pounds	≤ 18 tons	Under rivers and roadways
Mini	2 to 12 inches	≤ 15 feet	≤ 600 feet	≤ 950 ft-lbs.	≤ 20,000 pounds	≤ 90 tons	Telecommunications, Power cables, gas lines

Table 6.1 Comparison of the Main Features for Typical HDD methods (Najafi, 2004)

6.3 Description of ArrowBore_{TM} Method

One potentially promising market segment for HDD that may emerge in upcoming years is in the installation of gravity sewers. Engineers traditionally have avoided the specification of HDD for gravity installation because they do not consider it appropriate for line and grade installations. Line and grade installations are an essential requirement for gravity-flow systems for storm sewer and sanitary sewer installations. Many engineers hold to the mistaken belief that these installations are not possible because of limitations in the size of the product pipe that can be installed with HDD. Though this was true for early HDD boring machines, today relatively compact rigs can install pipe in diameters that were once thought to be impossible. Grade control was the primary roadblock for making these installations; today walkover tracking locators can measure grade in less than 1% increments, making the machines suitable for this type of work.

The ArrowBore method complements the existing electronics and incorporates physical verification of the location of the directional boring machine stem as it is advanced through the ground. Excavations, termed “sight-relief holes”, are used at certain points throughout the bore path to provide both the contractor and the utility owner or the owner’s representative with a way to visually inspect that the drill stem is installed in the correct place during the pilot bore, and prior to installation of the main during the backreaming process. Once the pilot bore is completed, a back reamer sized just slightly larger than the main line, typically ¼” to ½” larger than the outer diameter of the pipe, is connected and a hole is reamed ahead of the pipe to be installed. The sight-relief holes are then used during the backreaming process to relieve mud pressures, while a portable vacuum machine removes the excess spoils created during the placement of the main. This tight-fit hole actually eliminates the possible deflection and flotation of the pipe that may occur with conventional HDD when the hole is backreamed to a size 1.25 to 1.5 times the outer diameter of the pipe. This process also allows a project’s utilities to be installed at depths ranging from 15 to 25 feet depth with little change in cost.

This method has already been used on Missouri DOT right-of-way. One example is at the intersection of Routes 151 and 22 near Centralia, Missouri, where a concrete culvert pipe was installed under brand-new pavement. There have been no reports of settlement or heave that can be attributed to this installation. A photograph of this installation appears as Figure 6.1.



Figure 6.1. Installation of 24" Reinforced concrete storm drain pipe by ArrowBore™ method on Missouri Route 22 near Centralia, Missouri. Note inadequate and partially collapsed metal pipe to left of photograph. ArrowBore™ used in this manner may be a valuable tool for the retrofitting of storm drainage in MoDOT right-of-way. Photo by Ted Dimitroff.

6.4 Horizontal Directionally Drilled ArrowBore™ Field Evaluation

The final field evaluation to take place involved the installation of 24" centrifugally cast fiberglass reinforced polymer mortar pipe, manufactured by and donated by Hobas Pipe of Houston, Texas. A Ditch Witch 1720 directional drilling machine was used to install the pipe, with the drill rig set back 40 feet from the face of the launch pit. The drilling machine is self-mobile on rubber tracks, and requires minimal set-up.

Bentonite drilling mud was mixed to supply the drill rig, using a mixture of 2 pounds of soda ash (sodium carbonate), 2 quarts of Adomite, and 5 gallons of Baroid Industrial Drilling Fluid's Con-Det™ anionic surfactant drilling fluid additive in 500 gallons of water. The machine's drilling fluid supply pump is capable of circulating 15 gallons per minute. During the pilot bore, only 4 gallons per minute were required, and during the backream 10 gallons per minute were required. In total, 300 gallons of drilling fluid were used to drill the pilot hole. Rotational torque as measured while drilling the pilot bore was 500 pounds per square inch (psi), and thrust was 400 psi.

On the first day of drilling, the 80' pilot hole was bored completely in three hours, using only 300 gallons of drilling fluid. Twenty feet of backream was also completed during the first day. Backreaming was completed the following day with the same drilling fluid mixture, using a total of 3800 gallons for the backreaming, for a total of 4100 gallons for the entire bore. Backream rotational torque was 1800 psi, and backream pullback thrust was 500 psi. The first segment of CCFRPM pipe was installed the second day, and the remaining 7 segments installed the following day in under four hours. It is notable that though the entire pipe string weighs more than 11,000 pounds, only 900 pounds of pullback were required to install the pipe.

The contractor who performed the work, Mr. Ted Dimitroff of Natural Gas Systems, Inc. of Columbia, Missouri (aided by with Mr. Gene Kaiser of Kaiser Cable Services of Jefferson City, Missouri), indicated at first that he would be willing to do this bore if reinforced concrete pipe were used. After discussions were held at the evaluation site, he consented to use the CCFRPM pipe. Afterwards, Mr. Dimitroff was quite impressed by the pipe's ease of installation, among other pipe capabilities. He stated that he could have pulled in another 200 feet of 24" pipe with no additional difficulty using this smaller drilling rig. Furthermore, he informed us that he thought that a larger machine (Ditch Witch 4020 or its equivalent) could be capable of installing 300 or more feet of 60" CCFRPM pipe.

Figures 6.1. through 6.4. illustrate the ArrowBore™ process and tools used during the installation of the CCFRPM pipe. It is notable that this installation was the first time ever in the world that CCFRPM pipe was installed by an HDD rig. This claim has been verified with personnel of Hobas Pipe of Houston, Texas.



Figure 6.2. Drilling pilot bore and backreaming was completed from the bank area that sloped into the launch pit. A closer location would have been possible with a ramp near the launch pit.



Figure 6.3. CCFRPM pipe weighs substantially less than concrete, moved with compact equipment.



Figure 6.4. Minimal annulus space around pipe using ArrowBore™ method. Normal HDD procedure would create an annulus space around the pipe 0.5 to 1.5 times the pipe's outer diameter. The maximum measured annulus in this photograph is two inches.

Chapter 7

Discussion of Results

7.1 Types of Horizontal Boring Compared

The four horizontal boring installation methods chosen for observation represent distinct categories of equipment when considered across the range of possible equipment available for installations. There are seven traditionally recognized basic categories of horizontal boring that are used in the new installation of utility product pipe (Iseley and Ghokale, 1977):

1. Utility Tunneling
2. Soil compaction methods
3. Pipe ramming
4. Pipe jacking
5. Microtunneling
6. Auger boring
7. Horizontal directional drilling (HDD)

Utility tunneling is a method that involves man-entry inside of a pipe that is continually advanced by means of thrust. Soil compaction methods include rod pushing and the technique known as impact moling, or “missile” moling. Microtunneling is a process that uses pipe jacking and is remotely controlled. These three methods are not covered in the scope of this report, except in the development of performance specifications. Utility tunneling, being a man-entry method of horizontal boring, can be carried out with additional care to prevent heave and settlement and is only utilized in specialized circumstances in roadways and rights-of-way. This method is also declining due to increased use of microtunneling, pipe jacking, and pipe ramming. Soil compaction methods are intended for short-distance, small diameter pipe installations (usually less than 100’ length and 2 to 8 inches in diameter). These are not usually suitable for use under roadways and rights-of-way, due to their low accuracy. Microtunneling, or perhaps more descriptively, ‘remote-controlled pipe jacking’, involves the use of equipment which is expensive to the contractor and is also expensive to mobilize. It is normally used for longer distances and larger diameters (drives over 80 feet and up 4 feet diameter, though short lengths are usually completed as part of much larger projects due to equipment costs). The remaining four methods were considered in the scope of the field investigations, with guided boring being a part of the ‘auger boring’ category. Four different types of pipe were used, representing those pipes most commonly used under Interstate and high-type road rights-of-way, and those with the potential for that use according to MoDOT utility policy as presented in Chapter 7 of the Design Manual. All of the pipes are vertical load resistant. Also, all of the pipes used are either resistant to edge loading in the case of misalignment, or can be fitted with a resilient gasket material to prevent pipe damage and cracking in the event an obstruction is encountered during boring.

In each installation, measurements were taken at survey points that were pre-established prior to the start of the bore. Elevations were measured before, during, and following each installation. In all cases, the difference in elevation between pre-bore conditions and post-bore conditions was small to negligible. No differences at all were measured for the auger boring installation and for the ArrowBore™ installation. This is not surprising, since all of the bore operators were well-experienced in the types of bores being performed.

Pipe thicknesses varied for the types of pipe chosen. The thinnest pipe was the steel pipe used during pipe ramming, which was 0.75 inches thick. The thickest pipe was the vitrified clay pipe, which was approximately 3.5 inches thick. All cases involved the pipe being advanced by thrust forces acting on the circumference of the pipe. In no case was the maximum thrust allowed by a particular pipe type approached.

Drilling fluids were used for the pipe ramming installation and the ArrowBore™ installation. Since both of these installations were in clay, an anionic surfactant was used to prevent the clay from adhering to the steel pipe (which was rammed) and the drilling tools in the ArrowBore™ installation. In the ArrowBore™ installation, a commercially available anionic surfactant, Baroid’s ConDet™ was used. In the pipe ramming installation, a generally-available automatic dishwashing detergent (Cascade-brand liquid) was used with similar results. Differences between the drilling fluid mixes might have become apparent in a longer bore, but no differences were noted in this study.

A summary of the methods used in the installations is presented in the following table:

	Pipe Jacking MoDOT Job J2P0701	Auger Boring (Guided Boring)	Pipe ramming	Horizontal Directional Drilling (HDD) (ArrowBore™ method)
Equipment Used	Akkerman 5000 – Series Pipejack system	Akkerman GBM- 240	TT Technologies 24” Grundoram™ Taurus	Charles Machine Works (Ditch Witch) JT 1720
Length of Installation	106 feet	80 feet	80 feet	80 feet
Type of Pipe Installed	Class III RCP	Vitrified Clay	Steel	CCFRPM (Centrifugally Cast, Fiberglass Reinforced, Polymer Mortar)
Diameter of Pipe	60 inches	8 inches	24 inches	24 inches
Pipe Manufacturer	Kansas City Concrete Pipe	Mission Clay Pipe	Pittsburg Pipe	Hobas
Accuracy of Installation	Medium	High	Medium	High
Time Required for Installation (includes set-up)	6 days (3days for two pipes of 106’ length each)	3days	3 days	3 days

Table 7.1 Comparison of Borings Conducted

For MoDOT Job J2P0701, we were unable to recommend any improvement to the process that was conducted for pipe jacking. However, after road settlement occurred from incomplete compaction at the east side of the pipes following the installation, we suggest that compaction at the ends of pipes installed by this method be checked carefully prior to acceptance of the project prior to final payment. We recommend in all cases where pipe jacking is used in future MoDOT projects, that geotechnical investigation be conducted to prevent claims of change of conditions. Pipe jacking is a specialized operation requiring skill and training, with tight tolerance to line and grade where corrective action can be cost-prohibitive.

For the pipe ramming process, we were also unable to recommend any improvement, other than the observation that a Permalok-style pipe connection would have saved four man-days that were spent in welding connections between pipes. This type of pipe connection would have reduced installation time from 3 days to 1.5 days. Guided boring would have benefited from a narrower pit size so that thrust could have been established much more quickly. Other than this minor change, guided boring was the most accurate of the four methods by comparison.

The ArrowBore™ method of HDD is the newest of the four methods, and the one which shows the most promise for use by MoDOT for replacement of concrete culvert within the right-of- way. Its accuracy is comparable to guided boring, even though sight-relief holes were not used for the short distance bored. The training required to complete such a bore focuses on the method used. This prevents oversizing the bore and allows the maintenance of line and grade. The particular setup used in this bore would not have worked for coarse soil such as sand. Doing an ArrowBore™ type of HDD installation in sand is a different overall method. The use of CCFRPM pipe in this installation was appropriate for its light weight. An 11,000-pound string of pipe was pulled back through the hole with only 900 pounds of pullback pressure. This indicated to the contractor that a larger directional drill such as the Charles Machine Works’ Ditch Witch JT 4020 would be able to pull back nearly 300 feet of 60-inch CCFRPM pipe. Due to the smoothness of the pipe’s exterior, it was even postulated that CCFRPM pipe could be pulled back with no overcut for the hole whatsoever.

No deformational effects in the soil were seen in the soil upon close examination for any of the methods used at the Capsule Pipeline Field Station. This would indicate that with a careful installation by an experienced professional contractor, there would be no deleterious effect upon installation to adjacent structures or utilities.

7.2 Development of Performance Specifications

These observations led to the revision of Section 734 of the Missouri Standard Specifications for Highway Construction to include all possible types of horizontal boring. The simultaneous revision of the Standard Specifications to include performance specifications presented an ideal opportunity for this revision. The previous Section 734 only addressed one type of boring in its title, "Pipe Jacking". The newly developed version now includes all other methods, as "Installation of Pipe by Horizontal Boring Methods". A new section was also added to the Standard Specifications as well, Section 1075, or "Centrifugally-Cast Fiberglass Reinforced Polymer Mortar Pipe". Both Sections are attached in Appendix E.

The revision to Section 734 resulted from rapid advances in the field of trenchless technology, and horizontal borings in particular. It added pipe ramming, microtunneling, and horizontal directional drilling (HDD) to the potential list of approvable and accepted methods which can be used to install large-diameter pipes in the highway right-of-way and under roadway.

Section 734 was originally intended for the emplacement of reinforced concrete pipe, it was now expanded to include steel. This was done to allow casing underneath roadway lanes for fiber optic cable or wire as telecommunication cable for Intelligent Transportation System (ITS) use, or for communication to Variable Message Signage (VMS). Depth of installation was added to the description of the task to be reflective of the type of installation and the required diameter of pipe for the project. Steel casing, required for the methods of auger boring and pipe ramming, is now specified for those methods.

Other additions to the specification include surface monitoring measurements by the contractor to confirm or disprove settlement or heave, the prohibition of water jetting as a primary means of soil cutting (this was worded carefully to allow HDD, since HDD uses a mechanical means of soil cutting as its primary means, while its water jets are used to eject spoil from the hole), and limiting HDD to 24" without prior authorization. Steel casing pipe now requires a certified welder or have a mechanical means of locking joints into place. This was done to allow screw-fit steel connections or a Permalok connection. A statement regarding the stability of entry and exit pits or shafts was also added to conform with the Occupational Safety and Health Administration policy for trenches and excavations. Resilient joint cushioning materials will be required for pipe jacking and microtunneling, and with thickness requirements dependent upon the diameter of the pipe. This is also to prevent edge loading of the pipe that can lead to damage and cracking during installation. Auger boring and pipe ramming now also require the addition of a steel leading-edge band to prevent pipe damage in this specification. Contractors now know also that cost of disposal for excess drilling fluids, and cost of video inspection of pipe following installation is now included in the bid price for installation by horizontal boring.

Section 1075, or Centrifugally Cast Fiberglass Reinforced Polymer Mortar Pipe was written with respect to existing specifications from other areas, in particular one standard of the American Society for Testing and Materials, ASTM D3262, Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Sewer Pipe. Pipe acceptance will be based upon the manufacturer's certification and the acceptance of the project engineer.

Chapter 8

Trenchless Technology Training Workshops for MoDOT Engineers and Inspectors

On May 12, May 14, and May 16, 2003 a series of training workshops were held in St. Louis (Chesterfield), Jefferson City and Kansas City (Lees' Summit), respectively. The St. Louis workshop was held at MoDOT District 6 headquarters in Chesterfield, Missouri. The Jefferson City workshop was held at the MoDOT Materials Laboratory, and the Kansas City workshop was held at the MoDOT District 4 headquarters in Lees' Summit, Missouri. The materials presented were intended to educate MoDOT permit inspectors, designers, geotechnical, and utilities personnel in some of the fundamentals of trenchless technology to grant them a greater appreciation and knowledge of basic installation of subsurface utility product pipe by trenchless methods.

Each participant was given a notebook containing the entire Powerpoint presentations of each presenter, with space to make notes on individual points in the presentation. Also included in the notebook was a glossary of the terminology used in trenchless technology, a list of pertinent references and a short list of Internet websites for further reference. These workshops were specifically tailored to meet the needs of MoDOT, with cross-reference materials presented on MoDOT standards and specifications that relate to trenchless installations. Subjects covered were: the importance of trenchless technology in highway design and construction, MoDOT standards and specifications, HDD and sewer installations, drilling fluids, auger boring, pipe ramming and pipe bursting, pipe materials, microtunneling and pipe jacking, and geology/geotechnique.

Following the workshops, the participants completed a course evaluation form and a test. These were some measure of the success experienced in conducting the workshops. Participants took the test in three locations. The summary results are as follows for this 40-question test for each testing location:

	Monday, May 12, 2003 St. Louis, MO District 6 Office (41 attendees)	Wednesday, May 14, 2003 Jefferson City, MO Materials Laboratory (26 attendees)	Friday, May 15, 2003 Kansas City, MO District 4 Office (44 attendees)
Overall Test Average	92.74%	93.17%	90.96%
Maximum Grade	97.5%	100%	97.5%
Minimum Grade	67.5%	77.5%	60%
Median	95%	95%	92.5%

The evaluation form that was returned with the test also reflected a continuing need for training in the field of trenchless technology. The majority of respondents rated the workshop "Good" (71) or "Excellent" (39). Six respondents rated the workshop "Satisfactory", and zero respondents rated it as "Poor". All of the participants answered "Yes" to the question, "Did you find most of the information presented to be timely and of interest to you?" In addition, all of the respondents answered "Yes" to the question "Did you learn information from the workshop that will be of use to you later?"

Later answers in the evaluation form provided important clues to what these engineers and inspection personnel needed to know in relation to the technology also. One respondent stated that he/she wanted "more information about problems with boring applications, and more information that relates to road bores". Another respondent

listed that he/she would like an “outline of what to inspect, what to document, problems to look for, [and] how to correct [those problems].” One wanted to “compare MoDOT’s policies with standard industry practice.” Another wanted “ more information on planning and preventative solutions to trenchless procedures.”

Several respondents were interested in potential problems with horizontal boring and pavements. One wanted “precise guidelines related to pavement movements due to boring under roadways.” Another spoke of “humped road surface” and “sagged road surface” in relation to problems they faced in the field with trenchless installation. Two respondents talked about utilities in particular. One asked the pertinent questions “Can utility location be made any more accurate? Any new ways of locating? Too many utility as-builts are inaccurate, as well as city locates for sewers and water.” Another wanted to know about “Equipment and processes for locating buried utilities, [possibly] seminars on S.U.E [Subsurface Utility Engineering-ghd]. Is there technology that is easy to use and accurate and affordable enough to be used by MoDOT surveyors or specially trained staff?”

The 114 participants who attended these seminars considered them a success. In the interest of continuing education documentation, the names of all participants were forwarded to MoDOT’s Human Resources’ Employee Development section.

Chapter 9

Conclusions and Recommendations

9.1. Conclusions

The observation and measurements regarding the J2P0701 pipe jacking project on Route 63 and the three test borings at the Capsule Pipeline Field Station indicate that the trenchless road crossing, or horizontal boring methods chosen are capable of installing pipe with minimum or no ground movements with a trained operator and adequate advance geotechnical information. Though the field studies were conducted in only two types of soil (CL-lean clay and CH-fat clay by ASTM classification), the results obtained were incorporated with those from actual installations in other soil conditions. The results of these tests have been incorporated into the new MoDOT performance specification in the Missouri Standard Specifications for Highway Construction known as Section 734 – Installation of Pipe by Horizontal Boring Methods. This new specification is meant to address not only the four types of horizontal boring that were documented in actual and test installation, but other methods of installation including utility tunneling, impact moling, microtunneling, and auger boring. Another direct benefit of the testing was the identification of centrifugally-cast, fiberglass reinforced, polymer mortar (CCFRPM) pipe as a potential new material with advantages for trenchless crossings.

Indirect benefits of these field studies and training are the recognition and dispersal of information that indicates that trenchless installation may be one method for the preservation of pavement integrity on MoDOT rights-of-way. Cost and benefit of construction impacts goes beyond simple cost of construction and includes other parameters such as total economic impact and public affairs for MoDOT. The social costs of a project are a major element in identifying the total life cycle costs of a project, which to a large extent is a function of the method of installation adopted. Trenchless construction methods minimize the social costs of construction.

Despite numerous precautions taken to prevent damage during utility and drainage excavations, subsequent pavement restoration remains the most serious and expensive problem related to open-trench activity other than the obvious hazard of trench collapse. These types of excavations significantly contribute to a reduction in pavement life expectancy. Pavement trench excavations reduce pavement life expectancy by 50% or more according to one study (Shahin and Croveti, 1985). Inadequate restorations, which are often the case, create higher costs in maintenance due to the need for periodic repair. Road user costs are increased and citizen complaints are generated.

The possibility of damaging adjacent buried utilities is a problem that is faced by both open-cut and trenchless installations. However, with less area disturbed, the potential for damage to a buried utility by a trenched installation is greater than that for trenchless installation. The same relationship holds true for adjacent structures as well. Open-cut installation carries with it the concomitant possibility that adjacent highway structures may be damaged, particularly when dewatering is necessary. This can cause movement and/or settlement of adjacent structures. With trenchless techniques, this potential source of damage can often be eliminated.

Trenchless methods minimize or eliminate delay or slower movement of traffic by reducing or eliminating surface excavation and traffic disruption. Pedestrians, children, and the elderly utilize secondary roads as travel routes. Additional traffic from an open-cut installation's detour may impede traffic and create safety risks. The use of trenchless methods significantly minimizes this problem. The secondary roads that are used as detour routes are also not designed for increased traffic loads. The resulting damage to secondary pavement and its shortened life expectancy after a damage is avoided totally using trenchless methods.

Other cost savings and social cost savings include: decreased fuel consumption, avoiding potential environmental impacts and citizen complaints, significantly reduced site restoration costs, and decreased legal costs. The U.S. Department of Transportation's Federal Highway Administration issued a report in October 2002 entitled, "Manual for Controlling and Reducing the Frequency of Pavement Utility Cuts" that recognized pavement utility cuts as a major problem in the pavement infrastructure of the U.S. Their recommendations of potential solutions to utility cuts as a pavement problem included the implementation of incentive fee- and requirements-based policies, and the promotion and advancement of trenchless technology applications (Wilde, Grant, and Nelson, 2002).

Increased use of trenchless methods presents a challenge for the Missouri Department of Transportation. The use of a performance-based specification, Section 734 of the Missouri Standard Specifications for Highway Construction, is an advance in addressing MoDOT's needs. Continuing education in trenchless technologies by engineers, designers, and inspectors are critical to understanding the problems and solutions that may be created by, or eliminated by trenchless methods.

9.2 Recommendations

For benefits to MoDOT to continue as trenchless methods become more prevalent as a method of utility product pipe installation and renewal, we recommend the following:

1. Continued training and exposure to trenchless technologies, in particular those methods and techniques that pertain to road or right-of-way crossings. A person or persons who are experienced in, or have a comprehensive understanding of, those methods encountered most frequently could accomplish training in-house.
2. Adherence to the new Section 734 performance specifications during construction activities.
3. Use of industry-standard guidelines for method-specific techniques when designing trenchless installations.

A short list of these guidelines and informational sources is as follows:

- a. Guidelines for Impact Molding, TTC Technical Report 2001.03
 - b. Guidelines for Pipe Ramming, TTC Technical Report
 - c. Standard Practice for Direct Design of Precast Concrete Box Sections for Jacking in Trenchless Construction, ASCE Standard 28-00
 - d. Standard Practice for Direct Design of Precast Concrete Pipe for Jacking in Trenchless Construction, ASCE Standard 27-00
 - e. Horizontal Directional Drilling Good Practices Guidelines, HDD Consortium
 - f. Horizontal Auger Boring Projects, ASCE Manual and Reports on Engineering Practice #106
 - g. NUCA Trenchless Construction Methods and Soil Compatibility Manual
 - h. NCHRP Synthesis 242 – Trenchless Installation of Conduits Beneath Roadways
 - i. The textbook, Trenchless Technology published by McGraw-Hill.
- These sources are all in the ‘References’ section of this report. Other standard guidelines and practices are in preparation on a yearly basis, and should be explored and procured as needed.
4. Contractor prequalification in trenchless-oriented construction, or construction jobs that have a trenchless element. A short example prequalification questionnaire, developed by the Center for Underground Infrastructure Research and Education for the Michigan DOT, is presented in Appendix F.
 5. Review of the appropriate sections of the Materials and Design Manuals that pertain to trenchless construction, and making appropriate changes to encourage the use of trenchless methods.
 6. Requiring geotechnical evaluation prior to allowing horizontal boring, as knowledge of geology/geotechnique insures the success of bores by providing advance information to site conditions, and can prevent contractor change-in-condition claims.

These six items will advance the goal of insuring that trenchless methods are administered, inspected, and approved in a timely manner. Trenchless construction will be accomplished safely, and a potential method of insuring pavement integrity and the public safety will be established with the Missouri DOT.

References

- American Society of Civil Engineers, 2000. Standard practice for Direct Design of Precast Concrete Pipe for Jacking in Trenchless Construction. ASCE Standard 27-00. 51 pp.
- American Society of Civil Engineers, 2000. Standard Practice for Direct Design of Precast Concrete Box Sections for Jacking in Trenchless Construction. ASCE Standard 28-00. 52pp.
- American Society of Civil Engineers, 2004. Horizontal Auger Boring Projects. ASCE Manuals and Reports on Engineering Practice No. 106. 52pp.
- Bennett, David; Ariaratnam, Samuel; and Como, Casey, 2001. HDD Consortium Horizontal Good Practices Guidelines.
- Iseley, Tom, and Gokhale, Sanjiv B., 1997. Trenchless Installation of Conduits Beneath Roadways – a Synthesis of Highway Practice. National Research Council of Transportation Research Board, National Cooperative Highway Research Program NCHRP Synthesis 242. 76pp.
- Iseley, Tom; Najafi, Mohammed; and Tanwani, Raj, 1999 Trenchless Construction Methods and Soil Compatibility Manual, 3rd ed. 102pp.
- Najafi, Mohammad, 2004. Trenchless Technology – Pipeline and Utility Design, Construction, and Renewal. McGraw-Hill. 489pp.
- Shahin, M.Y., and Crovetti, J.A., 1985. Final Report for the Street Excavation Impact Assessment for the City of Burlington, Vermont. Prepared by ERES Consultants, Champaign, IL, June 12, 1985.
- Simicevic, Jadranka, and Sterling, Raymond L., 2001. Guidelines for Impact Molding. Trenchless Technology Center of Louisiana Technological University Technical Report #2001-03, prepared for the United States Army Corps of Engineers Engineering Research And Development Center. 19pp.
- Simicevic, Jadranka, and Sterling, Raymond L., 2001. Guidelines for Pipe Ramming. Trenchless Technology Center of Louisiana Technological University Technical Report #2001-04, prepared for the United States Army Corps of Engineers Engineering Research And Development Center, 23 pp.
- Wilde, W. James, Grant, Carolyn A., and Nelson, Patricia K., 2002. Manual for Controlling and Reducing the Frequency of Pavement Utility Cuts. Report No. FHWA-IF-02-064. United States Department of Transportation Federal Highway Administration. 173 pp.

Appendix A
Preconstruction Meeting Minutes

EMPLOYEE INVOLVEMENT
MEETING MINUTES

GROUP NAME: Pre-Construction Conference (J2P0701)
DATE OF MEETING: April 5, 2002 **TEAM LEADER:** Jeffrey L. Gander **PHONE NUMBER:** 660-385-3036
LOCATION OF MEETING: District 2 Training Room
ATTENDEES: Curtis Elam Jeffrey Gander Dennis Brucks Travis Wombwell Mike Herleth
Bret Davidson Gale March Ron Perkins Brett Gunnink George Davis Mike Mulligan
Casey Jones Don Lickteig Chrissy Owen

SUMMARY OF ITEMS COVERED THIS MEETING:

1. All attendees introduced themselves and it was noted that Mike Mulligan would be the project manager and that Donny Lickteig would be the boring superintendent.
2. Jeff reviewed the working days schedule and Mike noted that the projected completion date would be May 13, 2002.
3. Keith Contracting stated that they would be working 5-10 hour days.
4. Jeff stated that the only subcontractor that Keith Contracting would be utilizing would be Schrimpf Landscaping. They would be supplying the seed and mulch. Jeff also noted that we would only be paying for plan quantity and any area disturbed outside that necessary for jacking of the pipe would be seeded at the contractor's expense. Jeff noted that Type 3 mulch would most likely be used in lieu Type 4 mulch.
5. Jeff warned Keith Contracting about the frequent inspections by the Department of Natural Resources concerning erosion control.
6. Brett Gunnink informed Keith Contracting of what their research would involve. Basically, survey points will be established on the existing pavement and measurements will be taken before, during, and after the jacking of the pipe. In addition, 4 settlement gauges will be installed over the pipes. All of this data will be analyzed to determine ground movement during a pipe jacking operation. All of this work will be done by University of Missouri and MoDOT personnel and coordinated with the contractor's operation.

ACTION ITEMS: Distribute Meeting Minutes
PREPARED BY: Chrissy Owen
DISTRIBUTION: All Attendees

Appendix B

Narrative Report of Project on Completion

Prepared by Jeff Gander,
MoDOT Resident Engineer, Macon Project office

J2P0701

Pipe Jacking Project

Summer 2002

Project Purpose: This project was designed to improve drainage of an area on the west side of Route 63 in Macon, Missouri. This area was prone to flash flooding during heavy rains due to back-up from the existing culvert.

Project Scope: Under this contract two 60" RCP culverts were installed using pipe jacking methods under Route 63 and flared end sections were installed. Each pipe measured 106' in length. Also, rock blanket was installed to protect the ditch banks near the structures.

Construction: The construction of the two culverts went smoothly with no adverse affects on traffic in the area. The culverts were bored and installed separately using a single bore pit. Excavation of the bore pit was slowed by heavy rains in the area. After preparation of the bore pit, the pipes were jacked in about 1.5 days each. Heavy rains again fell after the pipe installation slowing the installation of the flared ends and rock blanket. Total time of construction of the two structures and other miscellaneous items was 41 calendar days. My estimation is that the construction could have been completed in 25 days with cooperative weather.

Research: Elevation shots were taken before, during, and after the pipe installation to settlement, if any, due to the pipe jacking operation. These shots were taken not only on the pavement surface but also on settlement gauges, which were installed previously. Minor settlements occurred at the pavement level with the highest being approximately 0.1 feet. This settlement was located on the centerline of the roadway, at the point between the two culverts. The settlements observed diminished going away from this point in all directions.

Benefits: The construction of this project had no adverse affects on traffic in the area. Installation of these structures by conventional methods would have meant having a one-lane traffic situation for an extended period of time or an inconvenient detour. I feel that the methods used for this project made it a success for MoDOT, the public and the trenchless industry.

DATE	ISSUED	SHEET NO.
63	MO	2
PROJECT NO. J2P0701		
PROJECT NO.		
COUNTY MACON		
DATE		

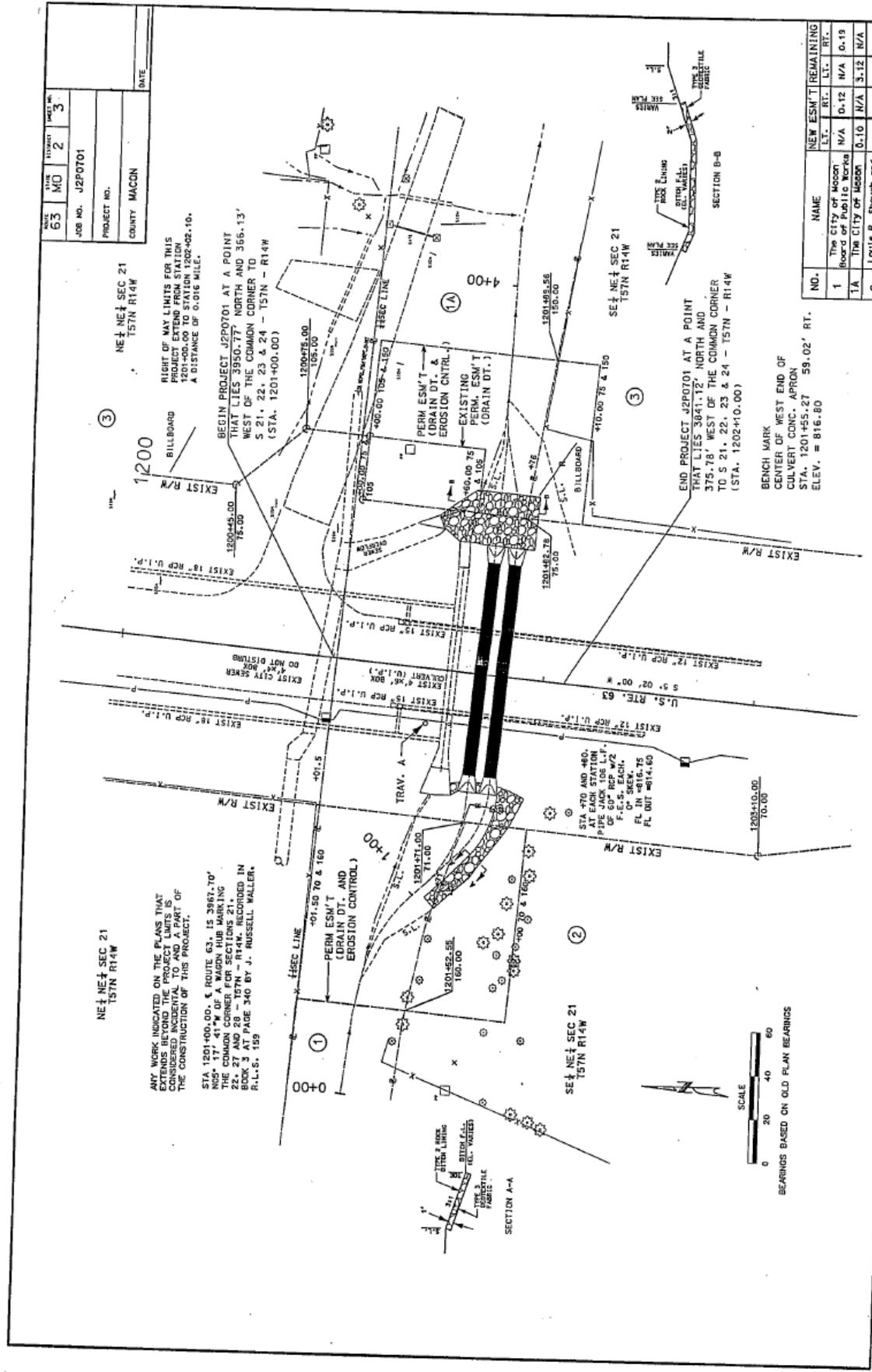
NE 1/4 SEC 21
157N R14W

RIGHT OF WAY LIMITS FOR THIS PROJECT EXTEND FROM STATION 1201+00.00 TO STATION 1202+02.10, A DISTANCE OF 0.016 MILE.

BEGIN PROJECT J2P0701 AT A POINT THAT LIES 3950.77' NORTH AND 366.13' WEST OF THE COMMON CORNER TO S 21, 22, 23 & 24 - 157N - R14W (STA. 1201+00.00)

END PROJECT J2P0701 AT A POINT THAT LIES 3841.12' NORTH AND 375.78' WEST OF THE COMMON CORNER TO S 21, 22, 23 & 24 - 157N - R14W (STA. 1202+10.00)

BENCH MARK
CENTER OF WEST END OF
CULVERT CONC. APRON
STA. 1201+55.27 59.02' RT.
ELEV. = 816.80



NO.	NAME	NEW ESM/T REMAINING	
		LT.	RT.
1	The City of Macon Board of Public Works	N/A	0.12
1A	The City of Macon	0.10	N/A
2	Louis R. Shoush and Margie L. Shoush	N/A	0.01
3	Macon Investors, Inc.	0.04	N/A
		1.24	0.13

NE 1/4 SEC 21
157N R14W

ANY WORK INDICATED ON THE PLANS THAT EXTENDS BEYOND THE PROJECT LIMITS IS CONSIDERED INCIDENTAL TO AND A PART OF THE CONSTRUCTION OF THIS PROJECT.

STA 1201+00.00, & ROUTE 63 IS 3987.70' N55° 17' 41" W OF A WADSWORTH MARKING THE COMMON CORNER FOR SECTIONS 21, 22, 23 AND 24 - 157N - R14W. RECORDED IN BOOK 3 AT PAGE 340 BY J. RUSSELL WALLER, P.L.S., 195

NE 1/4 SEC 21
157N R14W



BEARINGS BASED ON OLD PLAN BEARINGS

DATE	MO	YEAR	SHEET NO.
63	MO	2	8
JOB NO. J2P0701			
PROJECT NO.			
COUNTY MACON			
DATE			

SKEW ANGLE = 0°
 STA 1201+80.00
 1-60" X 106 LF
 OF JACKED PIPE
 CLASS 3 RCP
 2 - F.E.S.

1201+80.00
 UFL 816.75

SKEW ANGLE = 0°
 STA 1201+70.00
 1-60" X 106 LF
 OF JACKED PIPE
 CLASS 3 RCP
 2 - F.E.S.

1201+70.00
 UFL 816.75

EXIST. ROUTE 63

FL 15" P 106 C
 826.96
 19.5 R

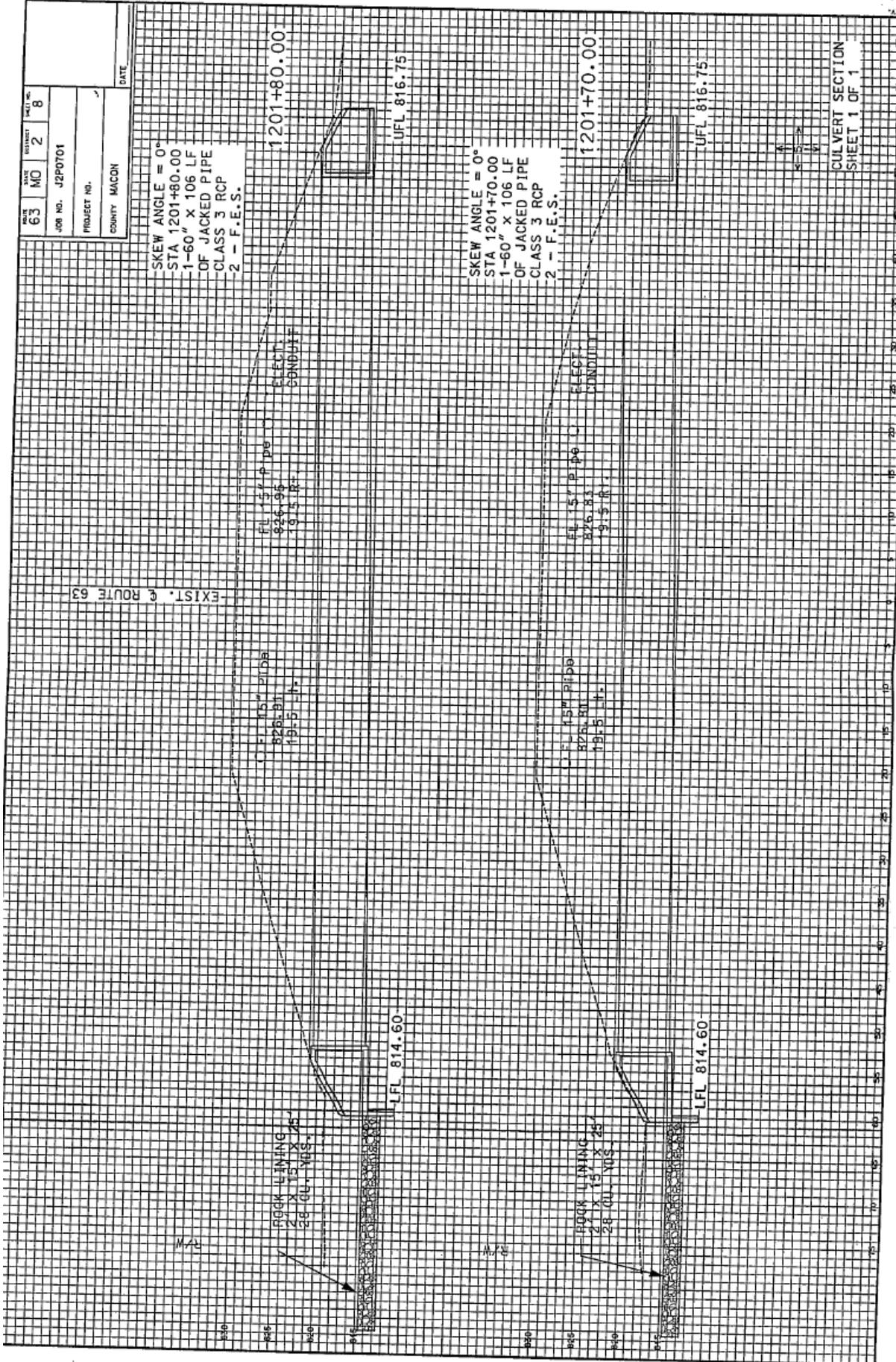
HOOK LINING
 24" X 15" X 25"
 28 (0) YES

HOOK LINING
 24" X 15" X 25"
 28 (0) YES

LFL 814.60

LFL 814.60

CULVERT SECTION
 SHEET 1 OF 1



Appendix D Logs of Borings Completed at Capsule Pipeline Field Station

Form T-737-IRM0
Rev. 05/01

MISSOURI DEPARTMENT OF TRANSPORTATION Construction and Materials BORING DATA (CORE & SPT)

Sheet 1 of 2

Job No.: SPR-03-ARS
 County: Boone Route: -- Design: --
 Over: South Side of Test Embankment Skew: --
 Logged by: Davis Operator: Murray
 Equipment: CME 850, 3" and 5" Shelby Tubes, Split Spoon Sampler Drillers Hole No.: V-02-48
 Hole Stab. by: Hollow Stem Augers Date of Work: 11/04/02
 Automatic Hammer Efficiency: 79 % Drill No.: G-7950

Bent	Station	Location	Surface Elevation

LOG OF MATERIALS*
 0.0-1.0' Dark grayish-brown lean clay, moist, very stiff.
 1.0-2.5' Dark brown fat clay, moist, hard, gray mottled, scattered iron concretions.
 2.5-5.0' Gray lean clay, moist, very stiff, yellowish-brown, mottled.
 5.0-31.5' Gray fat clay, moist, stiff to very hard, slickensided beginning at 8.0', trace coarse sand of quartz or carbonate concretions.

TEST DATA

Depth, ft.	SPT Blows/6"	N ₆₀	Pocket Pen., tsf
27.5	6-8-12	26	4.50
30.0	10-22-13	46	5.60

Depth, ft.	Torvane, tsf	Wn%	Pocket Pen., tsf
0.5	0.63	24.8	3.95
1.5	1.50	21.4	4.50
2.5	1.35	21.9	3.65
5.0	1.00	27.1	1.35
7.5	0.78	26.3	1.70
10.0	1.77	22.5	2.85
12.5	2.00	23.5	4.50
15.0	>2.50	21.9	4.60
16.5	2.00	22.9	4.50
19.0	>2.50	22.4	4.50
21.5	2.00	23.2	4.50
24.0	2.15	20.0	5.50
27.5	>2.50	17.9	4.50
30.0	>2.50	19.2	5.60

UNCONFINED COMPRESSIVE STRENGTH

TEST DATA		
Depth, ft.	Qu, tsf	P.P., tsf
2.5	1.18	3.65
7.5	0.76	1.70
12.5	1.15	4.50
19.0	4.21	4.50

UNIT WEIGHTS

Depth, ft.	γ _{sat} , pcf	γ _{moist} , pcf	% _{sat}
0.5	124.7		100 ⁽¹⁾
2.5		123.2	87.8 ⁽²⁾
5.0	129.0		100 ⁽¹⁾
7.5		120.3	96.9 ⁽²⁾
10.0	127.5		100 ⁽¹⁾
12.5		126.0	98.6 ⁽²⁾
15.0		125.3	96.2 ⁽²⁾
16.5	127.1		100 ⁽¹⁾
19.0	129.3		100 ⁽²⁾

(1) Assumed
(2) Actual

SOIL CLASSIFICATION TEST DATA

Depth, ft.	LL	PI	ASTM Class
0.5	42	15	ML & OL
1.5	60	35	CH
2.5	48	26	CL
7.5	65	46	CH
15.0	63	44	CH
21.5	57	37	CH
27.5	55	37	CH
30.0	53	32	MH & OH

CORING LOG (NX Double Tube Barrel)

From	To	Run	Rec	Loss	% RQD	Notes

WATER TABLE OBSERVATIONS

Date	Time Change	Depth Hole Open	Depth To Water

SHEAR TEST DATA

DRAINED DIRECT SHEAR TEST

Depth, ft.	σ' _o	c', psf
2.5	28.6	98.6
	(29.1)	(0)
7.5	15.4	354.4
	(18.9)	(0)
15.0	21.6	444.9
	(25.4)	(0)
21.5	17.1	697.1
	(23.5)	(0)

N₆₀ - Corrected N value for standard 60% SPT efficiency.

N₆₀ = (Em/60)Nm Em - Measured transfer efficiency in percent.

Nm - Observed N-value.

* Persons using this information are cautioned that the materials shown are determined by the equipment noted and accuracy of the "log of materials" is limited thereby and by judgment of the operator.
THIS INFORMATION IS FOR DESIGN PURPOSES ONLY.

**MISSOURI DEPARTMENT OF TRANSPORTATION
Construction and Materials
BORING DATA (CORE & SPT)**

Sheet 2 of 2

Job No.:	<u> SPR-03-ARS </u>	Design:	<u> -- </u>
County:	<u> Boone </u>	Route:	<u> -- </u>
Over:	<u> North Side of Test Embankment </u>	Skew:	<u> -- </u>
Logged by:	<u> Davis </u>	Operator:	<u> Murray </u>
Equipment:	<u> CME 850, Split Spoon Sampler </u>	Drillers Hole No.:	<u> V-02-47 </u>
Hole Stab. by:	<u> Hollow Stem Augers </u>	Date of Work:	<u> 11/04/02 </u>
Automatic Hammer Efficiency:	<u> 79 </u>	Drill No.:	<u> G-7950 </u>

Bent	Station	Location	Surface Elevation

LOG OF MATERIALS*

0.0-1.0' Brown lean clay, moist, medium stiff.
1.0-3.5' Grayish-brown fat clay, with iron concretions, moist, very stiff.
3.5-6.7' Grayish-brown lean clay, with iron concretions, moist, very stiff.
6.7-31.5' Gray fat clay, yellowish-brown mottles, moist, stiff, slickensided, trace carbonate concretions.

TEST DATA

Depth, ft.	SPT Blows/6"	N ₆₀	Pocket Pen., tsf
2.5	3-4-7	14	3.00
5.0	4-6-7	17	2.45
7.5	3-2-5	9	1.85
10.0	3-3-6	12	1.80
12.5	5-8-10	24	4.40
15.0	6-7-10	22	4.50
17.5	4-7-10	22	4.10
20.0	5-7-13	26	4.05
22.5	4-7-10	22	2.60
25.0	5-8-10	24	5.20
27.5	5-8-14	30	6.00
30.0	7-9-12	28	6.50

SOIL CLASSIFICATION TEST DATA

Depth, ft.	LL	PI	ASTM Class
2.5	63	34	CH
5.0	62	36	CH
10.0	66	40	CH
15.0	56	36	CH
20.0	52	32	CH
25.0	62	45	CH
30.0	27	6	ML

Depth, ft.	Torvane, tsf	Wn%	Pocket Pen., tsf
2.5	0.77	25.4	3.00
5.0	0.55	20.4	2.45
7.5	0.76	28.2	1.85
10.0	1.35	22.7	1.80
12.5	2.00	21.1	4.40
15.0	2.00	21.9	4.50
17.5	1.95	23.8	4.10
20.0	2.10	22.7	4.05
22.5	1.85	22.5	2.60
25.0	>2.50	20.2	5.20
27.5	2.25	19.3	6.00
30.0	>2.50	18.7	6.50

UNIT WEIGHTS

Depth, ft.	γ _{sat} , pcf	γ _{moist} , pcf	% _{sat}
2.5	124.5		100 ⁽¹⁾
5.0	129.9		100 ⁽¹⁾
10.0	127.3		100 ⁽¹⁾
15.0	128.1		100 ⁽¹⁾
20.0	127.3		100 ⁽¹⁾
25.0	130.1		100 ⁽¹⁾
30.0	131.9		100 ⁽¹⁾

- (1) Assumed
- (2) Actual

CORING LOG (NX Double Tube Barrel)

From	To	Run	Rec	Loss	% RQD	Notes

WATER TABLE OBSERVATIONS

Date	Time Change	Depth Hole Open	Depth To Water

N₆₀ - Corrected N value for standard 60% SPT efficiency.

N₆₀ = (Em/60)Nm Em - Measured transfer efficiency in percent.

Nm - Observed N-value.

* Persons using this information are cautioned that the materials shown are determined by the equipment noted and accuracy of the "log of materials" is limited thereby and by judgment of the operator.

THIS INFORMATION IS FOR DESIGN PURPOSES ONLY.

Appendix E Specifications

Section 734

Installation of Pipe by Horizontal Boring Methods

734.1 Description. This work shall consist of furnishing and installing reinforced concrete pipe culvert (gasket-type) or steel pipe by horizontal boring methods underneath existing pavements at locations shown on the plans or as directed by the engineer. The minimum depth of installation shall be dependent upon the method used and the diameter of the pipe, and will require review and approval from the engineer before the start of this work.

734.2 Material. The class of pipe specified in the contract item will be determined for vertical load only. Additional reinforcement or strength of pipe required to withstand jacking pressure shall be determined by the contractor and shall be furnished at the contractor's expense. If pipe ramming or auger boring is the horizontal boring method specified for use, steel casing pipe shall be used. All material shall be in accordance with Division 1000, Material Details, and specifically as follows:

Item	Section
Reinforced Concrete Culvert, Storm Drain and Sewer Pipe	1026
Fiberglass-Reinforced Polymer Mortar Pipe	1075

734.3 Construction Requirements.

734.3.1 The contractor shall protect the horizontal bore work area as shown on the plans.

734.3.2 Variations from theoretical alignment and grade for the completed pipe shall not exceed 0.5 feet (150 mm) for each 100 feet (30 m) of pipe. Pavement or ground surface heave or settlement above the installation will not be permitted. To determine if heave or settlement is occurring, the contractor shall undertake surface monitoring measurements.

734.3.3 The excavated hole shall be no more than 0.1 foot (30 mm) greater than the outside diameter of the pipe. Sluicing and jetting with water as a primary means of soil cutting will not be permitted. When material tends to cave in from outside these limits, a metal shield shall be used ahead of the first section of pipe when pipe jacking, microtunneling or auger boring.

734.3.4 If the excavated hole is formed by Horizontal Directional Drilling (HDD), the boring equipment used to bore the hole shall be of proper type and in proper working order to ensure the work is performed to the satisfaction of the engineer. The size of installations by the directional drilling method shall be limited to those that can be accomplished by using a 24-inch (600 mm) maximum-sized reamer, unless approved by the engineer.

734.3.5 Holes bored by HDD shall be cleaned of excess material before pipe is jacked or pulled into place. Holes bored by the methods of auger boring, microtunnelling or pipe jacking shall be cleaned as pipe is being jacked or pushed simultaneously into place.

734.3.6 Any areas resulting from caving or excavation outside the above specified limits shall be backfilled with a cellular concrete grout designed and produced in accordance with ASTM C 796, and with a method that will fill the voids. The excavated area around the pipe shall be sealed with grout for a minimum distance of 3 feet (1 m) from the outside face of the fill or cut slope.

734.3.7 If steel casing pipe to be left in place is used with this installation method, the contractor may delete the gasket type joints for the limits of the jacked pipe. Steel casing pipe shall be welded by a certified welder or shall have a mechanical means of locking pipe joints into place.

734.3.8 Entry or exit pits or shafts shall be adequately sloped and shored prior to boring.

734.3.9 If the horizontal boring method chosen for use is pipe jacking or microtunneling, resilient joint cushioning material shall be used between individual pipe segments during the pipe jacking or microtunneling process. This material shall be 0.5 inch (13 mm) thick for pipe

diameters up to 30 inches (750 mm), and shall be 0.75 inch (19 mm) thick for pipe diameters equal to or greater than 30 inches (750 mm).

734.3.10 If the horizontal boring method chosen for use is auger boring or pipe ramming, an adequate steel leading-edge band shall be used to protect the leading edge of the pipe from obstacles in the boring path.

734.4 Method of Measurement. Final measurement will not be made except for authorized changes during construction or where appreciable errors are found in the contract quantity. Where required, measurement of horizontal bore installed pipe, complete in place, will be made to the nearest foot (0.5 m) along the geometrical center of the pipe. The revision or correction will be computed and added to or deducted from the contract quantity. The length of structure may be increased by no more than 3 feet (1 m) as necessary to avoid cutting the pipe, but such increased length will not be included in the contract quantity for payment.

734.5 Basis of Payment.

734.5.1 All cost for work area protection will be paid for at the contract unit price for each of the pay items included in the contract.

734.5.2 The accepted quantities of horizontal bore installed pipe, complete in place, will be paid for at the contract unit price for each of the items included in the contract. Payment will be considered full compensation for excavation and backfilling of the jacking pits, disposal of excess excavation from boring operations, grout for filling voids, disposal of excess drilling fluids, video inspection or camera recording equipment, and any other incidental items or equipment necessary to complete the described work.

Section 1075

Centrifugally-Cast Fiberglass-Reinforced Polymer Mortar Pipe

1075.1 Scope. This specification covers centrifugally-cast fiberglass-reinforced polymer mortar pipe to be used in pipejacking and microtunneling for horizontal boring applications under roadways.

1075.2 Acceptance. Acceptance of the material will be based on the manufacturer's certification and upon the results of any tests required by the engineer.

1075.3 Manufacture.

1075.3.1 Pipe shall be manufactured from polyester resin systems with a proven history of acceptable performance for the particular application. The historical data shall have been acquired from a composite material of similar construction and composition as the proposed product.

1075.3.2 Pipe shall be manufactured from reinforcing glass fibers of commercial grade E-glass filaments with binder and sizing compatible with impregnating resins.

1075.3.3. Pipe shall be manufactured from silica sand, with a minimum of 98 percent silica, and a maximum moisture content of 0.2 percent.

1075.3.4 When used, resin additives, such as curing agents, pigments, dyes fillers, thixotropic agents, etc., shall not detrimentally affect the performance of the product.

1075.4 Documentation. The manufacturer shall provide certification to the contractor that the material provided is in accordance with ASTM D 3262 and that pipe joints meet the performance requirements of ASTM D 4161. The certification shall state the manufacturer's name and shall have attached typical results of tests on the material and pipe joints.

1075.5 Construction Inspection. Pipe will be inspected for defects prior to installation. Damaged pipe will be rejected. Any pipe that appears cracked near the joint will be rejected.

Appendix F

Questionnaire for Experience in Trenchless Road Crossing Methods

Questionnaire for Experience in Trenchless Road Crossing

Project Overview				
1. Project Name				
2. Project Duration	Start Date	Finish Date		Number of shifts
3. Location	City		State	
4. Contractor/ Consultant	Name of Company			
5. Contact Person	Name	Phone	Fax	e-mail
6. Type of Work				
7.Type of Utility (Circle)	Force Main Sewer Water Sewer Other ()	Gravity Water	Sanitary Sewer Gas Cable	Storm Sewer Electricity Phone
8. Location			Depth under pavement	
9. Construction Cost	\$() per foot		Shaft cost included? Yes No If yes, type of shaft?	
Site Condition				
10.Existence of Underground Utilities	Yes No (circle one)			
11. Site Access	Good Access Poor Access (Circle one) – explain if necessary			
12. Working Area	Open – Good working area Tight – Poor Working Area (Circle one) – explain as necessary			

Construction Data			
13. Bore Length			
14. Pipe Size	Inside Diameter	Outside Diameter	
15 Pipe material (circle one)	RCP	Steel	HDPE GFRP PVC VCP CCFRPM Other
16. Pipe Segment Length		17. Type of Joint	
18. Was grouting of the annular space required? Yes No Were casing spacers required? Yes No (circle one)			
19. Installation Depth	20. Crossing under		
21. Grade	Minimum grade required ()	Tolerance in grade ()	
22. Size of Pits	Entrance (W times L)	Exit (W times L)	
23. Overcut or final reamer diameter			
24. Deviation	Horizontal	Vertical	
25. Geotechnical Conditions (circle one or Explain)	Rock	Cobble	Boulders Wet Sand Dry sand Wet Clay Dry Clay Other (explain)
26. Ground water	Yes No (circle one) If yes, what was depth of groundwater table?		
27. Ground Movement	Yes No (circle one)	If, swelling or subsiding, how much?	
28. Risk/ Problems Encountered			