

1. Report No. FHWA/TX-11/0-6394-1		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle EVALUATING THE IMPACT OF OVERWEIGHT LOAD ROUTING ON BURIED UTILITY FACILITIES				5. Report Date October 2010 Published: February 2011	
				6. Performing Organization Code	
7. Author(s) Edgar Kraus, Emmanuel Fernando, Eric Yingfeng Li, Jeong Ho Oh, Nicholas Koncz, and Cesar Quiroga				8. Performing Organization Report No. Report 0-6394-1	
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. Project 0-6394	
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, Texas 78763-5080				13. Type of Report and Period Covered Technical Report: September 2009–August 2011	
				14. Sponsoring Agency Code	
15. Supplementary Notes Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration. Project Title: Evaluation of Overweight Load Routing on Buried Utility Plant URL: http://tti.tamu.edu/documents/0-6394-1.pdf					
16. Abstract Overweight traffic movements can negatively affect pavement integrity and quality. However, it is less known to what degree buried utility plant along and across the right of way is affected by these overweight loads, especially if the utility facility is aged, placed under an exception to the Utility Accommodation Rules (UAR), and/or subjected to repetitive loads. Routing decisions for repetitive overweight loads may be determined without consideration of cumulative impacts to utility infrastructure, particularly municipally owned lines that could be aged, accommodated under an exception, or of substandard materials. Given the growth in volume in overweight load (particularly mid-heavy and superload) permits, the adequacy of the UAR is unknown. This report focuses on the year one project objectives, which were (a) provide a review of technical design and engineering requirements for utility accommodation in Texas, (b) provide a preliminary assessment of potential impact of overweight loads on buried utilities, (c) provide a preliminary assessment of UAR adequacy to deal with overweight loads on buried utilities, (d) provide preliminary recommendations for a business process for TxDOT overweight routing coordination, and (e) provide recommendations for the phase 2 utility damage evaluation.					
17. Key Words Utility Accommodation Rules, UAR, Underground Utility, Utility Damage, Pipes, Heavy Load Damage, Overweight Load			18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Springfield, Virginia 22161 http://www.ntis.gov		
19. Security Classif.(of this report) Unclassified		20. Security Classif.(of this page) Unclassified		21. No. of Pages 212	
				22. Price	

EVALUATING THE IMPACT OF OVERWEIGHT LOAD ROUTING ON BURIED UTILITY FACILITIES

by

Edgar Kraus, P.E.
Associate Research Engineer
Texas Transportation Institute

Emmanuel Fernando
Senior Research Engineer
Texas Transportation Institute

Eric Yingfeng Li
Assistant Research Scientist
Texas Transportation Institute

Jeong Ho Oh
Assistant Research Engineer
Texas Transportation Institute

Nicholas Koncz
Assistant Research Scientist
Texas Transportation Institute

and

Cesar Quiroga, P.E.
Research Engineer
Texas Transportation Institute

Report 0-6394-1
Project 0-6394

Project Title: Evaluation of Overweight Load Routing on Buried Utility Plant

Performed in cooperation with the
Texas Department of Transportation
and the
Federal Highway Administration

October 2010
Published: February 2011

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

DISCLAIMER

The contents of this document reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This document does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. The engineer in charge of the project was Edgar Kraus, P.E. (Texas Registration #96727).

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

ACKNOWLEDGMENTS

This research was conducted in cooperation with TxDOT and FHWA. The researchers would like to acknowledge the assistance provided by many individuals at these agencies, in particular the following:

- Randy Anderson.
- John Campbell.
- Frank Espinosa.
- Raymond Hutchinson.
- Justin Obinna.
- Guy Sledge.
- Stephen Stakemiller.
- Duncan Stewart.
- Dean Wilkerson.
- Charon Williams.

The researchers also wish to acknowledge the support provided by Jerry Le with the analysis of the overweight truck routing data.

TABLE OF CONTENTS

	Page
LIST OF FIGURES	x
LIST OF TABLES	xii
LIST OF ACRONYMS, ABBREVIATIONS, AND TERMS	xv
CHAPTER 1. INTRODUCTION	1
CHAPTER 2. TECHNICAL DESIGN AND ENGINEERING REQUIREMENTS FOR UTILITY ACCOMMODATION	3
INTRODUCTION	3
UNDERGROUND UTILITY STRUCTURE TYPES AND MATERIALS.....	3
Underground Utility Structure Material Standards.....	4
UNDERGROUND UTILITY STRUCTURE CONSTRUCTION STANDARDS.....	11
Embedment and Backfill.....	11
Compaction	12
Casings.....	12
Depth of Cover.....	13
External Loads	13
REVIEW OF EXISTING PRACTICE FOR INSTALLATION OF UNDERGROUND UTILITY STRUCTURES IN TEXAS	26
City of Grapevine Water Utility Systems	27
City of Grapevine Water Sanitary Sewer System.....	30
City of North Richland Hills.....	33
City of Fort Worth	36
City of Bedford	38
Exxon Mobile Pipeline Company	39
ATMOS Energy	40
REVIEW OF MILITARY SPECIFICATIONS FOR UNDERGROUND UTILITIES	40
Introduction.....	40
Water Distribution	41
Sanitary Sewers.....	51
Natural Gas/Liquid Petroleum Piping.....	52
CHAPTER 3. DESIGN REQUIREMENTS FOR UNDERGROUND UTILITY STRUCTURES IN THE TEXAS UTILITY ACCOMMODATION RULES.....	59
INTRODUCTION	59
CURRENT UTILITY ACCOMMODATION RULES	59
SUMMARY OF CHANGES TO UTILITY ACCOMMODATION RULES SINCE 1979	63
Adopted Changes in 1982 (151)	63
Adopted Changes in 1989 (152)	63
Adopted Changes in 1990 (153)	67
Adopted Changes in 1996 (154)	67

Adopted Changes in 1997 (155)	67
Adopted Changes in 1998 (156)	67
Adopted Changes in 1999 (157)	67
Adopted Changes in 2001 (158)	67
Adopted Changes in 2005 (159)	68
Adopted Changes in 2008 (160)	69
Adopted Changes in 2009	70
RELEVANT SPECIAL PROVISIONS AT TXDOT DISTRICTS	73
Special Provisions for Underground Utility Facilities at the San Antonio District	73
Special Provisions for Underground Utility Facilities at the Bryan District	73
Special Provisions for Underground Utility Facilities at the Pharr District	73
 CHAPTER 4. REVIEW OF TXDOT BUSINESS PROCESS FOR OVERWEIGHT LOAD	
PERMITTING	75
INTRODUCTION	75
RELEVANT OVERWEIGHT PERMIT REGULATION	75
United States Code	75
Code of Federal Regulations	78
Texas Administrative Code	81
TXDOT MOTOR CARRIER DIVISION	83
Overweight Permits	83
TXDOT OVERWEIGHT PERMITTING PROCESS	89
Staffing and Quality Control	91
TxPROS	91
Preliminary Business Process for TxDOT Overweight Routing Coordination	92
 CHAPTER 5. ANALYSIS OF OVERWEIGHT LOADS ON TXDOT HIGHWAY SYSTEM	95
INTRODUCTION	95
OVERWEIGHT ROUTE DATA PROCESSING	95
Initial Data Analysis	95
DATA PROCESSING AND CLEANSING	105
Route Description Processing	105
Route Description Processing Example	108
ROUTE START AND ROUTE END PROCESSING	116
Phase 0	120
Phase 1	120
Phase 2	121
Phase 3	122
Phase 4	124
Phase 5	126
Phase 6	127
FINAL DATA PROCESSING AND MERGE	130
Phase 7	131
Phase 8	132
NEXT STEPS	137

CHAPTER 6. PHASE 1 UTILITY DAMAGE EVALUATION	139
INTRODUCTION	139
IDENTIFICATION OF CANDIDATE CASES FOR FORENSIC ANALYSIS.....	139
Introduction.....	139
Literature Review.....	140
Outreach and Notification of Stakeholders.....	141
Proactive Approach.....	141
SENSITIVITY ANALYSIS OF DAMAGES TO BURIED UTILITY STRUCTURES.....	144
Introduction.....	144
Risk Analysis Framework.....	144
Tools for Sensitivity Analysis.....	145
Setup of Sensitivity Analysis.....	146
Results of the Sensitivity Analysis	149
Summary of the Sensitivity Analysis.....	156
Analysis Limitations	157
CHAPTER 7. PRELIMINARY CONCLUSIONS AND RECOMMENDATIONS.....	159
SUMMARY OF FINDINGS	159
Review of Technical Design and Engineering Requirements for Utility Accommodation in Texas	159
Preliminary Assessment of UAR Adequacy to Deal with Overweight Loads on Buried Utilities.....	160
Preliminary Assessment of Potential Impact of Overweight Loads on Buried Utilities	162
Preliminary Recommendations for a Business Process for TxDOT Overweight Routing Coordination	163
Recommendations for Phase 2 Utility Damage Evaluation.....	163
REFERENCES	165
APPENDIX A. COMPARISON OF INSTALLATION SPECIFICATIONS FOR BURIED UTILITY FACILITIES IN THE 1979 AND 2010 UTILITY ACCOMMODATION RULES.	177
APPENDIX B. LETTER TO UTILITY STAKEHOLDERS.....	193

LIST OF FIGURES

	Page
Figure 1. Effect of Soil Settlement on (a) Rigid and (b) Flexible Pipes.....	4
Figure 2. Rigid Pipe in Trench.....	14
Figure 3. Computational Diagram for Load Coefficient (<i>I</i>).....	15
Figure 4. Positive Projecting Embankment Installation (7).....	16
Figure 5. Load Coefficient for Positive Projection Embankment Condition (7).....	18
Figure 6. Negative Projecting Embankment and Induced Trench Installation (7).....	19
Figure 7. Load Coefficient for Negative Projection and Induced Trench Condition (6).....	20
Figure 8. Stress Distributions Hypothesized by Spangler (<i>11</i>).....	22
Figure 9. Outside Diameter and Thickness of Pipe.....	31
Figure 10. Trench Embedment and Backfill Details (28).....	32
Figure 11. Storm Drain in Street (27).....	35
Figure 12. Trench Embedment and Backfill Details.....	36
Figure 13. Definition of Single Axle and Tandem Axle Weight in the Texas Transportation Code.....	79
Figure 14. MCD Organizational Chart.....	83
Figure 15. Sample Single Trip Permit.....	88
Figure 16. Sample Route Descriptions Starting with a Variation of “JCT.”.....	101
Figure 17. Unedited Text of Route Description Field.....	108
Figure 18. Route Description Text Edited by Process Step 1.....	108
Figure 19. Route Description Text Edited by Process Step 2.....	108
Figure 20. Route Description Text Edited by Process Step 3.....	109
Figure 21. Route Description Text Edited by Process Step 4.....	109
Figure 22. Route Description Text Edited by Process Step 5.....	109
Figure 23. Route Description Data Processing.....	111
Figure 24. Route Description with “Route Not Identifiable” Issue, Example 1.....	111
Figure 25. Route Description with “Route Not Identifiable” Issue, Example 2.....	112
Figure 26. Route Descriptions with “Missing Direction” Issue.....	112
Figure 27. Route Descriptions with “Unknown Information” Issue.....	113
Figure 28. Route Descriptions with “Unknown Route” Issue.....	114
Figure 29. Route Descriptions with “Multi-Spur Route” Issue.....	115
Figure 30. Development of Is Null and Is Not Null Datasets.....	122
Figure 31. Development of JCT and Not JCT Datasets.....	126
Figure 32. Development of Origin Destination and Path Datasets.....	134
Figure 33. Query for Merging of “Distinct Duplicates,” “Route Start and End Master, No Duplicates,” and “All Processed Route Descriptions” Datasets, Access Design View.....	135
Figure 34. TxDOT Districts and Water Utilities TTI Contacted.....	144
Figure 35. PLAXIS Verification with Field Data from Watkins and Reeve (<i>197</i>).....	147
Figure 36. PLAXIS Verification with Field Data from Arockiasamy et al. (<i>198</i>).....	148
Figure 37. Varied Axle Positions with Respect to Pipe.....	150
Figure 38. Sensitivity of Damage Ratio to the Axle Position.....	151
Figure 39. Sensitivity of Damage Ratio to the Axle Weight.....	152
Figure 40. Sensitivity of Damage Ratio to Number of Axles.....	152

Figure 41. Sensitivity of Damage Ratio to the Depth of Cover.....	153
Figure 42. Sensitivity of Damage Ratio to the Pipe Material.....	154
Figure 43. Sensitivity of Damage Ratio to the Pipe Wall Thickness.....	155
Figure 44. Sensitivity of Damage Ratio to the Compaction Level.....	156

LIST OF TABLES

	Page
Table 1. Grades of Steel Water Pipe Used in AWWA C200 (Standard for Steel Water Pipe 6 Inches and Larger) (3).....	5
Table 2. Selected Standards for Steel Pressure Pipes in Water System (1).....	6
Table 3. Selected Standards for Ductile Iron Pipe (4).	7
Table 4. Typical PVC Pipe Design Properties (1).	7
Table 5. Selected Standards for PVC Pipe (5).....	8
Table 6. Mechanical Properties Range of Fiberglass Pipe (6).....	8
Table 7. Selected Standards for Fiberglass Pipe (6).	9
Table 8. Range of Mechanical Properties of AC Pipe (1).	9
Table 9. Selected Standards for AC Pipe (1).	10
Table 10. Selected Standards for Clay Pipe (1).	10
Table 11. Selected Standards for Concrete Pipe (1).	11
Table 12. Design Values of Settlement Ratio (7).	17
Table 13. <i>K</i> -Value versus Bedding Angle (11).....	22
Table 14. Values for the Soil Support Combining Factor S_C (6).....	25
Table 15. Values for the Constrained Modulus of the Native Soil at Pipe Zone Elevation (6).....	25
Table 16. M_{sb} Based on Soil Type and Compaction Condition (6).	26
Table 17. List of Companies and Cities Contacted by Researchers.	27
Table 18. Nominal Thickness for Standard Pressure Classes of Ductile-Iron Pipe (17).....	28
Table 19. Dimensions of AWWA C301 Pipe (57).....	29
Table 20. Data Sheet for Blue Brute for Class 150 ^a (23).....	29
Table 21. SDR 35 PVC Pipe Dimensions and Weights (25).....	30
Table 22. Gradations of Gravel and Sand Materials.....	33
Table 23. Data Sheet for Blue Brute for AWWA C900 PVC Pipe (30).....	34
Table 24. Minimum Pressure Class (36).....	37
Table 25. City of Bedford Specifications for Pipe Dimensions.....	39
Table 26. Exxon Mobile Pipeline Specifications for Depth of Cover	40
Table 27. Summary of Requirements for Water Distribution Mains.....	42
Table 28. Summary of Requirements for Water Service Lines.	45
Table 29. Summary of Installation Requirements Related to Earthwork.	47
Table 30. Summary of Installation Requirements for Water Mains.	48
Table 31. Summary of Installation Requirements for Water Mains.	50
Table 32. Summary of Installation Requirements for Water Service Lines.	51
Table 33. Summary of Materials- and Design-Related Guidelines for Sanitary Sewers.....	53
Table 34. Summary of Requirements for Sanitary Sewers.....	55
Table 35. Numbering of Utility Accommodation Rules Before and After Revision and Reorganization of the Texas Administrative Code in 1979.....	62
Table 36. Historical Modifications to Utility Accommodation Rules after 1979.....	64
Table 37. Weight Limitations in the United States Code (166).....	76
Table 38. Maximum Gross Weight Exemptions in the United States Code (166).....	77
Table 39. Weight Limitations in the Texas Transportation Code (175, 176).....	80

Table 40. Maximum Permit Weight Limits in the Texas Administrative Code (178).	82
Table 41. Types and Authorization for Overweight Load Permits Issued by MCD (174, 176, 180, 181).	84
Table 42. Other Overweight Load Permits and Authorizations in the Texas Transportation Code (176).	86
Table 43. Action Items or Concerns Expressed by NETx Engineers (182).	91
Table 44. Total Overweight Load Permits.	95
Table 45. Structure of Overweight Load Route Permits Database Table.	96
Table 46. Types of Data Content for the Combination of Route Start, Route End, and Route Description, and Usefulness of the Data for Further Analysis.	102
Table 47. Counts of Data Combinations for ROUTE_START, ROUTE_END, and ROUTE_DESC Fields (Fiscal Years 2004–2009).	103
Table 48. Total Permits and Permits with Defined Routes in Route Description Field.	105
Table 49. Dataset Definitions during Route Description Data Processing.	107
Table 50. Permits with Clean and Permits with Flagged Route Descriptions after Five-Step Data Cleansing Process.	110
Table 51. Count of Route Descriptions with “Route Not Identifiable” Issue by Year.	112
Table 52. Count of Route Descriptions with “Missing Direction” Issue by Year.	113
Table 53. Route Descriptions with “Unknown Information” Issue.	114
Table 54. Count of Route Descriptions with “Unknown Route” Issue by Year.	115
Table 55. Count of Route Descriptions with “Multi-Spur” Issue by Year.	116
Table 56. Dataset Definitions during Route Start and Route End Data Processing.	119
Table 57. Sample of Records with Duplicate Permit Numbers.	120
Table 58. Duplicate Permit Records.	121
Table 59. Permits with Route Start and Route End Entries.	122
Table 60. Sample of “JCT” Dataset.	123
Table 61. Permits with “JCT” Occurrence in Route Description.	124
Table 62. Sample of Invalid Route Information in Route Description Field.	125
Table 63. “JCT” and “Not JCT” Permits with and without Valid Route Descriptions.	126
Table 64. Distinct Duplicate Permit Records.	127
Table 65. Sample Spellings of Cities in the Start Route Field.	128
Table 66. Sample Unknown Route Start Locations.	129
Table 67. Sample Standardized Route Start Values.	129
Table 68. Count of Records in Route Start and End Datasets.	130
Table 69. Dataset Definitions during Final Data Processing.	132
Table 70. Merged Datasets from Step 8.	133
Table 71. Counts of Records for the Origin Destination and Path Datasets.	133
Table 72. Emergency Repair Requests by Damage Type.	142
Table 73. Utility Type of Potentially Interesting Emergency Repair Request Records.	142
Table 74. Risk Areas and Factors of Preliminary Risk Analysis Framework.	145
Table 75. Variables Considered in Sensitivity Analysis.	149
Table 76. Material Properties of Pipe.	149
Table 77. Parameters for Mohr-Coulomb Model of Backfill Material.	149
Table 78. General Rules for Underground Utilities.	179
Table 79. Low Pressure Gas and Liquid Petroleum Lines.	182
Table 80. High Pressure Gas and Liquid Petroleum Lines.	184

Table 81. Water Lines and Non-Potable Water Control Facilities.	186
Table 82. Installation Specifications for Buried Utility Facilities – Sanitary Sewer Lines.	188
Table 83. Underground Electric Lines.	189
Table 84. Underground Communication Lines.	190

LIST OF ACRONYMS, ABBREVIATIONS, AND TERMS

AASHTO	American Association of State Highway and Transportation Officials
ABS	Acrylonitrile Butadiene Styrene
AC	Asbestos Cement
AFCESA	Air Force Civil Engineer Support Agency
ANSI	American National Standards Institute
ANSYS	ANalysis SYstem Software Program
ASTM	American Society for Testing and Materials
ASME	American Society of Mechanical Engineers
AWWA	American Water Works Association
CANDE	Culvert ANalysis and DEsign
CST	Construction Division at TxDOT
CFR	Code of Federal Regulations
EMPCo	Exxon Mobile Pipeline Company
FHWA	Federal Highway Administration
HDPE	High Density Polyethylene
HDPVC	High Density Polyvinyl Chloride
HS Truck	Hypothetical Standard Truck
KIP	Kilo Pound (Force) or One Thousand Pounds (Force)
LCV	Longer Combination Vehicle
LLDF	Live Load Distribution Factor
LRFD	Load and Resistance Factor Design
NASA	National Aeronautics and Space Administration
NAVFAC	Naval Facilities Engineering Command
NCHRP	National Cooperative Highway Research Program
NETx	North and East Texas
NOPI	Notices Of Proposed Installation
NTTA	North Texas Toll Authority
MCD	Motor Carrier Division at TxDOT
MDPE	Medium Density Polyethylene
MNT	Maintenance Division at TxDOT

OS/OW	Oversize/Overweight
PB	Polybutylene
PE	Polyethylene
PLAXIS	PLasticity AXISymmetric Software Program
PSI	Pounds (Force) per Square Inch
PSIG	Pounds (Force) per Square Inch Gauge
PVC	Polyvinyl Chloride
PVCO	Molecularly Oriented Polyvinyl Chloride
ROW	Right of Way Division at TxDOT
RPMP	Reinforced Plastic Mortar Pressure Pipe
RSC	Regional Support Center
RTRP	Reinforced Thermo-Setting Resin Pipe
SDHPT	State Department of Highways and Public Transportation
SDR	Standard Dimension Ratio
SQL	Structured Query Language
TxDOT	Texas Department of Transportation
TxPROS	Texas Permit Routing Optimization System
TAC	Texas Administrative Code
TTI	Texas Transportation Institute
TTC	Texas Transportation Code
UAR	Utility Accommodation Rules
UIR	Utility Installation Review
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specifications
USACE	U.S. Army Corps of Engineers
USC	United States Code
VBA	Visual Basic for Applications

CHAPTER 1. INTRODUCTION

Overweight traffic movements can negatively affect pavement integrity and quality. However, it is less known to what degree buried utility plant along and across the right of way is affected by these overweight loads, especially if the utility facility is aged, placed under an exception to the Utility Accommodation Rules (UAR), and/or subjected to repetitive loads. Routing decisions for repetitive overweight loads may be determined without consideration of cumulative impacts to utility infrastructure, particularly municipally owned lines that could be aged, accommodated under an exception, or of substandard materials. Given the growth in volume in overweight load (particularly mid-heavy and superload) permits, the adequacy of the UAR is unknown.

The research team proposed a two-phase approach to conduct the research. The objectives of Phase 1, accomplished during the first year of the project, were to (a) provide a review of technical design and engineering requirements for utility accommodation in Texas, (b) provide a preliminary assessment of potential impact of overweight loads on buried utilities, (c) provide a preliminary assessment of UAR adequacy to deal with overweight loads on buried utilities, (d) provide preliminary recommendations for a business process for TxDOT overweight routing coordination, and (e) provide recommendations for the Phase 2 utility damage evaluation.

The objectives of Phase 2, which will be accomplished during the second year of the project, are to (a) provide an assessment of overweight load impact on buried utilities based on documented and verified cases of load-associated damage to buried utilities, (b) provide a final assessment of UAR adequacy to deal with overweight loads on buried utilities and recommendations for changes to UAR, and (c) provide a revised business process of overweight permitting to enhance TxDOT coordination.

This report summarizes the work completed for Phase 1 of the research project. The report is organized as follows:

- Chapter 1 is this introductory chapter.
- Chapter 2 discusses technical design and engineering requirements for utility accommodation, and current practice for the installation of underground utility structures in Texas.
- Chapter 3 discusses rules and regulations for the design and accommodation of underground utility structures in Texas.
- Chapter 4 provides an overview of relevant overweight permit regulations and a review of the TxDOT business process for overweight load permitting.
- Chapter 5 provides an overview of the data cleaning process to analyze overweight load traffic on the TxDOT highways system.

- Chapter 6 discusses the structure and results of the Phase 1 damage evaluation and provides a preliminary assessment of potential impact of overweight loads on buried utility structures.
- Chapter 7 discusses preliminary conclusions and recommendations.

CHAPTER 2. TECHNICAL DESIGN AND ENGINEERING REQUIREMENTS FOR UTILITY ACCOMMODATION

INTRODUCTION

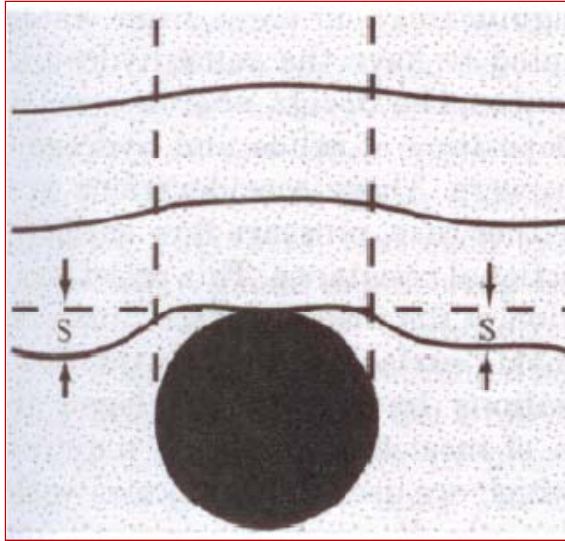
The utility industry uses a variety of underground utility structures, such as concrete, steel, and plastic pipes; conduits; and concrete slabs. During the first year of this project, researchers reviewed the types of buried utility structures found within the TxDOT right of way and their technical specifications for withstanding dead and live loads. The researchers gathered this information through communications with relevant TxDOT personnel and the utility industry, and from online and offline information resources. Researchers used the findings from this literature review to assess the impact of overweight loads on buried utilities and provide preliminary recommendations for changes to TxDOT policies.

UNDERGROUND UTILITY STRUCTURE TYPES AND MATERIALS

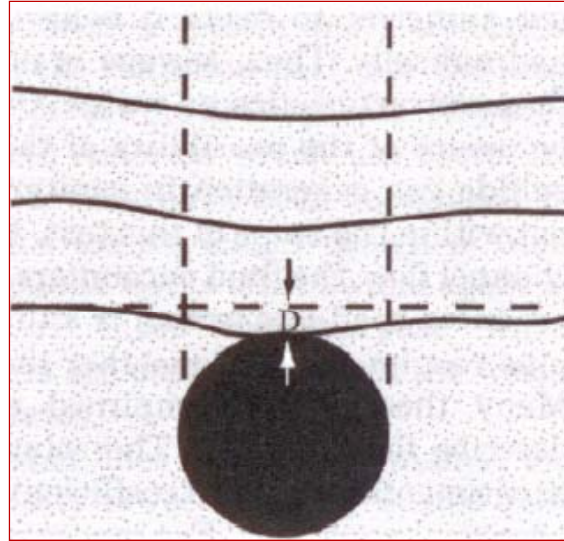
Underground utility structures have supplied essential services to the public in diverse applications such as sewer lines, drain lines, water mains, gas lines, telephone and electrical conduits, culverts, oil and coal slurry lines, and heat distribution lines (*1*). Among underground utility systems, water systems are considered lifelines of communities. The water system is divided into two parts: the transmission lines and the distribution system (*1*). A sewage system is composed of a collection system and a treatment system. Storm sewage systems can be separate from the sewage system or a combination of both. If storm sewers are separate, the sanitary sewer is usually buried relatively deep to allow for the pickup of water flow from basement while the storm sewer systems are not as deep.

In general, piping materials for underground utility structures are classified as flexible or rigid. A flexible pipe can withstand at least a 2 percent deflection without regard to structural distress. Materials that do not meet this criterion are generally considered rigid (*1*). Figure 2 illustrates schematically the behavior of flexible and rigid pipes buried in the ground. Steel, ductile iron or cast iron, and plastic pipes are usually considered flexible. For flexible pipes, stiffness is a critical factor in resisting structural failure such as ring deflection and buckling. Concrete and clay pipes are usually categorized as rigid pipe. For such pipes, strength to resist wall stress due to the internal pressure and external loads is critical in design.

Piping systems are typically designed to perform from 50 to 100 years since government and private sectors cannot generally afford to replace pipe systems at less than 50-year intervals. The service life is not just a function of pipe material itself, but is mainly tied to the loading or environmental conditions to which the pipe system is subjected (*1*).



(a) Rigid pipe



(b) Flexible pipe

Note: S indicates settlement of backfill for a rigid pipe and D represents vertical deflection of a flexible pipe under earth pressure (I).

Figure 1. Effect of Soil Settlement on (a) Rigid and (b) Flexible Pipes.

Underground Utility Structure Material Standards

As mentioned earlier, pipe materials are generally classified as flexible or rigid. The following section summarizes different types of pipe applications and material standards.

Flexible Pipe

Steel pipe is used in many applications such as sewer, water, and culvert systems. Most steel pipes used for gravity applications have a corrugated wall. Such pipes are generally coated with bitumen type materials, Portland cement, or polymers to protect from corrosion. Note that the linings or coatings are usually ignored in strength calculations. The American Water Works Association (AWWA) manual M11 provides procedures for determining the required thickness of steel pipe (2). For this material, the existing standard uses a design stress equal to 50 percent of the specified minimum yield strength as shown in Table 1 of AWWA Manual M11. With the given pressure, the pipe wall thickness is determined using the following equation:

$$t = \frac{P_i D}{2\sigma_{\max}} \quad (1)$$

where,

- t = minimum wall thickness (in.).
- P_i = internal pressure (psi).
- D = outside diameter of steel pipe cylinder (excluding coatings, in.).
- σ_{\max} = design stress (psi).

Table 1. Grades of Steel Water Pipe Used in AWWA C200 (Standard for Steel Water Pipe 6 Inches and Larger) (3).

Pipe Specification	Design Stress (psi)	Minimum Yield Point (psi)	Minimum Ultimate Tensile Strength (psi)
ASTM A36	18,000	36,000	58,000
ASTM A283 GR C	15,000	30,000	55,000
GR D	16,500	33,000	60,000
ASTM A570 GR 30	15,000	30,000	49,000
GR 33	16,500	33,000	52,000
GR 36	18,000	36,000	53,000
GR 40	20,000	40,000	55,000
GR 45	22,500	45,000	60,000
GR 50	25,000	50,000	65,000
ASTM A572 GR 42	21,000	42,000	60,000
GR 50	25,000	50,000	65,000
GR 60	30,000	60,000	75,000
ASTM A53 ASTM A135 GR A ASTM A139	15,000	30,000	48,000
ASTM A53 ASTM A135 GR B ASTM A139	17,500	35,000	60,000
ASTM A139 GR C	21,000	42,000	60,000
GR D	23,000	46,000	60,000
GR E	26,000	52,000	66,000

Table 2 shows a list of other applicable standards for different types of steel pressure pipes in water service.

Table 2. Selected Standards for Steel Pressure Pipes in Water System (1).

AWWA C203	Coal-tar protective coating and linings for steel water pipelines – enamel and tape applied hot.
AWWA C205	Cement-mortar protective lining and coating for steel water pipe – 4 in. and larger (shop applied).
AWWA C206	Field welding of steel water pipe.
AWWA C207	Steel pipe flanges for waterworks service – sizes 4 to 144 in.
AWWA C208	Dimensions for fabricated steel water pipe fittings.
AWWA C209	Cold-applied tape coatings for special sections, connections, and fittings for steel water pipelines.
AWWA C210	Coal-tar epoxy coating system for the interior and exterior of steel water pipe.
AWWA C213	Fusion-bonded epoxy coating for the interior and exterior of steel water pipelines.
AWWA C214	Tape coating systems for the exterior of steel water pipelines.
AWWA C602	Cement-mortar lining of water pipelines in place – 4 in. and larger.

Ductile iron pipe is very popular in public works with respect to repair and maintenance of waste water systems (1). Ductile iron pipe usually is coated with a cement-mortar lining to improve the hydraulic efficiency and provide some corrosion protection. Most ductile iron gravity sewer systems are designed to serve a minimum of 50 years without failure or infiltration/exfiltration in excess of 10 gallons per day per inch diameter per mile (4). The most common grade of iron is 70-50-05, with acceptance values as follows (5):

- Tensile strength: 70,000 psi.
- Yield strength: 50,000 psi.
- Elongation: 5 percent.

Another permissible grade is 60-42-10, with acceptance values as given in below:

- Tensile strength: 60,000 psi.
- Yield strength: 42,000 psi.
- Elongation: 10 percent.

Table 3 summarizes available standards for ductile iron pipe.

Table 3. Selected Standards for Ductile Iron Pipe (5).

AWWA C104	Cement mortar lining for ductile iron.
AWWA C105	Polyethylene encasement for ductile iron.
AWWA C110	Ductile iron and gray iron fittings.
AWWA C111	Rubber-gasket joints for ductile iron.
AWWA C115	Flanged ductile iron.
AWWA C116	Protective fusion-bonded epoxy coatings.
AWWA C150	Thickness design of ductile iron pipe.
AWWA C151	Ductile iron pipe in metal- and sand-lined molds.
AWWA C153	Ductile iron compact fittings for water service.
AWWA C600	Installation of ductile iron water mains and their appurtenances.
ASTM E8	Materials' properties test.
ASTM A539	Physical properties.
ASTM A746	Ductile iron gravity sewer pipe.

Thermoplastic pipes are also widely used in various water systems. There are four principal materials used: polyvinyl chloride (PVC), acrylonitrile-butadiene-styrene (ABS), polyethylene (PE), high-density polyethylene (HDPE), and polybutylene (PB) (*1*). Most plastic pressure or sewer pipes are made of PVC. The main advantage of PVC pipe is its high strength-to-weight ratio and resistance to almost all types of corrosion from chemical and electrochemical processes. Thus, any type of lining or coating is not required for PVC pipe (*6*). However, the performance of PVC pipe is significantly affected by its operating temperature. Table 4 and Table 5 present typical PVC pipe design properties and available standards.

Table 4. Typical PVC Pipe Design Properties (*1*).

Hydrostatic design basis	4000 psi
Hydrostatic design stress	1600 to 2000 psi
Elastic modulus (pressure formulation)	400,000 psi
Elastic modulus (sewer formulation)	400,000 to 550,000 psi
Tensile stress	7000 psi

Table 5. Selected Standards for PVC Pipe (6).

AWWA C605	Underground installation of PVC.
AWWA C900	PVC pressure pipe, 4 to 12 in. for water system.
AWWA C950	PVC water transmission pipe 14 to 36 in.
ASTM D2672	Bell-end PVC pipe.
ASTM F800	Corrugated PVC tubing and compatible fittings.
ASTM D3915	PVC and related plastic pipe and fitting compounds.
ASTM F512	Smooth-wall PVC conduit and fittings for underground installation.
ASTM F679	PVC large diameter plastic gravity sewer pipe and fittings.
ASTM F789	Type PS-46 PVC plastic gravity-flow sewer pipe and fittings.
ASTM F758	Smooth-wall PVC plastic underdrain systems for highway and airport.

Fiberglass pipe, another material used for flexible pipe systems, is made from glass fiber reinforcements embedded in or surrounded by cured thermosetting resin (7). Since the 1960s, fiberglass pipe has been used for municipal water and sewage applications due to temperature, chemical, abrasion, and weathering resistance. Table 6 shows typical mechanical properties for fiberglass pipe, and Table 7 lists several specifications relevant to fiberglass pipe products.

Table 6. Mechanical Properties Range of Fiberglass Pipe (7).

Tensile strength (psi)	2000 ~ 80,000
Tensile modulus (psi)	500,000 ~ 5,000,000
Flexural strength (psi)	4000 ~ 70,000
Flexural modulus (psi)	1,000,000 ~ 5,000,000
Coefficient of thermal expansion ($\mu\epsilon/^\circ\text{F}$) ^a	8 ~ 30
Specific gravity	1.2 ~ 2.3
Compressive strength (psi)	10,000 ~ 40,000

^a The high coefficient of thermal expansion should be considered in design and installation to accommodate expansion and contraction, especially in above ground applications. Fiberglass pipe in water system is not affected by service temperatures that generally range from 33°F to 90°F (8).

Table 7. Selected Standards for Fiberglass Pipe (7).

ASTM D2310	Machine-made fiberglass pipe.
ASTM D2517	Reinforced epoxy resin gas pressure pipe and fittings.
ASTM D3262	Fiberglass sewer pipe (applicable for pipes 8 to 144 in.).
ASTM D3517	Fiberglass pressure pipe (applicable for pipes 8 to 144 in.).
ASTM D3567	Determining dimensions of fiberglass pipe and fittings.
ASTM D3839	Underground installation of fiberglass pipe.
ASTM D2105	Test method for longitudinal tensile properties of fiberglass.
ASTM D695	Test method for compressive properties of rigid plastics.
ASTM D1598	Test method for time-to-failure of plastic pipe under constant internal pressure.
ASTM D2143	Test method for cyclic pressure strength of reinforced pipe.
ASTM D2924	Test method for external pressure resistance of fiberglass pipe.
ASTM D5365	Test method for long-term ring-bending strain of fiberglass pipe.

Rigid Pipe

Rigid pipes are mainly classified into three types based on material type used: asbestos-cement (AC) pipe, clay pipe, and concrete pipe (*I*). AC pipes are applicable for both gravity and pressure systems. However, production of this pipe has been halted in the U.S. because of hazardous risks associated with asbestos concrete. Table 8 and Table 9 present typical physical properties used in design and applicable standards for AC pipe.

Table 8. Range of Mechanical Properties of AC Pipe (*I*).

Modulus of elasticity (psi)	3,000,000
Tensile strength (psi)	3,000 ~ 4,000
Shear strength (psi)	4,000 psi across pipe axis
Modulus of rupture (psi)	5,000 ~ 6,000
Compressive strength (psi)	7,000
Coefficient of thermal expansion ($\mu\epsilon/^\circ\text{F}$)	4 ~ 5
Moisture coefficient of expansion (in./in./% of moisture change)	1.5 ~ 2.0

Table 9. Selected Standards for AC Pipe (I).

AWWA C400	AC distribution pipe, 4 to 16 in. in diameter.
AWWA C401	Selection of AC distribution pipe.
AWWA C603	Installation of AC water pipe.
ASTM C296	AC pressure pipe.
ASTM C428	AC non-pressure sewer pipe.
ASTM C500	Methods of testing AC pipe.
ASTM D1869	Rubber rings for AC water pipe.

Vitrified clay pipe is manufactured from clay and shale, which are chemically inert (I). This type of pipe is very corrosion and abrasion resistant but only used for non-pressure applications due to its inherent low strength. Available pipe size ranges from 3 to 42 in. in nominal diameter. The strength (as determined by the three-edge bearing test) varies with diameter and ranges from 2000 to 7000 psi (I). Table 10 shows available standards for clay pipe.

Table 10. Selected Standards for Clay Pipe (I).

ASTM C700	Clay pipe, vitrified, extra-strength, standard strength, and perforated.
ASTM C425	Compression joints for vitrified clay pipe and fittings.
ASTM C301	Test method for vitrified clay pipe.
ASTM C12	Installing vitrified clay pipe lines.
ASTM C828	Low-pressure air test of vitrified clay pipe lines.

Several types of concrete pressure pipes are manufactured and used in the U.S. There are pre-stressed concrete cylinder pipe, reinforced concrete cylinder pipe, reinforced concrete non-cylinder pipe, and concrete bar-wrapped cylinder pipe (8). Pre-stressed concrete pipe has been manufactured in the U.S. since 1942 and is the most widely used type of concrete pressure pipe (8). AWWA C301 covers pre-stressed concrete cylinder pipe 16 in. in inside diameter and larger. Lengths are typically 16 to 24 ft. The minimum wall thickness is 1/16 of the pipe diameter. Pre-stressed concrete cylinder pipe has been designed to accommodate pressures greater than 400 psi and earth covers in excess of 100 ft. AWWA C304 covers the design of this type of pipe.

Reinforced concrete pipe was dominant prior to manufacturing of pre-stressed concrete pipe. The difference in construction of this pipe from pre-stressed concrete is that mild steel reinforcement is cast into the wall of the pipe instead of pre-stressing with high strength wire. The minimum wall thickness is 1/12 the inside diameter. AWWA 300 covers design and size of this pipe. Table 11 lists available standards for concrete pipes.

Table 11. Selected Standards for Concrete Pipe (I).

AWWA C302	Reinforced concrete pressure pipe, non-cylinder type for water and other liquids.
AWWA C303	Reinforced concrete pressure pipe, steel cylinder type, pre-tensioned for water and other liquids.
ASTM C118	Concrete pipe for irrigation or drainage.
ASTM C14	Concrete sewer, storm drain and culvert pipe.
ASTM C505	Non-reinforced concrete irrigation pipe with rubber-gasket joints.
ASTM C985	Non-reinforced concrete specified strength culvert, storm drain, and sewer pipe.
ASTM C654	Porous concrete pipe (used as underdrains beneath earth dams).
ASTM C506	Reinforced concrete arch culvert, storm drain, and sewer pipe.
ASTM C76	Reinforced concrete culvert, storm drain, and sewer pipe.
ASTM C655	Reinforced concrete D load culvert, storm drain, and sewer pipe.
ASTM C507	Reinforced concrete elliptical culvert, storm drain, and sewer pipe.
ASTM C361	Reinforced concrete low-pressure pipe.
ASTM C924	Low-pressure air test of concrete pipe sewer lines.

UNDERGROUND UTILITY STRUCTURE CONSTRUCTION STANDARDS

Underground utility structures such as pipe and conduit systems are expected to withstand induced stresses from live and dead loads, have a robust system of joints and connections, and be somewhat chemically inert with respect to soil and water to serve the expected service life. This section presents details on design or construction parameters for underground utility structures.

Embedment and Backfill

When any type of pipe is installed, soil is a major component of the soil-pipe interaction. The following basic rules of thumb are followed in evaluating buried pipe structures (I):

- A narrow trench should be excavated to have enough side clearance to place the pipe and compact the soil. The minimum clearance between the pipe and the trench wall should be no less than 9 in. (7).
- Minimum bedding thickness of 4 in. should be provided. Full contact of embedment against the pipe should be assured to prevent any voids in the backfill that results in pressure concentration around the pipe.
- Soil protects the pipe based on arching action. Compaction should be conducted on surrounding soil and bedding to create soil arch. However, compaction right over the pipe should be avoided.

- Minimizing native soil disturbance leads to a qualified pipe installation. A bored tunnel or micro tunneling minimizes soil disturbance.
- In saturated soil deposits, most pipes tend to float rather than sink.
- Soil density is a key property in installation of pipes especially when the pipe is installed under the water table. For many soils, the critical density is fairly high and in the range of 88 to 92 percent of standard Proctor density.
- Generally, maximum particle size for backfill material should be limited to 3/4 in. or less. For smaller pipe, a maximum particle size of about 10 percent of the nominal pipe diameter is recommended.
- Coarse and open-graded material should not be placed adjacent to a finer material to prevent migration of fine material resulting in loss of pipe support.

Compaction

When specifying the amount of compaction required, it is crucial to take into account the degree of soil compaction that can economically be achieved in the field. The density and supporting strength of the native soil should be equal to or greater than that of the compacted backfill. The densification of the backfill must include the haunches under the pipe to control both horizontal and vertical pipe deflections (8).

Mechanical compaction of the soil in lifts has been widely used for densifying soils. There are various types of compaction methods: rolling, kneading, impacting, and vibrating. In common practice, density tests are conducted to confirm that the specified compaction is achieved during installation. Vibration compaction is effective in compacting loose soil. Jetting, which uses a high-pressure water jet to flush soil into place against the pipe, is also particularly effective for soil compaction around large buried structures (1).

Casings

Casings can prevent damage to pipe structures caused by soil erosion or settlement in case of pipe failure or leakage (6). Casings provide the following advantages:

- Permit economical pipe removal and placement in the future.
- Accommodate regulations or requirements imposed by public or private owners.
- Permit boring rather than excavation where trenching would not be possible.

Casings are generally sized to provide an inside clearance that is at least 2 in. greater than the maximum outside diameter of the pipe.

Depth of Cover

Depth of cover requirements vary depending on the pipe type, pressure class, soil condition, expected loads, and the condition of the adjacent location. In practice, a minimum 3-ft depth of cover for buried pipes is typical (2).

External Loads

The loads imposed on buried pipes depend upon the stiffness properties of both the pipe structure itself and the surrounding soil, which is frequently called “soil-structure” interaction. As depicted in Figure 2, when designing rigid pipes, it is generally assumed that the pipe is affected mainly by vertical pressure caused by soil and traffic and that the horizontal reacting pressure is negligible. For flexible pipes, the pipe deflection due to the vertical load results in a horizontal reacting soil pressure.

Marston and Anderson (9) developed the Marston theory to determine earth loads on rigid pipes. The load on an underground structure is greatly affected by installation conditions and the weight of backfill over the structure. Marston’s formula can be used to assess earth loads for trench conduits and embankment conduits (8).

Trench Conduits

The resultant load on an underground structure is equal to the weight of the material above the top of the conduit minus the shearing or friction forces on the sides of the trench.

$$W_d = C_d \gamma B_d^2 \quad (2)$$

where,

W_d	=	earth load on pipe in trench (lb/linear ft).
C_d	=	load coefficient.
γ	=	unit weight of backfill (lb/ft ³).
B_d	=	width of trench at top of pipe (ft).

The load coefficient C_d depends upon the soil properties, the width of trench, and the height of backfill, and is calculated as follows:

$$C_d = \frac{1 - e^{-2K\mu'(H/B_d)}}{2K\mu'} \quad (3)$$

where,

H	=	height of backfill above top of pipe (ft) as shown in Figure 2.
K	=	Rankine’s ratio.
μ'	=	coefficient of friction (between backfill and sides of trench).

Recommended values of the product $K\mu'$ for various soils are:

- 0.1924 for cohesionless granular materials.
- 0.1650 maximum for sand and gravel.
- 0.15 maximum for saturated top soil.
- 0.13 maximum for ordinary clay.
- 0.11 maximum for saturated clay.

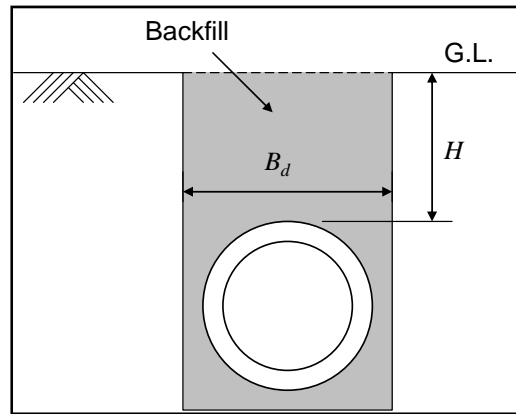


Figure 2. Rigid Pipe in Trench.

In equation (3), the Rankine's ratio (K) is the ratio of active lateral unit pressure to vertical unit pressure. Based on this equation, the load coefficient C_d is plotted as a function of H/B_d for various soil types as defined by $K\mu'$, which is function of the coefficient of internal friction of the backfill material as shown in Figure 3. Therefore, the load coefficient can be determined using equation (3) or the computational diagram in Figure 3.

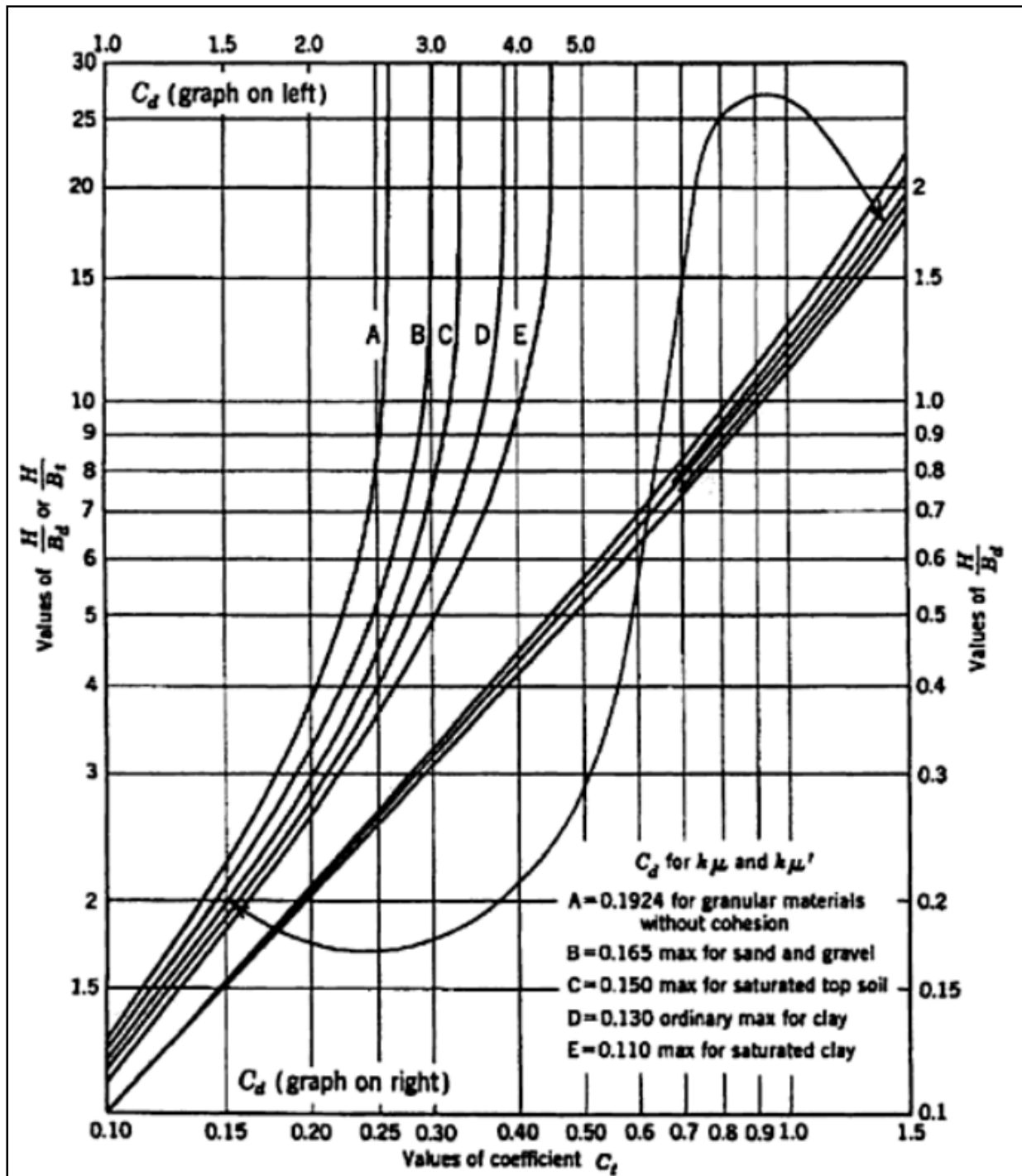


Figure 3. Computational Diagram for Load Coefficient (I).

Embankment Conduits

These conduits are covered by fills or embankments, such as railway embankments, highway embankments, and earth dams. There are three types of installations, as follows:

- Positive projection pipe: The pipe is installed above the natural ground surface without trenching.
- Negative projection pipe: The pipe is installed below the natural ground surface along with relatively shallow trenches.
- Induced trench pipe: The pipe is initially installed as positive projection and then negative projection installation is followed along with trenching.

For positive projection installations, the design considers the settlement of the prism of fill directly above the pipe and bounded by vertical planes tangent to the side of the pipe as shown in Figure 4.

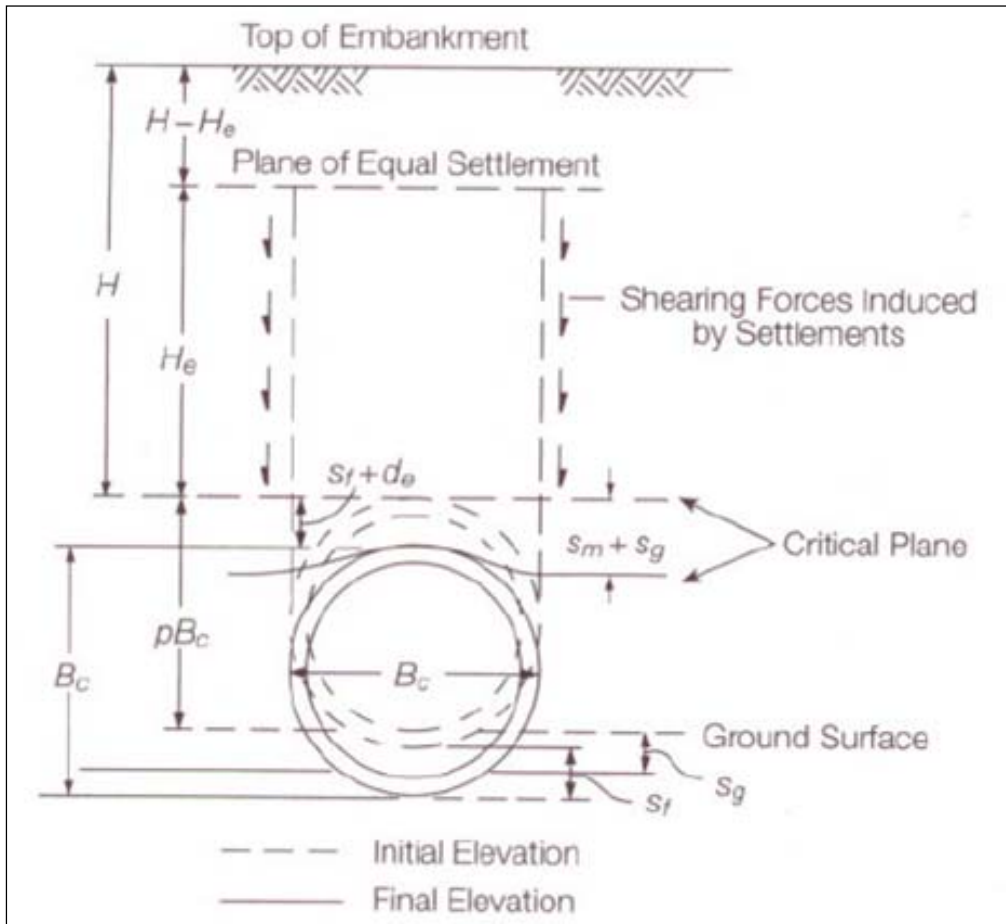


Figure 4. Positive Projecting Embankment Installation (8).

The load on a positive projecting pipe is calculated as follows:

$$W_c = C_c \gamma B_c^2 \quad (4)$$

Parameters are similarly defined as equation (2) except that B_c is the outside diameter of the pipe (ft) and C_c is given as follows:

$$C_c = \frac{e^{\pm 2K\mu(H/B_c)} - 1}{\pm 2K\mu}, \quad H \leq H_e$$

$$C_c = \frac{e^{\pm 2K\mu(H_e/B_c)} - 1}{\pm 2K\mu} + [(H/B_c) - (H_e/B_c)]e^{\pm 2K\mu(H_e/B_c)}, \quad H > H_e \quad (5)$$

where H_e is the height of the plane of equal settlement above the top of pipe (ft). To calculate C_c , it is necessary to compute H_e from the following equation:

$$\left[\frac{1}{2K\mu} \pm \left(\frac{H}{B_c} - \frac{H_e}{B_c} \right) \pm \frac{r_{sd}p}{3} \right] \frac{e^{\pm 2K\mu(H_e/B_c)} - 1}{\pm 2K\mu} \pm \frac{1}{2} \left(\frac{H_e}{B_c} \right)^2$$

$$\pm \frac{r_{sd}p}{3} \left(\frac{H}{B_c} - \frac{H_e}{B_c} \right) e^{\pm 2K\mu(H_e/B_c)} - \frac{1}{2K\mu} \times \frac{H_e}{B_c} \mp \frac{H}{B_c} \times \frac{H_e}{B_c} = \pm r_{sd}p \frac{H}{B_c} \quad (6)$$

where r_{sd} is a settlement ratio and p is a projection ratio defined as the vertical distance between the outside top of pipe and the ground or bedding surface divided by the outside diameter of the pipe B_c . The upper signs in equation (6) are used for the incomplete projection condition when r_{sd} is positive, and the lower signs are used for the incomplete trench condition when r_{sd} is negative. Table 12 shows recommended r_{sd} values corresponding to these conditions. In design practice, setting H equal to H_e is generally accepted to solve for H_e . For simplicity, Figure 5 provides a graphical solution for C_c .

Table 12. Design Values of Settlement Ratio (8).

Installation condition	Foundation condition	r_{sd} design value
Positive projection	Rock or unyielding soil	1.0
	Ordinary soil	0.3 for semi-rigid and 0.5 for rigid
	Yielding soil	0.3
Negative projection	$p' = 0.5^a$	-0.1
	$p' = 1.0$	-0.3
	$p' = 1.5$	-0.5
	$p' = 2.0$	-1.0
Induced trench	$p' = 0.5$	-0.5
	$p' = 1.0$	-0.7
	$p' = 1.5$	-1.0
	$p' = 2.0$	-2.0

^a p' = negative projection ratio, which is the depth of the top of pipe below the critical plane divided by the width of the trench B_d .

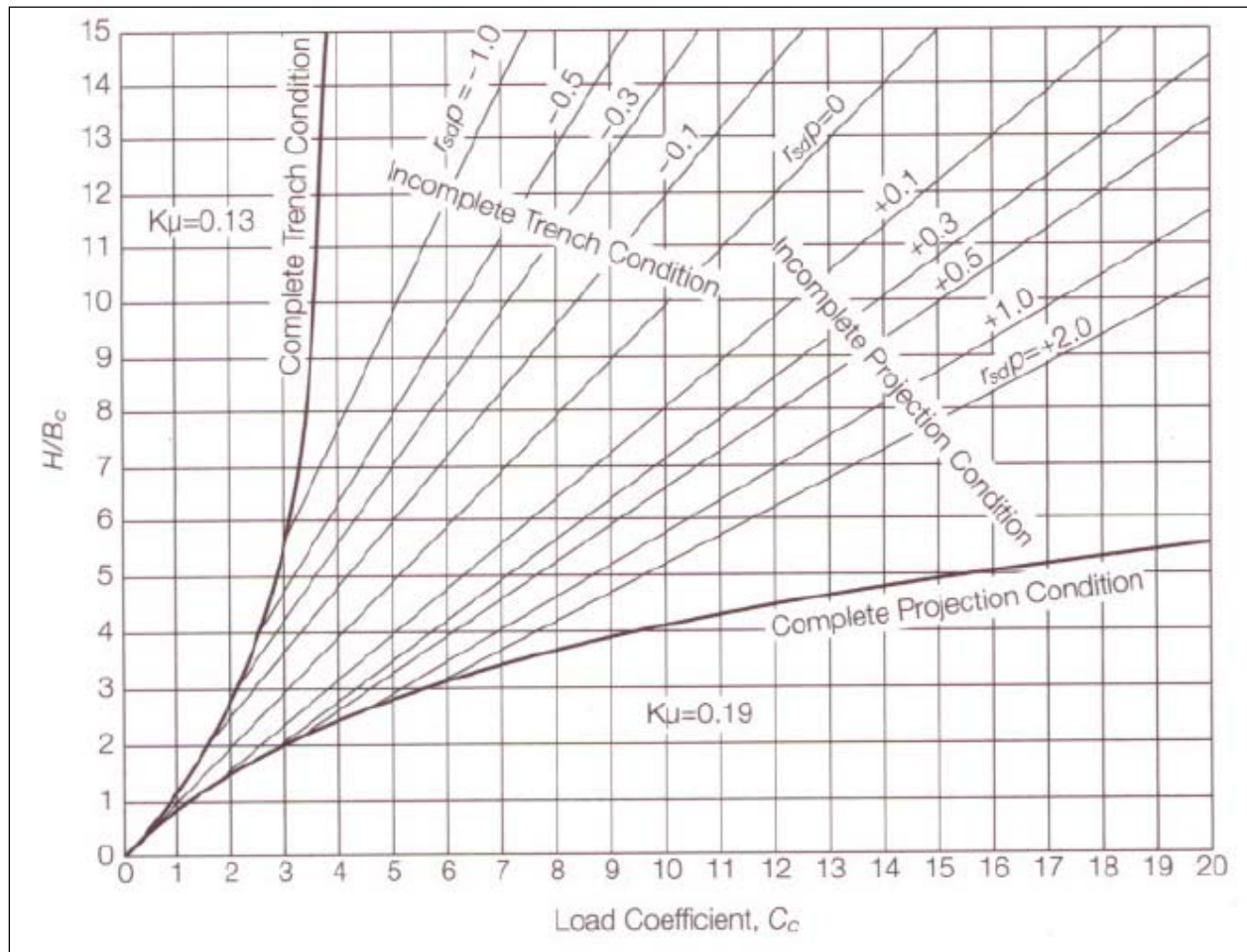
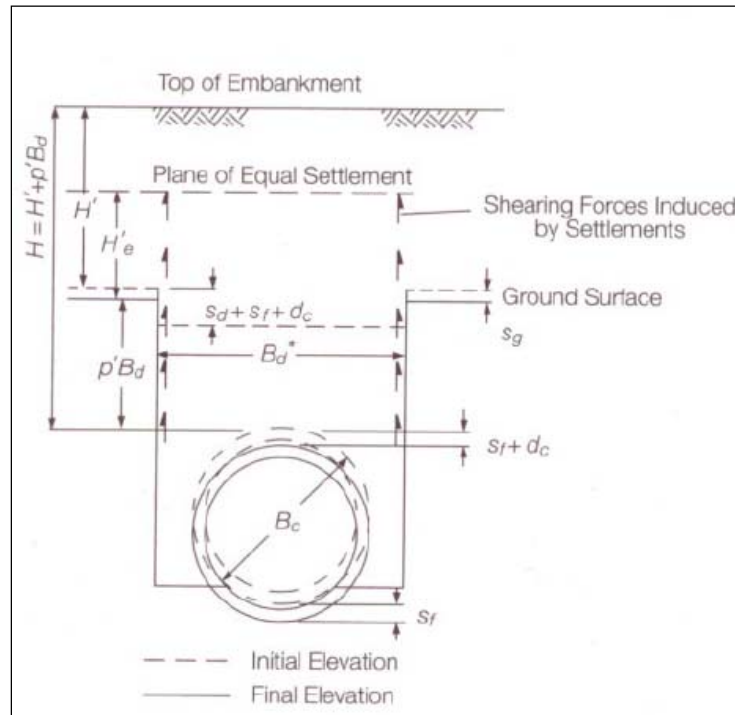


Figure 5. Load Coefficient for Positive Projection Embankment Condition (8).

In negative projection theory, the load transmitted to the pipe is equal to the weight of the interior prism of soil above the pipe minus the frictional forces along the sides of that prism as depicted in Figure 6.

(a) Negative Projecting Embankment



(b) Induced Trench Installation

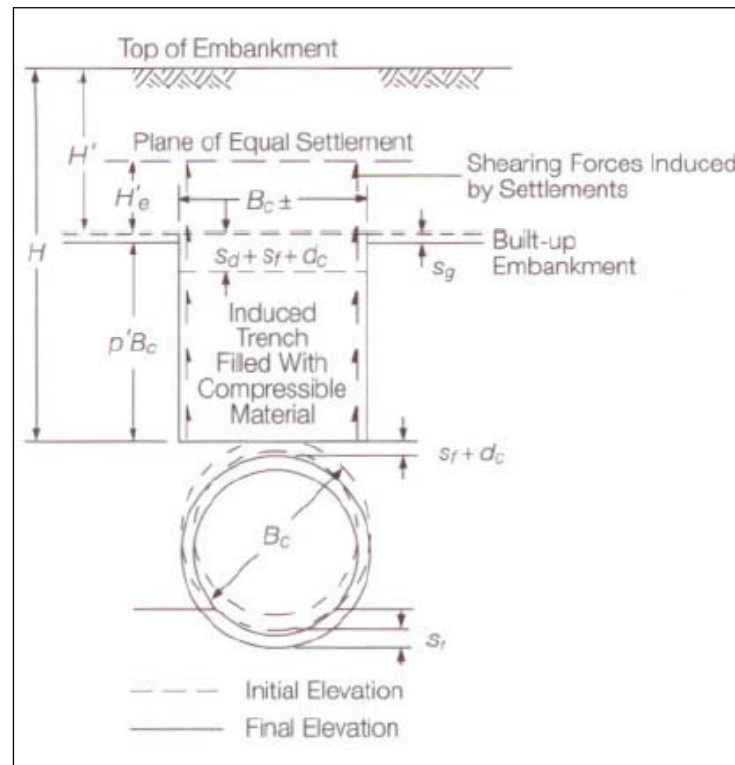


Figure 6. Negative Projecting Embankment and Induced Trench Installation (8).

The load for negative projections and induced trench pipe is computed from the equation:

$$W_n = C_n \gamma B_d^2 \quad (7)$$

C_n is defined as:

$$C_n = \frac{e^{-2K\mu(H/B_d)} - 1}{-2K\mu}, \quad H \leq H_e$$

$$C_n = \frac{e^{-2K\mu(H_e/B_d)} - 1}{-2K\mu} + [(H/B_d) - (H_e/B_d)]e^{-2K\mu(H_e/B_d)}, \quad H > H_e \quad (8)$$

To avoid calculating H_e using the complex equation given earlier for positive projection installations, Figure 7 provides graphical solutions to determine C_n .

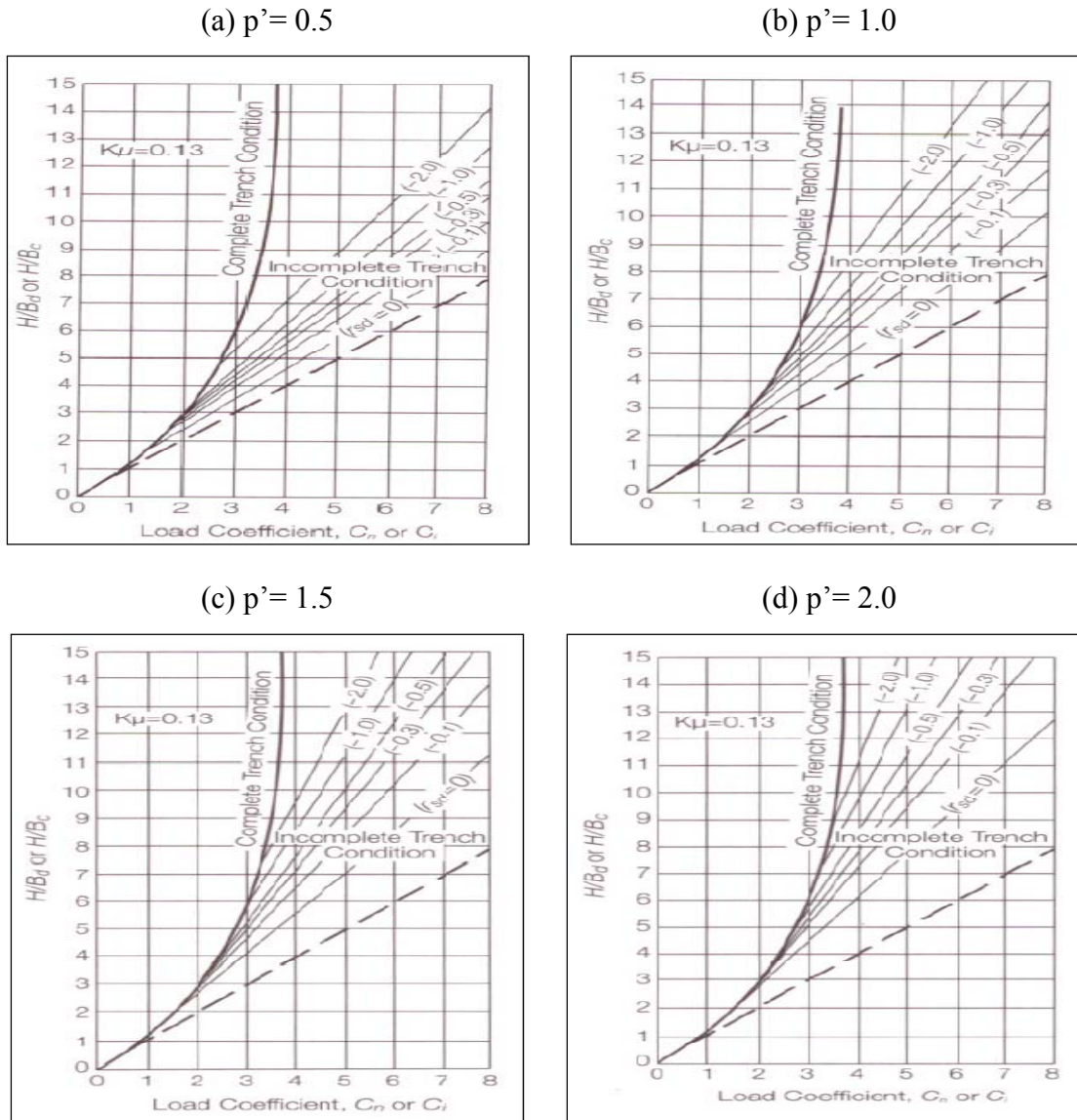


Figure 7. Load Coefficient for Negative Projection and Induced Trench Condition (7).

M. G. Spangler, a student of Anson Marston, discovered that the Marston formula for calculating earth loads on buried pipe was not adequate for a flexible pipe system (1). For flexible pipe evaluation, Spangler incorporated the effects of the surrounding soil on the pipe's deflection based on following assumptions:

- The load applied on the pipe is uniformly distributed along the plane at the top of the pipe.
- A uniform pressure exists over part of the bottom, depending on the bedding angle.
- The horizontal pressure on each side is proportional to the deflection of the pipe.

Spangler developed the original Iowa formula to calculate the horizontal deflection of a buried flexible pipe structure, combining the elastic ring theory and fill-load hypothesis based on the stress distribution diagram shown in Figure 8 (10). Watkins and Spangler revised the original formula to the current “modified” form (11):

$$\frac{\Delta x}{d}(\%) = \frac{100D_L KP}{0.149(PS) + 0.061E'} \quad (9)$$

where,

Δx	=	horizontal deflection.
D	=	diameter of undeformed pipe (= 2r where r is the pipe radius).
P	=	vertical pressure on pipe $\left(= \frac{0.5W_c}{r}\right)$.
W_c	=	vertical load on pipe.
PS	=	pipe stiffness.
E'	=	modulus of soil reaction (= $e \cdot r$).
e	=	modulus of passive soil resistance.
DL	=	time lag factor (1.0 ~ 1.5).
K	=	bedding constant as presented in Table 13.

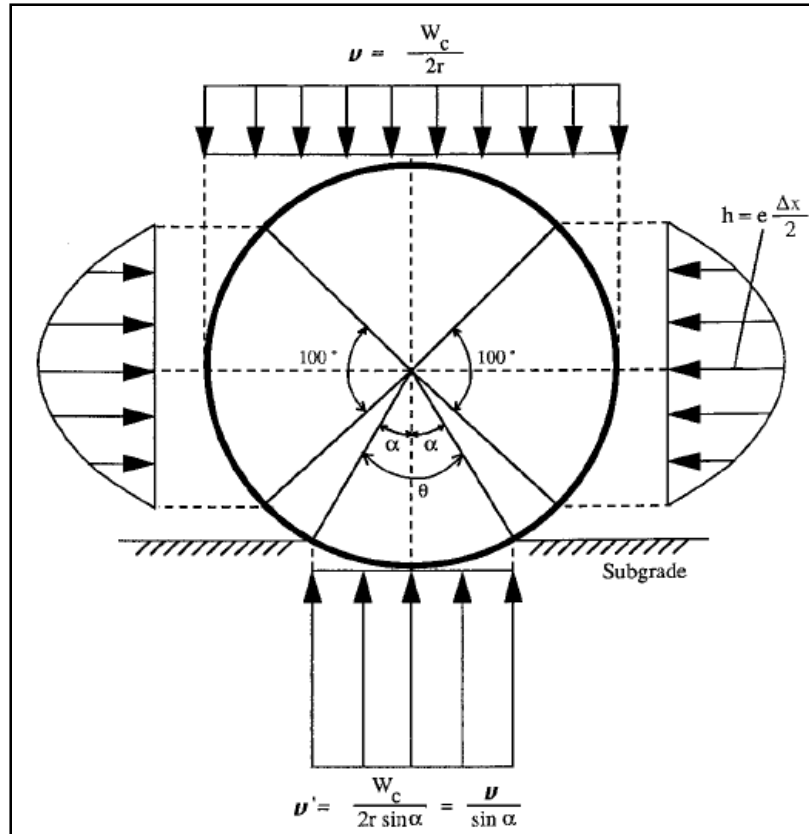


Figure 8. Stress Distributions Hypothesized by Spangler (12).

Table 13. *K*-Value versus Bedding Angle (12).

Bedding Angle (°)	<i>K</i>
0	0.1100
15	0.1092
30	0.1075
45	0.1050
60	0.1020
75	0.0986
90	0.0951
105	0.0919
120	0.0890
135	0.0868
150	0.0852
165	0.0844
180	0.0843

Allowable pipe deflections for various lining and coating systems are given as follows (1):

- Mortar-lined and coated = 2 percent of pipe diameter.
- Mortar-lined and flexible coated = 3 percent of pipe diameter.
- Flexible lined and coated = 5 percent of pipe diameter.

Equation (9) has been widely used in flexible pipeline designs, even though difficulties have been encountered in its application since the vertical deflection is assumed to be approximately equal to the horizontal deflection. Masada derived an expression for the vertical deflection based on Spangler's theory that is given by the following (12):

$$\frac{\Delta y}{d} = \frac{P}{E'} \left[\frac{KE'}{(0.149PS)} \left\{ \frac{0.0595E'}{(0.149PS) + 0.061E'} - 1 \right\} \right] \quad (10)$$

The above formulas require an estimate of the vertical load on the pipe (W_c) and the modulus of soil reaction (E'). Vertical load is composed of soil and traffic loads. For the case where the flexible pipe is buried in a ditch less than two times the width of the pipe, the earth load is computed as follows (2):

$$W_c = C_d \gamma B_d^2 \left(\frac{B_c}{B_d} \right) \quad (11)$$

where the parameters are as defined previously. B_c is the diameter of pipe (ft). For the case where the pipe is buried in an embankment or wide trench, the load is computed using equation (4). Since the settlement ratio (r_{sd}) is assumed to be zero for flexible pipes, C_c is simply defined as the ratio between the height of fill above top of pipe (H_c) to the pipe diameter B_c . Therefore, the earth load is calculated as:

$$W_c = C_c \gamma B_c^2 = \frac{H_c}{B_c} \gamma B_c^2 = \gamma B_c H_c \quad (12)$$

For use in the Iowa deflection formula given in equation (9), the load obtained from equation (12) should be divided by 12 for U.S. Customary units and by 1000 for metric units.

Live traffic load can be determined based on the requirements of the AASHTO Load and Resistance Factor Design (LRFD) (13). These calculations consider AASHTO standard HS-20 or HS-25 trucks traveling perpendicular to the pipe on an unpaved or paved flexible pavement. The live load on the pipe is determined using the following equation:

$$W_L = \frac{M_p P I_f}{L_1 L_2} \quad (13)$$

where,

W_L	=	live load on pipe (psi).
M_p	=	multiple presence factor = 1.2.
P	=	wheel load (16 kips for AASHTO Hypothetical Standard (HS)-20 truck and 20 kips for AASHTO HS-25 truck).
I_f	=	impact factor.
L_1	=	load width parallel to direction of travel (in.).
L_2	=	load width perpendicular to direction of travel (in.).

Furthermore,

$$I_f = 1 + 0.33[(96 - h)/96] \geq 1.0 \quad (14)$$

$$L_1 = t_l + LLDF(h) \quad (15)$$

$$L_2 = t_w + LLDF(h) \quad \text{for } h \leq h_{\text{int}} \quad (16)$$

$$L_2 = \frac{t_w + 72 + LLDF(h)}{2} \quad \text{for } h \geq h_{\text{int}} \quad (17)$$

where,

h	=	depth of cover (in.).
t_l	=	length of tire footprint (10 in.).
$LLDF$	=	factor to account for live load distribution with depth of fill (1.15 for backfills SC1 and SC2 and 1.0 for all other backfills).
t_w	=	width of tire footprint (20 in.).
h_{int}	=	depth at which load from wheels interacts, $\frac{72 - t_w}{LLDF}$.

The vertical loads on a flexible pipe cause a decrease in the vertical diameter and an increase in the horizontal diameter. The horizontal movement develops a passive soil resistance, which depends on the soil type and degree of compaction (7). The modulus of soil reaction E' is used to characterize soil stiffness in design of flexible pipes and adjusted to the constrained modulus M_s given in equation (18) based on the work done by McGrath (14).

$$M_s = S_C M_{sb} \quad (18)$$

where,

S_C = dimensionless soil support combining factor presented in Table 14 and Table 15.

M_{sb} = constrained soil modulus of the pipe zone embedment presented in Table 16.

Table 14. Values for the Soil Support Combining Factor S_C (7).

M_{sn}/M_{sb}	$B_d/D = 1.25$	$B_d/D = 1.5$	$B_d/D = 1.75$	$B_d/D = 2$	$B_d/D = 2.5$	$B_d/D = 3$	$B_d/D = 4$	$B_d/D = 5$
0.005	0.02	0.05	0.08	0.12	0.23	0.43	0.72	1.00
0.01	0.03	0.07	0.11	0.15	0.27	0.47	0.74	1.00
0.02	0.05	0.10	0.15	0.20	0.32	0.52	0.77	1.00
0.05	0.10	0.15	0.20	0.27	0.38	0.58	0.80	1.00
0.1	0.15	0.20	0.27	0.35	0.46	0.65	0.84	1.00
0.2	0.25	0.30	0.38	0.47	0.58	0.75	0.88	1.00
0.4	0.45	0.50	0.56	0.64	0.75	0.85	0.93	1.00
0.6	0.65	0.70	0.75	0.81	0.87	0.94	0.98	1.00
0.8	0.84	0.87	0.90	0.93	0.96	0.98	1.00	1.00
1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.5	1.40	1.30	1.20	1.12	1.06	1.03	1.00	1.00
2	1.70	1.50	1.40	1.30	1.20	1.10	1.05	1.00
3	2.20	1.80	1.65	1.50	1.35	1.20	1.10	1.00
≥ 5	3.00	2.20	1.90	1.70	1.50	1.30	1.15	1.00

NOTE: In-between values of S_C may be determined by straight-line interpolation from adjacent values.

Table 15. Values for the Constrained Modulus of the Native Soil at Pipe Zone Elevation (7).

Native In Situ Soils*						
Granular		Cohesive			M_{sn}	
		q_u		Description		
Blows/ft [†] (0.3 m)	Description	$tons/sf$	kPa			psi
>0-1	very, very loose	>0-0.125	0-13	very, very soft	50	0.34
1-2	very loose	0.125-0.25	13-25	very soft	200	1.4
2-4		0.25-0.50	25-50	soft	700	4.8
4-8	loose	0.50-1.0	50-100	medium	1,500	10.3
8-15	slightly compact	1.0-2.0	100-200	stiff	3,000	20.7
15-30	compact	2.0-4.0	200-400	very stiff	5,000	34.5
30-50	dense	4.0-6.0	400-600	hard	10,000	69.0
>50	very dense	>6.0	>600	very hard	20,000	138.0

Table 16. M_{sb} Based on Soil Type and Compaction Condition (7).

Inch-Pound Units					
Vertical Stress Level (see note 5), <i>psi</i>	Depth for $\gamma_s =$ 120 pcf, <i>ft</i>	Stiffness Categories 1 and 2 (SC1, SC2)			
		SPD100, <i>psi</i>	SPD95, <i>psi</i>	SPD90, <i>psi</i>	SPD85, <i>psi</i>
1	1.2	2,350	2,000	1,275	470
5	6	3,450	2,600	1,500	520
10	12	4,200	3,000	1,625	570
20	24	5,500	3,450	1,800	650
40	48	7,500	4,250	2,100	825
60	72	9,300	5,000	2,500	1,000
Stiffness Category 3 (SC3)					
1	1.2		1,415	670	360
5	6		1,670	740	390
10	12		1,770	750	400
20	24		1,880	790	430
40	48		2,090	900	510
60	72		2,300	1,025	600
Stiffness Category 4 (SC4)					
1	1.2		530	255	130
5	6		625	320	175
10	12		690	355	200
20	24		740	395	230
40	48		815	460	285
60	72		895	525	345

REVIEW OF EXISTING PRACTICE FOR INSTALLATION OF UNDERGROUND UTILITY STRUCTURES IN TEXAS

TTI researchers contacted utility companies and departments of public works in several cities to gather information on their practices for installing buried utilities within the right of way. This contact list included electric, communications, water, and gas/petroleum utility companies as well as local public agencies (Table 17). Through telephone calls, emails, and visits to pertinent websites, researchers gathered the following information, which are documented in the remainder of this section:

- Types of materials used for underground utilities.
- Specifications or guidelines on required depths of cover.
- Typical dimensions such as outer/inner pipe diameters, wall thickness, etc.

- Material specifications such as Young’s modulus, tensile or compressive strengths, allowable stresses, pressures or displacements, and fatigue properties.
- Method or procedure used to design buried utilities, including types of loads considered (for example, overburden pressure, traffic loads, internal pressures for water and gas lines, etc.), determination of required depth of placement, material selection, and sizing of buried utilities.

Table 17. List of Companies and Cities Contacted by Researchers.

Utility Type	Company/City
Communication	AT&T/SBC
Gas/Petroleum	Atmos Energy
	Exxon Mobile Oil
Water, Wastewater, and Storm Water	City of North Richland Hills
	City of Fort Worth
	City of Grapevine
	City of Bedford

City of Grapevine Water Utility Systems

Water lines in the City of Grapevine are located in the area between the back of the curb and the street right of way, also known as “parkway,” generally 3.5 ft back of the curb on the north side of east-west streets and on the east side of north-south streets. Typical water lines are placed to have a minimum cover depth of 3 ft after grading. Cast-iron, AC, and PVC pipes are used for water lines (15).

Cast-Iron Pipe

Current city standards require ductile iron pipes meeting the requirement of AWWA C151/ANSI A21.51 “Standard for Ductile-Iron Pipe, Centrifugally Cast” (16). The ductile iron pipe should be designed for more than 150 psi working pressure (Class 150) with 100 psi surge allowance for 8-ft cover, trench and truck loads. The pressure class is defined as the rated water working pressure of the pipe in psi. The pipe wall thickness varies with the pressure class as shown in Table 18, which is reproduced from AWWA standard C150/ANSI A21.50 (17).

Table 18. Nominal Thickness for Standard Pressure Classes of Ductile-Iron Pipe (18).

Size (in.)	Outside diameter (in.)	Pressure Class ^a					Casting tolerance (in.)
		Nominal thickness (in.)					
		150	200	250	300	350	
3	3.96	—	—	—	—	0.25 ^b	0.05
4	4.8	—	—	—	—	0.25 ^b	0.05
6	6.9	—	—	—	—	0.25 ^b	0.05
8	9.05	—	—	—	—	0.25 ^b	0.05
10	11.1	—	—	—	—	0.26	0.06
12	13.2	—	—	—	—	0.28	0.06
14	15.3	—	—	0.28	0.3	0.31	0.07
16	17.4	—	—	0.3	0.32	0.34	0.07
18	19.5	—	—	0.31	0.34	0.36	0.07
20	21.6	—	—	0.33	0.36	0.38	0.07
24	25.8	—	0.33	0.37	0.4	0.43	0.07
30	32	0.34	0.38	0.42	0.45	0.49	0.07
36	38.3	0.38	0.42	0.47	0.51	0.56	0.07
42	44.5	0.41	0.47	0.52	0.57	0.63	0.07
48	50.8	0.46	0.52	0.58	0.64	0.7	0.08
54	57.56	0.51	0.58	0.65	0.72	0.79	0.09
60	61.61	0.54	0.61	0.68	0.76	0.83	0.09
64	65.67	0.56	0.64	0.72	0.8	0.87	0.09

^a Pressure classes are defined as the rated water pressure of the pipe in psi. The thicknesses shown are adequate for the rated water working pressure plus a surge allowance of 100 psi. Calculations are based on a minimum yield strength of 42,000 psi and a 2.0 safety factor times the sum of the working pressure and 100 psi surge allowance.

^b Calculated thicknesses for these sizes and pressure rating are less than 0.25 in., which is the lowest nominal thickness available in these sizes.

Concrete Pressure Pipe

Current city standards require that all concrete cylinder pipes should be manufactured in accordance with AWWA C303-78 or AWWA C301-72 (19, 20). The pipe should be designed for more than 150 psi working pressure (Class 150). The cement used for inside and outside mortar coatings should be Type II Portland cement and the mortar strength should be less than 45 ksi after 28-day, as determined by compression tests on 2 by 2-in. cubes.

Table 19. Dimensions of AWWA C301 Pipe (57).

Nominal diameter (in.)	Inside diameter (in.)	Core thickness (in.)	Approximate Weight (lb/ft)
15.75	15.98	0.98	154
17.72	17.99	1.14	181
19.69	20.00	1.26	201
23.62	24.02	1.50	255
29.53	30.00	1.89	376
35.43	35.98	2.24	476
41.34	42.01	2.64	651
47.24	47.99	2.99	825
53.15	54.02	3.39	979
59.06	60.00	3.74	1100

Asbestos-Cement Pipe

Asbestos-cement pipe for water systems in the City of Grapevine should conform to ASTM C296 (21) or AWWA C400 (22). The pipe should be designed to withstand a working pressure of 150 psi for the water distribution line.

PVC Pipe

Current city standards require that PVC pipe for water lines should be Class 150 conforming to AWWA C900 (23). The pipe should be Blue Brute manufactured by Johns Manville or approved equivalent. Information on Blue Brute pipe for Class 150 is given in Table 20.

Table 20. Data Sheet for Blue Brute for Class 150^a (24).

Pipe size (in.)	Average Outer Diameter (in.)	Nominal Inside Diameter (in.)	Minimum Wall Thickness (in.)	Approximate Weight (lb/ft)
4	4.80	4.23	0.267	5.25
6	6.90	6.09	0.383	6.40
8	9.05	7.98	0.503	7.05
10	11.10	9.79	0.617	8.20
12	13.20	11.65	0.733	8.80

^a Minimum burst pressure at 73°F is 755 psi.

City of Grapevine Water Sanitary Sewer System

In the City of Grapevine, sanitary sewer lines are generally located in the street halfway between the street centerline and the curb on the south side of east-west streets and on the west side of north-south streets. Sewer service lines 4 to 15 in. in diameter are required to be PVC. Vitrified clay pipes are required for lines larger than 15 in. in diameter.

PVC Pipe

According to city standards, PVC pipe should meet the requirement of ASTM D 3034 whose dimensions are listed in Table 21 (25). Additional information can be obtained from (26). The standard dimension ratio (SDR) is defined as the ratio of pipe diameter to wall thickness:

$$SDR = \frac{D}{s} \quad (19)$$

where,

D = pipe outside diameter (mm).
s = pipe wall thickness (mm).

Figure 9 illustrates the dimensions used in the above formula. A high SDR pipe has a low-pressure rating while a low SDR pipe has a high-pressure rating. The deflection allowance for installed pipe is 5 percent of the inside diameter of the sewer line and the minimum pipe stiffness at the deflection allowance is 46 ksi for all sizes when calculated in accordance with ASTM D 2412 (27).

Table 21. SDR 35 PVC Pipe Dimensions and Weights (26).

Nominal Pipe Size (in.)	Average Outside Diameter (in.)	Base Inside Diameter (in.)	Minimum Wall Thickness (in.)	Approximate Weight (lb/100')
4	4.215	3.890	0.120	110
6	6.275	5.742	0.180	250
8	8.400	7.665	0.240	440
10	10.500	9.563	0.300	690
12	12.500	11.361	0.360	990
15	15.300	13.898	0.437	1500
18	18.701	16.976	0.536	2260
21	22.047	20.004	0.632	3170
24	24.803	22.480	0.711	4030

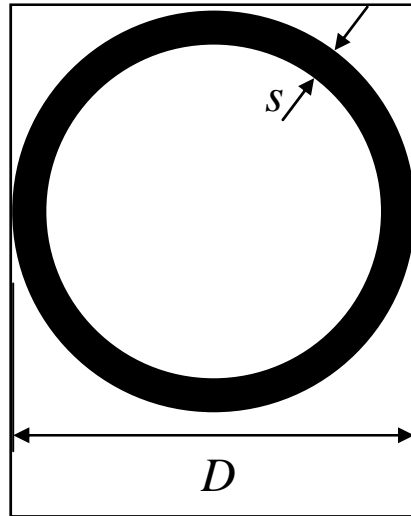


Figure 9. Outside Diameter and Thickness of Pipe.

Vitrified Clay Sewer Pipe

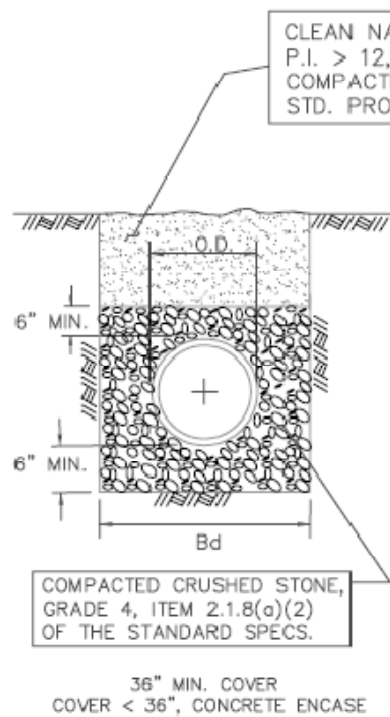
In the City of Grapevine, vitrified clay pipe should be used for all sewer pipes larger than 15-in. diameter. The pipe should be manufactured in accordance with ASTM C700 (28).

Pipe Embedment and Backfill

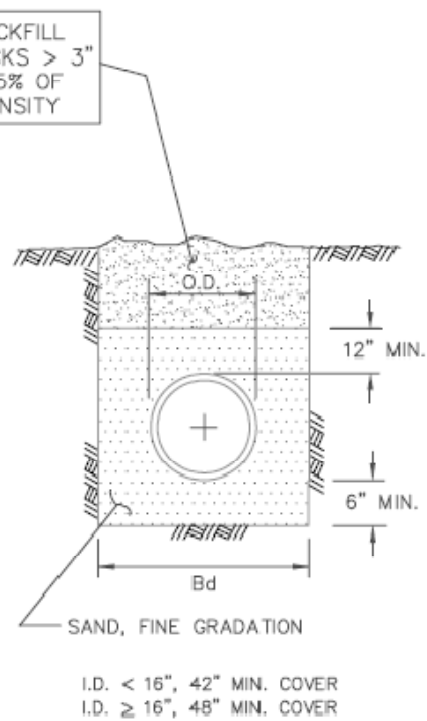
Current city standards require that all pipelines are installed in trench filled with sand and/or granular embedment. The minimum and maximum allowable trench widths are determined as the outside pipe diameter plus 12 and 24 in., respectively. The trench wall should be vertical in the pipe zone without any slopes. While water pipe lines are bedded on more than 6-in. of sand material, sewer pipe lines are required to be on a minimum 6-in. of gravel. Sand material is used for backfill of both pipelines, with the sand backfill placed to level at least 12-in. and 6-in. above the top of water and sewer pipes, respectively. Figure 10 illustrates the trench embedment and backfill of each pipeline.

After backfilling, the trench may be filled to the top with sand or native material if the trench is located a minimum of 3 ft from existing or proposed street paving, or in an easement. The materials for embedment and backfill should be wetted to approximate optimum moisture content and compacted using mechanical methods in 12-in. lifts or less. The compaction should be performed to achieve a minimum density of 95 percent of the standard Proctor density for sand or gravel, or 90 percent of the standard Proctor density for native material.

(a) Sanitary Sewer



(b) Water Line



(c) Storm Sewer

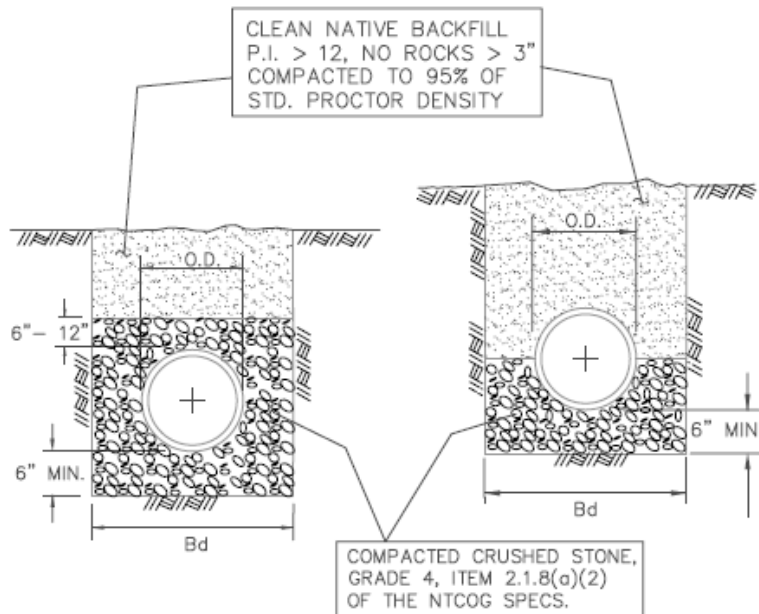


Figure 10. Trench Embedment and Backfill Details (29).

Table 22 lists the gradations of gravel and sand materials used for the embedment and backfill.

Table 22. Gradations of Gravel and Sand Materials.

Sieve Size	Retained on Sieve (%)	
	Gravel ¹	Sand ²
1 3/4	0	
1 1/2	0 ~ 5	
3/4	30 ~ 65	
3/8	70 ~ 90	0
No. 4	95 ~ 100	0 ~ 5
No. 8		0 ~ 20
No. 16		15 ~ 30
No. 30		35 ~ 75
No. 50		70 ~ 90
No. 100		90 ~ 100
No. 200		97 ~ 100

¹ Washed gravel ranging in size from 0.75 in. to 1.25 in. in diameter.

² Plasticity index for the portion passing No. 4 sieve should not be greater than 2.

City of North Richland Hills

Water Utility Systems

In the City of North Richland Hills, all water, sanitary sewer, and drainage installations should be in accordance with the current city standard and specification (30). The water system in the city should be of sufficient size to provide adequate domestic service and fire protection for all lots and to conform to the City's Master Water Distribution System Plan. The city requires all water pipes to be designed as PVC in accordance with AWWA C900, and SDR 18 for more than 150 psi working pressure (Class 150). Table 23 presents the dimension of AWWA C900 PVC pipe for each pressure class.

Table 23. Data Sheet for Blue Brute for AWWA C900 PVC Pipe (31).

Pipe Size (in.)	Average Outer Diameter (in.)	Nominal Inside Diameter (in.)	Minimum Wall Thickness (in.)	Approximate Weight (lb/ft)
Pressure Class 150 (SDR 18)				
4	4.80	4.23	0.267	5.25
6	6.90	6.09	0.383	6.40
8	9.05	7.98	0.503	7.05
10	11.10	9.79	0.617	8.20
12	13.20	11.65	0.733	8.80
Pressure Class 200 (SDR 14)				
4	4.8	4.07	0.343	5.25
6	6.9	5.86	0.493	6.4
8	9.05	7.68	0.646	7.05
10	11.1	9.42	0.793	8.2
12	13.2	11.20	0.943	8.8

While the diameter of water pipe in single-family residential areas should be more than 6 in., the pipe diameter in all other areas should be more than 8 in. The depth of water pipe is required to be a minimum of 3 ft for diameters smaller than 10 in., and 3.5 ft for larger than 10 in. However, additional depth (such as more than 5 ft for a limited distance) should be achieved by one of following measures:

- Pipe deflection may be used if the total length of the deflection can be accomplished within 50 ft for each direction of adjustment.
- Bend fittings must be used.

Water pipes and storm drain or sanitary sewer pipes should be installed with horizontal separation. The minimum separation between a water pipe and a storm drain is 2.5 ft or half of the depth of the water line, whichever is greater. Water and sanitary sewer pipe lines are separated in accordance with regulations set forth by the Texas Commission on Environmental Quality (32).

Sanitary Sewer Systems

In the City of North Richland Hills, all sanitary sewer pipes should be more than 6 in. in diameter of SDR 35 PVC in accordance with ASTM D3034 (25). All sewer lines should be installed with the maximum depth of 10 ft. If a proposed sewer line will be deeper than 10 ft, then SDR 26 pipe should be used. The minimum separation between any sanitary sewer line and a storm drain facility is 2.5 ft or half of the depth of the sewer line, whichever is greater.

Storm Drainage Systems

Storm drainage pipe embedded in the streets of the city is reinforced concrete, classified as Class III in accordance with ASTM C76 (33). While the minimum size of pipe is 24 in. in diameter, the size is designed based on the calculation of storm runoff in drainage areas. However, if a lateral pipe, which is a small, usually reinforced concrete pipe that conveys water from catch basins or other inlets to the mainline storm drainage pipe, is less than 50 ft, an 18-in. diameter pipe may be used. Figure 11 illustrates a typical storm drainage system under a street in the city.

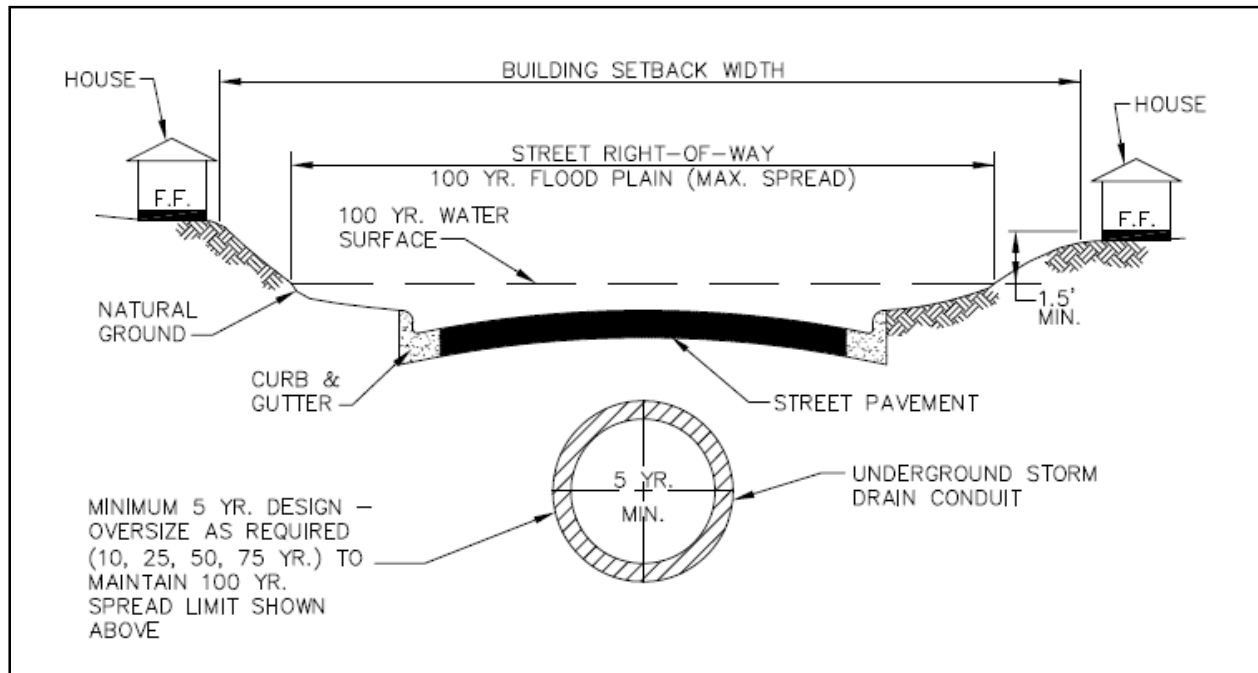


Figure 11. Storm Drain in Street (27).

Trench Embedment and Backfill

In the city, open cutting pavement to install new utilities is not allowed. The contractor must bore the utility under the existing street and use 3/8-in. steel encasement pipe (minimum class 51 steel). Loads exerted on buried pipes can be calculated using the pressure of backfill soil on a pipe for water, sewer, or storm drain. The City of North Richland Hills provides a trench embedment and backfill type for each buried pipe as shown in Figure 12. All trench backfill should be compacted to 95 percent of the standard Proctor dry density based on ASTM D 698 (34). If trench backfill is compacted mechanically, the backfill should be placed in 6-in. lifts or less.

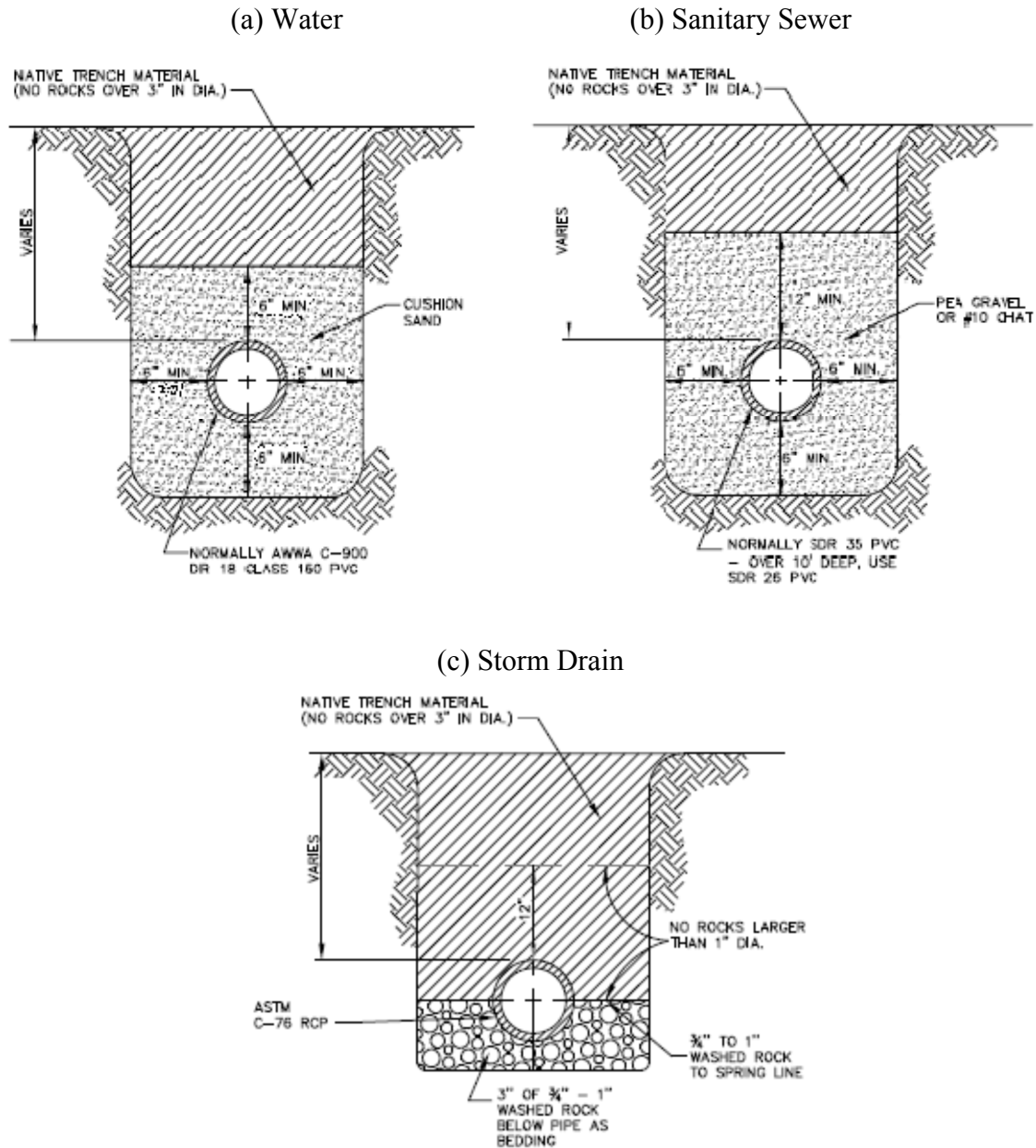


Figure 12. Trench Embedment and Backfill Details.

City of Fort Worth

Water Utility Systems

In the City of Fort Worth, ductile iron pipe in accordance with AWWA C110, AWWA C111, AWWA C150, and AWWA C151 is the preferred material for water utility installations (35, 36, 17, 16). All pipes are required to be cement mortar coated, and all buried pipes must be polyethylene encased. The pressure classes given in Table 24 provide the minimum standard for different pipe sizes.

Table 24. Minimum Pressure Class (37).

Diameter Pipe (in.)	Minimum Pressure Class (psi)
3" to 12"	350
14" to 20"	250
24"	250
30" to 64"	250

Concrete pipes that are used in the City of Fort Worth must be designed, manufactured, and tested in accordance with AWWA C303 and AWWA M 9 (38, 8). Steel pipes used in the City of Fort Worth must be designed according to AWWA Manual M 11 and AWWA C200 (2, 3). The design of pipe installations shall be based on trench conditions with the following parameters:

- Unit weight of fill: 130 lb/ft³.
- Live load: AASHTO H-20 truck for unpaved conditions, or Cooper E-80 for railroad conditions.
- Trench depth and width: As indicated in plans, with a minimum depth of cover of 12 in.
- Coefficient $K\mu'$: 0.150 (0.1 for steel pipe), where K = ratio of active lateral unit pressure to vertical unit pressure, and μ' = coefficient of friction between fill materials and sides of trench.
- Maximum calculated deflection: 3 percent for polyurethane coated steel pipe, and 2 percent for mortar coated steel pipe.
- Maximum stress at working pressure: 23 kilopound per square inch, for polyurethane coated steel pipe and 18 kilopound per square inch for mortar coated steel pipe.
- Bedding conditions: as indicated in plans.
- Pressure class: 150 psi minimum working pressure.
- Surge allowance: 100 psi minimum, where total pressure would be 250 psi (working pressure + surge).
- Deflection lag factor: 1.0.
- Soil reaction modulus, E' : less than 1000 psi.

Casing pipe is also widely used in the City of Fort Worth. Casing pipe must be steel conforming to American Society of Mechanical Engineers (ASME) B36.10 and the following special provisions (39):

- Field strength: 35,000 lb per square inch or more.
- Wall thickness: 0.312 in. minimum (0.5 in. for railroad crossings).

Grout must be Portland cement grout of with a minimum compressive strength of 2,000 psi at 28 days.

City of Bedford

The research team collected the following information regarding practices for installations of underground utility installations in the City of Bedford. The City of Bedford uses copper, polyvinyl chloride, ductile iron, concrete, concrete cylinder, and high-density polyvinyl chloride (HDPVC) pipes, in addition to steel casing pipe for bores. Depth of cover for underground utility installations are determined using the Marston formula (2) to calculate allowable depths for concrete pipe, and the Spangler formula (9) to calculate allowable depths for plastic and composite pipe.

Installations may deviate from the above requirements if the utility contractor, with the approval of the design engineer, has conducted sufficient lab soil tests along the route of proposed installation and can show by approved analysis and recognized procedures that his proposed installation is safe, adequate, and will provide long-term structural integrity under proposed trench loads and depths. The standard bury depths are a minimum of 42 in. of cover for water lines, and 60 in. of cover if adjacent to thoroughfares and major roadways. The City of Bedford also has the following requirements and specifications for pipe dimensions, materials, and design methods:

- **Pipe Dimensions.** Typical pipe dimensions should be established in accordance with the specifications in Table 25.
- **Material Specifications.** The City of Bedford has very few additional specification requirements for underground utilities. The city usually relies on the relevant ASTM, AWWA, design engineer, or product specifications. For example, the City of Bedford requires all water or sanitary sewer lines with less than 24 in. of cover to be constructed of ductile iron pipe with concrete encasement as needed.
- **Method of Design.** In general, most underground utility installations are classified as “standard laying condition” environments that are not normally subject to excessive or potentially damaging loads over the respective trench line areas. The City of Bedford’s preferred requirement for pipe bedding is Type 4 with crushed stone bedding under and adjacent to the pipe with a tamped or compacted (95 percent) ASTM D698/AASHTO T-99 backfill area from pipe zone to top of ditch (34). Trench load is based on AASHTO H-20 single truck on flexible pavement. For situations that require excessive depth of cover over utility lines, the City of Bedford requires an evaluation by the design engineer for analysis and recommendations on type of pipe to be used, treatment of backfill material, trench design, and all calculations necessary to install the proposed utility. The data are then be submitted to the city engineer for review and comment.

Table 25. City of Bedford Specifications for Pipe Dimensions

Material Type	Specification
Concrete (storm drains)	ASTM C76/Class III /Class IV (33)
Pretensioned Concrete Cylinder Pipe	AWWA C303 (19)
Copper Pipe	ASTM B88, Type K / AWWA C800 Type K (40, 41)
Ductile Iron	ANSI/AWWA C150/A21.50, ANSI/AWWA C151/A21.51 (17, 16)
PVC Water	
Class 150 (SDR 18)	AWWA C900 (23)
PVC Sanitary Sewer	
SDR 35	ASTM D3034 (25)
SDR 26	ASTM D2241 (42)
Schedule 40	ASTM D1785 (43)
HDPVC Sewer Pipe Lining	ASTM D3035/F-714, AWWA C901, and AWWA C906 (44, 45, 46)

Exxon Mobile Pipeline Company

The research team collected the following general requirements for installation and modification of pipelines, roads, and utility lines crossing existing Exxon Mobile Pipeline Company (EMPCo) pipelines:

- All pipelines, utility lines, and other underground facilities (except electrical power and telecommunications cables) constructed across EMPCo pipelines shall cross the pipeline easement at an angle of 30 degrees or more, must be under the EMPCo pipelines with a minimum vertical separation of 24 in. between structures.
- Electrical power cables must be enclosed in conduit made of steel or PVC and covered with concrete over a minimum width of 6 in. on each side and above the conduit. The conduit and concrete must extend a minimum of 25 ft on either side of the centerline of EMPCo pipelines.
- Any road, driveway, or street should cross the pipeline easement at an angle of 30 degrees, and be constructed with a depth of cover, as measured from the top of the pipelines to the top of the surface of the road, driveway, or street as shown in Table 26.
- No trucks or heavy equipment should cross the pipeline right of way without approval from EMPCo. If EMPCo determines that the integrity of the pipelines based on soil conditions, depth, and character of the pipelines may be jeopardized, a temporary road crossing will be built to the specifications of EMPCo.

Table 26. Exxon Mobile Pipeline Specifications for Depth of Cover.

Location	Minimum cover (in.)
Under driveway on residential lot	18
Under all other surfaces within the right of way	36
Under road or street	48

ATMOS Energy

ATMOS Energy provided the following information about underground utility installation standards and practices:

- **Types of materials used for underground utilities.** ATMOS Energy uses medium density polyethylene (MDPE) for internal pressures of 60 psig or less, and steel for pressures greater than 60 psig.
- **Specifications or guidelines on required depths of placement.** The normal depth of cover for utility lines is 36 to 48 in. Steel pipe under roadways typically has 60 in. depth of cover.
- **Typical pipe dimensions.** ATMOS Energy uses iron or steel pipe with nominal outside diameters of 2 to 36 in., and PVC pipes with 2 to 12 in. nominal outside diameters. Typical wall thickness is 0.188 in. and thicker.
- **Utility facility material specifications.** For steel pipe, ATMOS Energy uses a Young's modulus of 29,000,000 psi, internal pressures up to 1000 psig, and allowable internal stresses generally 20 to 50 percent of the specified minimum yield stress.
- **Types of loads considered.** Pipe design considers both internal pressure and traffic loading.

REVIEW OF MILITARY SPECIFICATIONS FOR UNDERGROUND UTILITIES

Introduction

The research team conducted a review of military specifications for underground utilities that are included in the Unified Facilities Guide Specifications (UFGS). This set of specifications is maintained through a joint effort of the U.S. Army Corps of Engineers (USACE), the Naval Facilities Engineering Command (NAVFAC), the Air Force Civil Engineer Support Agency (AFCESA), and the National Aeronautics and Space Administration (NASA). UFGS are used to specify construction for the military services. This review covers specifications for water distribution, sanitary sewers, and natural gas/liquid petroleum piping.

Water Distribution

UFGS section 33 11 00 covers requirements for potable and non-potable water distribution systems in which the largest sized pipe is 24 in. in diameter, and the maximum working pressure does not exceed 200 psi for pipes 12 in. and smaller, and 150 psi for pipes larger than 12 in. (47). The specification covers exterior water distribution systems only, including water supply, distribution/service lines, and connections to a point approximately 5 ft outside of buildings and structures.

Requirements for Water Distribution Mains

For Army projects, UFGS section 33 11 00 stipulates referencing Unified Facilities Criteria (UFC) 3-230-10A *Water Supply: Water Distribution* for design considerations in pipe material selection (48). Ferrous metal piping is not allowed to be buried in the vicinity of switchyards or hydroelectric powerhouses due to experience with rapid failure of this pipe as a result of galvanic corrosion from nearby large copper ground mats. For Navy projects, ductile-iron, molecularly oriented polyvinyl chloride (PVCO), or PVC pressure pipes may be specified for water distribution mains 4 to 12 in. in diameter. For larger sized mains, ductile-iron or concrete pipes may be used. Table 27 summarizes the pertinent requirements for the different pipe materials allowed in this specification.

Table 27. Summary of Requirements for Water Distribution Mains.

Pipe Material	Design/Material Requirements
Ductile-Iron	<ul style="list-style-type: none"> Determine pressure/thickness class using AWWA C151/A21.51 <i>Tables for Pressure Class and Thickness Class</i> (16). Include UFGS section 26 42 13.00 20 <i>Cathodic Protection by Galvanic Anode</i> for underground pipe installations in a corrosive environment (49). Cement-mortar linings with twice the standard thickness may be specified for pipes conveying unusually aggressive waters following AWWA C104/A21.4 (50). Polyethylene encasement will apply where soil conditions warrant, in accordance with Appendix A of AWWA C105/A21.5 (51).
PVC/PVCO	<ul style="list-style-type: none"> Use pressure class 150 (DR 18) except when pressure class 200 (DR14) is necessary (refer to Appendix A of AWWA C900) (23). Use only pressure class 150 for PVCO pipe with cast-iron-pipe equivalent OD. Do not use PVC when pipe of greater strength than class 200 is required due to external loading. Do not use plastic when the pipe will be subjected to temperatures in excess of 100°F or exposed to heat from adjacent lines or equipment under installed usage.
Polyethylene (PE)	<ul style="list-style-type: none"> PE pipes, tubings, and heat-fusion fittings shall conform to AWWA C906 (46).
Reinforced Thermo-Setting Resin Pipe (RTRP)	<ul style="list-style-type: none"> RTRP is not used on Navy projects. Refer to AWWA M45 for design considerations (7). RTRP pipe shall have a quick-burst strength of at least four times the normal working pressure determined in accordance with ASTM D1599 (52). RTRP type I pipe (filament bound) shall conform to ASTM D2996 except that the pipe shall have an outside diameter equal to cast iron or standard weight steep pipe outside diameter (53). The pipe shall be suitable for a normal working pressure of 150 psi at 73°F and be lined on the inner surface with a smooth uniform continuous resin-rich material conforming to ASTM D 2996. All RTRP-I materials shall come from one manufacturer. RTRP type II pipe (centrifugally cast) shall conform to ASTM D 2997, with an outside diameter equal to that of standard weight steel pipe (54).
Reinforced Plastic Mortar Pressure Pipe (RPMP)	<ul style="list-style-type: none"> RPMP is not used on Navy projects. Refer to AWWA M45 for design considerations (7). RPMP pipe shall be in accordance with AWWA C950 (55). RPMP shall be produced by centrifugal casting, and shall have a 150 psi pressure rating with a minimum pipe stiffness of 36 psi.

Table 27. Summary of Requirements for Water Distribution Mains (Continued).

Pipe Material	Design/Material Requirements
Reinforced and Pre-Stressed Concrete	<ul style="list-style-type: none"> • Concrete pipes are used for raw water. • Use 150 psi pressure rating except when a higher rating, up to 200 psi, is necessary. • AWWA recommends a minimum 6 ft depth of earth cover for ordinary conditions. However, the engineer can specify a different depth and pressure rating for designing the pipe. Applicable AWWA publications for different pipe diameters are given in the following list: <ul style="list-style-type: none"> ➤ 10 to 42 in. OD: AWWA C303 (reinforced concrete) (38) ➤ 24 to 144 in. OD: AWWA C300 (reinforced concrete) (56) ➤ 16 to 144 in. OD: AWWA C301 (prestressed concrete) (57) • In localities where 6- and 8-in. prestressed concrete pipes are available, the pipes shall conform to AWWA C303 with the following exceptions: <ul style="list-style-type: none"> ➤ Nominal lining thickness: 0.25 in. ➤ Nominal coating thickness: 1 in. ➤ Class 150 total steel area: 0.94 in.²/ft ➤ Class 150 minimum steel cylinder thickness: 16 gauge • Minimum conditions used for pipe design are AASHTO H 20 truck loading and water hammer pressure equal to 40 percent of pressure rating. • In areas of the U.S. where pipe will convey sulfate-bearing waters or where pipe will be buried in soils containing sulfates, specify concrete pipe made of sulfate-resisting cement. Cement type to be used varies according to sulfate concentrations as follows: <ul style="list-style-type: none"> ➤ From 0.1 to 0.2 percent sulfates in soil, or 150 to 1000 ppm in water: Type II cement ➤ Greater than 0.2 percent sulfates in soil or higher than 1000 ppm in water: Type V cement • In areas where reactive aggregates are known to occur, specify low-alkali cement.
Steel	<ul style="list-style-type: none"> • Steel pipes shall conform to AWWA C200 (3). • Pipes and fittings for underground lines shall have cement-mortar lining, and cement-mortar, coal-tar enamel, or coal-tar epoxy coating. Refer to the AWWA M11 chapter on protective coatings for information on the relative merits of cement-mortar and coal-tar enamel coatings (2). See foreword to AWWA C210 for information on coal-tar epoxy coating (58). The following requirements apply for linings and coatings: <ul style="list-style-type: none"> ➤ Under ordinary conditions, steel pipes come furnished with factory-applied cement-mortar lining. If in-place cement-mortar lining will be done during construction, the materials for this lining shall conform to AWWA C602 (59). ➤ If cement-mortar lining and cement-mortar coating are to be applied at the shop, the applicable provisions in AWWA C205 shall be used (60).

Table 27. Summary of Requirements for Water Distribution Mains (Continued).

Pipe Material	Design/Material Requirements
Steel (continued)	<ul style="list-style-type: none"> ➤ For high-sulfate soils or waters, specify cement conforming to ASTM C 150/C 150M Type II Portland cement (17). When reactive aggregates are used, specify cement conforming to ASTM C 150/C 150M low-alkali Portland cement. ➤ Except as otherwise specified, prepare, prime, and coat pipe with hot-applied coal-tar enamel and a bonded single layer of felt wrap in accordance with AWWA C203, or double felt wraps in accordance with AWWA C203 (61). Apply double felt wraps when pipe is to be buried in soil classified as Group IV, unusually corrosive as defined in chapter 10 of AWWA M11; or as Class 4, extreme, as defined in the Navy Design Manual on water supply systems; or where the electrical soil resistivity has been measured at less than 2000 ohms/cc (2). Asbestos felt is not permitted. The felt material shall be fibrous-glass mat as specified in Section 10 of AWWA C203 (61). Shop-apply coating. ➤ Coal-tar epoxy coating shall be applied at the shop in accordance with AWWA C210 (58). • The wall thickness of steel pipe and fittings is determined by the pipe manufacturer based on the minimum conditions specified in the plans that include the pressure rating and earth cover. The design shall be carried out in accordance with the methods given in chapters 4, 5 and 6 of AWWA M11 (2). The engineer specifies a 150 psi pressure rating for design except when a higher rating, up to 200 psi, is deemed necessary. A minimum earth cover of 5 ft is recommended for ordinary conditions. Other minimum conditions used in determining the pipe wall thickness are: <ul style="list-style-type: none"> ➤ Water hammer: 40 percent of pressure rating ➤ Live load: AASHTO H 20 truck loading ➤ Allowable deflection: 2 percent of nominal pipe diameter <p>For calculating the wall thickness of the steel water main, the designer shall use a realistic value for the modulus of soil reaction based on the expected fill compaction, as opposed to assuming a theoretical value. The wall thickness is determined based on an allowable fiber stress equal to 50 percent of the minimum yield strength of the steel pipe. The yield strength is specified in the plans.</p>

In Table 27, RTRP and RPMP are fiberglass pipes that can be used for potable water systems. Advantages associated with fiberglass material are durability and corrosion resistance, which eliminate the need for linings or coatings. However, the engineer should pay special attention to bedding and pipe support requirements. Pipe leaks are difficult to locate due to the manufacturing process.

RTRP pipes are classified by the method of manufacture as type I (filament bound) or type II (centrifugally cast). Pipe grade is determined by construction and bonding material. Grade 1 is glass-fiber reinforced epoxy, while Grade 2 is glass-fiber reinforced polyester.

Requirements for Water Service Lines

UFGS section 33 11 00 does not expect working pressures in service lines to exceed 150 psi. Should the need arise to install service lines with operating pressures in excess of 150 psi, section 33 11 00 advises the engineer to consult the various pipe, fitting, and valve specifications referenced in this UFGS section to determine the applicable pressure rating designation for the given material and higher pressure. The engineer should then modify the appropriate paragraphs in section 33 11 00 as necessary, and insert these modifications in the plans. Table 28 summarizes the UFGS requirements for water service lines.

Installation Requirements

UFGS section 33 11 00 provides specifications for installation of pipelines that include location of water lines, earthwork, pipe laying and jointing, connections to existing water lines, penetrations (i.e., pipes passing through walls of valve pits and structures), and installation of water mains, service lines, and tracer wire. Table 29, Table 30, and Table 32 summarize, respectively, installation requirements related to earthwork, water mains, and service lines that are considered relevant to this research project. For information on installation requirements covering other areas, please refer to UFGS section 33 11 00.

Table 28. Summary of Requirements for Water Service Lines.

Pipe Material	Design/Material Requirements
Copper	<ul style="list-style-type: none">• Pipe shall conform to ASTM B42 with regular, threaded ends (62).• Fittings shall be brass or bronze conforming to ASME B16.15, 125 psi rating (63).• Tubings shall conform to ASTM B88, Type K (40).• Fittings for solder-type joint shall conform to ASME B16.18 or ASME B16.22 while fittings for compression-type joint shall conform to ASME B16.26, flared tube type (64, 65, 66).
PVC with screw joints	<ul style="list-style-type: none">• ASTM D 1785 Schedule 40 or ASTM D 2241 with standard dimension ratio (SDR)* selected to provide 150 psi minimum pressure rating (43, 42).• Fittings shall conform to ASTM D 2466 or ASTM D 2467 (67, 68).• Pipes and fittings shall be made of the same plastic material and fall into one of the pipe/fitting combinations listed in UFGS 33 11 00 (47).
PVC with elastomeric-gasket joints	<ul style="list-style-type: none">• Pipe shall conform to dimensional requirements given in ASTM D 1785 Schedule 40, with joints meeting requirements for 150 psi working pressure and 200 psi hydrostatic test pressure, unless otherwise shown or specified in the plans (43).
PVC with solvent cement joints	<ul style="list-style-type: none">• Pipe shall conform to dimensional requirements given in ASTM D 1785 or ASTM D 2241, with joints meeting requirements for 150 psi working pressure and 200 psi hydrostatic test pressure (43, 42).
PE plastic pipe	<ul style="list-style-type: none">• Pipe tubing and heat fusion fitting shall conform to AWWA C901 (45).

Table 28. Summary of Requirements for Water Service Lines (Continued).

Pipe Material	Design/Material Requirements
Acrylonitrile-butadiene-styrene (ABS)	<ul style="list-style-type: none"> ASTM D 1527 or ASTM D 2282, with pipe schedule or SDR selected as necessary to provide 150 psi minimum pressure rating (69, 70). Fittings shall conform to ASTM D 2468, selected as required to provide barrel wall thickness not less than that of pipe (71). Solvent cement for jointing shall conform to ASTM D 2235 (72).
PVCO	<ul style="list-style-type: none"> AWWA C909, plain end or gasket bell end, pressure class 150 with cast iron pipe equivalent outside diameter (73).
RTRP	<ul style="list-style-type: none"> Table 1 requirements for RTRP water mains also apply to RTRP pipes used for water service lines. RTRP-I joints shall be bell and spigot with elastomeric gasket, mechanical coupling with elastomeric gasket, threaded and bonded coupling, or tapered bell and spigot with compatible adhesive. RTRP-II joints shall be the bell and spigot type with elastomeric gasket; bell and spigot with adhesive; butt-jointed with adhesive bonded reinforced overlay; or mechanical, flanged, threaded or commercially available proprietary joints, provided they are capable of conveying water at the pressure and temperature of the pipe.
RPMP	<ul style="list-style-type: none"> Table 1 requirements for RPMP water mains also apply to RPMP pipes used for water service lines. <p>Fittings and specials shall be compatible with the pipe supplied, and suitable for the working and testing pressures specified for the pipe. The following provides additional requirements for pipe fittings:</p> <ul style="list-style-type: none"> ➤ Filament wound or molded fittings up to 6 in. in diameter shall conform to AWWA C950 (55). ➤ Iron fittings shall be cement-mortar lined in accordance with AWWA C104/A21.4, and shall conform to AWWA C110/A21.10 and AWWA C111/A21.11 (50, 35, 36). <ul style="list-style-type: none"> Joints shall be bell and spigot gasket coupling utilizing an elastomeric gasket in accordance with ASTM D 4161 (74).
Steel	<ul style="list-style-type: none"> Steel pipes shall conform to ASTM A 53/A 53M, standard weight, zinc-coated (75, 76). Fittings shall conform to ASME B16.4, class 125, zinc-coated or to ASME B16.3, class 150, zinc-coated and threaded (77, 78). Protective materials for galvanized pipe less than 3 in. in diameter will be required only when the pipe is within the zone of influence of adjacent buried cathodic protection systems.

Table 28. Summary of Requirements for Water Service Lines (Continued).

Pipe Material	Design/Material Requirements
Steel (continued)	<ul style="list-style-type: none"> Protective materials for steel pipe, except as otherwise specified, shall be mechanically applied in a factory or plant especially equipped for this purpose. Pipes and fittings less than 3 in. in diameter shall be thoroughly cleaned of foreign material by wire brushing and solvent cleaning, and then given 1 coat of coal-tar primer and 2 coats of coal-tar enamel conforming to AWWA C203 (61). Threaded ends of pipes and fittings shall be adequately protected prior to coating.
Ductile-iron	<ul style="list-style-type: none"> Table 1 requirements for ductile-iron water mains also apply to ductile-iron water service lines.

*SDR is the ratio of the pipe diameter to wall thickness.

Table 29. Summary of Installation Requirements Related to Earthwork.

Item	Installation Requirements
Pipe trenches	<ul style="list-style-type: none"> Excavate to the dimensions indicated on plans. Grade bottom of trenches to provide uniform support for each section of pipe after pipe bedding placement. Tamp if necessary to provide a firm pipe bed. Excavate recesses to accommodate bells and joints to provide uniform pipe support throughout entire length. Where rock is encountered, excavate to a depth of at least 6 in. below the bottom of the pipe.
Pipe bedding and backfill	<ul style="list-style-type: none"> Except as specified otherwise, provide bedding for buried piping in accordance with AWWA C600, Type 4 (79). Backfill to top of pipe shall be compacted to 95 percent of ASTM D 698 maximum density (80). Plastic piping shall have bedding to spring line of pipe. Provide ASTM D 2321 materials as follows (81): <ul style="list-style-type: none"> ➤ Class I: Angular, 0.25 to 1.5 in. graded stone, including a number of fill materials that have regional significance such as coral, slag, cinders, crushed stone, and crushed shells. ➤ Class II: Coarse sands and gravels with maximum particle size of 1.5 in., including various graded sands and gravels containing small percentages of fines, generally granular and noncohesive, either wet or dry. Soil Types GW, GP, SW, and SP are included in this class as specified in ASTM D 2487 (82). Specify type of bedding or backfill material and show where material is required in the plans. <ul style="list-style-type: none"> ➤ Class II: Coarse sands and gravels with maximum particle size of 1.5 in., including various graded sands and gravels containing small percentages of fines, generally granular and noncohesive, either wet or dry. Soil Types GW, GP, SW, and SP are included in this class as specified in ASTM D 2487 (82).

Table 29. Summary of Installation Requirements Related to Earthwork (Continued).

Item	Installation Requirements
Pipe bedding and backfill (continued)	<ul style="list-style-type: none"> Specify type of bedding or backfill material and show where material is required in the plans.
Pipeline casing	<ul style="list-style-type: none"> Where traffic can be interrupted, UFGS 33 11 00 considers trenching in a pipeline to be more economical with the same advantages of allowing future work without interrupting traffic. Use ASTM A 139/A 139M Grade B, or ASTM A 252 Grade 2 smooth wall pipe for casing. Casing size shall be of the outside diameter and wall thickness as indicated in the plans. Protective coating is not required on casing pipe (83, 84, 85). Mechanically bore holes and case through the soil with a cutting head on a continuous auger mounted inside the casing pipe. Weld lengths of pipe together in accordance with AWS D1.1/D1.1M (86). Do not use water or other fluids in connection with the boring operation. Attach a pipe-cleaning plug to the boring rig and pass it through the pipe to remove dirt, weld splatters, and other foreign matter that would interfere with insertion of the pipe utility. Install pipe utility in casing using wood supports adjusted to obtained grades and elevations indicated. After installation of pipe utility, provide watertight end seals at each end of pipeline casing between casing and pipe utility.

Table 30. Summary of Installation Requirements for Water Mains.

Pipe Material	Installation Requirements
Ductile Iron	<ul style="list-style-type: none"> Unless otherwise specified, install pipe and fittings in accordance with <i>General Requirements for Installation of Pipelines</i> given in UFGS 33 11 00, and with the requirements of AWWA C600 for pipe installation, joint assembly, valve-and-fitting installation, and thrust restraint. The maximum allowable deflection shall be as given in AWWA C600. If the alignment requires deflection in excess of the specified tolerance, special bends, or a sufficient number of shorter lengths of pipe shall be furnished to provide angular deflections within the limit set forth.

Table 30. Summary of Installation Requirements for Water Mains (Continued).

Pipe Material	Installation Requirements
Ductile Iron (Continued)	<p>Provide concrete thrust blocks (reaction backing) or a metal harness for pipe anchorage. Thrust blocks shall be in accordance with the requirements of AWWA C600 for thrust restraint, except that size and positioning of thrust blocks shall be as indicated in the plans. Use concrete, ASTM C 94/C 94M, having a minimum compressive strength of 2,500 psi at 28 days; or use concrete of a mix not leaner than one part cement, 2 1/2 parts sand, and 5 parts gravel, having the same minimum compressive strength. Metal harness shall be in accordance with the requirements of AWWA C600 for thrust restraint, using tie rods and clamps as shown in NFPA 24, except as otherwise indicated in the plans (87, 88, 89).</p> <ul style="list-style-type: none"> • When required, completely encase buried ductile iron pipelines with polyethylene tube or sheet, using Class A or Class C polyethylene film, in accordance with AWWA C105/A21.5.
PVC	<ul style="list-style-type: none"> • Unless otherwise specified, install pipe and fittings in accordance with <i>General Requirements for Installation of Pipelines</i> given in UFGS 33 11 00; with the requirements of UBPPA UNI-B-3 for laying of pipe, joining PVC pipe to fittings and accessories, and setting of hydrants, valves, and fittings; and with the recommendations for pipe joint assembly and appurtenance installation in AWWA M23, Chapter 7, <i>Installation</i> (90, 6). • Provide concrete thrust blocks (reaction backing) or a metal harness for pipe anchorage. Thrust blocks shall be in accordance with the requirements of UBPPA UNI-B-3 for reaction or thrust blocking and plugging of dead ends, except that size and positioning of thrust blocks shall be as indicated in the plans. Use concrete, ASTM C 94/C 94M, having a minimum compressive strength of 2,500 psi at 28 days; or use concrete of a mix not leaner than one part cement, 2 1/2 parts sand, and 5 parts gravel, having the same minimum compressive strength. Metal harness shall be as indicated in the plans. • Fittings shall be installed in accordance with AWWA C605 (91).
PVCO	<ul style="list-style-type: none"> • Install PVCO pressure piping in accordance with AWWA C605.
Polyethylene	<ul style="list-style-type: none"> • PE pipes shall be installed in accordance with ASTM D 2774 (92).

Table 31. Summary of Installation Requirements for Water Mains.

Pipe Material	Installation Requirements
RTRP-I, RTRP-II, and RPMP	<ul style="list-style-type: none"> • These materials are not used on Navy projects. • RTRP shall be installed in accordance with ASTM D 3839 (93). • RPMP shall be installed in accordance with the manufacturer's recommendations.
Reinforced and Pre-Stressed Concrete	<ul style="list-style-type: none"> • Except as otherwise specified, install pipe and fittings in accordance with <i>General Requirements for Installation of Pipelines</i> given in UFGS 33 11 00; with the laying and joining requirements specified in AWWA M9, Chapter 14, <i>Guide Specifications for Installation of Pipe</i>; and with the recommendations given in AWWA M9, Chapter 7, <i>Thrust Restraining Methods</i> (8). • Provide concrete thrust blocks (reaction backing) or a metal harness for pipe anchorage when required. Thrust blocks shall be in accordance with the recommendations of AWWA M9, Chapter 7, <i>Thrust Restraining Methods</i>, except that size and positioning of thrust blocks shall be as indicated. Use concrete, ASTM C94/C94M, having a minimum compressive strength of 2,500 psi at 28 days; or use concrete of a mix not leaner than one part cement, 2 1/2 parts sand, and 5 parts gravel, having the same minimum compressive strength. Metal harness shall be in accordance with the recommendations for tied joints in AWWA M9, Chapter 7, <i>Thrust Restraining Methods</i>.
Steel	<ul style="list-style-type: none"> • Unless otherwise specified, install pipe and fittings in accordance with AWWA M11, Chapter 12, <i>Transportation, Installation, and Testing</i>. • Welded joints should not be allowed for pipes less than 24 in. in diameter, except when pipeline is to be cement-mortar lined in place after installation. Make welded joints in accordance with AWWA C206 and with the recommendations given for installation of pipe in AWWA M11, Chapter 12, <i>Transportation, Installation, and Testing</i> (94). • Under ordinary conditions, steel pipes come furnished with factory-applied cement-mortar lining. If in-place cement-mortar lining will be done as part of installation, the materials for this lining shall conform to AWWA C602. • Provide concrete thrust blocks or a metal harness for pipe anchorage as required. Thrust blocks shall be in accordance with the recommendations for thrust restraint in AWWA M11, Chapter 13, <i>Supplementary Design Data and Details</i>, except that size and positioning of thrust blocks shall be as indicated. Use concrete, ASTM C 94/C 94M, having a minimum compressive strength of 2500 psi at 28 days, or use concrete of a mix not leaner than one part cement, 2 1/2 parts sand, and 5 parts gravel, having the same minimum compressive strength. Metal harness shall be in accordance with the recommendations for joint harnesses in AWWA M11, Chapter 13, <i>Supplementary Design Data and Details</i>, except as otherwise indicated. Metal harness shall be fabricated by the pipe manufacturer and furnished with the pipe.

Table 32. Summary of Installation Requirements for Water Service Lines.

Pipe Material	Installation Requirements
Metallic Piping	<ul style="list-style-type: none">• Install pipe and fittings in accordance with <i>General Requirements for Installation of Pipelines</i> given in UFGS 33 11 00 and with the applicable requirements of AWWA C600 for pipe installation, unless otherwise specified.• Unless otherwise specified, prepare, prime, and coat exterior surface of zinc-coated steel pipe and associated fittings to be buried with hot-applied coal-tar enamel with a bonded single layer of felt wrap in accordance with AWWA C203 or double felt wraps in accordance with AWWA C203. For the felt wrap material, use fibrous-glass mat as specified in AWWA C203; use of asbestos felt is not permitted. Use solvent wash only to remove oil, grease, and other extraneous matter from zinc-coated pipe and fittings.
Plastic Piping	<ul style="list-style-type: none">• Install pipe and fittings in accordance with <i>General Requirements for Installation of Pipelines</i> given in UFGS 33 11 00 and with the applicable requirements of ASTM D 2774 and ASTM D 2855, unless otherwise specified (92, 95).• Handle solvent cements used to join plastic piping in accordance with ASTM F 402 (96).

Sanitary Sewers

UFGS section 33 30 00 covers requirements for piping and appurtenant structures for an exterior sanitary sewer system (97). UFGS 33 30 00 provides guidelines and specifications on material selection, pipe design, joint selection, and pipe protection from degradation caused by chemical reactions occurring within the operational environment of the buried utility. The guidelines can be categorized as either materials- or design-related, and are summarized in Table 6. Table 7 summarizes the specifications for sanitary sewers according to the material used.

UFGS section 33 30 00 includes a provision for deflection testing of non-pressure plastic pipes upon completion of work adjacent to and over the pipeline, including leakage tests, backfilling, grading, paving, concreting, and any other superimposed loads determined in accordance with ASTM D2412. The section requires that the pipe deflection under external loads be no greater than 4.5 percent of the average inside diameter of the installed pipe. The test is conducted using a pull-through device or a deflection-measuring device.

In the pull-through method, the test device is passed through each run of pipe by either pulling it through or flushing it through with water. If the device fails to pass freely through a pipe run, the contractor is required to replace the pipe showing the excessive deflection. A retest is conducted in the same manner and under the same conditions after replacement of defective pipes.

If a deflection-measuring device is used, the specification requires that the device be sensitive to 1.0 percent of the diameter of the pipe to be tested and accurate to 1.0 percent of the indicated dimension. The deflection-measuring device shall be approved prior to use. In this test, the

contractor measures the deflections through each run of installed pipe. If deflection readings in excess of 4.5 percent of the average inside pipe diameter are obtained, the pipe is retested by running the device along the opposite direction. If the retest continues to show a deflection in excess of 4.5 percent, the contractor is required to replace the pipe showing the excessive deflection. A retest is conducted in the same manner and under the same conditions after replacement of defective pipes.

Natural Gas/Liquid Petroleum Piping

UFGS section 33 11 23 covers requirements for exterior and interior fuel gas piping (98). This guide specification is intended for use when specifying buried polyethylene piping up to 8 in. in nominal diameter, and at pressures and other conditions governed by ASME B31.8 *Gas Transmission and Distribution Piping Systems* (99). The specification stipulates totally PE piping for buried plastic lines. PE pipe is required to conform to ASTM D2513, 100 psig working pressure, with SDR no greater than 11.5 (100).

Excavation and backfilling of pipe trenches are performed in accordance with UFGS section 31 00 00 *Earthwork* (101). PE pipe is placed directly on the trench bottom and covered with a minimum 3 in. of sand to the top of pipe. If the trench bottom is rocky, the pipe is placed on a 3-in. bed of sand and then covered as stated previously. The pipe is buried 24 in. below finished grade or deeper according to the plans. The required compaction is expressed as a percentage of the maximum density obtained using ASTM D1557 unless soil borings indicate a gradation that may include coarse material where more than 30 percent is retained on the 3/4-in. sieve (102). In that case, the required compaction is expressed as a percentage of the maximum density based on AASHTO T180 and corrected with AASHTO T224 (103, 104).

Table 33. Summary of Materials- and Design-Related Guidelines for Sanitary Sewers.

Category	Pertinent Guidelines
Materials-Related	<ul style="list-style-type: none"> • Pipe materials, which are known to be unsuitable for local conditions (i.e., corrosion, root penetration, etc.), should not be permitted for the project. Consider use of more effective protective coatings and jointing methods where economically feasible. • In areas where problems with root penetration are anticipated, specify pipe with joints that will successfully resist root penetration. In general, the more watertight the joint, the greater the resistance to root penetration. For this problem, rubber-gasketed, compression-type, or solvent-cemented joints are preferred. When more than one type of joint is applicable, permit each joint as a contractor's option except where watertight joints are necessary in areas where root penetration problems are anticipated. Use fuel resistant joint gaskets when required. • For cases where corrosive conditions are expected during service, investigate the materials for resistance to the particular chemicals of concern to the engineer. Corrosion-resistant materials other than those specified herein may be used. • Further information on clay pipe may be found in the Clay Pipe Engineering Manual of the National Clay Pipe Institute (105). Information on the selection of concrete sewer pipe and jointing materials may be obtained from the American Concrete Pipe Association's Concrete Pipe Design Manual and the Concrete Pipe Handbook (106, 107). For cases where concrete pipe is used, consider chemical requirements for cement when concrete pipe will convey sulfate-bearing waters, or when the pipe will be buried in soil containing sulfates. Use caution if considering concrete pipe for septic flows. Depending on septicity, these pipes may not be satisfactory. • Where required for special applications, reinforced concrete arch pipe conforming to ASTM C 506 or reinforced concrete elliptical pipe conforming to ASTM C 507 may be specified (108, 109). • Plastic pipe is subject to temperature limitations that must be observed when specifying this pipe for service from laundries, kitchens, and other facilities discharging large quantities of water at elevated temperatures. • Do not use ABS pipe for applications where high chemical resistance is required, such as in lines from laboratories or hospitals.

Table 33. Summary of Materials- and Design-Related Guidelines for Sanitary Sewers (Continued).

Category	Pertinent Guidelines
Design-Related	<ul style="list-style-type: none"> Specify equivalent pipe design for the project conditions (using the applicable criteria) for each pipe material insofar as is practicable. American Society of Civil Engineers (ASCE) Manual No. 37 <i>Design and Construction of Sanitary and Storm Sewers</i> contains methods for calculating pipe structural requirements (110). The required strengths for pipes of various materials may be determined from these calculations. Investigate external loads, including earth, truck, seismic, and impact loads in the design stage of the project. Give special attention in the design stage to plastic pipe materials, particularly with respect to superimposed external loads, which could cause excessive deflection of the pipe. The degree of side fill compaction should be considered realistically, particularly in marginal cases. For sanitary gravity sewer systems, pipes that may be considered for installation include clay, concrete, ductile-iron, ABS, composite plastic, and PVC. Sanitary sewer pressure lines may be of ductile iron, concrete, or PVC plastic pressure pipe. Tables of trench loadings, trench backfill loads, and supporting strengths of clay pipe are included in the Clay Pipe Engineering Manual. The required strength of clay pipe can be derived from these tables when the depth of trench is known. For concrete gravity sewer pipes, the load per linear foot of pipe diameter must be calculated on the basis of project conditions to determine the applicable class or strength of pipe. The Concrete Pipe Design Manual contains design information and methods by which the applicable class or strength of pipe can be determined when the depth of trench is known. For concrete pressure sewer pipes, ASTM C 361M/C 361 covers pipe for up to 125 ft of hydrostatic head (approximately 55 psi) (111, 112). AWWA C302 covers pipe and fittings for 45 psi pressure rating (100 ft of hydrostatic head) (113). ASTM C 361M/C 361 contains tables giving design requirements for pipes in all combinations of 100 and 125 ft of hydrostatic head with 5, 10, 15, and 20 ft of earth cover. Where higher pressure ratings are necessary, pipes conforming to AWWA C300, C301, or C303 should be specified. ASTM A 746 contains design information and methods by which the required thickness class of ductile-iron gravity pipe can be determined when the depth of trench is known (114).

Table 34. Summary of Requirements for Sanitary Sewers.

Pipe Material	Design/Material Requirements
Concrete	<ul style="list-style-type: none"> • Cement mortar shall conform to ASTM C 270, Type M with Type II cement (115). Type II cement normally will be specified when water-soluble sulfates in the soil are in the range of 0.1 to 0.2 percent, or 150 to 1000 ppm in water. Type V cement will be specified when the soil contains in excess of 0.2 percent water-soluble sulfates, or the wastewater contains sulfates in excess of 1000 ppm. Type I cement may be permitted when water-soluble sulfates in the soil will be less than 0.1 percent, and the wastewater will contain less than 150 ppm over the project's design life. • The contractor shall submit certificates of compliance stating the type of cement used in the manufacture of concrete pipe, fittings, and precast manholes. Portland cement shall conform to ASTM C 150/C 150M, Type II or V for concrete used in concrete pipe, concrete pipe fittings, and manholes (116, 117). Cement type is optional with the contractor for cement used in concrete cradle, concrete encasement, and thrust blocking. Air-entraining admixture conforming to ASTM C 260 shall be used with Type V cement (118). Where aggregates are alkali reactive, as determined by Appendix XI of ASTM C 33/C 33M, cement containing less than 0.60 percent alkalis shall be used (119, 120). • For projects where concrete is mixed onsite, specify concrete aggregates conforming to ASTM C 33/C 33M and concrete consisting of 1 part Portland cement, 2-1/2 parts sand, and 5 parts gravel, with just enough water for workable consistency. Portland cement concrete shall conform to ASTM C 94/C 94M, compressive strength of 4000 psi at 28 days, except for concrete cradle and encasement, or concrete blocks for manholes. Concrete used for cradle and encasement shall have a compressive strength of 2500 psi minimum at 28 days. Concrete in place shall be protected from freezing and moisture loss for 7 days. • Concrete gravity sewer pipes shall be either non-reinforced conforming to ASTM C 14M or ASTM C 14, or reinforced conforming to ASTM C 76M or ASTM C 76 of class as specified in the plans (121, 122, 123, 124). Cement used in manufacturing pipe and fittings shall be Type II, Type V, or low alkali cement conforming to ASTM C 150/C 150M. Concrete pressure sewer pipes shall conform to AWWA C302 or to ASTM C361M/C361. Pipe shall be designed for hydrostatic head of 100 or 125 ft and external loading of 5, 10, 15, or 20 ft of earth cover. Cement used in manufacturing pipe and fittings shall be Type II, Type V, or low alkali cement conforming to ASTM C150/C150M. Fittings shall conform to AWWA C302. • Circular concrete pipes with elliptical reinforcement shall have a readily visible line at least 12 in. long painted or otherwise applied on the inside and outside of the pipe at each end so that when the pipe is laid in the proper position, the line will be at the center of the top of the pipe. Fittings and specials shall conform to the applicable requirements specified for the pipe and shall be of the same strength as the pipe.

Table 34. Summary of Requirements for Sanitary Sewers (Continued).

Pipe Material	Design/Material Requirements
Ductile Iron	<ul style="list-style-type: none"> Ductile iron pipes for gravity sewer systems shall conform to ASTM A 746 with the thickness class specified in the plans. Fittings shall have strength at least equivalent to that of the pipe. Ductile iron pressure pipe is used in sizes ranging from 3 to 64 in. Use thickness class 52 for Atlantic Division, Naval Facilities Engineering Command projects. Ductile-iron pipe shall conform to AWWA C151/A21.51, of the thickness class specified in the plans. Flanged pipe shall conform to AWWA C115/A21.15. Fittings shall have pressure rating at least equivalent to that of the pipe (I25). Fittings shall conform to AWWA C110/A21.10 or AWWA C153/A21.53. Fittings with push-on joint ends shall conform to the same requirements as fittings with mechanical-joint ends, except that the bell design shall be modified as approved by the Contracting Officer, for push-on joint. Ends of pipe and fittings shall be suitable for the joints specified. Pipe and fittings shall have cement-mortar lining conforming to AWWA C104/A21.4, standard thickness.
ABS	<ul style="list-style-type: none"> Use ASTM D 2680 for ABS composite plastic pipe and fittings (I26). Use ASTM D 2751, SDR 35 with ends suitable for either solvent cement joints or elastomeric joints for ABS solid-wall plastic piping (I27). Solvent cement for solvent cement joints shall conform to ASTM D 2235. Elastomeric joints shall conform to ASTM D 3212 and the gaskets for these joints shall conform to ASTM F 477 (I28, I29).
PVC	<ul style="list-style-type: none"> For gravity sewer systems, use ASTM D 3034, SDR 35, or ASTM F 949 with ends suitable for elastomeric gasket joints (25, I30). Use ASTM F 794, Series 46, for ribbed sewer pipe with smooth interior, size 8- through 48-in. diameters (I31). For pressure sewer systems, PVC plastic pipes and fittings less than 4 in. in diameter shall be manufactured of materials conforming to ASTM D 1784, Class 12454B (I32). Pipes 4 to 12 in. in diameter shall conform to AWWA C900 and shall be plain end or gasket bell end, pressure class 150 (DR 18), with cast-iron-pipe equivalent OD. Fittings shall be gray-iron or ductile-iron conforming to AWWA C110/A21.10 or AWWA C153/A21.53 and shall have cement-mortar lining conforming to AWWA C104/A21.4, standard thickness (I33). Fittings with push-on joint ends shall conform to the same requirements as fittings with mechanical-joint ends, except that bell design shall be modified as approved, for push-on joint suitable for use with the specified PVC plastic pressure pipe.
HDPE	<ul style="list-style-type: none"> ASTM F 894, Class 63, for 18- through 120-in. pipe sizes (I34). ASTM F 714, for 4- through 48-in. sizes (I35). The polyethylene shall be certified by the resin producer as meeting the requirements of ASTM D 3350, cell Class 334433C (I36). The pipe stiffness shall be greater than or equal to 1170/D for cohesionless material pipe trench backfills.

Table 34. Summary of Requirements for Sanitary Sewers (Continued).

Pipe Material	Design/Material Requirements
RPMP	<ul style="list-style-type: none">• Pipe shall be produced be in accordance with ASTM D 3262 and shall have an outside diameter equal to ductile iron pipe dimensions from 18-in. to 48-in. (137). The inner surface of the pipe shall have a smooth uniform continuous resin-rich surface liner. The minimum pipe stiffness shall be 36 psi.
RTRP	<ul style="list-style-type: none">• Use ASTM D 3262. Filament wound RTRP-I pipe shall conform to ASTM D 2996, except that the pipe shall have an outside diameter equal to cast iron outside diameter or standard weight steel pipe. The pipe shall be suitable for a normal working pressure of 150 psi at 73°F. The inner surface of the pipe shall have a smooth uniform continuous resin-rich surface liner conforming to ASTM D 2996. Centrifugally cast RTRP-II pipe shall conform to ASTM D 2997. Pipe shall have an outside diameter equal to standard weight steel pipe.

CHAPTER 3. DESIGN REQUIREMENTS FOR UNDERGROUND UTILITY STRUCTURES IN THE TEXAS UTILITY ACCOMMODATION RULES

INTRODUCTION

The installation of underground utilities within state right of way is subject to a range of federal, statewide, and industry-specific regulations or rules. The Utility Accommodation Rules (UAR) specify that the design of any utility installation, adjustment, or relocation on the state right of way is the responsibility of utility owners and needs to meet a standard acceptable to TxDOT (138). Longitudinal utility installations on right of way are generally not allowed beneath any pavement including shoulders, in the center median, and in the outer separation if frontage roads exist. In the current UAR, rule §21.40 (Underground Utilities) contains installation specifications pertaining to all types of underground utility facilities allowed on state right of way. Examples of other regulations applicable to underground utility facilities within state right of way include (138):

- National Electrical Safety Code (139).
- Title 49 of the Code of Federal Regulations Part 192, *Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards* (140).
- Title 49 of the Code of Federal Regulations Part 195, *Transportation of Hazardous Liquids by Pipeline* (141).
- The latest American Society for Testing and Materials (ASTM) specifications.
- Title 30 of the Texas Administrative Code, Sections 290.38 – 290.47, relating to Rules and Regulations for Public Water Systems (142).

CURRENT UTILITY ACCOMMODATION RULES

The current version of the UAR is a result of years of rule evolution. The origin of the state utility accommodation policy can be traced to a number of documents that provided early guidelines for the installation of underground utility facilities in the late 1940s and early 1950s. The development of these early specifications was likely subject to county and district engineer opinion and experience, personal bias, and engineering judgment. Examples of documents used by TxDOT, which at the time was called the Texas Highway Department, include the following (143):

- **Texas Transportation Commission Minute 23630 of August 1, 1947.** This Commission Minute provided general rules and regulations governing the handling of requests for placements of pole lines or pipelines on state right of way.
- **Administrative Circular 62-49 of November 29, 1949.** This Administrative Circular permitted single-pole power lines and applicable water transmission lines on state right of way.

- **Administrative Order 17-55 of April 19, 1955.** This Administrative Order outlined the construction procedures to be followed when placing pipelines on state right of way.
- **Administrative Order 12-56 of May 10, 1956.** This Administrative Order included encasement requirements for rural pipeline crossings of expressways, U.S. and state highways, and farm roads.
- **Administrative Circular 16-56 of June 26, 1956.** This Administrative Circular legalized the rights of several types of public utilities, including telegraph, telephone, water, sewer, gas, oil, and salt brine lines, to occupy highway right of way.

Over time, more research and national guidance became available that influenced the process of creating or modifying rules for the accommodation of buried utilities in the right of way. The following major documents contributed significantly to the development of the UAR and its evolution its current version:

- **Title 23 of the Code of Federal Regulations Part 645B, Accommodation of Utilities (144).** This part of the Code of Federal Regulations describes general policies and procedures for accommodating utility facilities on the right of way of federal-aid or direct federal highway projects. It includes general requirements on the contents and standards of utility accommodation policies of state transportation agencies. However, the code does not contain technical specification requirements on the design and installation of utility facilities.
- **A Policy on the Accommodation of Utilities within Freeway Right of Way (145).** The policy was first adopted by the Bureau of Public Roads, the agency preceding the FHWA, as a design standard for Interstate projects. This policy was later expanded to cover all access-controlled freeways regardless of system and has values for partially access-controlled highways. The latest version of this policy was published in 2005. The policy was intended to promote uniformity of utility treatment among states while ensuring that highway safety and operations are not negatively impacted. It does not contain detailed specifications regarding the installation and protection of buried utility facilities.
- **A Guide for Accommodating Utilities within Highway Right of Way (146).** The guide was first adopted by Bureau of Public Roads in 1969 and the current version was published in 2005. This document provides a set of general guidelines to assist states in establishing and administering reasonably uniform policies for utility facilities within highway right of way. For underground facilities, for instance, the document provides guidelines for establishing specifications from aspects such as location, highway structure attachments, cover, separation, encasement, and construction.
- **Highway/Utility Guide (147).** The guide is a comprehensive document reviewing policies, procedures, and practices related to right of way utilities, especially the coordination practices between highway and utility agencies. The document was intended to be a general guide to assist state and local agencies in developing utility-

related manuals and policies. As such, it does not include detailed specifications pertaining to underground utility facilities.

With the passage of the Administrative Procedure and Texas Register Act in 1975, state agency rule writers began the organization and systematic dissemination of state agency rules (148). In 1977, Texas Legislature directed the Office of the Secretary of State to compile, index, and cause to be published the Texas Administrative Code under the Administrative Code Act. The rules of the then State Department of Highways and Public Transportation (SDHPT) were organized into sections and subsections, with 32 rules under Utility Accommodation of the Right of Way Division (149).

In October 1979, the Texas Administrative Code was reorganized into titles and chapters and the format has been generally followed ever since (150). During this reorganization, the previous Transportation section became Title 43, and the Right of Way Division subsection became Chapter 21. In addition, the utility accommodation rules were renumbered and several were combined, as shown in Table 35. The rules, particularly those pertaining to underground utility facilities, underwent two comprehensive revisions and reorganizations in 1989 and 2005, and several additional rounds of less comprehensive revisions. Table 35 provides an overview of the rule numbering before and after the Texas Administrative Code was revised and reorganized in 1979.

Table 35. Numbering of Utility Accommodation Rules Before and After Revision and Reorganization of the Texas Administrative Code in 1979.

Before 1979 Revision	After 1979 Revision
.001 Utilities	§21.31 Definitions
.002 Low Volume Highways and Low Volume Farm to Market Roads	Combined into §21.31
.003 High and Low Pressure Gas Lines	
.004 Clear Roadside Policy	
.005 Pavement Structure	
.006 Active Project	
.007 District Engineer	
.008 Department	
.015 Purpose	§21.32 Purpose
.016 Application	§21.33 Application
.017 Scope	§21.34 Scope
.018 Exceptions	§21.35 Exceptions
.019 Authority of Utilities	§21.36 Authority of Utilities
.025 Location	§21.37 Location
.026 Design	§21.38 Design
.027 Aesthetics	§21.39 Aesthetics
.028 Safety	§21.40 Safety
.029 Miscellaneous	§21.41 Miscellaneous
.030 Pipelines – General	§21.42 Pipelines – General
.031 High Pressure Gas and Liquid Petroleum Lines	§21.43 High Pressure Gas and Liquid Petroleum Lines
.032 Low Pressure Gas Lines	§21.44 Low Pressure Gas Lines
.033 Water Lines	§21.45 Water Lines
.034 Sanitary Sewer Lines	§21.46 Sanitary Sewer Lines
.040 Utility Structures	§21.47 Utility Structures
.041 Traffic Structures	§21.48 Traffic Structures
.045 Overhead Power and Communication Lines	§21.49 Overhead Power and Communication Lines
.050 Underground Power Lines	§21.50 Underground Power Lines
.055 Underground Communication Lines	§21.51 Underground Communication Lines
.060 Forms – General	§21.52 Forms – General
.061 Use and Occupancy Agreement Forms	§21.53 Use and Occupancy Agreement Forms
.062 Notice Forms	§21.54 Notice Forms
.063 Abandoned Interests	§21.55 Abandoned Interests

SUMMARY OF CHANGES TO UTILITY ACCOMMODATION RULES SINCE 1979

Since the reorganization of the Texas Administrative Code in 1979, the UAR have been amended or otherwise modified 11 times, on average about every three years. Some of the UAR updates have been small in scope, other updates have been more substantial. The first comprehensive revision of the UAR was in 1989 followed by a major revision in 2005 and further amendments in 2008 and 2009. Table 36 provides an overview of these changes since the beginning of the new rule structure in 1979, and indicates which sections of the UAR underwent minor or major changes, including amendments, rule additions, rule repeal, and rule repeal and replacement. The following provides a summary of the specific changes to the UAR for the year when the new rules went into effect.

Adopted Changes in 1982 (151)

The department amended rule §21.48 (Traffic Structures) in relation to the permissive attachment of utility lines to highway bridges at no cost to the state and payment of rental fees. These changes did not affect underground utility facilities.

Adopted Changes in 1989 (152)

The department officially adopted major amendments to rules §§21.31 – 32, 21.35, 21.37 – 40, 21.42 – 46, 21.48 – 51, and 21.53 – 54, and new (i.e., replaced the previous) rules §§21.33 and 21.41, to improve safety, avoid unnecessary utility adjustment and installation delays, and reflect changes in methods and technology of the highway and utility industries. The amendments and new rules were adopted temporarily in December 1988 on an emergency basis. This was the first comprehensive revision of the rules since they were recompiled in 1979.

- **Rule §21.31: Definitions.** The changes to this rule included insertion of new definitions and expansion of several previous terms. The modifications were necessary due to the amendments to the following rules.
- **Rule §21.32: Purpose.** New statements were added in the rule to further emphasize the safety and protection of highways in consideration for utility installations.
- **Rule §21.33: Application.** The new rule defined that the utility accommodation rules applied to new utility installations, additions to existing installations, adjustments or relocations of utilities incident to highway construction, and existing utility installations for which applicable waivers might be authorized.
- **Rule §21.35: Exceptions.** This rule was amended to allow persons other than the State Engineer-Director to approve exceptions.
- **Rule §21.37: Location.** The rule was amended by inserting new provisions for longitudinal utility installations.

Table 36. Historical Modifications to Utility Accommodation Rules after 1979.

Year ^a	Utility Accommodation Rule																														
	21.31	21.32	21.33	21.34	21.35	21.36	21.37	21.38	21.39	21.40	21.41	21.42	21.43	21.44	21.45	21.46	21.47	21.48	21.49	21.50	21.51	21.52	21.53	21.54	21.55	21.56					
1979																															
1982																		A													
1989 ^b	A	A	R		A		A	A	A	A	R	A	A	A	A	A		A	A	A	A										
1990			A																												
1996																											N				
1997					A																										
1998																											A				
1999					A																										
2001	A		c	c														c		c	c	c	c	c	c						
2005 ^c	R	R	R	R	R	R	R	R	R	R	R	X	X	X	X	X	X	X	X	X	X										
2008	A				c		c	c	A	c												c	A	A	c						
2009	A		A	c		A	c					N																			

c: Minor change (mainly grammatical changes to improve clarity).

A: Major amendment (such as change to title, insertion of new provisions, and significant changes to existing provisions).

N: New rule added.

R: Rule repealed and replaced.

X: Rule repealed (no replacement).

^a Year of rule adoption, excluding the temporary adoptions of amendments or new rules on an emergency basis.

^b Most rules pertaining to underground utility facilities were amended, including changes to the requirements on depth of cover, encasement, and manholes.

^c Rule §21.40 (Underground Utilities) newly adopted with installation specifications on all types of underground utility facilities. All provisions remain in use today with minor changes.

- **Rule §21.38: Design.** The amended rule included a number of new references. In addition, it inserted a new specification on clearances between underground utilities and sewers, and new general design requirements for manholes previously included separately for individual utilities.
- **Rule §21.39: Aesthetics.** The amended rule had more specific requirements on tree replacement and tree value.
- **Rule §21.40: Safety.** The rule was amended to include requirements on proper signs, markers, and barricades during utility constructions on right of way.
- **Rule §21.41: Site Clean Up.** The department repealed and replaced the existing rule (§21.41: Miscellaneous). The new rule included additional provisions to require right of way to be restored to the original or better condition after utility installations.
- **Rule §21.42: Pipelines – General.** The amended rule included new provisions to regulate boring operations on state right of way. The new requirements included:
 - For rural highway crossings, all borings needed to extend beneath travel lanes plus 30 ft from freeway mainlanes and other high-speed, high-volume roads, 16 ft from high-speed, low-volume highways and ramps, or 10 ft from low-speed roads.
 - For urban highway crossings, all borings needed to extend beneath travel and parking lanes and extend beyond the back of curb plus 30 ft from high-speed facilities and 3 ft from low-speed facilities plus any additional width to clear an existing sidewalk.
 - Additional protection measures such as the use of fence if these clearances could not be met.
- **Rule §21.43: High Pressure Gas and Liquid Petroleum Lines.** The amendment clarified the requirements on depth of cover and included new requirement on markers and aboveground appurtenances associated with high-pressure gas and liquid petroleum lines.
- **Rule §21.44: Low Pressure Gas Lines.** The major modifications included the clarification of the requirements on depth of cover to include longitudinal lines, new requirements on markers, and new requirement prohibiting aboveground appurtenances. The department also changed the maximum size of plastic lines for crossings from 6 to 24 in. and that of longitudinal lines, which was previously not specified separately, remained 6 in.
- **Rule §21.45: Water Lines.** The rule was amended to specify the rural standard of roadway center median width (76 ft).

- **Rule §21.46: Sanitary Sewer Lines.** The amended rule changed the required material for sanitary sewer lines from cast iron to ductile iron and had several other relatively minor modifications on the provisions pertaining to material and manholes.
- **Rule §21.48: Traffic Structures.** The rule was amended to renumber some existing provisions and to add procedures for applications for attachment to structures.
- **Rule §21.49: Overhead Power and Communications Lines.** The amendment was to include minimum vertical clearances for cable television lines and to revise horizontal clearances for poles and guys.
- **Rule §21.50: Underground Power Lines.** The amended rule had new requirements regarding depth of cover, encasement, crossings, markers, and manholes. The major new requirements were:
 - Longitudinal power lines might be unencased and the minimum depth of cover should be 30 in. for lines with a voltage of 22,000 or less, 36 in. for lines with a voltage between 22,001 and 40,000, and 42 in. for lines with a voltage of 40,001 or greater.
 - Crossings should be encased and the minimum depth was 48 in. under ditches or 72 in. below pavement surface.
 - Requirements on manholes were the same as the general requirements in Rule §21.38: Design.
- **Rule §21.51: Underground Communication Lines.** The major changes to this rule included the following:
 - More specific requirements on depths of cover. The new rule specified that the minimum depth cable television and copper cable communications lines was 24 in. for longitudinal installations, and 24 in. under ditches or 18 in. beneath the bottom of the pavement structure, whichever is greater, for crossings. The minimum depth for a fiber optic facility was 42 in. if installed longitudinally, and 42 in. below the ditch grade or 60 in. below the top of the pavement structure, whichever is greater, for crossings.
 - Requirements on manholes changed to the same as the general requirements in rule §21.38: Design.
 - Addition of requirements on large equipment housings on right of way.
 - Additional requirements on markers, placement of the lines, and manholes.

- **Rule §21.53: Use and Occupancy Agreement Forms.** The amended rule changed its title from *Use of Occupancy Agreement Forms* and the inserted a new requirement on contents of occupancy agreement forms.
- **Rule §21.54: Notice Forms.** The rule was amended to include a new requirement on the contents of notice forms.

Adopted Changes in 1990 (153)

The department amended rule §21.33 (Application) to secure approval of highway plans from FHWA on projects that involve federal-aid and direct federal projects.

Adopted Changes in 1996 (154)

TxDOT added rule §21.56 (Metric Equivalents) to enable the use of metric system in its business and project development processes concerning utility accommodation. The new rule required utility companies to use metric measurements when submitting requests for utility accommodations starting October 1, 1996.

Adopted Changes in 1997 (155)

Previously, exceptions to UAR could be authorized by the bridge engineer, chief engineer of highway design, or chief engineer of maintenance and operations. In 1997, TxDOT amended rule §21.35 (Exceptions) to place the authority for approving all exceptions with the Right of Way Division Director.

Adopted Changes in 1998 (156)

TxDOT amended rule §21.56 (Metric Equivalents) to eliminate the mandatory use of metric units in utility accommodation requests as a result of an FHWA statement that the use of metric units was at the option of individual states.

Adopted Changes in 1999 (157)

In 1999, TxDOT amended rule §21.35 (Exceptions) to place the authority of approving requests for exceptions with the Maintenance Division Director instead of the previously Director of the Right of Way Division.

Adopted Changes in 2001 (158)

TxDOT amended rules §§21.31, 21.43 – 44, 21.48, and 21.50 – 21.54. Amendments to most of the rules were relatively minor and are grammatical in nature.

- **Rule §21.31: Definitions.** The amended rule deleted several definitions relevant to manager titles that are no longer used by TxDOT, such as bridge engineer, chief engineer of highway design, and chief engineer of maintenance and operations. The new rule also included grammatical changes to some other definitions.

- **Rules §§21.43, 21.44, 21.48, and 21.50 – 21.54.** The amended rules included minor grammatical changes, such as the use of *right of way* and *that* instead of previously *right of way* and *which*, respectively, and the deletion of the term *State Department of Highways and Public Transportation* or *SDHPT*.

Adopted Changes in 2005 (159)

In 2005, TxDOT repealed the rules §§21.31 – 21.51 and adopted new rules §§21.31 – 21.41. This significant amendment was intended to reorganize the rules for clarity, enable the use of updated utility construction methods and materials, and improve right of way management by requiring better plans and record drawings for utility installations.

- **Rule §21.31: Definitions.** The new rule abandoned most of the previous terms and redefined the rest for clarity. In addition, the new rule included several new terms pertaining to new utility procedures and processes, job functions, and occupational and departmental titles.
- **Rule §21.32: Purpose.** The new rule redefined the purpose of the Utility Accommodation subchapter for clarity.
- **Rule §21.33: Applicability.** The new rule changed its previous title (Application) and contained more detailed provisions defining the applicability of the rules.
- **Rule §21.34: Scope.** The scope was redefined in the new rule to specify the matters it governed; the superiority of other laws, codes, regulations, rules, or orders that had stricter requirements; detailing of district supplemental requirements; and general utility appealing process.
- **Rule §21.35: Exceptions.** The new rule redefined the requirements for requesting and criteria for considering an exception to the provisions of UAR.
- **Rule §21.36: Rights of Utilities.** The new rule changed its previous title (Authority of Utilities) and clarified some of the existing provisions.
- **Rule §21.37: Design.** The new rule replaced the previous rule §21.37 (Location) and included the design requirements for utility installations. In addition to the location requirements on right of way utility installations, it also included requirements regarding the submission of plans, the design of utility tunnels and bridges, the joint use of highway and utility structures, and relevant aesthetic features.
- **Rule §21.38: Construction and Maintenance.** The new rule replaced the previous rule §21.38 (Design) and included standards and requirements for the construction and maintenance of utility lines on state right of way.
- **Rule §21.39: Ownership/Abandonment/Idling.** The new rule replaced the previous rule §21.39 (Aesthetics) and included requirements pertaining to property interests of

relocated utility facilities, abandoned utility facilities, and idling facilities on state right of way.

- **Rule §21.40: Underground Utilities.** The new rule replaced the previous rule §21.40 (Safety) and included the provisions previously in several individual rules for the installation of various types of underground utilities on right of way. The new rule had new and expanded requirements for standards pertaining to materials, conditions under which underground utilities may be placed on the right of way, multiple conduits, abandonment, location and placement, and markers organized into the following sections:
 - General requirements.
 - Gas and liquid petroleum lines.
 - Nonpotable water control facilities.
 - Sanitary sewer lines.
 - Electric and communication lines.

With a few minor grammatical changes in 2008, the major specifications on underground utility facility installation included in this rule have remained unchanged.

- **Rule §21.41: Overhead Electric and Communication Lines.** This new rule replaced the previous rule §21.41 (Site Clean-up) and included requirements for the installation, maintenance, and relocation of overhead power and communication lines on state right of way.
- **Rules §§21.42 – 51.** These rules were repealed but not replaced.

Adopted Changes in 2008 (160)

TxDOT amended rules §§21.33, 21.35, 21.37 – 21.40, and 21.52 – 21.55. The amendments were intended to improve clarity of existing language, consistency between federal and state regulations, reflection of current practice, and implementation of the intent of the rules.

- **Rule §21.31: Definitions.** This amended rule contained changes to several definitions and inserted two new definitions (i.e., *joint use agreement* and *use and occupancy agreement*). None of these changes were directly related to the installation specifications.
- **Rule §21.35: Exceptions.** The amended rule had a few minor modifications on the text of the exceptions, none of which directly affect the installation specifications.
- **Rule §21.37: Design.** The amended rule included minor modifications to some text, but none of the modifications directly pertained to the installation specifications.
- **Rule §21.38: Construction and Maintenance.** The amended rule used the term *use and occupancy agreement* instead of the previous *Utility Joint Use Acknowledgement or*

Utility Installation Request. The change was not directly related to the installation specifications.

- **Rule §21.39: Ownership, Function, Abandonment, and Idling of Facilities.** The amended rule changed the previous rule title (Ownership/Abandonment/Idling), deleted the general provision, inserted a provision on change of utility function and additional text on the procedures/requirements pertaining to change of ownership and abandonment or idling of facility, and made minor modifications to some other existing provisions.
- **Rule §21.40: Underground Utilities.** The amended rule included three minor changes to the rule text to improve clarity. Most of the changes are grammatical in nature.
- **Rule §21.52: Forms – General.** The amended rule contained a few minor changes in text including the use of *right(s) of way* instead of *right(s)-of-way*. Those changes were not directly related to the installation specifications.
- **Rule §21.53: Joint Use Agreement Forms.** The previous title of this rule was *Use and Occupancy Agreement Forms*. In addition to changing its title, the amended rule contained changes to all clauses in the rule, many of which were grammatical.
- **Rule §21.54: Use and Occupancy Agreement Forms.** The previous title of this rule was *Notice Forms*. The amended rule had several changes to a number of provisions including two newly inserted clauses pertaining to the use and occupancy agreement forms.
- **Rule §21.55: Abandoned Interests.** The amended rule changed all instances of *right(s)-of-way* to *right(s) of way*. The change was not related to installation specifications for the buried utility facilities.

Adopted Changes in 2009

TxDOT adopted new rule §21.42 in September of 2009 (161) and amendments to rules §§21.31, 21.33 – 34, and 21.36 – 37 in December of 2009 (162). The major purpose of these amendments was to clarify existing language and change some provisions to comply with House Bill 2572, 81st Legislature, Regular Session, 2009 (81(R) HB 2572). The Bill amended Utilities Code §181.005 and authorized gas corporations to lay and maintain gas pipelines along public roads, subject to relevant Railroad Commission of Texas safety regulations, state and federal regulations, and limitations on state reimbursement for the cost of pipeline relocations caused by highway improvement projects.

- **Rule §21.31: Definition.** The proposed amendment contained changes to several definitions including three newly inserted terms and their definitions (i.e., *director*, *engineering study*, and *traffic impact analysis*).

- **Rule §21.33: Applicability.** The proposed amendment contained changes requiring district engineers to detail any supplemental accommodation requirements in writing when they are stricter than the minimum requirements in UAR.
- **Rule §21.34: Scope.** The proposed rule had minor modifications to the scope description for better clarity.
- **Rule §21.36: Rights of Utilities.** The proposed amendment made minor modifications to the existing provisions defining the rights of utilities to occupy state right of way. It also included additional requirements related to requests of new utility facility installations.
- **Rule §21.37: Design.** The proposed amendment expanded the procedures and requirements on longitudinal installations proposed with existing access denial lines of a controlled access highway without frontage roads and included minor modifications on other provisions. None of the modifications is directly related to installation specifications for buried utility facilities.
- **Rule §21.42: Appeal Process.** This is a new rule that was proposed to be added to the current UAR. The rule will provide procedures and requirements for utilities to file a petition of appeal to contest a supplemental accommodation requirement and the denial of the utility's request for a utility installation/adjustment or an exception to any UAR provisions.

Appendix A provides a comparison between installation specifications for underground utility facilities in the 1979 and the most recent, 2010 version of the UAR (138, 145). As shown in the comparison, most of the rules pertaining to underground utility facilities were reorganized and clarified. The new rules in general have stricter requirements on encasement and casing materials. In addition, there are some stricter or new requirements partly in response to new materials and installation techniques. Nevertheless, many technical requirements on aspects such as encasement and minimum depths of cover remained the same. The research team also noticed conflicting requirements in certain sections, including the specifications on the minimum depth of cover for electric lines. Below are the major changes of the requirements pertinent to this research:

- **New requirements associated with new materials and new installation methods.** The current rule specifies in the general encasement requirement that HDPE must be used if horizontal directional drilling is used to place the casing, which was not included in the original version. In addition, it included new minimum depth of cover requirements for underground fiber optic communication lines due to the increasingly popular use of the material as communication lines. The required minimum depth of cover for all conditions is generally stricter than the minimum for traditional copper lines.
- **Increases of minimum depth of cover.** The current rule included stricter requirements of minimum depth of cover for the following types of underground utility facilities:

- Low-pressure gas and liquid petroleum. The required minimum depth of cover for lines outside pavement was increased from the general 24-in. requirement to 48 in. for unencased lines, 30 in. for unencased sections of encased lines, or 36 in. for longitudinal lines, which became consistent with those for high-pressure gas and liquid petroleum lines.
- Water lines, non-potable water control facilities, and sanitary sewer lines. The required minimum depth of cover increased from 24 in. to 30 in. for lines outside the pavement structure.
- Electric lines. The original rule used the same requirements as those for encased high-pressure gas and liquid petroleum lines (30 in. for the encased portion and 36 in. for the unencased portion). The current rule adopted the requirements in the National Electrical Safety Code, which requires a deeper depth of cover (i.e., 42 in.) for lines of which voltage is higher than 40,000 volts.
- **Encasement Requirements.** The requirements for encasement have changed as follows:
 - General Required Material. Utility lines crossing a highway must be encased in steel, concrete, or plastic pipes, and the strength of the encasement material must equal or exceed structural requirements for drainage culverts.
 - General Length of Encasement. Encasement must be provided as follows:
 - Cut sections: from the top of backslope to top of backslope.
 - Fill sections: 5 ft beyond the toe of slope.
 - Curb sections: 5 ft beyond the face of the curb.
 - Water Lines. Water lines crossing paved highways must be encased in steel encasement within the limits of the right of way. Encasement may be omitted under center medians, outer separations, and side road entrances. Existing unencased water lines may remain unencased if buried 24 in. or deeper under the pavement of new low volume highways.
 - Non-Potable Water Control Facilities. Non-potable water control lines crossing paved highways must be encased in steel encasement within the limits of the right of way, unless the district approves another type of encasement. Encasement may be omitted under center medians, outer separations, and side road entrances.
 - Sanitary Sewer Lines. Sanitary sewer lines crossing paved highways must be encased in steel encasement within the limits of the right of way. Gravity flow lines not conforming to the minimum depth of cover must be encased in steel or concrete. Encasement may be omitted under center medians, outer separations, and side road entrances.

RELEVANT SPECIAL PROVISIONS AT TXDOT DISTRICTS

In addition to UAR, many TxDOT districts have special provisions that provide supplemental requirements for utility accommodation and utility facility relocation. Many of these special provisions include specifications related to underground utility facilities, some of which are stricter than UAR. The following is a summary of the stricter specifications applicable to underground utility facilities at a sample of districts.

Special Provisions for Underground Utility Facilities at the San Antonio District

The current special provisions in San Antonio District require a stricter minimum depth of cover for the following utility facilities mainly to avoid conflicts with traffic sign foundations (163):

- **Low or high-pressure natural gas and liquid petroleum products:** 60 in. if crossing pavement or parallel less than 10 ft from pavement edge and 48 in. otherwise. UAR requires the same depth for unencased crossing lines while a lesser depth for encased crossing lines and longitudinal installations.
- **Copper telephone cables and TV cables:** 60 in. if crossing pavement or parallel less than 10 ft from pavement edge and 24 in. otherwise. UAR requires 24 in. under ditches or 18 in. beneath the bottom of the pavement structure, whichever is greater.
- **Water and sanitary sewer:** 60 in. if crossing pavement or parallel less than 10 ft from pavement edge and 30 in. otherwise. UAR requires a minimum depth of 30 in., but not less than 18 in. below the pavement structure for crossings.

Special Provisions for Underground Utility Facilities at the Bryan District

Bryan District requires a 60-in. minimum depth of cover for high-pressure natural gas facilities that are under a drainage ditch or channel (164). UAR requires 30 in. for encased crossing lines or 48 in. for unencased crossing lines for high-pressure natural gas facilities.

Special Provisions for Underground Utility Facilities at the Pharr District

The special provisions in Pharr District contain stricter requirements of the minimum cover of depth for the following utility facilities (165):

- **Low-pressure natural gas lines:** 60 in. for lines crossing pavements and 36 in. for all lines under a drainage ditch or channel, and for parallel lines under natural ground that are more than 10 ft from pavement edges. These requirements are stricter than the requirements in the UAR for encased crossing low-pressure natural gas lines. For encased crossings, UAR requires a depth of 18 in. or 1/2 the diameter of the pipe, whichever is greater, under pavement structure; 24 in. outside pavement structure and under ditches; or 30 in. for unencased sections of encased lines outside of pavement structure. However, UAR requires a 48-in. depth for unencased crossing lines outside pavement and under ditches, which is stricter than that of the special provisions.

- **High-pressure natural gas:** 60 in. for all lines crossing pavements and 48 in. for lines under a drainage ditch or channel, and for parallel lines under natural ground that are more than 10 ft from pavement edges. UAR has the same requirements for unencased lines but less strict requirements for encased crossing lines.
- **Copper telephone cables or TV cables:** 60 in. for all lines crossing pavements and 24 in. for lines under a drainage ditch or channel, and for parallel lines under natural ground that are more than 10 ft from pavement edges. UAR requires a depth of 24 in. under ditches or 18 in. beneath the bottom of the pavement structure, whichever is greater.
- **Water and sanitary sewer lines:** 60 in. for lines crossing pavements and 30 in. for lines under a drainage ditch or channel, and for parallel lines under natural ground that are more than 10 ft from pavement edges. UAR requires a minimum depth of 30 in., but not less than 18 in. below any pavement structure for all lines.

CHAPTER 4. REVIEW OF TXDOT BUSINESS PROCESS FOR OVERWEIGHT LOAD PERMITTING

INTRODUCTION

One objective of this research was to review the TxDOT business process for overweight load permitting to identify institutional issues, highlight areas where improvements are needed or required, and to identify potential integration points that can promote better coordination among TxDOT divisions as well as between TxDOT and utilities. As a result, the research team evaluated current and planned practices at TxDOT to manage overweight load routing and permitting. Specifically, the researchers performed a review of the overweight load permitting process in terms of procedures, data/information flows, and stakeholders, and gathered available information from the TxDOT Motor Carrier Division (MCD). The researchers interviewed TxDOT representatives from MCD and the TxDOT Right of Way Division (ROW) to complete the research team's understanding of overweight load permitting process activities and user data needs and to accomplish the following:

- **Review TxDOT's Overweight Permit Application Process.** The research team reviewed TxDOT's current overweight load permitting process and anticipated future changes. Discussion points during a meeting with MCD included the application process for various types of permits, data flows, applicant requirements, and certifications.
- **Review TxDOT's Overweight Routing Process.** The research team reviewed TxDOT's current overweight load routing process and anticipated changes due to the implementation of the Texas Permit Routing Optimization System (TxPROS). Discussion points for a meeting with MCD included data sets, data sources, data availability, data gaps, data flows, networks, routing algorithms, routing analysis results, routing options, and limitations. The research team requested data samples from relevant databases such as TxPROS to develop an understanding of the routing process.

To aid with the understanding of these issues, the chapter provides an overview of both state and federal overweight permit regulations, organization of permitting activities at MCD, and an overview of the TxDOT overweight permitting process, including the TxDOT overweight routing process.

RELEVANT OVERWEIGHT PERMIT REGULATION

United States Code

Title 23 Section 127 of the United States Code (USC) provides vehicle weight limitations for the interstate highway system (Table 37) (166). All states are required to allow vehicles on the interstate highways system with a weight up to but not more than the weight limits given in this section, unless a state decides to forfeit all its apportioned federal aid highway funds.

Table 37. Weight Limitations in the United States Code (166).

	Maximum Axle Load (lb)		Maximum Gross Weight (lb)	Section
	Single Axle	Tandem Axle		
General weight limit	20,000	34,000	up to 80,000 (by formula)	23 USC 127 (a) (1)
Heavy duty vehicles equipped with idle reduction technology	20,400	34,400	up to 80,400 (by formula)	23 USC 127 (a) (12)

The formula used to determine the maximum gross weight, also known as the Federal Bridge Formula, is as follows:

$$W = 500 \left(\frac{LN}{N-1} + 12N + 36 \right) \quad (20)$$

where

- W = overall gross weight on any group of two or more consecutive axles.
- L = distance between the extreme of any group of two or more consecutive axles.
- N = number of axles in group under consideration.

Section 127 also includes numerous exemptions for vehicles with higher maximum gross weights, as shown in Table 38. The first three exemptions to gross weight limits, shown with a grey highlight in Table 38, are exemptions that apply to all states: loads that cannot be easily dismantled but can be permitted in accordance with state laws, loads that comply with state weight regulations that predate the passing of this law (grandfathered states), and Longer Combination Vehicles (LCVs) authorized by state law before June 1, 1991. In addition to these exemptions there are also numerous state-specific exemptions to the maximum gross weight that have amended the law since the weight regulations first become law in 1958. Table 38 does not list temporary exemptions for over-the-road buses, intrastate public agency transit passenger buses, and firefighting vehicles because the exemptions expired without extension.

Table 38. Maximum Gross Weight Exemptions in the United States Code (166).

Exemption Description	Max Gross Weight (lb)	Section
Loads that cannot be easily dismantled or divided, which have been issued special permits in accordance with state laws (nondivisible loads).	exempt	23 USC 127 (a)
Vehicles operating under state laws or regulations allowing higher weights established before July 1, 1956; or February 1, 1960, in the case of Hawaii; or May 1, 1982, in the case of Michigan; or June 1, 1993, in the case of Maryland; or January 1, 1987, in the case of Interstate 89, 93, and 95 in New Hampshire State (grandfathered states).	exempt	23 USC 127 (a)
Longer Combination Vehicles, if authorized by state laws in actual lawful operation on a regular or periodic basis on or before June 1, 1991.	exempt	23 USC 127 (d)
Vehicles operating on Interstate 29 between Sioux City, Iowa, and the Iowa/South Dakota border.	exempt	23 USC 127 (a)
Vehicles operating on Interstate 129 between Sioux City, Iowa, and the Iowa/Nebraska border.	exempt	23 USC 127 (a)
Motor vehicles hauling tank trailers, dump trailers, or ocean transport trailers after September 1, 1989.	exempt	23 USC 127 (a)
Sugarcane vehicles during harvest season, up to 100 days per year in Louisiana.	100,000	23 USC 127 (a)
Vehicles operating on certain portions of the Maine Turnpike.	exempt	23 USC 127 (a)
Additional vehicle configurations authorized by state law no later than November 3, 1992, in Wyoming.	117,000	23 USC 127 (d)
Additional vehicle configurations authorized by state law in certain parts of Ohio, Alaska, and Iowa.	exempt	23 USC 127 (d)
Certain specialized hauling vehicles with a steering and tridem axle for coal, logs, and pulpwood on Interstate 68 in Maryland.	exempt	23 USC 127 (e)
Certain specialized hauling vehicles in certain areas of Wisconsin and Pennsylvania.	exempt	23 USC 127 (f) and (g)
Jet fuel bulk shipments in parts of Maine during national emergencies.	Exempt as determined by Secretary of Transportation	23 USC 127 (h)

Code of Federal Regulations

Section 127 of Title 23 USC is implemented in the Title 23 of the Code of Federal Regulations, in particular in sections 657 and 658 (*167, 168*). Section 657 provides the requirements for participating states to administer an enforcement program for these vehicle weight limits, including guidelines for the formulation of a plan for enforcement, evaluation of enforcement operations, FHWA certification, and effects of failure to enforce or certify state laws adequately. Section 658 identifies a national network of highways for oversize/overweight (OS/OW) travel and prescribes the national policy for truck and bus size and weights. As such, Section 658 restates the general axle and gross weight limits and state exemptions given in 23USC127, including the option for states to issue special permits without regard to axle weight, gross weight, or Federal Bridge Formula requirements for nondivisible loads. Appendix A of Section 658 lists all routes that are designated federal routes on the national network in addition to interstate highways. In Texas, no additional routes have been federally designated, so federal routes on the national network in Texas include all routes that were designated as federal-aid primary highways prior to June 1, 1991. Appendix C of Section 658 lists the weight and size provisions for LCVs that were in effect before the June 1, 1991, freeze, subject to public law 102-240. Since Texas did not have any special weight and size regulations for LCVs in place before the freeze, there are no regulations listed for Texas in this appendix.

Texas Transportation Code

Title 7 of the Texas Transportation Code Chapters 643, 645, and 646 require TxDOT to regulate motor carriers and motor transportation brokers to protect the welfare of the public and ensure fair treatment of consumers by household goods carriers (*169, 170, 171*). Additional requirements for TxDOT to prevent highway damage caused by overweight commercial motor vehicles can be found in Texas Transportation Code Chapters 201 and 370 (*172, 173*).

Transportation Code Chapter 621 defines single and tandem axle weights: a single axle weight is the total weight transmitted to the road by all wheels whose centers may be included between two parallel transverse vertical planes 40 in. apart, extending across the full width of the vehicle (*174*). A tandem axle weight is the total weight transmitted to the road by two or more consecutive axles whose centers may be included between parallel transverse vertical planes spaced more than 40 in. and not more than 96 in. apart, extending across the full width of the vehicle (*174*). Figure 13 is an illustration of the definitions for single and tandem axle weights showing a truck from the bird's eye view.

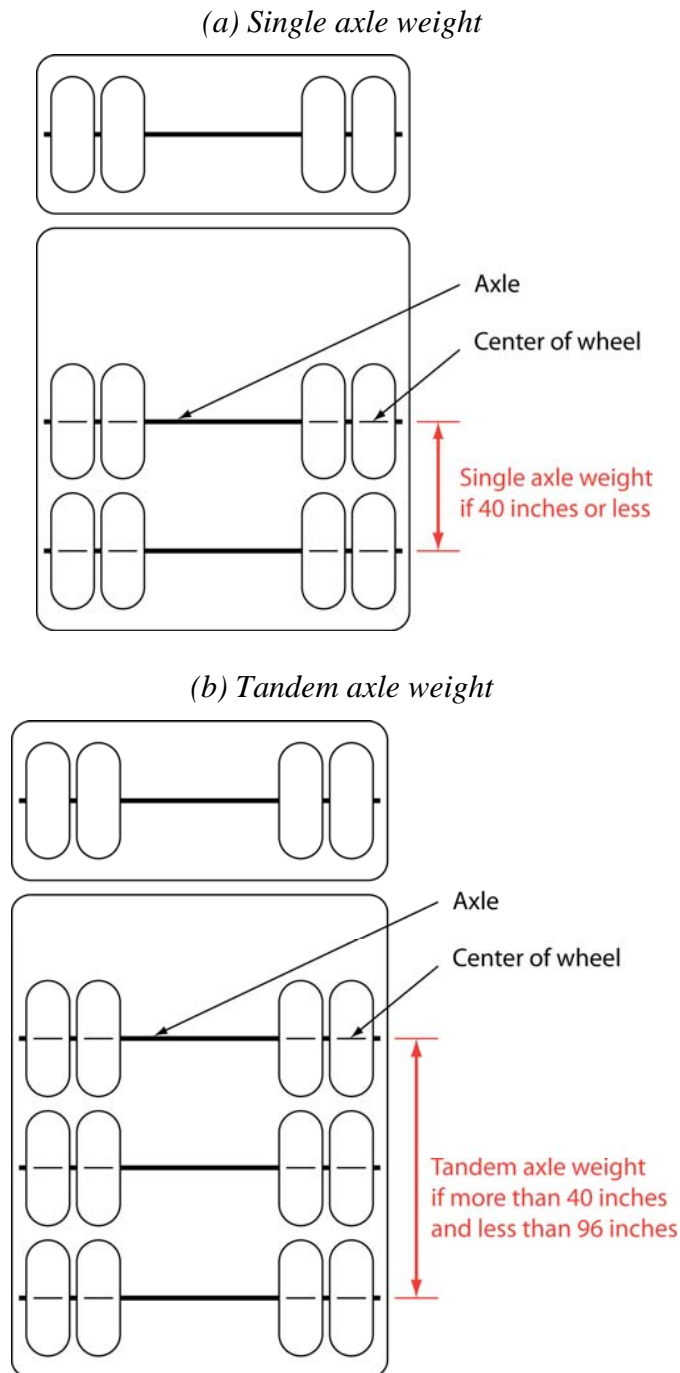


Figure 13. Definition of Single Axle and Tandem Axle Weight in the Texas Transportation Code.

Texas Transportation Code Section 621.101 provides the maximum axle and gross weights applicable for vehicles on highways in Texas, which follows the same limitations set forth in the United States Code (Table 39). Chapters 622 and 623, however, provide a number of special provisions and exceptions for oversize and overweight vehicles (175, 176). Most of the vehicles described in Chapter 622 do not need a permit, although a surety bond is required for some

vehicle types. Only certain heavy equipment and oil well servicing and drilling machinery requires a permit. Table 39 summarizes the maximum axle load and gross weight restrictions of Chapters 622 and 623.

Table 39. Weight Limitations in the Texas Transportation Code (175, 176).

	Maximum Axle Load (lb)		Maximum Gross Weight (lb)	Section	Permit
	Single Axle	Tandem Axle			
General	20,000	34,000	by formula, up to 80,000	621.101	None
Ready-Mix Concrete Trucks	23,000 25,300	46,000 50,600	by formula, up to 80,000 if less than 69,000	622.012	Exempt with bond approval
Vehicles transporting milk ¹	68,000 per axle group		-	622.031	Exempt
Vehicles transporting timber or timber products	-	-	80,000 ^a	622.0431 - 622.0435	Exempt
Recyclable Materials Trucks	21,000	44,000	64,000	622.131	Exempt with bond approval
Seed Cotton Transporters	-	-	64,000	622.953	Exempt
Chile Pepper Module Transporters	-	-	54,000	622.953	Exempt
Tow Trucks	-	-	-	622.954	Exempt
Commodity Trucks Crossing Highways	-	-	110,000 ^b	623.052	Contract and bond approval required
Certain Heavy Equipment	-	-	120,000 ^c	623.017, 623.071	Permit and bond required
Oil Well Servicing and Drilling Machinery	-	-	-	623.141	Permit required
Solid Waste	21,000	44,000	64,000	623.161	Exempt with bond approval

¹ If distance between front wheel of forward tandem axle and rear wheel of rear tandem axle is 28 ft or more.

^a If vehicle is not longer than 90 ft, is not a truck tractor, and travels 125 miles or less, using an outer bridge of 39 ft or more except on bridges with lower maximum loads.

^b If vehicle is transporting grain, sand, stones, rock, caliche, or other commodity.

^c Cylindrical shaped bales of hay, oilfield drill pipe or drill collars stored in a pipe box, implement of husbandry by a dealer, water well drilling machinery and equipment, harvesting equipment, and superheavy equipment that cannot be reasonably dismantled not exceeding.

Texas Administrative Code

The Texas Administrative Code Title 43, Chapter 18 prescribes the policies and procedures for the regulation of motor carriers, transportation brokers, and other transportation businesses (177). Chapter 18 has six subchapters that cover general provisions, motor carrier registration, records and inspections, motor transportation, consumer protection, and enforcement. Chapter 28 of the Title 43 of the Texas Administrative Code provides regulations for oversize and overweight vehicles and loads (178). This chapter has 11 subchapters that provide general provisions; detail regulations for several types of overweight permits; and regulations for compliance, records and inspections, and enforcement.

The Texas Administrative Code defines that in general, TxDOT can issue permits for the transportation of cargo that cannot be reasonably dismantled when the gross weight exceeds the limits allowed by law, and several specific types of cargo such as cylindrically shaped bales of hay (179). The Code also states that a permit for an overweight transport is not a guarantee that the highway can safely support the movement, and that the transporter is responsible for any damage to the highway structure or its appurtenances.

The Administrative Code does not define maximum allowable axle weights, but rather provides limits for axle weights for which a permit can be requested. There is no overall maximum gross weight that may be permissible according to the Administrative Code, as long as all axle weights are within the permissible limits. However, some types of permits can only be acquired up to a certain gross weight. Table 40 provides a summary of maximum permissible weight limits for motor vehicles in the Texas Administrative Code.

Table 40. Maximum Permit Weight Limits in the Texas Administrative Code (178).¹

Permit Type	Single Axle (lb)	2-Axle Group (lb)	3-Axle Group (lb)	4-Axle Group (lb)	5-Axle Group (lb)	Trunnion Axle (lb)	Steerable Axle (lb/in. of tire)	Other Axle (lb/in. of tire)	Code Section
General overweight permit	25,000	46,000	60,000	70,000	81,400	60,000	650	650	28.11 (d)
General overweight permit, load restricted roads	22,500	41,400	54,000	63,000	73,260	54,000	650	650	28.11 (d)
Subchapter D single trip permit	25,000	46,000	60,000	70,000	81,400	60,000	650	650	28.12 (b)
Subchapter D single trip permit, load restricted road	22,500	41,400	54,000	63,000	73,260	54,000	650	650	28.12 (b)
Subchapter D single trip permit, self-propelled off road vehicle	45,000	-	-	-	-	-	650	650	28.12 (b)
Single-trip mileage permit, oil well related and unladen lift equipment vehicle	30,000 ^a	-	-	-	-	-	950	850	28.42 (b), 28.62 (b)
Quarterly hubometer permit, oil well related vehicle and unladen lift equipment vehicle	30,000 ^a	-	-	-	-	-	950	850	28.43 (b), 28.63 (b)
Annual permit, oil well related vehicle	25,000	-	-	-	-	-	850	-	28.44 (a)
Annual permit, unladen lift equipment vehicle ²	25,000	46,000	60,000	70,000	81,400	60,000	650	650	28.64 (a)
Annual permit, unladen lift equipment vehicle, load restricted roads ³	22,500	41,400	54,000	63,000	73,260	54,000	650	650	28.64 (a)
Port of Brownsville port authority permit ³	25,000	46,000	60,000	70,000	81,400	60,000	650	650	28.92 (c)
Chambers County permit ⁴	25,000	46,000	60,000	70,000	81,400	60,000	650	650	28.102 (c)

¹ For axle groups with an axle spacing of less than 12 ft. The lesser of axle group weight or weight per in. of tire applies.

² For vehicles not exceeding 120,000 lb gross weight.

³ For vehicles not exceeding 125,000 lb gross weight.

⁴ For vehicles not exceeding 100,000 lb gross weight.

^a Single axle not connected to another axle by a weight equalizing suspension system.

TXDOT MOTOR CARRIER DIVISION

The TxDOT Motor Carrier Division (MCD) consists of three sections: the Business Services Section, the OS/OW Permit Section, and the Motor Carrier Operations Section (Figure 14). The OS/OW Permit Section has five branches, two Single Trip Routed Permits Branches, one Special Services Permits Branch, the Permit Applications & TPM Programs Branch, and the Super Loads Permits Branch. The division is an active member of the Western Association of State Highway and Transportation Officials (WASHTO) and Southeastern Association of State Highway and Transportation Officials (SASHTO).

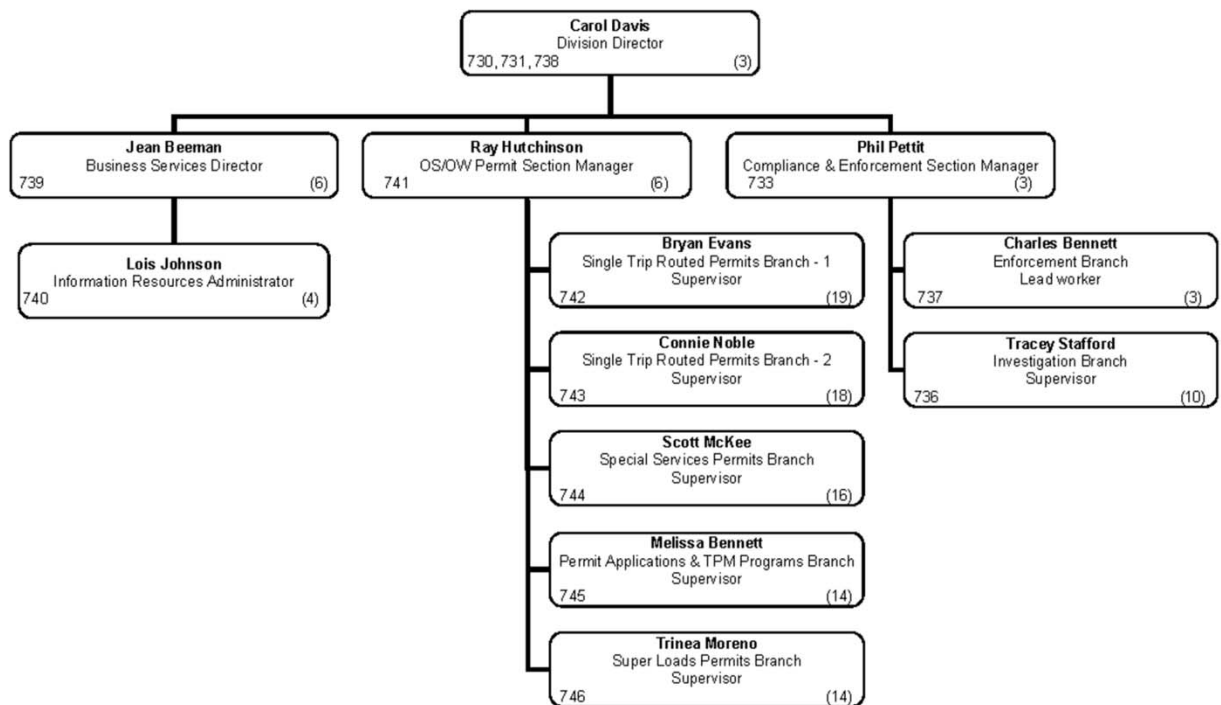


Figure 14. MCD Organizational Chart.

Overweight Permits

MCD handles approximately 500,000 permit applications per year for 25 different types of OS/OW permits and generates annual revenue of over \$100 million, which makes the MCD OS/OW Permit Section one of the largest OS/OW load permitting offices in the United States. Transportation Code Chapter 623 defines permits for oversize or overweight vehicles. Table 41 provides a listing of permit types and descriptions for overweight loads that are issued by MCD.

Table 41. Types and Authorization for Overweight Load Permits Issued by MCD (174, 176, 180, 181).

Permit Name	Permit Description	Permit Applicability	Section
<i>Permit for Excess Axle or Gross Weight</i>	Annual permits for loads that cannot be reasonably dismantled (over axle/over gross weight tolerances permit)	<ul style="list-style-type: none"> • valid for vehicles registered for a maximum gross weight of 80,000 lb • allows axle weights up to 110% of the allowable axle weight and a gross weight of up to 105% of the allowable gross weight • excludes movements on interstate highways and load-posted bridges when exceeding posted limits unless the bridge is the only public vehicular access to the permit holder's origin or destination • permit can be issued for one or more counties 	Subchapter B (623.011 – 623.019)
<i>Contract for Crossing Roads</i>	Permit to cross a highway from private property to other private property	<ul style="list-style-type: none"> • grain, sand, or another commodity or product transporters with a gross weight up to 110,000 lb • unlicensed vehicles transporting sand, gravel, stones, rock, caliche, or similar commodity 	Subchapter C (623.051 – 623.052)
<i>Permit to Move Certain Heavy Equipment</i>	Single-trip, 30, 60, and 90-day permit for overweight (and oversize) loads (general oversize/overweight permit)	• oilfield drill pipe or drill collars stored in a pipe box using farm-to-market or ranch-to-market roads	Subchapter D (623.071 – 623.082)
	Single-trip, 30, 60, and 90-day permit for the transportation of cylindrically shaped bales of hay	• cylindrical shaped bales of hay	623.071
	Annual permit for superheavy equipment (annual envelope permit)	<ul style="list-style-type: none"> • loads that cannot be reasonably dismantled up to 120,000 lb • up to 12 ft wide, 110 ft long, 14 ft high • may be issued to a truck or a company 	623.071

Permit Name	Permit Description	Permit Applicability	Section
	Annual permit for water well drilling machinery and implements of husbandry	<ul style="list-style-type: none"> • water well drilling machinery • farm/harvesting equipment • movement of an implement of husbandry by a dealer 	623.071
	Single-trip permit for a superheavy load. Requires analysis and routing by a TxDOT engineer	<ul style="list-style-type: none"> • vehicle exceeding 200,000 lb with axle spacing less than 95 ft • vehicles exceeding 254,000 lb regardless of axle spacing. 	623.078
<i>Oil Well Servicing Units and Drilling Machinery Permit</i>	Single-trip, quarterly, and annual permit for oil well machinery	<ul style="list-style-type: none"> • movement of oil well servicing and drilling permits 	Subchapter G (623.141-623.150)
<i>Unladen Lift Equipment Motor Vehicle Permit</i>	Single-trip, quarterly, and annual permit for the movement of unladen lift equipment motor vehicles (mobile crane permit)	<ul style="list-style-type: none"> • motor vehicles designed for use as lift equipment 	Subchapter I (623.181-623.182) and Subchapter J (623.191 – 623.200)
<i>Multi-State Permit</i>	Single-trip permit under reciprocal agreement with a state participating in the WASHTO Western Regional Permitting program	<ul style="list-style-type: none"> • single axle weight up to 21,500 lb • tandem axle weight up to 43,000 lb • tridem axle weight up to 53,000 lb • gross weight up to 160,000 lb • valid on highways of the regional network only 	621.003
<i>Temporary Registration Permit</i>	Single-trip, 72 hour, or 144 hour permit	<ul style="list-style-type: none"> • for commercial vehicles and buses owned by residents of the U.S., Canada, or Mexico • allows the operator of vehicle to temporarily increase the maximum allowable weight for which a vehicle has been registered, up to the state axle and gross weight limits 	502.352

There are also a number of overweight load permits or authorizations in Chapter 623 that are not administered by MCD, as summarized in Table 42.

Table 42. Other Overweight Load Permits and Authorizations in the Texas Transportation Code (176).

Permit Name	Permit Description	Permit Applicability	Section
<i>Authorization for Vehicles Transporting Solid Waste</i>	Solid waste transporters that carry a surety bond and present a copy to an officer authorized to enforce this section upon request.	<ul style="list-style-type: none"> • vehicles with single axle weight up to 21,000 lb • tandem axle weight up to 44,000 lb • gross weight up to 64,000 lb • excludes movements on interstate highways 	Subchapter H (623.161 – 623.182)
<i>Port Authority Permit</i>	Permit for the movement of overweight (or oversize) load.	<ul style="list-style-type: none"> • movements on state highways contiguous to the Gulf of Mexico or a bay or inlet opening into the Gulf and bordering Mexico • The Port of Brownsville and the Port of Victoria have authority to issue this permit. 	Subchapter K (623.210 – 623.219)
<i>Victoria County Navigation District Permit</i>	Permit for the movement of overweight (or oversize) load in Victoria County.	<ul style="list-style-type: none"> • certain portions of FM 1432 • vehicles with a gross weight up to 125,000 lb 	Subchapter L (623.230 – 623.239)
<i>Chambers County Permit</i>	Permit for the movement of overweight (or oversize) load in Chambers County.	<ul style="list-style-type: none"> • certain portions of FM 1405 • a portion of the SH 99 frontage road • certain portions of FM 565 • certain portions of FM 2354 • vehicles with a gross weight up to 100,000 lb 	Subchapter M (623.250 – 623.254)

Table 39. Other Overweight Load Permits and Authorizations in the Texas Transportation Code (176) (Continued).

Permit Name	Permit Description	Permit Applicability	Section
<i>Port of Corpus Christi Authority Permit</i>	Permit for the movement of overweight (or oversize) load on a roadway owned by the Port of Corpus Christi Authority.		Subchapter O (623.280 – 623.288)
<i>Port of Corpus Christi Authority Special Freight Corridor Permit</i>	Permit for the movement of overweight (or oversize) load on a roadway owned by the Port of Corpus Christi Authority.		Subchapter O (623.301– 623.310)

A permit does not guarantee that the overweight movement can be made without damage to the highway, and many permits require the execution of surety bonds prior to the movement, in case there is damage to the highway. Other permits require a highway maintenance fee that increases with the gross weight of the vehicle, and for vehicles heavier than 200,000 lb a vehicle supervision fee that includes the cost for a bridge structural analysis, monitoring of trip progress, and movement of traffic control devices. Some permits are issued by rule of the Texas Transportation Commission. For these permits, specific language for applicability, limits, and requirements are not included in the Transportation Code. Regulations with respect to permit fees, validity period, and others for these permits are thus the responsibility of the Texas Transportation Commission, who must develop and pass the regulation by rule.

Permits for superheavy loads following section 623.078 require that TxDOT provide a specific route for the movement that the permit holder must follow. This type of permit, which is valid for a single movement only, is the most frequently issued permit at MCD and accounts for about 65–70 percent of the total permits issued by the office. Although routed permits for superheavy loads are the most frequently issued permit, superheavy loads are not the most frequent overweight load transports on the highway system. MCD issues other types of permits that are valid for unlimited trips over the duration of several weeks up to a year and thus may produce numerous trips using one permit. Figure 15 provides a sample of a single-trip, routed overweight permit for a movement with a gross weight of 92,000 lb.

In 2008, the number of annual and routed permits the division issued reached a peak of about 580,000. More recently, this number has decreased by about 20 percent due to reduced demand for permits that might be attributed to a general economic slowdown. MCD’s mission is to find a way to route OS/OW loads to their destinations following state and federal regulations and without undue damage to the TxDOT maintained infrastructure. In addition, when MCD determines a route it must consider numerous local restrictions such as height, size, and weight limitations. Frequently, the office has to develop innovative solutions to allow the delivery of heavy loads.



Texas Oversize/Overweight Single Trip Permit and/or Temporary Registration

Name: [REDACTED]	Permit Number: [REDACTED] 4825
Address: [REDACTED]	Issued On : 11/30/2009 Time: 15:49:01
Account: [REDACTED] Phone: [REDACTED]	Effective : 11/30/2009
Applicant: [REDACTED]	Expiration : 12/04/2009
	Permit Officer : [REDACTED]

Load Description: JOHN DEERE 624J FORKLIFT	Gross Weight: 92,000
Max. Width: 10' 0" Max Height: 13' 6" Max. Length: Legal	ROH: Legal FOH: Legal

Axle:	1	2	3	4	5
Distances:	19	4	36	4	
Weights:	12,000	20,000	20,000	20,000	20,000
# of Tires:	2	4	4	4	4
Tire Sizes:	11	11	11	11	11

Truck:	Trailer:	Temporary Registration	
2001 / Peterbilt		Truck	Trailer
18443		Start:	Start:
P589523 / IL		End:	End:

Route Description:	Starting City: TOMBALL	Ending City: NM LINE
...JCT TIMBERTECH LN/SH249n, X-OVER @ NORTHPOINT BLVD TO SH249s, N.BW8.FRw/s, IH10w, SAN ANTONIO E.LP1604n/w, IH10w...		
BEXAR COUNTY/8PM TO 6AM: CAUTION MUST BE USED ON ALL STATE MAINTAINED HIGHWAYS WHEN TRAVELING ON OR INSIDE LP1604 DUE TO NIGHTLY LANE OR HIGHWAY CLOSURES; LOADS MAY BE DIVERTED TO FRONTAGE ROADS OR CITY STREETS.		
THIS IS A LOWBOY TRAILER LOAD #2777042		

Special Conditions:

Use caution at all railroad crossings. Railroad crossing hotline: 1-888-877-7267.

Permit is valid for one trip only. Not valid without movement conditions sheet attached.

Escorts: Over 14' wide, or 110' long = one escort. Over 16' wide, or 125' long = two escorts.

Over 17' high = front escort with height pole. Over 18' high = front escort with height pole and rear escort.

If the load is over two dimensions that require escorts, then front and rear escorts are required.

A rear escort is required when the front or rear overhang exceeds 20'. When one escort is required, escort should be in front on a two lane hwy and in rear on a multi-lane highway. Only overweight/overlength loads may travel IH35 inside travel lane in Austin.

Self-propelled oil well servicing units that do not exceed 9' wide, 14' high, or 65' long are allowed night movement.

All loads exceeding 8'6" wide and/or 13'6" high may not travel on the main lanes of IH35 between US183/SH71 in Austin.

El Paso District: Over 17'6" high= front escort with height pole.

Odessa, San Angelo & Abilene Districts: Over 16' wide= one escort. Over 18' wide= front & rear escorts.

Odessa, San Angelo & Abilene Districts: 16' wide & 95' long combination = front & rear escorts. Over 18' high =front escort with height pole.

Lubbock District-Gaines & Dawson Counties only: Over 16' wide= one escort. Over 18' wide= front & rear escorts.

Lubbock District-Gaines & Dawson Counties only: 16' wide & 95' long combination = front & rear escorts. Over 18' high =front escort with height pole.

 Amadeo Saenz Jr., P.E., Executive Director Texas Department of Transportation	Payment Method : PAC	Permit Fee:	\$30.00
	Trace # : [REDACTED]	Registration Fee:	\$0.00
	Wire Co. Name:	Overweight Fee:	\$150.00
	Permit Destination: McDonough, GA.	Other Fee:	\$30.00
	Amendments :	Total Fee:	\$210.00

State law requires permit to be carried in vehicle until one day after expiration.
For more information, call the Texas "One Stop Shop" toll free number at 1-800-299-1700 or
visit our website at www.txdot.gov .

Figure 15. Sample Single Trip Permit.

TXDOT OVERWEIGHT PERMITTING PROCESS

The permitting process at MCD mainly includes the following four steps:

1. **Application Submission.** To apply for a permit, a customer needs to first submit an application for an overweight permit to MCD. Specialists at the Permit Applications & TPM Program branch take all applications that MCD receives and input the information into the queue for the correct permit type. MCD receives about 75 percent of their applications online through their central permitting system (CPS). The rest are submitted through phone, fax, and mail. Very rarely, customers submit applications in person at district offices, which then submit the application to MCD.
2. **Application Processing.** After permit application information enters into the permitting system, the information is passed to the appropriate permit specialist based on the conditions of the application. The specialist extracts required information about loads, origins, and destinations, and determines the correct permit type. If the permit requires a defined route, the specialist will identify a suitable route that does not have restrictions or other barriers. Permit applicants sometimes indicate preferred routes in their applications. In these cases, permit specialists will need to verify the preferred route against the restriction map as well as the temporary restrictions and approve the routes or otherwise identify an alternative permittable route.
3. **Permit Delivery.** Upon approval of an application, MCD will issue a permit and mail the permit to the applicant.
4. **Post Processing.** In some cases, customers find the route provided by MCD is not optimal, or may request an alternative route. Upon receipt of a request for an alternative route, MCD reviews the request and if the movement is possible on the requested route, may issue a permit amendment or a new permit, as necessary. The special services permits branch handles all special permits as well as permit amendments.

The goal of MCD is to process 90 percent of the general permits within 90 minutes after they are submitted. On a busy day, many permits may actually take up to 120 minutes. Processing applications for superheavy load permits takes much longer, frequently weeks, due to the separate analyses needed for those permits.

The most challenging activity in the permitting process is the identification of appropriate routes for superheavy loads. As described in the previous sections, numerous regulations, special permits, and exceptions allow overweight loads, with different regulations for federal and state highways. Depending on the specifics of the load that needs to be routed, interstate highways may or may not be included. In some cases, it is necessary to use county roads, for which a permit cannot be obtained through MCD but must be acquired from the County, which results in a route that ends at the county road and starts up again at the next state highway.

The main difficulty of identifying an appropriate route for overweight loads is to ensure that the route complies with current local highway restrictions. Currently, this is a manual process that starts with a current set of district highway maps and numerous folders that contain memos and

descriptions of highway restrictions in each district. Each MCD routing specialist must then systematically and meticulously transcribe all restrictions from the memo sheets to the district maps to create a set of district maps with current highway restrictions. To determine an appropriate route, the MCD specialist reviews his restriction map set and develops a route by selecting the shortest possible route between requested origin and destination that does not violate a restriction. The restriction map set must be carefully updated every morning when MCD receives updates on current and new restrictions from district officials.

MCD primarily relies on individual districts for temporary restriction information. Districts are supposed to notify MCD at least 24 hour prior to a temporary restriction goes into effect and update the information with MCD as soon as it is canceled. One issue that MCD has identified is the communication between MCD and district staff. MCD is dependent on information from the districts about new restrictions and old restrictions that are no longer required. For the most part, districts are very pro-active about new restrictions and notify MCD in a timely manner. However, districts are less efficient with regard to notifying MCD when an existing, temporary restriction is no longer needed. Occasionally, district restrictions affect routing at MCD long after the restriction is no longer required because MCD was not notified to remove the restriction.

Communication issues between MCD and districts were also one of the findings from the Oversize/Overweight Working Group that consists of engineers from the north and east Texas (NETx) district and division representatives. A meeting of maintenance and operations engineers in Tyler in November 2006 resulted in the formation of a “Superheavy and Overweight Load/Seal Coat Damage Prevention Work Group,” consisting of staff from NETx districts, MCD, the Construction Division (CST), and MNT (182). The kick-off meeting of this working group occurred in April 2007 and resulted in eight key issues that were subsequently reduced to the topic areas of reduce seal coat damage, improve route options for OS/OW loads by maintaining open corridors, and improve communications between districts and divisions regarding OS/OW routes.

Based on these objectives, the working group identified problem areas and developed a list of major action items or concerns. Table 43 summarizes issues related to improving communication between districts and divisions, which illustrate the need for the development of a business process to improve communication and coordination of stakeholders.

Table 43. Action Items or Concerns Expressed by NETx Engineers (182).

Description of Action Item or Concern	Potential Solution	Additional Needs
Districts do not always tell MCD about carriers not complying with routes or other permit requirements.	GroupWise account and enforcement.	Better education of process to districts.
MCD permit coordinators do not always inform districts of permit issue and expiration dates.	Establish GroupWise proxy account.	TxPROS will allow districts to view routing info.
District route restrictions must be kept current.	Better communication from MCD to districts.	Review restrictions quarterly.
Districts are not being notified by carriers as load is moved even though instructed to do so.	Enforcement, carrier, and MCD meetings.	Technology to track permit load via satellite.
Better communication from seal coat contractor since work is done on county basis and unpredictable.	Better communication from contractor to TxDOT.	Penalty for not complying.
Districts must discuss with each other open routes and construction plans.	GroupWise proxy account.	Each district has two N-S corridors, one always open.

The research team confirmed that MCD has dedicated map coordinators who coordinate with districts closely to verify restrictions and update existing information. MCD also conducts quarterly routine verifications with individual districts to update all temporary restrictions.

Staffing and Quality Control

To ensure productive and high-quality operations, the MCD permitting section has established effective staff training programs and quality control mechanisms. Staff are sufficiently trained and tested before they can participate in the highly technical application process. Each branch within the office has an efficient management hierarchy consisting of team leaders, lead workers, and regular permit specialists. Permitting specialists must have a 94 percent overall accuracy rate. A quality inspection team conducts daily quality inspection of permits randomly drawn from each permit specialist. Inspection results are also reflected in staff performance evaluations. The inspection also allows the office to identify incorrect permits and correct them before the movement occurs on unsuitable roadways.

TxPROS

TxPROS is an automatic OS/OW load permit processing system that is currently under development. The new system will have a permitting component and a GIS map component and is based on an Oracle database. Compared to the current permitting process that heavily involves manual processing, the upcoming system has several advantages. For example, it can apply restrictions automatically to all permits as soon as they are entered into the system. When a new restriction comes into effect, the system can also identify all affected on-going permits and send

out notifications to customer automatically. MCD has been using the beta version of TxPROS for testing. Some users will be able to use the system in 2010 for further testing and feedback. The final public release of the system is currently scheduled at the end of 2010.

Currently, TxDOT only permits routes on the state highway system. Customers will need to coordinate with affected counties and/or cities in order to travel on off-system roadways to the final destinations. TxPROS is designed to have the ability for multi-jurisdictional routings, although TxDOT currently does not have authority to route OW/OS loads on off-system roadways. Some counties and cities (e.g., Harris County) have started efforts to modify relevant regulations and laws so that MCD can route loads on their roadways as well. It is MCD's intention that TxPROS can operate on a roadway network combining all on- and off- system roadways with restrictions directly inputted from TxDOT as well as counties and cities.

TxPROS will provide a wealth of data, including a GIS map of routes assigned for superheavy loads. This map will allow TxDOT to identify routes that are more heavily impacted by superheavy loads. MCD has also plans to convert the last four years of permits in the current CPS and enter them into the TxPROS.

TxPROS has two methods to limit travel on specific network routes, which are temporary restrictions and impedances. In TxPROS, all restrictions and impedances are applied to a network segment.

- **Temporary Restrictions.** Temporary restrictions disallow the movement of a restricted load over that segment and effectively block the segment for inclusion in the routing determination.
- **Impedances.** TxPROS uses impedances to identify the optimum route when multiple options are available. An example of a TxPROS impedance is roadway length. TxPROS permitting specialists can manually adjust the length values of certain road sections so that road selections for routes are more balanced over the road network, or to encourage the system to use more preferred routes.

According to MCD, if locations of buried, critical utility infrastructure can be identified, the information would be most likely used as a load restriction in the system so that unsuitable loads are not routed over the buried utility. Alternatively, wear and tear on the utility facility could be reduced by introducing a local segment impedance.

Preliminary Business Process for TxDOT Overweight Routing Coordination

In the research proposal, the research team outlined a procedure to develop a preliminary business process for the coordination of TxDOT overweight routing activities between MCD and other organizational units within TxDOT, for the purpose of sharing information about locations of critical, buried utility infrastructure. The main steps of that procedure would be to identify the organizational units within TxDOT that have data about critical, buried utility infrastructure; identify and describe the format and content of that data; and describe a method to exchange that data among TxDOT units and integrate the information with MCD's overweight permitting process.

The research team found that currently there is no organizational unit within TxDOT that could provide data on critical, buried utility infrastructure. Furthermore, the team was thus far unable to identify locations of critical, buried utility infrastructure with the help of utility stakeholders, although the research team has taken several steps to reach out to the utility community. These outreach efforts included a general review of trade magazines, newspapers, and journals focusing on utilities damaged by overweight transports; a letter from the Right of Way Division to utility stakeholders requesting information about utility lines that were damaged or were suspected to be damaged due to overweight load transports in Texas; a review of emergency work authorizations of the Utility Installation Review system; and numerous follow-up phone calls to utility representatives, as described in more detail in Chapter 6.

Since the efforts to locate critical, buried utility infrastructure did not produce the results that the research team anticipated, the research team, with concurrence of the project monitoring committee, intensified activities in the search for damages to buried utility infrastructure in the second half of the first project year. The research team targeted four districts with known large numbers of overweight traffic (Beaumont, Houston, Corpus Christi, and Fort Worth) inquired at the district and area office level about known sections with heavy overweight traffic and used that information to contact local water and sewer utilities to inquire about utility lines on those sections with suspected damage. These efforts are also described in more detail in Chapter 6. However, they did not produce any cases of buried utilities damaged by overweight loads.

Since the research team was unable to find any cases of buried utilities damaged by overweight loads, there was no opportunity to develop a preliminary business process for TxDOT overweight routing coordination to protect critical buried utility infrastructure. Instead, the research team proposed a modification to the research plan to include the development of this process in the second project year, if needed, as more information from the Phase 2 Utility Damage Evaluation becomes available.

CHAPTER 5. ANALYSIS OF OVERWEIGHT LOADS ON TXDOT HIGHWAY SYSTEM

INTRODUCTION

The TxDOT Motor Carrier Division (MCD) provided the research team with six fiscal years (2004–2009) of overweight load permit history for analysis and reporting purposes. The raw data were in the format of dBase V databases tables. Table 44 shows the number of records available for each year, the percent increase of overweight load permits from one year to the next, and the total number of records available to the research team. The raw dataset includes about half a million overweight load permits annually. From 2004 to 2009, the increase in processed permits was more than 19 percent, equivalent to an average annual increase of about 3.8 percent per year. From 2008 to 2009 the number of processed permits decreased by about 9 percent.

Table 44. Total Overweight Load Permits.

Fiscal Year	Number of Permits	Percent Increase
2004	445,081	
2005	482,230	8.3%
2006	523,474	8.6%
2007	556,338	6.3%
2008	582,583	4.7%
2009	529,900	−9.0%
Total	3,119,606	

The goal of the data processing was to analyze the route descriptions and convert the available text information into route segments that could then be converted to route features in a GIS. The outcome of the process would be a geodatabase that would contain route features of permitted overweight truck movements for fiscal years 2004 through 2009. The geodatabase could then be used for example to display permitted overweight routes on a map of Texas highways.

OVERWEIGHT ROUTE DATA PROCESSING

Initial Data Analysis

The first step of the initial data analysis was to import the route information into a Microsoft Access 2007 database in order to perform a review of the data structure. The oversize/overweight load permits database consists of 128 fields in one table that is not normalized. Table 45 provides an overview of the fields of the oversize/overweight load permits database table along with field type, field, size, and field description, and thus provides the complete data structure of the overweight load route permit data provided by TxDOT.

Table 45. Structure of Overweight Load Route Permits Database Table.

Field Name	Field Description	Type	Size
PERMIT_NBR	TxDOT Assigned Permit Number	Text	12
PERMIT_TYP	TxDOT Assigned Permit Type	Text	50
TRUCK_YR	Year of Semi Truck's Manufacture	Text	4
TRUCK_MAKE	Manufacturer of Semi Truck	Text	30
LOAD_DESC	Permit Load Description	Text	50
WIDTH_FT	Semi Truck Width in Feet	Double	8
WIDTH_IN	Semi Truck Width in Inches	Double	8
LEGAL_WIDT	Semi Truck Legal Width	Text	1
HEIGHT_FT	Semi Truck Height in Feet	Double	8
HEIGHT_IN	Semi Truck Height in Inches	Double	8
LEGAL_HEIG	Semi Truck Legal Height	Text	1
LENGTH_FT	Semi Truck Length in Feet	Double	8
LENGTH_IN	Semi Truck Length in Inches	Double	8
LEGAL LENG	Semi Truck Legal Length	Text	1
FOH_FT	Semi Truck FOH Length in Feet	Double	8
FOH_IN	Semi Truck FOH Length in Inches	Double	8
LEGAL_FOH_	Semi Truck FOH Legal Length	Text	1
ROH_FT	Semi Truck ROH Length in Feet	Double	8
ROH_IN	Semi Truck ROH Length in Inches	Double	8
LEGAL_ROH_	Semi Truck ROH Legal Length	Text	1
WEIGHT	Semi Truck Weight	Double	8
WEIGHT_OVE	Semi Truck Weight Over	Text	1
WEIGHT_RED	Semi Truck Weight Red	Text	1
LEGAL_WEIG	Semi Truck Legal Weight	Text	1
ROUTE_START	TxDOT Permit Route Start City Name	Text	30
ROUTE_END	TxDOT Permit Route End City Name	Text	30
ROUTE_DESC	TxDOT Permit Route Description	Text	255
PERMIT_STA	TxDOT Permit Start Date	Date/Time	8
PERMIT_END	TxDOT Permit End Date	Date/Time	8
SPACING1	Semi Truck Spacing 1st Increment	Double	8
SPACING2	Semi Truck Spacing 2nd Increment	Double	8
SPACING3	Semi Truck Spacing 3rd Increment	Double	8
SPACING4	Semi Truck Spacing 4th Increment	Double	8
SPACING5	Semi Truck Spacing 5th Increment	Double	8
SPACING6	Semi Truck Spacing 6th Increment	Double	8
SPACING7	Semi Truck Spacing 7th Increment	Double	8
SPACING8	Semi Truck Spacing 8th Increment	Double	8
SPACING9	Semi Truck Spacing 9th Increment	Double	8
SPACING10	Semi Truck Spacing 10th Increment	Double	8
SPACING11	Semi Truck Spacing 11th Increment	Double	8
SPACING12	Semi Truck Spacing 12th Increment	Double	8
SPACING13	Semi Truck Spacing 13th Increment	Double	8
SPACING14	Semi Truck Spacing 14th Increment	Double	8
SPACING15	Semi Truck Spacing 15th Increment	Double	8
SPACING16	Semi Truck Spacing 16th Increment	Double	8
SPACING17	Semi Truck Spacing 17th Increment	Double	8
SPACING18	Semi Truck Spacing 18th Increment	Double	8

**Table 43. Structure of Overweight Load Route Permits Database Table
(Continued).**

Field Name	Field Description	Type	Size
SPACING19	Semi Truck Spacing 19th Increment	Double	8
SPACING20	Semi Truck Spacing 20th Increment	Double	8
SPACING21	Semi Truck Spacing 21st Increment	Double	8
SPACING22	Semi Truck Spacing 22nd Increment	Double	8
SPACING23	Semi Truck Spacing 23rd Increment	Double	8
SPACING24	Semi Truck Spacing 24th Increment	Double	8
WEIGHT1	Semi Truck Weight 1st Increment	Double	8
WEIGHT2	Semi Truck Weight 2nd Increment	Double	8
WEIGHT3	Semi Truck Weight 3rd Increment	Double	8
WEIGHT4	Semi Truck Weight 4th Increment	Double	8
WEIGHT5	Semi Truck Weight 5th Increment	Double	8
WEIGHT6	Semi Truck Weight 6th Increment	Double	8
WEIGHT7	Semi Truck Weight 7th Increment	Double	8
WEIGHT8	Semi Truck Weight 8th Increment	Double	8
WEIGHT9	Semi Truck Weight 9th Increment	Double	8
WEIGHT10	Semi Truck Weight 10th Increment	Double	8
WEIGHT11	Semi Truck Weight 11th Increment	Double	8
WEIGHT12	Semi Truck Weight 12th Increment	Double	8
WEIGHT13	Semi Truck Weight 13th Increment	Double	8
WEIGHT14	Semi Truck Weight 14th Increment	Double	8
WEIGHT15	Semi Truck Weight 15th Increment	Double	8
WEIGHT16	Semi Truck Weight 16th Increment	Double	8
WEIGHT17	Semi Truck Weight 17th Increment	Double	8
WEIGHT18	Semi Truck Weight 18th Increment	Double	8
WEIGHT19	Semi Truck Weight 19th Increment	Double	8
WEIGHT20	Semi Truck Weight 20th Increment	Double	8
WEIGHT21	Semi Truck Weight 21st Increment	Double	8
WEIGHT22	Semi Truck Weight 22nd Increment	Double	8
WEIGHT23	Semi Truck Weight 23rd Increment	Double	8
WEIGHT24	Semi Truck Weight 24th Increment	Double	8
WEIGHT25	Semi Truck Weight 25th Increment	Double	8
TIRES1	Semi Truck 1st Tire	Double	8
TIRES2	Semi Truck 2nd Tire	Double	8
TIRES3	Semi Truck 3rd Tire	Double	8
TIRES4	Semi Truck 4th Tire	Double	8
TIRES5	Semi Truck 5th Tire	Double	8
TIRES6	Semi Truck 6th Tire	Double	8
TIRES7	Semi Truck 7th Tire	Double	8
TIRES8	Semi Truck 8th Tire	Double	8
TIRES9	Semi Truck 9th Tire	Double	8
TIRES10	Semi Truck 10th Tire	Double	8
TIRES11	Semi Truck 11th Tire	Double	8
TIRES12	Semi Truck 12th Tire	Double	8
TIRES13	Semi Truck 13th Tire	Double	8
TIRES14	Semi Truck 14th Tire	Double	8

**Table 43. Structure of Overweight Load Route Permits Database Table
(Continued).**

Field Name	Field Description	Type	Size
TIRES15	Semi Truck 15th Tire	Double	8
TIRES16	Semi Truck 16th Tire	Double	8
TIRES17	Semi Truck 17th Tire	Double	8
TIRES18	Semi Truck 18th Tire	Double	8
TIRES19	Semi Truck 19th Tire	Double	8
TIRES20	Semi Truck 20th Tire	Double	8
TIRES21	Semi Truck 21st Tire	Double	8
TIRES22	Semi Truck 22nd Tire	Double	8
TIRES23	Semi Truck 23rd Tire	Double	8
TIRES24	Semi Truck 24th Tire	Double	8
TIRES25	Semi Truck 25th Tire	Double	8
SIZE1	Semi Truck 1st Size	Double	8
SIZE2	Semi Truck 2nd Size	Double	8
SIZE3	Semi Truck 3rd Size	Double	8
SIZE4	Semi Truck 4th Size	Double	8
SIZE5	Semi Truck 5th Size	Double	8
SIZE6	Semi Truck 6th Size	Double	8
SIZE7	Semi Truck 7th Size	Double	8
SIZE8	Semi Truck 8th Size	Double	8
SIZE9	Semi Truck 9th Size	Double	8
SIZE10	Semi Truck 10th Size	Double	8
SIZE11	Semi Truck 11th Size	Double	8
SIZE12	Semi Truck 12th Size	Double	8
SIZE13	Semi Truck 13th Size	Double	8
SIZE14	Semi Truck 14th Size	Double	8
SIZE15	Semi Truck 15thSize	Double	8
SIZE16	Semi Truck 16th Size	Double	8
SIZE17	Semi Truck 17thSize	Double	8
SIZE18	Semi Truck 18th Size	Double	8
SIZE19	Semi Truck 19th Size	Double	8
SIZE20	Semi Truck 20th Size	Double	8
SIZE21	Semi Truck 21st Size	Double	8
SIZE22	Semi Truck 22nd Size	Double	8
SIZE23	Semi Truck 23rd Size	Double	8
SIZE24	Semi Truck 24th Size	Double	8
SIZE25	Semi Truck 25th Size	Double	8

The table's PERMIT_NBR field provides a unique number for each permit in the table. However, the subsequent analysis showed that multiple records in the database may have the same permit number, and thus PERMIT_NBR is not a unique identifier of a record in the database.

The researchers observed that the analysis of overweight load permit route data needed to focus on three data elements, which are highlighted in Table 45 as follows:

- ROUTE_START.
- ROUTE_END.
- ROUTE_DESC.

For the majority of records, the field ROUTE_START provided the starting city of the route, and the field ROUTE_END provided the city in which the route ended. The field ROUTE_DESC provided a description of the specific route between the ROUTE_START and ROUTE_END cities.

The route information provided in the route description field was not immediately ready for use with a GIS because of several reasons:

- The syntax used for route starts, route ends, and route descriptions was not standardized and contained spelling errors, blank entries, and unknown entries.
- Abbreviations used for route starts, route ends, and route descriptions were not consistent.
- The route description field contained multi-line records in which only one line corresponded to the route information.
- Some records contained uncommon characters such as “ Γ ” that cluttered the picture and made it more difficult to use the information.

In order to create route features in a GIS, the research team determined that spelling errors and abbreviation variations of Texas cities in the ROUTE_START and ROUTE_END fields had to be resolved using an intensive data cleaning process.

The research team reviewed the data in the fields ROUTE_DESC, ROUTE_START, and ROUTE_END to get a better understanding of the permit data, determine which portion of the dataset would be useful for further processing, and develop an appropriate data cleaning process. Following the review, the research team classified the data into the following categories:

- **ROUTE_START.** The content of this field was one of the following:
 - A city name.
 - An unprintable character, e.g., carriage return/line feed, which was sometimes followed by additional content on the following lines.
 - The abbreviation “TX.”

- Null, which means the field was empty or more specifically, the content of the field was equal to the ASCII code “null” (i.e., a hexadecimal code of ‘00’).
- The wording “TX 006030058C.”
- **ROUTE_END.** The content of this field was one of the following:
 - A city name.
 - An unprintable character, e.g., carriage return/line feed, which was sometimes followed by additional content on the following lines.
 - The abbreviation “TX.”
 - Null, which means the field was empty or more specifically, the content of the field was equal to the ASCII code “null” (i.e., a hexadecimal code of ‘00’).
- **ROUTE_DESC.** The content of this field was one of the following:
 - A route description with “JCT” or related variation. (“JCT” could appear at the beginning of the record or somewhere within the route description.)
 - A route description starting with a descriptor other than “JCT” (e.g., “IH30w”). (“JCT” or a related variation did not appear in this route description).
 - A city name.
 - An unprintable character, e.g., carriage return/line feed, which was sometimes followed by additional content on the following lines.
 - The abbreviation “TX.”
 - Null, which means the field was empty or more specifically, the content of the field was equal to the ASCII code “null” (i.e., a hexadecimal code of ‘00’).
 - The field started with an uncommon delimiter, e.g., “&.”

Approximately 70 percent of the permits contained a route description with “JCT” or related variation that indicated the junction of two highways. A review of these records found several variations of “JCT,” such as “...JCT,” “..JCT,” “.JCT,” “..**JCT,” “**JCT,” and several others. For those routes that contained a variation of the JCT descriptor, it was necessary to standardize the route description using the standard descriptor “JCT.” Some of the “JCT” variations are shown in Figure 16, which provides a sample of permit route descriptions stored in the route description field.

<p>⌈ JCT 2 MILES EAST OF SH 326 ON US 90w,SH 326n,US 69s,SH 327e,US 96n,e,FM 2246e,SH 62s,SH 12n,e,SH 87s, to JCT IH 10⌈</p> <p>UNIT # 4034</p> <p>..JCT US287/US380e, IH35n, DENTON: NW.LP288e,s, US380e, IH30e...</p> <p>US380: 20K SINGLE AXLE; 34K TANDEM AXLE</p> <p>ICC#259050</p> <p>...JCT RALPH FAIR RD/ IH10e, FM3351n, FM473w, FM473e, JCT FM1376,... SEVEN SISTERS DRROUTING IS THE SOLE RESPONSIBILITY OF THE APPLICATE ON CITY STREETS & COUNTY RDS</p> <p>JCT.SP50/IH35Wn, IH20e, FT WORTH/EXIT BU287, IH20SFR, US287WFRs, TO 1ST XOVER, US287n, IH20e, US175se, JCT.FM2860...</p> <p>....JCT SHADY GROVE/ W.LP12s, SP408s, IH20e, US67sw, SH174s, SH171se, HILLSBORO- SH81s, IH35.W.FRs PAST FM310, IH35s, @TEMPLE: EXIT @ AVE H, IH35.W.FRs PAST S.LP363, IH35s, (PALMER)FM734se, JCT YAGER,...</p> <p>αα JCT FEDERAL/IH10w, E.IH610n/w, IH45n, HUNTSVILLE***S.SH75n (PRISON EXIT), DROP @ SOUTHWOOD RD (HUNTSVILLE)αP/UP @ IH45 EFRn*** 1st ON-RAMP: IH45n, DETOUR LOW STRUCTURE @ANGUS RD IN ANGUS, IH45N, IH20E, IH635N,W, SH78N, **SH190 NFRw, US75n, US380w, SH</p> <p>**jct Holmes Rd/SH288WFRs, SH288s,* S.BW8FR, x-under @ fm865 to BW8FRw, us90Aw, sp762s/w, fm762s, fm2218sw, us59sw, sh36n, fm1640w, sp529sw, us59sw, sp10n, us90Aw, fm3013s, fm102nw, fm950w, sh71nw, us90Aw, sh97n, us90w, sh304n, sh71w, fm969n, fm1704ne, e</p> <p>"αJCT JUDSON RD/LP1604e/s, IH35n, IH35En, IH20e, IH45n, IH345n, US75n, JCT IH635α" ROUTE APPROVED BY SUSAN/DALLAS DISTRICT**LOAD MAY TRAVEL AT NIGHT TO DESTINATION DURING DALLAS CURFEW HOURS. MUST TRAVEL INSIDE LANE & LOWER LEVEL OF IH35 IN AUSTIN FR</p> <p>*****jct sh329/sh349/s, to jct of south sh290*****</p> <p>*RQ ROUTE* JCT IH20.SFR/SH149s, SH322s, US259s, US79sw, PALESTINE: NE.LP256s&w, US79sw, JCT FM542...</p> <p>..... JCT N. FM 2943 / US60sw, US385n, US87e, US287n, JCT FM 297</p> <p>... IH10w, SH62s, SH87s, JCT FM3322...</p> <p>⌈ JCT FEDERAL/IH10w, E.IH610n/w/s, IH10w, E.LP1604n/w, IH10w, JCT NM LINE⌈ File Code: T\LOUISIANA TRAN\HOU-NM10</p>
--

Figure 16. Sample Route Descriptions Starting with a Variation of “JCT.”

The database did not contain all possible combinations of these types of content. The researchers found that depending on the fiscal year, only the following nine combinations for content appeared in the route start, end, and description fields (Table 46).

Table 46. Types of Data Content for the Combination of Route Start, Route End, and Route Description, and Usefulness of the Data for Further Analysis.

ID	Route Start	Route End	Route Description	Useful for Route Analysis?	Useful for O-D Analysis?
1	City name	City name	Route description with “JCT”	Yes	Yes
2	City name	City name	Route description without “JCT”	Yes	Yes
3	City name	City name	Null	No	Yes
4	City name	City name	Carriage return/line feed	Yes	Yes
5	City name	City name	Uncommon delimiter	No	Yes
6	Null	Null	Null	No	No
7	“TX”	“TX”	“TX”	No	No
8	“TX 006030058C”	City name	City name	No	No
9	City name	City name	City name	No	Yes

Table 47 displays the combinations of types of data provided in Table 46 that appear in the dataset of each fiscal year and the total count for each combination. The totals for each year provided a control mechanism that needed to be equal to the total number of records in all categories for each fiscal year. Evidently, the annual totals provided in Table 47 are identical with the annual totals provided in Table 44.

Table 47. Counts of Data Combinations for ROUTE_START, ROUTE_END, and ROUTE_DESC Fields (Fiscal Years 2004–2009).

FY 2004			
Route Start	Route End	Route Description	Number of Permits
City name	City name	Route description with “JCT”	206,709
City name	City name	Route description without “JCT”	12,765
City name	City name	Null	85
City name	City name	Carriage Return/Line Feed	167,552
City name	City name	Uncommon delimiter	5
Null	Null	Null	57,965
Total			445,081
FY 2005			
Route Start	Route End	Route Description	Number of Permits
City name	City name	Route description with “JCT”	228,792
City name	City name	Route description without “JCT”	18,842
City name	City name	Null	171
City name	City name	Carriage Return/Line Feed	169,457
City name	City name	Uncommon delimiter	1
Null	Null	Null	64,967
Total			482,230
FY 2006			
Route Start	Route End	Route Description	Number of Permits
City name	City name	Route description with “JCT”	391,277
City name	City name	Route description without “JCT”	23,977
City name	City name	Null	33
City name	City name	Carriage Return/Line Feed	30,689
City name	City name	Uncommon delimiter	1
Null	Null	Null	77,497
Total			523,474

Table 47. Counts of Data Combinations for ROUTE_START, ROUTE_END, and ROUTE_DESC Fields (Fiscal Years 2004 -2009) (Continued).

FY 2007			
Route Start	Route End	Route Description	Number of Permits
City name	City name	Route description with “JCT”	417,362
City name	City name	Route description without “JCT”	23,043
City name	City name	Null	2
City name	City name	Carriage Return/Line Feed	23,210
City name	City name	Uncommon delimiter	5
Null	Null	Null	92,716
Total			556,338
FY 2008			
Route Start	Route End	Route Description	Number of Permits
City name	City name	Route description with “JCT”	441,431
City name	City name	Route description without “JCT”	20,759
City name	City name	Null	3
City name	City name	Carriage Return/Line Feed	20,943
City name	City name	Uncommon delimiter	1
Null	Null	Null	99,446
Total			582,583
FY 2009			
Route Start	Route End	Route Description	Number of Permits
City name	City name	Route description with “JCT”	396,028
City name	City name	Route description without “JCT”	4,654
City name	City name	Null	2
City name	City name	Carriage Return/Line Feed	21,604
City name	City name	Uncommon delimiter	10
Null	Null	Null	96,125
TX	TX	TX	499
TX # 006030058C	City name	City name	24
City name	City name	City name	10,954
Total			529,900

DATA PROCESSING AND CLEANSING

A result of the initial data analysis was a need for extensive data cleansing in order to develop GIS routes of oversize/overweight vehicles. The research team found that data entered in the route description field were not selected from a set of valid values and did not follow a defined data standard. This lack of data integrity and standards in the data entry process was the primary reason for the extensive data cleansing process, including the restructuring of several tables before the data could be utilized for processing or recreation of overweight routes.

Given the amount of data and lack of quality control in the dataset, the research team realized it would be an enormous task to parse and process this data. In order to be more efficient in this process, the task of data cleansing and processing was divided and assigned to two separate task forces. Task force one located in College Station focused on the processing and cleaning of the route description field, and task force two located in San Antonio focused on the processing and cleaning of the route start and route end fields.

Route Description Processing

The processing of the route descriptions started with a separation of permits that did contain data in the route description field from those that did not contain any data in the route description field. Table 48 shows the total number of permits, the number of permits that did not contain route information, and the number of permits with route information. These 2.6 million records, or 84 percent of all permit records, were used in the subsequent data cleaning process.

Table 48. Total Permits and Permits with Defined Routes in Route Description Field.

Fiscal Year	All Permits	Permits without Route Descriptions	Permits with Route Descriptions	Permits with Route Descriptions (% of All)
2004	445,081	57,965	387,116	87.0%
2005	482,230	64,967	417,263	86.5%
2006	523,474	77,498	445,976	85.2%
2007	556,338	92,717	463,621	83.3%
2008	582,583	99,447	483,136	82.9%
2009	529,900	96,136	433,764	81.9%
Total	3,119,606	488,730	2,630,876	84.3%

The College Station task force developed a five-step string parse data cleansing process using Microsoft Excel and Visual Basic for Applications (VBA) to clean the 2.6 million records with route information. The data cleansing process included the following five steps:

- **Step 1: Standardize Route.** Route names are standardized to follow a 2-character-4-digit convention, which is used in the “Route” database. For example, “IH10” becomes

“IH0010” and “Loop 1604” becomes “LP1604.” Results are stored by fiscal year in separate tables (tbl_FY04_STEP1 - tbl_FY09_STEP1) in the “Standardized routes” dataset.

- **Step 2: Separate Multi Line Records.** There are a large number of records with data that spans multiple lines. This step separates each line into individual fields. Results are stored by fiscal year in separate tables (tbl_FY04_STEP2 - tbl_FY09_STEP2) in the “Multiline routes” dataset.
- **Step 3: Identify Valid Route Information.** This step identifies the line of the multi-line records that contains valid route descriptions. Results are stored by fiscal year in separate tables (tbl_FY04_STEP3 - tbl_FY09_STEP3) in the “Valid route information” dataset.
- **Step 4: Remove Unwanted Characters.** This step included the following processes:
 - Replace all occurrences of “_” with a space.
 - Search for “ [” and “] ” and replace with “ (” and “) ,” respectively, so brackets can be used to indicate segments in Step 5. This needed to be done manually because sometimes it was desirable to remove the brackets instead of replacing the brackets with parentheses.
 - Search for “ \$ ” and “ ? ” and replace them with spaces so that these symbols can be used to mark the beginning and end of questionable information in Step 5. This needed to be done manually because of some cases where a different character than a space was a more appropriate replacement of “ \$ “ and “ ? .” For example, a portion of an actual route in the database was as follows:

IH0035n,W.SL1604s/e?n,IH0010e
 - When reviewing this information, it becomes clear that the route originates from IH 35, continues on Loop 1604 going south, then east, then north, and finally east on IH 10. Therefore, the “ ? ” in this example should be replaced with “ _ ” rather than a space.
 - Results are stored by fiscal year in separate tables (tbl_FY04_STEP4 - tbl_FY09_STEP4) in the “Clean characters” dataset.
- **Step 5: Route Data Cleaning.** Implement the route data cleaning logic as follows:
 - Use “ [” and “] ” to mark the beginning and end of landmark description, respectively. If the landmark is a junction of two roadways, the second roadway is duplicated and added after the closing bracket. This allows the separation of the information within the bracket from the route without changing the actual Route.

- Use “ ? ” and “ \$ ” to mark the beginning and end of questionable information, respectively.
- Use “ _ ” for direction information.
- Results are stored by fiscal year in separate tables (tbl_FY04_STEP5 - tbl_FY09_STEP5) “clean route descriptions” dataset.

To aid with the understanding of the process, Table 49 provides a listing of datasets that are created by the five-step data cleaning process along with a dataset definition and the process step that produces the dataset.

Table 49. Dataset Definitions during Route Description Data Processing.

Step	Dataset Name	Dataset Definition
0	All permits	The permit records provided by TxDOT.
0	Permits with route descriptions	The portion of all permits that contains route descriptions.
0	Permits without route descriptions	The portion of all permits that does not contain route descriptions.
1	Standardized routes	A portion of “Permits with route descriptions” that contain a route that could be standardized by the process.
2	Multiline routes	A portion of “Permits with route descriptions” that contain a multi-line route description that could be separated by the process.
3	Valid route information	A portion of “Permits with route descriptions” that contain valid route information from a multi-line record.
4	Clean characters	A portion of “Permits with route descriptions” that contain route information that could be cleaned of unwanted characters.
5	Clean route descriptions	A portion of “Permits with route descriptions” that contain route descriptions that were cleaned by the 5-Step process.
5	Flagged Route Descriptions	A portion of “Permits with route descriptions” that contain route descriptions that were flagged by the 5-Step process.

Route Description Processing Example

The following provides an example of an actual route description and how the data were cleaned and processed using the five-step process. Modifications of the data from one process step to the next are highlighted in light gray. The example begins with the unedited text that the record provided in the route description field (Figure 17).

```
...JCT Everman Parkway/IH35Wn, IH20e, IH45s, N.IH610e?s,  
IH10e, JCT Sheldon Rd...  
  
Not lowboy  
  
AFFIDAVIT STATUS: PWG
```

Figure 17. Unedited Text of Route Description Field.

In Step 1, the text was edited by the process and the route names were standardized as follows (Figure 18).

```
...JCT Everman Parkway/IH0035Wn, IH0020e, IH0045s,  
N.IH0610e?s, IH0010e, JCT Sheldon Rd...  
  
Not lowboy  
  
AFFIDAVIT STATUS: PWG
```

Figure 18. Route Description Text Edited by Process Step 1.

In Step 2, the process separated the multi lines into three separate fields (Figure 19).

```
...JCT Everman Parkway/IH0035Wn, IH0020e, IH0045s,  
N.IH0610e?s, IH0010e, JCT Sheldon Rd...  
  
Not lowboy  
  
AFFIDAVIT STATUS: PWG
```

Figure 19. Route Description Text Edited by Process Step 2.

In Step 3, the process identified valid route information in field 1. The research team retained the information in that field, and for the purpose of this project, ignored the information in fields two and three.

...JCT Everman Parkway/IH0035Wn, IH0020e, IH0045s, N.IH0610e?s, IH0010e, JCT Sheldon Rd...
Not lowboy
AFFIDAVIT STATUS: PWG

Figure 20. Route Description Text Edited by Process Step 3.

In Step 4, the researchers manually removed and cleaned up special characters in the descriptions (Figure 21).

...JCT Everman Parkway/IH0035Wn, IH0020e, IH0045s, N.IH0610e/s, IH0010e, JCT Sheldon Rd...

Figure 21. Route Description Text Edited by Process Step 4.

In Step 5, the process standardized the route information and grouped data elements into route segments using the “[” and “]” symbols. This data cleaning process produced the following cleaned route description (Figure 22).

[JCT Everman Parkway/IH0035Wn]IH0035W_n,IH0020_e, IH0045_s, N.IH0610_e_s,IH0010_e,[JCT Sheldon Rd]

Figure 22. Route Description Text Edited by Process Step 5.

Only a portion of the records with route information produced clean, useable route information at the conclusion of the five-step data cleansing process. More than half of the records were flagged by the process because of one or multiple issues that prevented the data cleaning. The process assigned a flag to each record to indicate a clean route description or problematic route description, as follows:

- **Flag = 0.** These overweight permits contain completely clean route descriptions with no problems that are ready for GIS processing.
- **Flag = 1.** These overweight permits contain route descriptions with at least one problem and require further processing before they can be used in a GIS analysis. Problems could be one of the following:

- Route not identifiable.
- Missing direction.
- Unknown information.
- Unknown route.
- Multi-spur route.

At the end of the route description processing, the research team created two data subsets: Clean routes and routes that contained a problem or error. Table 50 shows the number of records that contain clean versus flagged route descriptions after the five-step data cleansing process. Figure 23 shows the size of the datasets at the conclusion of the data cleansing process.

Table 50. Permits with Clean and Permits with Flagged Route Descriptions after Five-Step Data Cleansing Process.

Fiscal Year	Permits with Routes	Permits with Clean Route Descriptions	Permits with Flagged Route Descriptions
2004	387,116	188,829	198,287
2005	417,263	188,993	228,270
2006	445,976	202,272	243,704
2007	463,621	191,157	272,464
2008	483,136	220,369	262,767
2009	433,764	216,692	217,072
Total	2,630,876	1,208,312	1,422,564

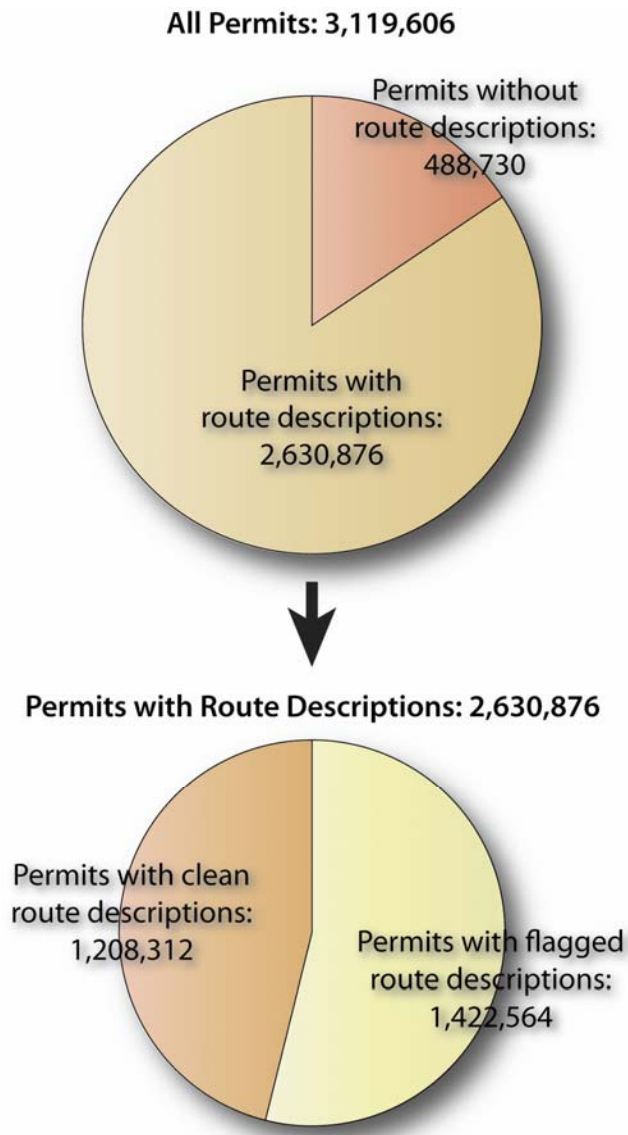


Figure 23. Route Description Data Processing.

The following discussion provides a description of the conditions that resulted in a flag indicating a problem along with an example of a route description that was flagged for that problem.

Route Not Identifiable Issue

A number of permits were flagged because the entry in the route description could not be programmatically identified as a valid route. The following are two examples of route descriptions that were flagged as “no route.”

?Jct FM3167/FM0649n- SH0016n- Jct US0059\$
--

Figure 24. Route Description with “Route Not Identifiable” Issue, Example 1.

In Figure 24, the operator used a hyphen to separate route information instead of a comma. Since no comma is found, the program cannot positively determine whether this is a valid route description, and thus the record is flagged for “no route.”

?*SEE ATTACHED SHEETS FOR ROUTE AND RESTRICTION
INFORMATION*\$

Figure 25. Route Description with “Route Not Identifiable” Issue, Example 2.

In Figure 25, the route description field entry is not empty, but it is clearly not a route description. This record is thus also flagged for “no route.” Table 51 provides a count of records that were flagged because of the “no route” condition.

Table 51. Count of Route Descriptions with “Route Not Identifiable” Issue by Year.

Fiscal Year	Permits with Routes	Routes Not Identifiable	Routes Not Identifiable (%)
2004	387,116	24,301	6.3%
2005	417,263	28,695	6.9%
2006	445,976	29,218	6.6%
2007	463,621	25,096	5.4%
2008	483,136	31,074	6.4%
2009	433,764	21,864	5.0%
Total	2,630,876	160,248	6.1%

Missing Direction Issue

A number of permits were flagged because the entry in the route did not provide a valid direction, e.g., n, e, s, w, in the route description. The following is an example of route information that was flagged as “missing direction” (Figure 26).

[JCT WALLISEVILLE
D/E.IH0610s]E.IH0610_s,IH0010_e,E.SL0008_n,US0090_e,
SH0326_n,US0069_n,FM0418_e,[SILSBEE]?BU0096E\$,US0096_n
,FM0363_e,US0190_e

Figure 26. Route Descriptions with “Missing Direction” Issue.

In this case, “BU0096E” is not found in the route database. Since there is no suffix indicating the direction, the record was flagged for “no direction.” Table 52 provides a count of records that were flagged because of the “missing direction” condition.

Table 52. Count of Route Descriptions with “Missing Direction” Issue by Year.

Fiscal Year	Permits with Routes	Routes with Missing Direction	Routes with Missing Direction (%)
2004	387,116	35,057	9.1%
2005	417,263	43,179	10.3%
2006	445,976	53,415	12.0%
2007	463,621	57,729	12.5%
2008	483,136	45,144	9.3%
2009	433,764	43,250	10.0%
Total	2,630,876	277,774	10.6%

Unknown Information Issue

Some permits were flagged because the entry in the route description field provided unknown information before the term “JCT” in the route description. The following is an example of route information that was flagged as “unknown information.”

[VICTORIA.....3 MILES NORTH OF BU0059ON] US0087_n,US0077_s,US0059_n,W.IH0610_s_e,SH0225_e,SH014 6_n,?TO THE \$[JCT. SP0330.....BAYTOWN]

Figure 27. Route Descriptions with “Unknown Information” Issue.

In this case, “TO THE” is marked as “unknown information before JCT,” and the record was flagged for “unknown information.” Table 53 provides a count of records that were flagged because of the “unknown information” condition.

Table 53. Route Descriptions with “Unknown Information” Issue.

Fiscal Year	Permits with Routes	Routes with Unknown Information	Routes with Unknown Information (%)
2004	387,116	52,090	13.5%
2005	417,263	74,346	17.8%
2006	445,976	72,212	16.2%
2007	463,621	83,527	18.0%
2008	483,136	66,789	13.8%
2009	433,764	36,482	8.4%
Total	2,630,876	385,446	14.7%

Unknown Route Issue

Other permits were flagged because the entry in the route contained a highway that could not be recognized in the database. In contrast, if multiple highways were found for a record, this flag was not assigned. The following is an example of route information that was flagged as “unknown route” (Figure 28).

```
[JCT FM0480/SH0027e]SH0027_e, [COMFORT]?BU0087_s$,  
IH0010_e,N.SL1604_w,?LA CANTERA (WEST OF IH10)  
CROSSUNDER$,SL1604_e,US0281_n,US0190_e,US0183_n,US0281  
_n,FM1690_ne,FM0183_ne,US0084_e,S.SL0340_e_n,US0084_e,  
W.SL0256_n_e_s,US0079_n,US0259_n,IH0020_e,US0059_n,IH0  
030_e
```

Figure 28. Route Descriptions with “Unknown Route” Issue.

In this case, “BU0087” is not shown in the route database, thus the record was flagged for “unknown route.” In addition, there is no route information in “LA CANTERA (WEST OF IH10) CROSSUNDER,” which would have triggered an “unknown route” flag as well. Table 54 provides a count of records that were flagged because of the “unknown information” condition.

Table 54. Count of Route Descriptions with “Unknown Route” Issue by Year.

Fiscal Year	Permits with Routes	Unknown Routes	Unknown Routes (%)
2004	387,116	129,914	33.6%
2005	417,263	143,640	34.4%
2006	445,976	158,662	35.6%
2007	463,621	184,573	39.8%
2008	483,136	171,542	35.5%
2009	433,764	158,662	36.6%
Total	2,630,876	946,993	36.0%

Multi-Spur Route Issue

A small number of permits were flagged because the entry in the route contained a highway designated as a spur with multiple matches in the route description. The following is an example of route information that was flagged as “multi-spur” (Figure 29).

```
[JCT. IH0035/S.SL0013E]S.SL0013_e,?SP0122_s$,
IH0410_e_n, US0087_s ,[SAN ANTONIO]E.SL1604_e_n,
IH0035_n,[BUDA]S. FM1626 _n _e,FM2304_n,[JCT SLAUGHTER
LN...P/U S.SL0001ne]S.SL0001_ne ,FM0734_se,IH0035_n,
FM0093_e,SH0095_n,[TEMPLE]S.SL0363_n_w,IH0035_s,[JCT
SH0053]
```

Figure 29. Route Descriptions with “Multi-Spur Route” Issue.

In the route database, there were records of FS0122 and SS0122. As a result, the research team was unable to determine which one this record referred to, and therefore the record was flagged for “multi-spur.” Table 55 provides a count of records that were flagged because of the “multi-spur” condition.

Table 55. Count of Route Descriptions with “Multi-Spur” Issue by Year.

Fiscal Year	Permits with Routes	Routes with Multi-Spur	Routes with Multi-Spur (%)
2004	387,116	328	0.1%
2005	417,263	404	0.1%
2006	445,976	445	0.1%
2007	463,621	706	0.2%
2008	483,136	830	0.2%
2009	433,764	850	0.2%
Total	2,630,876	3,563	0.1%

ROUTE START AND ROUTE END PROCESSING

The second portion of the data cleansing process was carried out by the San Antonio task force, focusing on the fields ROUTE_START and ROUTE_END. The purpose of the analysis was to review and clean these fields as needed, to develop data elements that would be useful to provide the longitude and latitude for start and end of each routes. These data could then be used for the development of GIS route or origin-destination maps. The data standardization process consisted of six phases and multiple steps, which are described below. Following the description are sections that provide additional process information and examples for each phase separately.

- **Phase 0: Data Conversion.** Phase 0 consisted of converting each fiscal year’s information received from TxDOT from a dBase V format database into a Microsoft Access 2007 database.
- **Phase 1: Remove Duplicates.** Phase 1 consisted of setting aside records with a duplicate permit ID and storing these records in the “duplicates” dataset. Remaining data are stored in “distinct permits” dataset.
- **Phase 2: Remove Null Data.** Phase 2 consisted of separating permit records that do not have a route start, route end, and route description (“is null” dataset).
 - Step 1. Identify “is null” records and store them in the “is null” dataset. This dataset is not further used.
 - Step 2. Identify “is not null” records and store them in the “is not null” dataset. This dataset is used in Phase 3.
- **Phase 3: Identify JCT Records.** Phase 3 consisted of identifying records in the “is not null” dataset (Phase 2, Step 2) that use the term “JCT” (Junction) or a variety of that term in the route description field.

- Step 1. Identify records with a “JCT” (Junction) descriptor in the route description and store in “JCT” dataset.
- Step 2. Identify all records that do not contain a “JCT” descriptor in the route description, and store in the “not JCT” dataset.
- **Phase 4: Identify Valid Route Descriptions.** Phase 4A consisted of parsing both the “JCT” and the “not JCT” dataset for information in the route description field that contained valid route descriptions.
 - Step 1. Manually parse the “JCT” dataset (Phase 3 Step 1) to remove any records that do not contain valid route information, and store in “JCT, not valid route description” dataset.
 - Step 2. Compare “JCT” with “JCT, not valid route description,” and store in “JCT, valid route description” dataset.
 - Step 3. Manually parse the “not JCT” dataset (Phase 3 Step 2) to remove any records that do not contain valid route information, and store in “not JCT, not valid route description” dataset.
 - Step 4. Compare “not JCT” with “not JCT, not valid route description,” and create “not JCT, valid route description” dataset.
- **Phase 5: Remove Duplicate Records in the Duplicates Dataset.** Phase 4B consisted of reviewing the dataset of records with duplicate permit IDs (“duplicates,” Phase 1) and eliminate records where all fields are equal.
 - Identify distinct records of the “duplicates” dataset, and store the result in the “distinct duplicates” dataset.
- **Phase 6: Standardize Route Descriptions.** Phase 5 consisted of standardizing the content in the route start and route end fields.
 - Step 1. Create a separate database of all 3,119,606 records that only contains the fields ROUTE_START and ROUTE_END.
 - Step 2. Create two separate tables, one that contains distinct route starts, and one that contains distinct route ends. Each table also included a second field for the cleaned version of the route start or route end.
 - Step 3. Manually review distinct route starts and route ends to determine how they can be standardized.
 - Step 3a. Identify all route starts that cannot be identified as a location, and store as “unknown route start locations” dataset.

- Step 3b. Identify all route ends that cannot be identified as a location, and store as “unknown route end locations” dataset.
 - Step 3c. Review the “unknown route start locations” and “unknown route end locations” datasets, and determine locations manually.
- Step 4. Create standardized entries for route starts and route ends using the naming convention of the GNIS TX_FEATURES dataset.
- Step 5. Review distinct route starts and modify problematic entries with standardized feature names created in Step 4, and create the “distinct, standardized route starts” dataset.
- Step 6. Review distinct route ends and modify problematic entries with standardized feature names created in Step 4, and create the “distinct, standardized route ends” dataset.
- Step 7. Combine the two datasets created in Step 5 and 6 into a single table called “route start and end master.” This table includes both route start and route end locations in one column and may include multiple values for a start or end location.
- Step 8. Review the “route start and end master” table for duplicates, and create a “route start end master, no duplicates” dataset.

To aid with the understanding of the process, Table 56 provides a listing of datasets that were created by the six-phase data cleaning process along with a dataset definition and the process phase that produced the dataset.

Table 56. Dataset Definitions during Route Start and Route End Data Processing.

Phase	Dataset Name	Dataset Definition
0	All permits	The permit records provided by TxDOT.
1	Duplicates	The permit records with duplicate permit ID values.
1	Total non duplicate permits	All permits minus the duplicates.
2	Is null	Distinct permits without route information.
2	Is not null	Distinct permits with route information.
3	JCT	A portion of the “is not null” dataset that contains the JCT descriptor.
3	Not JCT	A portion of the “is not null” dataset that does not contain the JCT descriptor.
4	JCT, valid route description	A portion of the “JCT” dataset that contains valid route description information.
4	JCT, not valid route description	A portion of the “JCT” dataset that does not contain valid route description information.
4	Not JCT, valid route description	A portion of the “Not JCT” dataset that contains valid route description information.
4	Not JCT, not valid route description	A portion of the “Not JCT” dataset that does not contain valid route description information.
5	Distinct duplicates	All records of the “Duplicates” dataset except those that appear multiple times in the “Duplicates” dataset.
6	Unknown route start locations	A list of route start values assembled from all permits that cannot be easily identified as a location.
6	Unknown route end locations	A list of route end values assembled from all permits that cannot be easily identified as a location.
6	Distinct, standardized route starts	A list of distinct route start values assembled from all permits that have been standardized using the GNIS TX_FEATURES dataset.
6	Distinct, standardized route ends	A list of distinct route end values assembled from all permits that have been standardized using the GNIS TX_FEATURES dataset.
6	Route start and end master	The combination of the datasets “Distinct, standardized route starts” and “Distinct, standardized route ends.”
6	Route start and end master, no duplicates	The “Route start and end master” dataset without any duplicate entries.

Phase 0

At the beginning of the analysis, the research team imported each fiscal year's information into a Microsoft Access 2007 databases using a Microsoft Access 2003 format, creating the "All permits" dataset.

Phase 1

For Phase 1, the research team reviewed the permit dataset for duplicate records, using the primary key "PERMIT_NBR." The research team found that a small number of records, about 0.5 percent of all permits, had duplicate permit IDs but different associated data. For example, the same permit number may have been issued for two trucks with different axle configurations and loads (Table 57).

Table 57. Sample of Records with Duplicate Permit Numbers.

Permit Number	Load Description	Axle Spacing 1	Axle Spacing 2	Axle Spacing 3	Axle Spacing 4	Axle Spacing 5
...0423	Windmill base section	14	4	4	32	4
...0423	Windmill base section	19	4	66	4	4
...0136	Solar turbine	15	4	27	4	4
...0136	Solar turbine	12	4	4	36	4
...0136	Solar turbine	13	4	33	4	0
...0152	Crane	4	14	5	0	0
...0152	Crane	7	5	6	5	0
...0152	Crane	16	4	29	4	4
...0151	Well Service Unit (S/P mileage)	4	14	4	4	0
...0151	Well Service Unit (S/P mileage)	17	4	0	0	0
...0151	Well Service Unit (S/P mileage)	19	4	38	4	0

Because of the potential for problems during the data analysis, the research team removed duplicate records from the dataset into a dataset called "Duplicates" and used only the dataset of total non duplicate permits for the subsequent analysis. Table 58 shows the number of duplicate records in the dataset by fiscal year.

Table 58. Duplicate Permit Records.

Fiscal Year	All Permits	Duplicate Permits	Total Non Duplicate Permits	Total Non Duplicate Permits (% of All)
2004	445,081	1,497	443,584	99.7%
2005	482,230	6,810	475,420	98.6%
2006	523,474	1,554	521,920	99.7%
2007	556,338	3,768	552,570	99.3%
2008	582,583	4,329	578,254	99.3%
2009	529,900	4,889	525,011	99.1%
Total	3,119,606	22,847	3,096,759	99.3%

Phase 2

For Phase 2, the research team reviewed the content of the route start and route end fields, and found that several records did not contain any values. The research team divided the data into two separate datasets, the “is null” dataset and the “is not null” dataset, as follows:

- **Is Null Dataset (Distinct Permits *without* Route Start, Route End, and Route Description).** The “is null” dataset contains permit records that do not have a route start, route end, and route description, i.e., all three fields have to be empty. Other fields of the permit record such as permit start date and permit end date may be populated. This dataset consists of 487,546 records.
- **Is Not Null Dataset (Distinct Permits *with* Route Start, Route End, and Route Description).** The “is not null” dataset contains permit records that have a route start, route end, and a route description. This dataset contained the data that the research team further analyzed with a total of 2,609,213 records.

Table 59 shows the number of permits that did contain values in the route start and route end fields, and the percentage out of all distinct permits by fiscal year. Over the last six fiscal years, 84 percent of the records contained a route start and end, for a total of about 2.6 million records.

Table 59. Permits with Route Start and Route End Entries.

Fiscal Year	Total Non Duplicate Permits	Is Null	Is Not Null	Is Not Null (% of Total Non Duplicate Permits)
2004	443,584	57,672	385,912	87.3%
2005	475,420	64,173	411,247	86.5%
2006	521,920	77,482	444,438	85.2%
2007	552,570	92,692	459,878	83.2%
2008	578,254	99,436	478,818	82.8%
2009	525,011	96,091	428,920	81.7%
Total	3,096,759	487,546	2,609,213	84.3%

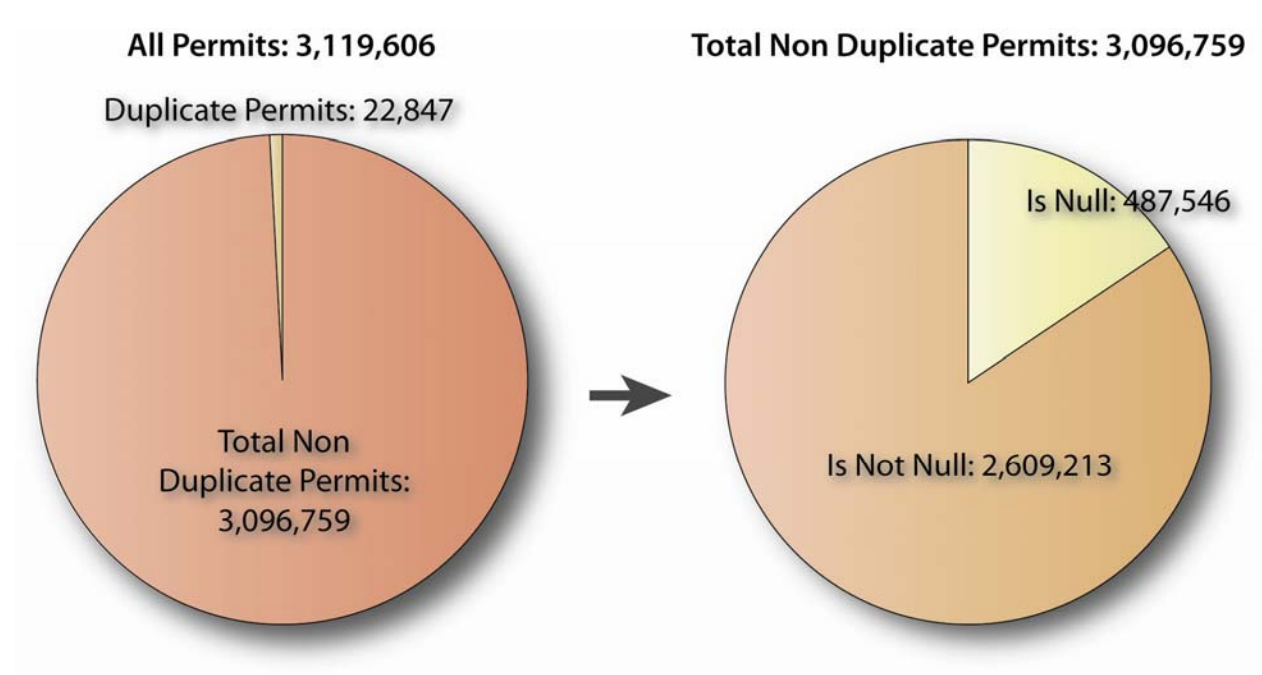


Figure 30. Development of Is Null and Is Not Null Datasets.

Phase 3

In Phase 3, the research team reviewed the route description filed of the “is not null” dataset for occurrences of the term JCT to create the “JCT” dataset and the “not JCT” dataset. Table 60 provides a sample of the “JCT” dataset.

Table 60. Sample of “JCT” Dataset.

...JCT OK State Line/US60sw, FM282w, FM283n, JCT Quarterhorse Rd...
Certificate Information
Number: 005094046C Status: Active
...JCT OK State Line/US69se, US82e, Paris:W.LP286s/e/n, US271se, US67e, US259s, IH20w, SH42s, SH31se, JCT SH135...
ICC# 348837
...JCT OK State Line/US75s, FM691w, FM1417s, US82w, US377s, US380w, Denton:E.LP288n/w, IH35s, IH35Ws, Fort Worth:N.IH820w/s, IH20w, US281s, Lampasas:S.US183s, US190w, US281s, San Antonio:N.LP1604e/s, IH35s, N.IH410s/w, IH35s, Laredo:N.LP20sw, FM1472se, JC
...JCT OK State Line/US75s, SH91s, FM120e, US69s, US82e, Paris:W.LP286s/e, SH19s, **IH30SFR, SH154s, SH37s, **US69se, IH20NFRw to the 1st x-over, IH20e, US69se, Tyler:N.LP323e/s/w, SH110s, US84w, US69se, SH7sw, SH103e, Lufkin:W.LP287s/e, US59s, Livingst
...JCT OK State Line/US75s, US69se, JCT US82...
...JCT OK State Line/US75s, US82e, SH78s, Bonham:SP205e/s, SH56w, SH78s/w, US69s, Tyler:N.323e/s/w, SH110se, JCT Shiloh Rd x-ing FM2964, x-ing FM756, P/U Shiloh Rd/US69s,
US175w, SH155s, Palestine:N.LP256e/s, US84w, IH45s, Houston:N.LP8FR, US90w, E.IH
...JCT OK State Line/US75s, US82e, US69s, Tyler:N.LP323e/s/w, SH110se, FM2964s, JCT Shiloh Rd, x-ing FM756, P/U @ Shiloh Rd/US69s, Lufkin:N.LP287s/e, US59s, FM3460s, FM2914w, US59s, N.LP8FR, **to 1st turnaround S. of Houston:BU90, E.LP8FRn, **Houston:B
...JCT OK State Line/US75s, US82e, US69s, Tyler:N.LP323e/s/w, SH110se, FM2964s, JCT Shiloh Rd, x-ing FM756, P/U @ Shiloh Rd/US69s, Lufkin:N.LP287s/e, US59s, FM3460s, FM2914w, US59s, N.LP8FR, to 1st turnaround S. of Houston:BU90, E.LP8FRn, Houston:BU90e
...JCT OK State Line/US75s, US82w, Denton:IH35s, IH35Ws, Fort Worth:N.IH820w/s, IH20w, US281s, Lampasas:S.US183s, US190w, US281s, San Antonio:N.LP1604w/s, SH16se, W.IH410s, IH35s, Laredo:N.LP20sw, FM1472nw, JCT E.O.S.M
Spring Branch:US281:use center of

Table 61 provides the totals of route descriptions with an occurrence of “JCT” and those without. More than 90 percent of the record with route start, route end, and route description included an occurrence of “JCT” in the route description.

Table 61. Permits with “JCT” Occurrence in Route Description.

Fiscal Year	Is Not Null	Not JCT (Permits without “JCT” Occurrence)	JCT (Permits with “JCT” Occurrence)	JCT (% of Is Not Null)
2004	385,912	28,490	357,422	92.6%
2005	411,247	29,866	381,381	92.7%
2006	444,438	34,421	410,017	92.3%
2007	459,878	34,878	425,000	92.4%
2008	478,818	36,426	442,392	92.4%
2009	428,920	32,637	396,283	92.4%
Total	2,609,213	196,718	2,412,495	92.5%

Phase 4

For Phase 4, the research team reviewed the route information in the “JCT” and “not JCT” datasets. Since both datasets included valid route descriptions, the research team separated those records that did not include valid route information and created four datasets:

- “JCT, valid route description.”
- “JCT, not valid route description.”
- “not JCT, valid route description.”
- “not JCT, not valid route description.”

Table 62 provides a sample of route information that could not be validated, and Table 63 provides the totals for the four datasets by fiscal year. Although the datasets “JCT, not valid route description” and “not JCT, not valid route description” do not contain any useful route information, they may include useful route start and route end information. Figure 30 shows the size of the datasets from Phase 1 to Phase 4.

Table 62. Sample of Invalid Route Information in Route Description Field.

<p>*SEE ATTACHED SHEETS FOR ROUTE AND RESTRICTION INFORMATION*</p> <p>*PERMIT VOID UNLESS ATTACHED SHEETS ACCOMPANY PERMIT*</p> <p>ROUTE INSPECTION ON FILE - T\MAMMOET\BRIDGEPORT TO GIBTOWN</p> <p>*LOCAL LAW ENFORCEMENT MAY NOT REDIRECT THIS LOAD OVER ANY BRIDGE NOT LISTE</p>
<p>see attached sheets for routing and restrictions</p> <p>accompanying sheets must be attached or permit is void</p> <p>file code:t\turner\hou-glen</p> <p>total weight is 656,000 lb.</p> <p>AMEND DATE DUE TO WEATHER @ 08:10 ON 10-30-03 BY LEE CARTER</p>
564
ANY STATE MAINTAIN HWY
<p>*SEE ATTACHED SHEETS FOR ROUTE AND RESTRICTION INFORMATION*</p> <p>*PERMIT VOID UNLESS ATTACHED SHEETS ACCOMPANY PERMIT*</p> <p>*ROUTE INSPECTION ON FILE - T\PALLETIZED\GAL-HOU*</p> <p>*LOCAL LAW ENFORCEMENT MAY NOT REDIRECT THIS LOAD OVER ANY BRIDGE NOT LISTED ON THE</p>
<p>*SEE ATTACHED SHEETS FOR ROUTE AND RESTRICTION INFORMATION*</p> <p>*PERMIT VOID UNLESS ATTACHED SHEETS ACCOMPANY PERMIT*</p> <p>*ROUTE INSPECTION ON FILE - T\PALLETIZED\GAL-HOU*</p> <p>*LOCAL LAW ENFORCEMENT MAY NOT REDIRECT THIS LOAD OVER ANY BRIDGE NOT LISTED ON THE P</p>

Table 63. “JCT” and “Not JCT” Permits with and without Valid Route Descriptions.

Fiscal Year	Distinct Permits with Route Start, End, and Description	JCT, Valid Route Descriptions	JCT, not Valid Route Descriptions	Not JCT, Valid Route Description	Not JCT, Not Valid Route Description
2004	385,912	200,628	156,794	18,124	10,366
2005	411,247	223,838	157,543	19,547	10,319
2006	444,438	381,641	28,376	29,650	4,771
2007	459,878	403,240	21,760	30,592	4,286
2008	478,818	438,969	3,423	33,386	3,040
2009	428,920	373,699	22,584	29,289	3,348
Total	2,609,213	2,022,015	390,480	160,588	36,130

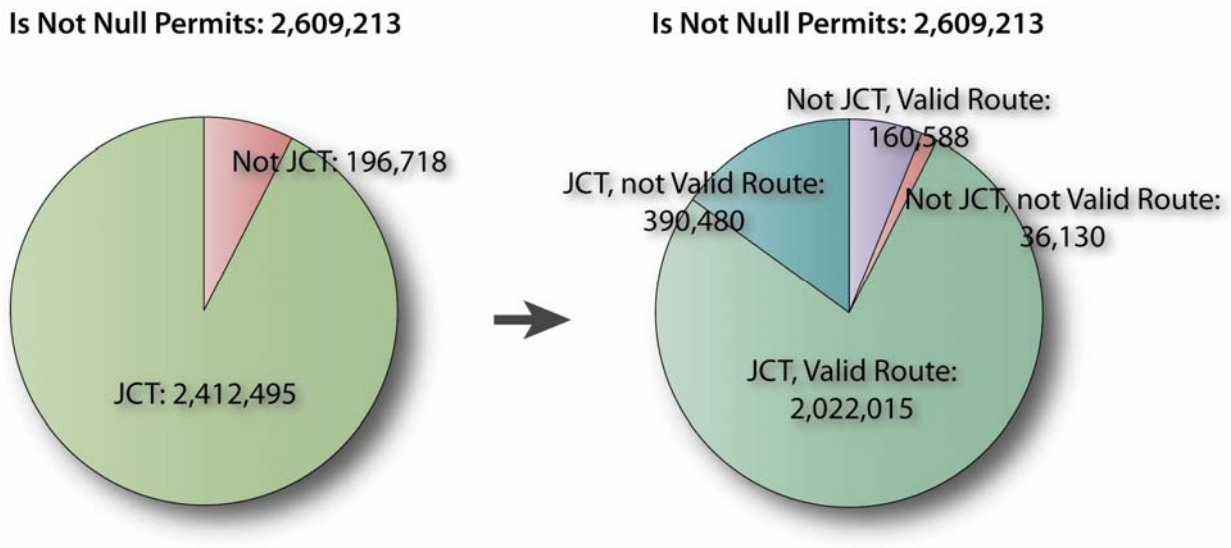


Figure 31. Development of JCT and Not JCT Datasets.

Phase 5

For Phase 5, the research team reviewed the dataset of duplicate records created in Phase 1 and eliminated all records where not only the Permit ID was identical, but the complete record was identical. This dataset was needed for a subsequent step of the data processing. The research team called the resulting dataset “distinct duplicates.”

Table 64. Distinct Duplicate Permit Records.

Fiscal Year	All Permits	Duplicates	Distinct Duplicates
2004	445,081	1,497	743
2005	482,230	6,810	3,343
2006	523,474	1,554	776
2007	556,338	3,768	2,157
2008	582,583	4,329	2,135
2009	529,900	4,889	2,435
Total	3,119,606	22,847	11,589

Phase 6

For Phase 6, the research team processed information in the route start and route end fields. The goal was to process and standardize the information in a way that would enable an automated GIS process to use the information. As provided, the route start and route end information was not immediately useable. For example, city names in the route start field appeared in a multitude of standards and spellings, and appeared to be entered without spell checking the entry. Table 65 provides a sample of inconsistent spellings of cities in the route start field.

Table 65. Sample Spellings of Cities in the Start Route Field.

Sample Values in Field ROUTE_START
* SAN ANTONIO *
\SAN ANTONIO
MSAN ANTONIO
HOUSTON
0HOUSTON
HOUST6ON
☺CORPUS CHRIST
CORPUS
CORPUS CHRI
1DALLAS
DALLLAS
DA;;AS
AAMARILLO
AMARILL0
AMARILLLO

The research team created two separate tables, one that contained distinct route starts and one that contained distinct route ends. Each table also included a second (empty) field for the cleaned version of the route start or route end, called ROUTE_ORIGIN and ROUTE_DESTINATION. The research team then manually reviewed distinct route starts and route ends to determine how they can be standardized. The research team began this process by identifying all route starts that could be easily identified and stored the remaining locations as the “unknown route start locations” dataset. Table 66 provides a sample of route start locations that could not be immediately identified.

In the next step, the researchers repeated the process for the route end field, and stored locations that could not be immediately identified in the “unknown route end locations” dataset. The step that followed reviewed both the “unknown route start locations” and the “unknown route end locations” datasets and attempted to determine the actual locations using a manual process.

Table 66. Sample Unknown Route Start Locations.

6 MILES SOUTH OF LEH
A;VARADO
ASDF
CIT
DESSA
R.R.A.D
SSS
T.S.L.
UFKIN
UNCERTAIN
VARIES

The research team then created standardized entries for all route starts and route ends using the naming convention of the GNIS TX_FEATURES dataset. Subsequently, the research team added the standardized name in the previously empty fields ROUTE_ORIGIN and ROUTE_DESTINATION that the researchers added at the start of this phase. The results of this process were two datasets, the “distinct, standardized route starts” dataset, and the “distinct, standardized route ends” dataset. Table 67 provides a sample of records from the “distinct, standardized route starts” table.

Table 67. Sample Standardized Route Start Values.

Route Start	Route Origin
* SAN ANTONIO *	San Antonio
\SAN ANTONIO	San Antonio
MSAN ANTONIO	San Antonio
HOUSTON	Houston
0HOUSTON	Houston
HOUST6ON	Houston
☺CORPUS CHRIST	Corpus Christi
CORPUS	Corpus Christi
CORPUS CHRI	Corpus Christi
1DALLAS	Dallas
DALLAS	Dallas
DA;;AS	Dallas
AAMARILLO	Amarillo
AMARILL0	Amarillo
AMARILLLO	Amarillo

In the next step, the researchers combined the two datasets “distinct, standardized route starts” and “distinct, standardized route ends” into a single table called “route start and end master,” which included both route start and route end locations in one column. However, many of the start locations were also end locations and vice versa, so it was necessary to review the “route start and end master” table for duplicates, remove the duplicates, and create a “route start end master, no duplicates” dataset.

Table 68. Count of Records in Route Start and End Datasets.

Distinct, Standardized Route Starts	Distinct, Standardized Route Ends	Route Start and End Master	Route Start and End Master, No Duplicates
31,860	41,137	72,997	58,236

FINAL DATA PROCESSING AND MERGE

In the final data processing and merge step, the researchers combined datasets from Phase 6 to create datasets for the development of GIS maps. The merge was completed in two phases and multiple steps, as follows:

- **Phase 7: Import All Route Descriptions.** Phase 7 consisted of preparing the cleaned route description field that was processed by the College Station task force to the dataset.
 - Step 1. Import Excel spreadsheet information into Microsoft Access 2007 database using Access 2003 format, and create “all processed route descriptions” dataset.
- **Phase 8: Merge Datasets.** Phase 8 consisted of combining databases created in previous steps.
 - Step1. Create the “Distinct duplicates merge” dataset.
 - Step 1a. Merge the “Distinct duplicates” dataset created in Phase 5 with the “Route start and end master, no duplicates” (Phase 6) and the “all processed route descriptions” dataset (Phase 7) to create the fields ROUTE_ORIGIN, ROUTE_DESTINATION, and ROUTE_PATH.
 - Step 1b. Group the result of the dataset created in Step 1a by Permit ID to remove records that are duplicates.
 - Step 2. Merge the “JCT, valid route descriptions” dataset (Phase 4) with the “Route start and end master, no duplicates” (Phase 6) and the “all processed route descriptions” dataset (Phase 7) to create the fields ROUTE_ORIGIN, ROUTE_DESTINATION, and ROUTE_PATH in the “JCT, valid route descriptions, merge” dataset.

- Step 3: Merge the “Not JCT, valid route descriptions” dataset (Phase 4) with the “Route start and end master, no duplicates” (Phase 6) and the “All processed route descriptions” dataset (Phase 7) to create the fields ROUTE_ORIGIN, ROUTE_DESTINATION, and ROUTE_PATH in the “Not JCT, valid route descriptions, merge” dataset.
- Step 4: Merge the “JCT, *not* valid route descriptions” dataset (Phase 4) with the “Route start and end master, no duplicates” (Phase 6) and the “All processed route descriptions” dataset (Phase 7) to create the fields ROUTE_ORIGIN, ROUTE_DESTINATION, and ROUTE_PATH in the “JCT, not valid route descriptions, merge” dataset.
- Step 5: Merge the “Not JCT, *not* valid route descriptions” dataset (Phase 4) with the “Route start and end master, no duplicates” (Phase 6) and the “All processed route descriptions” dataset (Phase 7) to create the fields ROUTE_ORIGIN, ROUTE_DESTINATION, and ROUTE_PATH in the “Not JCT, not valid route descriptions, merge” dataset.
- Step 6: For route processing in a GIS, merge the datasets created in Steps 1, 2, and 3, and store in “Path” dataset.
- Step 7: For route start and route end processing in a GIS, merge the datasets created in Steps 4 and 5, and store in “Origin destination” dataset.

To aid with the understanding of the process, Table 69 provides a listing of datasets that are created by the data merging process along with a dataset definition and the process step that produces the dataset.

Phase 7

Phase 7 prepared the dataset processed by the College Station task force for subsequent merging in Phase 8. The main task of this phase was to import the data from an Excel spreadsheet into a Microsoft Access 2007 database using Access 2003 format. The researchers called this dataset the “all processed route descriptions” dataset.

Table 69. Dataset Definitions during Final Data Processing.

7	All processed route descriptions	A merge of the clean route descriptions and flagged route descriptions datasets of the 5-Step route description cleaning process.
8	Distinct duplicates merge	A merge of the datasets “distinct duplicates,” “route start and end master, no duplicates,” and “all processed route descriptions.”
8	JCT, valid descriptions, merge	A merge of the datasets “JCT, valid route descriptions,” “route start and end master, no duplicates,” and “all processed route descriptions.”
8	Not JCT, valid route descriptions, merge	A merge of the datasets “Not JCT, valid route descriptions,” “route start and end master, no duplicates,” and “all processed route descriptions.”
8	JCT, not valid route description, merge	A merge of the datasets “JCT, <i>not</i> valid route descriptions,” “route start and end master, no duplicates,” and “all processed route descriptions.”
8	Not JCT, not valid route descriptions, merge	A merge of the datasets “Not JCT, <i>not</i> valid route descriptions,” “route start and end master, no duplicates,” and “all processed route descriptions.”
8	Path	A merge of the datasets “Distinct duplicates merge,” “JCT, valid route descriptions, merge,” and “Not JCT, valid route descriptions merge.”
8	Origin destination	A merge of the datasets “JCT, <i>not</i> valid route description, merge” and “Not JCT, <i>not</i> valid route description, merge.”

Phase 8

This phase focused on the merging of several datasets to produce the final, clean datasets for GIS processing. In the first step, the researchers merged the datasets “distinct duplicates” created in Phase 5 with the “route start and end master, no duplicates” (Phase 6) and the “all processed route descriptions” dataset (Phase 7) to create the fields ROUTE_ORIGIN, ROUTE_DESTINATION, and ROUTE_PATH in the dataset “Distinct duplicates, merge.” ROUTE_ORIGIN contains the standardized location definition from the “Route start and end master, no duplicates” that refers to the original location definition in the route start field of the “Distinct duplicates” dataset. Similarly, ROUTE_DESTINATION contains the standardized location definition from the “route start and end master, no duplicates” that refers to the original location definition in the route end field of the “Distinct duplicates” dataset. Further, ROUTE_PATH contains the processed routing information from the “all processed route descriptions” dataset. Table 70 provides an overview of the counts for the merged datasets.

Table 70. Merged Datasets from Step 8.

Fiscal Year	Distinct Permits without Nulls	Path			Origin Destination	
		Distinct Duplicates Merge	JCT Valid Route Description, Merge	Not JCT, Valid Route Description, Merge	JCT, Not Valid Route Description, Merge	Not JCT, Not Valid Route Descriptions, Merge
2004	386,655	743	200,628	18,124	156,794	10,366
2005	414,590	3,343	223,838	19,547	157,543	10,319
2006	445,214	776	381,641	29,650	28,376	4,771
2007	462,035	2,157	403,240	30,592	21,760	4,286
2008	480,953	2,135	438,969	33,386	3,423	3,040
2009	431,355	2,435	373,699	29,289	22,584	3,348
Total	2,620,802	11,589	2,022,015	160,588	390,480	36,130

Table 71 provides an overview of the counts for the datasets “Origin destination” and “Path.” Out of the 2.62 million records of distinct permits without nulls, the research team was able to create a dataset with detailed route information for 2.19 million records, or about 84 percent. The remaining 16 percent of data (0.42 million records) provide origin and destination data only.

Table 71. Counts of Records for the Origin Destination and Path Datasets.

Fiscal Year	Distinct Permits without Nulls	Origin Destination	Path	Path (% of Distinct Permits without Nulls)
2004	386,655	167,160	219,495	56.8%
2005	414,590	167,862	246,728	59.5%
2006	445,214	33,147	412,067	92.6%
2007	462,035	26,046	435,989	94.4%
2008	480,953	6,463	474,490	98.7%
2009	431,355	25,932	405,423	94.0%
Total	2,620,802	426,610	2,194,192	83.7%

Figure 32 is a graphical representation of the 6 datasets that make up the complete dataset of 2.6 million records of distinct permits without nulls, and how these datasets were combined to form the “Path” and “Origin destination” datasets.

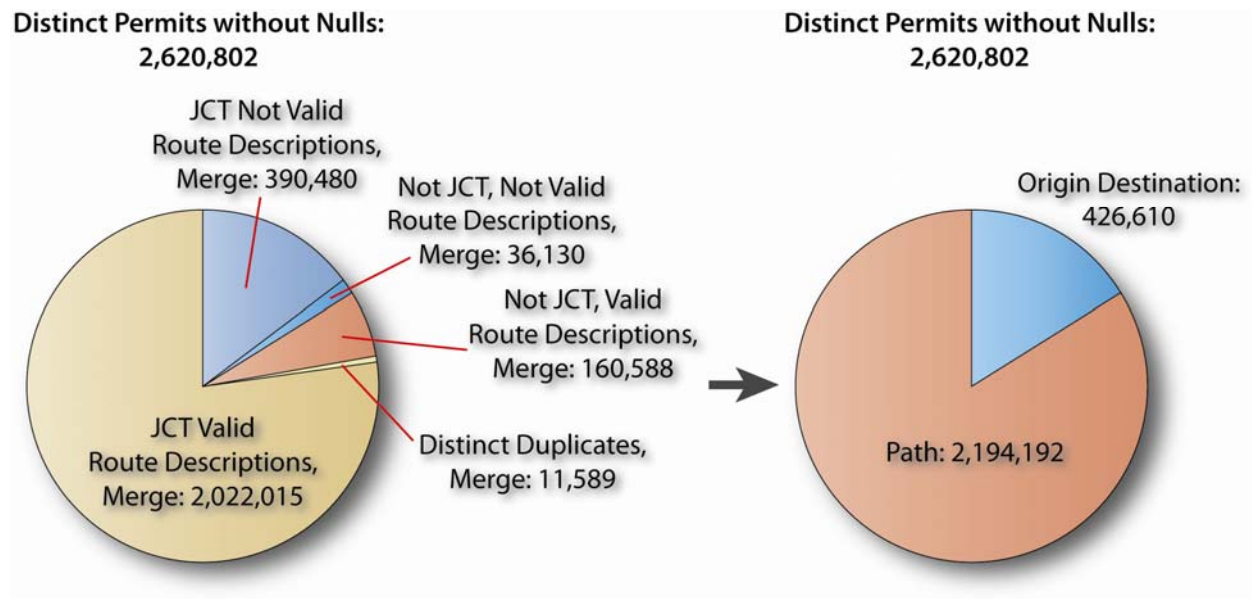


Figure 32. Development of Origin Destination and Path Datasets.

Figure 33 provides a relationship view of the query in Access followed by the syntax of the query in SQL.

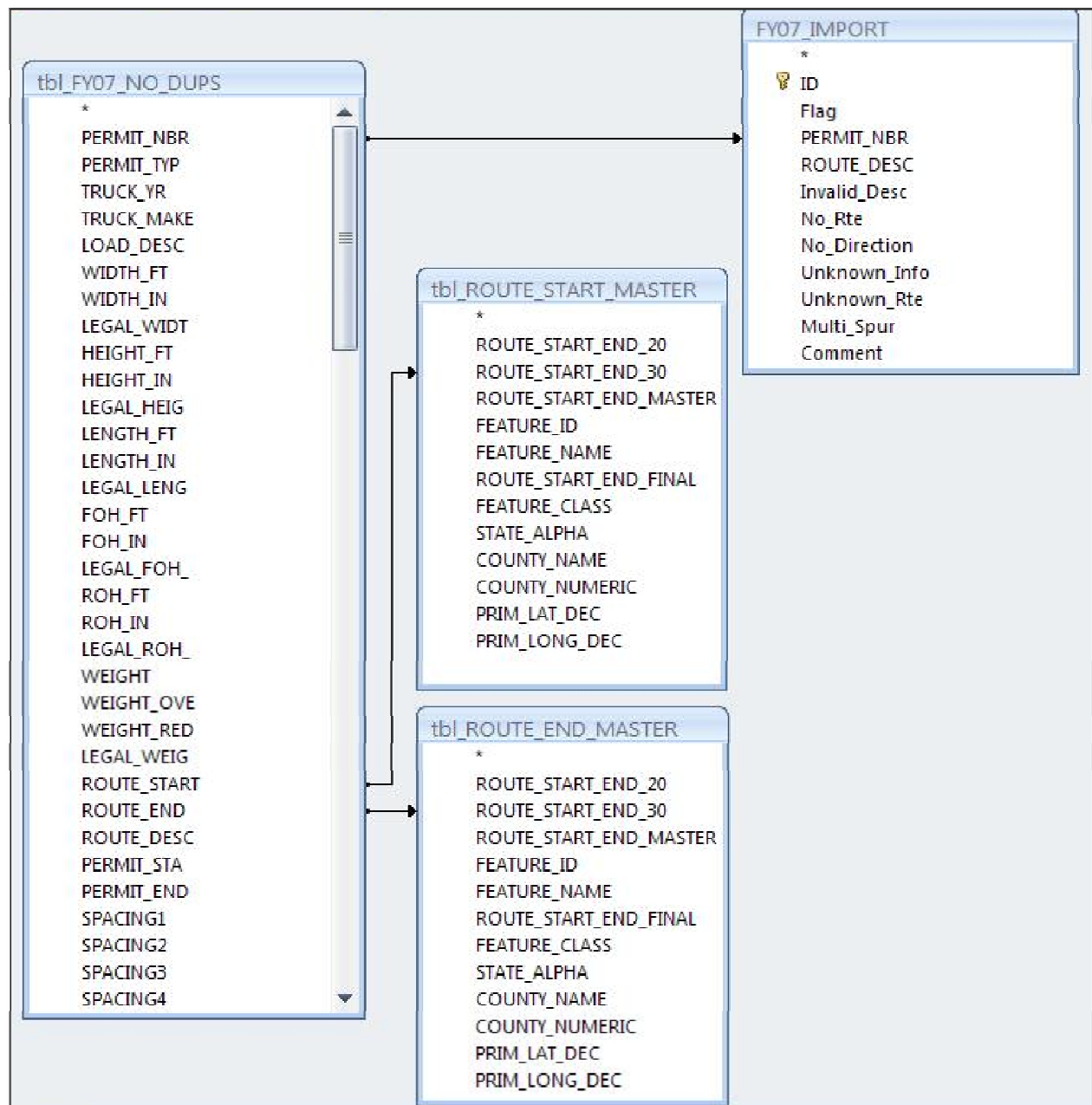


Figure 33. Query for Merging of “Distinct Duplicates,” “Route Start and End Master, No Duplicates,” and “All Processed Route Descriptions” Datasets, Access Design View.

The SQL statement for the query in Figure 33 is as follows:

```
SELECT tbl_FY07_NO_DUPS.PERMIT_NBR, tbl_FY07_NO_DUPS.PERMIT_TYP,
tbl_FY07_NO_DUPS.TRUCK_YR, tbl_FY07_NO_DUPS.TRUCK_MAKE,
tbl_FY07_NO_DUPS.LOAD_DESC, tbl_FY07_NO_DUPS.WIDTH_FT, tbl_FY07_NO_DUPS.WIDTH_IN,
tbl_FY07_NO_DUPS.LEGAL_WIDT, tbl_FY07_NO_DUPS.HEIGHT_FT, tbl_FY07_NO_DUPS.HEIGHT_IN,
tbl_FY07_NO_DUPS.LEGAL_HEIG, tbl_FY07_NO_DUPS.LENGTH_FT, tbl_FY07_NO_DUPS.LENGTH_IN,
tbl_FY07_NO_DUPS.LEGAL LENG, tbl_FY07_NO_DUPS.FOH_FT, tbl_FY07_NO_DUPS.FOH_IN,
tbl_FY07_NO_DUPS.LEGAL_FOH, tbl_FY07_NO_DUPS.ROH_FT, tbl_FY07_NO_DUPS.ROH_IN,
tbl_FY07_NO_DUPS.LEGAL_ROH, tbl_FY07_NO_DUPS.WEIGHT, tbl_FY07_NO_DUPS.WEIGHT_OVE,
tbl_FY07_NO_DUPS.WEIGHT_RED, tbl_FY07_NO_DUPS.LEGAL WEIG,
tbl_FY07_NO_DUPS.ROUTE_START, tbl_FY07_NO_DUPS.ROUTE_END,
tbl_FY07_NO_DUPS.ROUTE_DESC, tbl_ROUTE_START_MASTER.ROUTE_START_END_FINAL AS
ROUTE_ORIGIN, tbl_ROUTE_END_MASTER.ROUTE_START_END_FINAL AS ROUTE_DESTINATION,
FY07_IMPORT.ROUTE_DESC AS ROUTE_PATH, FY07_IMPORT.Flag AS ROUTE_FLAG,
tbl_FY07_NO_DUPS.PERMIT_STA, tbl_FY07_NO_DUPS.PERMIT_END, tbl_FY07_NO_DUPS.SPACING1,
tbl_FY07_NO_DUPS.SPACING2, tbl_FY07_NO_DUPS.SPACING3, tbl_FY07_NO_DUPS.SPACING4,
tbl_FY07_NO_DUPS.SPACING5, tbl_FY07_NO_DUPS.SPACING6, tbl_FY07_NO_DUPS.SPACING7,
tbl_FY07_NO_DUPS.SPACING8, tbl_FY07_NO_DUPS.SPACING9, tbl_FY07_NO_DUPS.SPACING10,
tbl_FY07_NO_DUPS.SPACING11, tbl_FY07_NO_DUPS.SPACING12, tbl_FY07_NO_DUPS.SPACING13,
tbl_FY07_NO_DUPS.SPACING14, tbl_FY07_NO_DUPS.SPACING15, tbl_FY07_NO_DUPS.SPACING16,
tbl_FY07_NO_DUPS.SPACING17, tbl_FY07_NO_DUPS.SPACING18, tbl_FY07_NO_DUPS.SPACING19,
tbl_FY07_NO_DUPS.SPACING20, tbl_FY07_NO_DUPS.SPACING21, tbl_FY07_NO_DUPS.SPACING22,
tbl_FY07_NO_DUPS.SPACING23, tbl_FY07_NO_DUPS.SPACING24, tbl_FY07_NO_DUPS.WEIGHT1,
tbl_FY07_NO_DUPS.WEIGHT2, tbl_FY07_NO_DUPS.WEIGHT3, tbl_FY07_NO_DUPS.WEIGHT4,
tbl_FY07_NO_DUPS.WEIGHT5, tbl_FY07_NO_DUPS.WEIGHT6, tbl_FY07_NO_DUPS.WEIGHT7,
tbl_FY07_NO_DUPS.WEIGHT8, tbl_FY07_NO_DUPS.WEIGHT9, tbl_FY07_NO_DUPS.WEIGHT10,
tbl_FY07_NO_DUPS.WEIGHT11, tbl_FY07_NO_DUPS.WEIGHT12, tbl_FY07_NO_DUPS.WEIGHT13,
tbl_FY07_NO_DUPS.WEIGHT14, tbl_FY07_NO_DUPS.WEIGHT15, tbl_FY07_NO_DUPS.WEIGHT16,
tbl_FY07_NO_DUPS.WEIGHT17, tbl_FY07_NO_DUPS.WEIGHT18, tbl_FY07_NO_DUPS.WEIGHT19,
tbl_FY07_NO_DUPS.WEIGHT20, tbl_FY07_NO_DUPS.WEIGHT21, tbl_FY07_NO_DUPS.WEIGHT22,
tbl_FY07_NO_DUPS.WEIGHT23, tbl_FY07_NO_DUPS.WEIGHT24, tbl_FY07_NO_DUPS.WEIGHT25,
tbl_FY07_NO_DUPS.TIRES1, tbl_FY07_NO_DUPS.TIRES2, tbl_FY07_NO_DUPS.TIRES3,
tbl_FY07_NO_DUPS.TIRES4, tbl_FY07_NO_DUPS.TIRES5, tbl_FY07_NO_DUPS.TIRES6,
tbl_FY07_NO_DUPS.TIRES7, tbl_FY07_NO_DUPS.TIRES8, tbl_FY07_NO_DUPS.TIRES9,
tbl_FY07_NO_DUPS.TIRES10, tbl_FY07_NO_DUPS.TIRES11, tbl_FY07_NO_DUPS.TIRES12,
tbl_FY07_NO_DUPS.TIRES13, tbl_FY07_NO_DUPS.TIRES14, tbl_FY07_NO_DUPS.TIRES15,
tbl_FY07_NO_DUPS.TIRES16, tbl_FY07_NO_DUPS.TIRES17, tbl_FY07_NO_DUPS.TIRES18,
tbl_FY07_NO_DUPS.TIRES19, tbl_FY07_NO_DUPS.TIRES20, tbl_FY07_NO_DUPS.TIRES21,
tbl_FY07_NO_DUPS.TIRES22, tbl_FY07_NO_DUPS.TIRES23, tbl_FY07_NO_DUPS.TIRES24,
tbl_FY07_NO_DUPS.TIRES25, tbl_FY07_NO_DUPS.SIZE1, tbl_FY07_NO_DUPS.SIZE2,
tbl_FY07_NO_DUPS.SIZE3, tbl_FY07_NO_DUPS.SIZE4, tbl_FY07_NO_DUPS.SIZE5,
tbl_FY07_NO_DUPS.SIZE6, tbl_FY07_NO_DUPS.SIZE7, tbl_FY07_NO_DUPS.SIZE8,
tbl_FY07_NO_DUPS.SIZE9, tbl_FY07_NO_DUPS.SIZE10, tbl_FY07_NO_DUPS.SIZE11,
tbl_FY07_NO_DUPS.SIZE12, tbl_FY07_NO_DUPS.SIZE13, tbl_FY07_NO_DUPS.SIZE14,
tbl_FY07_NO_DUPS.SIZE15, tbl_FY07_NO_DUPS.SIZE16, tbl_FY07_NO_DUPS.SIZE17,
tbl_FY07_NO_DUPS.SIZE18, tbl_FY07_NO_DUPS.SIZE19, tbl_FY07_NO_DUPS.SIZE20,
tbl_FY07_NO_DUPS.SIZE21, tbl_FY07_NO_DUPS.SIZE22, tbl_FY07_NO_DUPS.SIZE23,
tbl_FY07_NO_DUPS.SIZE24, tbl_FY07_NO_DUPS.SIZE25 INTO FY07_TxDOT_PERMIT_EXPORT
FROM ((tbl_FY07_NO_DUPS
LEFT JOIN tbl_ROUTE_START_MASTER
ON tbl_FY07_NO_DUPS.ROUTE_START = tbl_ROUTE_START_MASTER.ROUTE_START_END_30)
LEFT JOIN tbl_ROUTE_END_MASTER
ON tbl_FY07_NO_DUPS.ROUTE_END = tbl_ROUTE_END_MASTER.ROUTE_START_END_30)
LEFT JOIN FY07_IMPORT
ON tbl_FY07_NO_DUPS.PERMIT_NBR = FY07_IMPORT.PERMIT_NBR;
```

The researchers repeated this process for the “JCT, valid route descriptions” dataset (Phase 4), merging it also with the “route start and end master, no duplicates” (Phase 6) and the “all processed route descriptions” dataset (Phase 7) to create the fields ROUTE_ORIGIN,

ROUTE_DESTINATION, and ROUTE_PATH in the dataset “JCT, valid route descriptions, merge.” In the next step, the research team repeated this process using the “Not JCT, valid route descriptions” dataset (Phase 4), creating the fields ROUTE_ORIGIN, ROUTE_DESTINATION, and ROUTE_PATH in the dataset “Not JCT, valid route descriptions, merge.” Similarly, the research team created the datasets “JCT, not valid route descriptions, merge” using the “JCT, not valid route descriptions” dataset, and “Not JCT, not valid route descriptions, merge” using the dataset “Not JCT, not valid route descriptions.”

Finally, the researcher merged the datasets “Distinct duplicates, merge,” “JCT, valid route descriptions, merge,” and “Not JCT, valid route descriptions, merge” to create one dataset called “Path.” This dataset was created for GIS processing of the route description. The researchers also merged the datasets “JCT, not valid route descriptions, merge” and “Not JCT, not valid route descriptions, merge” to create one dataset called “Origin destination.” This dataset was created for GIS processing of the route start and route end field. The “Path” dataset will be useful to convert route data to GIS features, which will allow the actual mapping of statewide overweight routes on the transportation system. The “Origin destination” dataset will be useful to develop maps showing the flow of overweight traffic from origins to destinations in Texas.

NEXT STEPS

Due to the magnitude of the overweight route data processing task, the effort of cleaning the datasets was shared among the projects 0-6498 (“Texas Energy Developments and TxDOT Right of Way”) 0-6404 (“Accommodating Oversize and Overweight Loads”) and this project 0-6394. For fiscal year 2011, project 0-6404 has assumed the sole responsibility to complete outstanding processing tasks, including the generation of routes in a GIS. However, as routing information becomes available from the data processing, the 0-6394 research team will use the information in the Phase 2 Damage Evaluation.

CHAPTER 6. PHASE 1 UTILITY DAMAGE EVALUATION

INTRODUCTION

This chapter summarizes the findings of Task 5 “Conduct Phase 1 Utility Damage Evaluation” of research project 0-6394 “Evaluation of Overweight Load Routing on Buried Utility Plant.” The purpose of this task was to develop a risk analysis framework and begin efforts to assess vulnerability of buried utility plant to the effects of overweight vehicles. The research team proposed to develop the risk framework based on a forensic field investigation at selected sites with known damages to buried utility infrastructure caused by overweight loads. This task includes the following two subtasks:

- **Subtask 1: Identification of Damage Cases.** The research team developed strategies to identify damage to buried utilities caused by overweight vehicle movements and contacted stakeholders to identify locations for field investigations in the state right of way.
- **Subtask 2: Sensitivity Analysis of Damages to Buried Utility Structures.** The research team conducted a sensitivity analysis using a 2D-finite element program based on typical and critical parameters for the installation of utilities in the state right of way. This analysis was useful to develop a preliminary assessment of the vulnerability of buried utility plant in the state right of way.

The following provides a detailed description of the activities of the research team for the subtasks outlined above.

IDENTIFICATION OF CANDIDATE CASES FOR FORENSIC ANALYSIS

Introduction

The research team was tasked with the identification of cases where buried utilities were damaged by heavy or overweight vehicles, and select a number of cases for further in-depth analysis in the field. Guidance by the research oversight committee and various TxDOT officials provided that, while covering all utilities, the research team should prioritize water and sewer facilities within state right of way. These types of utilities frequently cross state routes, are generally large in diameter, and include some of the oldest utility installations that can be found in the Texas right of way today. Materials and structures that were installed many years ago can be particularly vulnerable and prone to damage due to material aging and outdated installation specifications. A collapse of a water or sewer line or their encasement has a potential to cause dramatic damage to pavement structure and impose hazards to the traveling public.

To identify potential cases for further analysis, the research team used a multi-prong approach, including a comprehensive literature review utilizing both online and offline sources, a request for information sent to a wide range of stakeholders, a review of Utility Installation Review System (UIR) data, telephone/email conversations with several TxDOT districts, and telephone

interviews with various water and sewer utilities in cities where overweight loads are frequently routed.

These efforts resulted in a number of cases with damaged buried utilities. However, the research team was not able to confirm for any of these cases that the damage to the buried utility could be attributed to a heavy or overweight vehicle. The following is a description of the activities and findings of the research team related to the identification of cases with damage to buried utilities.

Literature Review

The research team performed a literature review of both online and offline sources including local newspapers, transportation research reports, relevant journals and magazines, and utility companies' websites. For the review of newspapers, the research team used the LexisNexis® Academic database available at the Texas A&M University libraries (183). This database is a comprehensive online information resource that contains a large collection of full-text current and archived articles from national and regional newspapers, wire services, broadcast transcripts, and international news. The researchers reviewed the news archives of a number of local newspapers in Texas, in particular newspapers that serve Texas cities with frequent overweight load traffic. The following are a sample of the newspapers included in the review:

- Houston Chronicle (184).
- Corpus Christi Caller-Times (185).
- San Antonio Express-News (186).
- Fort Worth Star-Telegram (187).
- Abilene Report News (188).
- Beaumont Enterprise (189).
- Port Arthur News (190).

The research team used the following keywords to find newspaper articles with descriptions of overweight vehicles that caused damage to buried utilities: “Buried,” “underground,” “utility,” “pipe,” “pipeline,” “damage,” “break,” “heavy,” “overweight,” “superload,” “truck,” “traffic,” etc.

Review of Underground Focus Magazine

The *Underground Focus Magazine* disseminates information about events of underground utility damages and new technologies related to underground utility infrastructure (191). As recommended by the research panel, the research team included this magazine in the literature review. Since the full contents of the magazine were not available, the research team reviewed the tables of contents of the last seven (2004–2010) years' issues of the magazine that were made available online.

Also available at the magazine website was an underground utility accident database named *Accident File* (192). This database includes events of accidental damage to underground utility

facilities in North America that were reported in newspapers. The records are grouped by state/province and were kept update until June 3, 2009. In the case of Texas, the database includes a number of records between 2006 and 2009 associated with buried gas, water/sewer, power, and communication utilities. The review of both *Underground Focus Magazine* and its Accident File did not provide any instance of a buried utility that was damaged by a heavy or overweight vehicle.

Outreach and Notification of Stakeholders

Upon approval of the project panel, the research team developed a letter to request cases of buried utility facilities damaged by heavy vehicle loads. The letter was sent to a large number of stakeholders across Texas whose contact information was obtained through sources such as TxDOT directory, previous research experience, and online directories of targeted public agencies and utility companies. The recipients included:

- 323 contacts at local public agencies and all 254 Texas Counties.
- 66 right of way and utility contacts at all 25 TxDOT districts and 4 regional support centers.
- 10 utility companies.
- 9 Texas utility and other relevant associations.
- 1 North Texas Toll Authority (NTTA).

About four months after dissemination of the letter, there had been only a limited number of responses and none of them was able to provide existing cases of underground utility damage caused by heavy vehicle loads. The low responding rate could be partly due to the fact that the recipients were not aware of such cases.

Proactive Approach

Given the limited responses to the request letters, the research team took a more proactive approach by directly interviewing a number of stakeholders through telephone. As recommended by the project panel, this effort was primarily focused on TxDOT Beaumont, Corpus Christi, Fort Worth, and Houston Districts.

Review of Utility Installation Review System Data

The UIR system is a web-based system used by TxDOT to facilitate the processing and management of utility installation requests on the state right of way, also known as notices of proposed installations (NOPI) (193). Since it was first implemented in late 2005, TxDOT has expanded the system to several districts including Austin, Bryan, Fort Worth, Houston, Pharr, San Antonio, and Waco.

UIR stores in its database all information about a utility installation as included on the request, such as its location, date, utility type, and description. Among the utility permits, the research

team was particularly interested in emergency repair requests or emergency work authorizations, which are submitted by utility owners upon an emergent utility facility failure. At the time of this analysis, the UIR database included 24,419 permits, including active, approved, and closed permits. Of these permits, 683 permits pertained to emergency repair requests for buried utility facilities. The research team then queried the installation description field of these 683 permits for the use of the following keywords: “damage,” “break,” “load,” “crush,” “load,” “weight,” “excessive,” “vehicle,” “truck,” and “carrier.” The query was structured to mark a record if any of these keywords was used in the installation description field and returned 121 records. The researchers then reviewed the damage type of these 121 records and sorted them into potentially interesting and not interesting damage types. Table 72 shows the results of this analysis and lists the records by damage type.

Table 72. Emergency Repair Requests by Damage Type.

Not of Interest		Potentially of Interest	
Damage Type	Number of Permits	Damage Type	Number of Permits
Damage by TxDOT contractor	5	Utility facility failure, break, or leakage	57
Lightning	2	Unspecified damage	39
Other damage	2	Exposure, lack of cover, or washed out	6
Damage by utility contractor	1	Third party/vehicle accident	5
Boring accident	1	Crushed line	1
No damage	1		
Total	13	Total	108

The research team focused on the 108 records of potential interest, determined the utility type, and reviewed the installation description for the cause of the damage. Table 73 provides a summary of the utility type for the 108 records that had a potentially related damage type.

Table 73. Utility Type of Potentially Interesting Emergency Repair Request Records.

Utility Type	Number of Permits
Water and Sewer	53
Communication	46
Gas	4
Other	4
Total	108

Most records did not provide a cause of damage in the installation description, so the research team contacted the utility owners in order to find out the causes of damages. This effort allowed the research team to determine that none of the 108 emergency repairs was a result of damage that was caused by a heavy vehicle load.

Contacts to TxDOT Districts and Water Utilities

The research team first contacted the TxDOT district maintenance directors. Upon contact, some of them requested their maintenance supervisors to assist with the research. Then, the researchers interviewed the water/sewer departments of several major cities in these districts. In many cases, the researchers were able to talk with their senior crew members who had relatively rich experience in utility facility maintenance. However, none of them was aware of cases involving utility damages by heavy vehicle loads. A city utility official noted a possible water line damage caused by heavy vehicle loads driving off-roads (e.g., on ditches or other places where the depth of cover is shallow), yet he could not provide any further information about the incident and were not sure if it occurred on state right of way. The interviewed water/sewer utilities included:

- City of Beaumont Water Utilities Department.
- City of Port Arthur Water Utilities Department.
- City of Corpus Christi Water Department.
- City of Kingsville Water Department.
- City of Houston Department of Public Works and Engineering.
- City of Texas City Utilities Department.
- City of Big Spring Utility Maintenance Department.
- Trinity River Authority (Northern Region).

Among the utilities listed above, the City of Big Spring was not located within the four selected districts. However, the project panel recommended this historic city due to a combination of factors. The city is located at the intersection of IH20, US87, SH176, SH350, and the Missouri Pacific railroad. It has been one of the major transportation hubs for heavy or super-heavy vehicle loads generated by the ongoing wind industry boom in the region. On the other hand, many of the water/sewer lines in the area were installed decades ago and the aged facilities can be vulnerable to those loads. Figure 34 shows the TxDOT districts and utility companies the research team contacted.

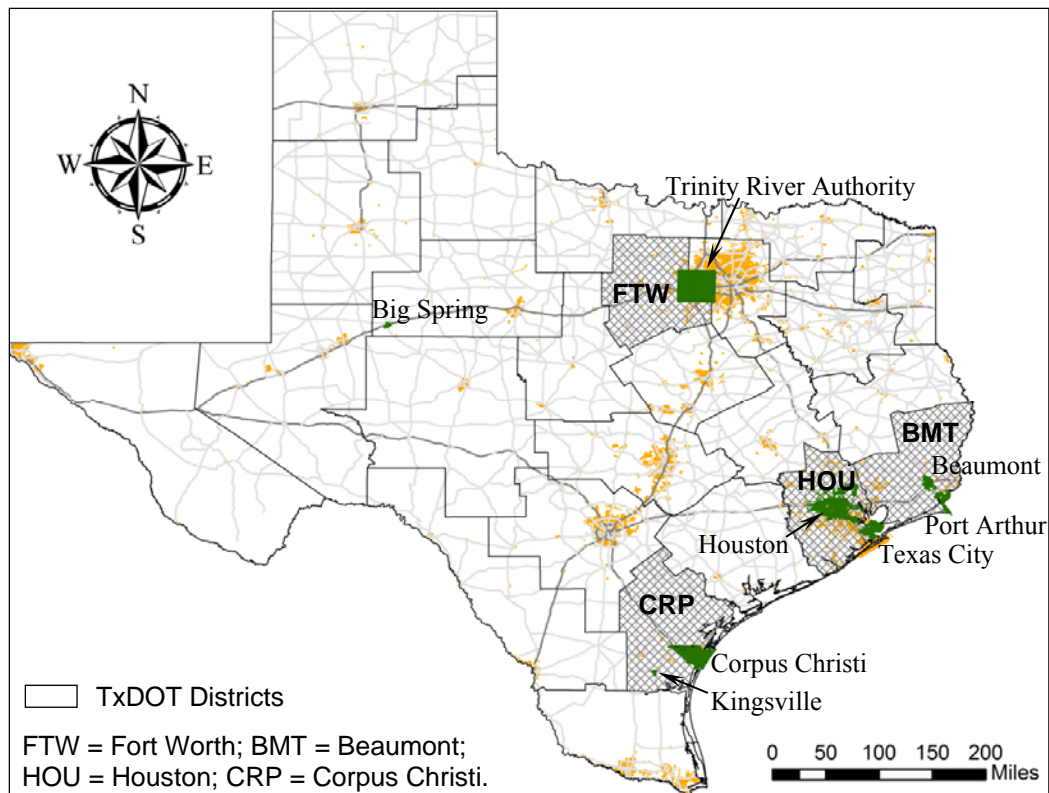


Figure 34. TxDOT Districts and Water Utilities TTI Contacted.

Regardless of the thorough efforts devoted, the research team was unable to identify any cases of underground utility facilities damaged by heavy vehicle loads. For a lack of cases, the research team did not carry out any forensic field investigations.

SENSITIVITY ANALYSIS OF DAMAGES TO BURIED UTILITY STRUCTURES

Introduction

In a proactive approach to identify critical parameters that affect buried utility structures, the research team conducted sensitivity analysis. The objective of this task is (a) to determine characteristics of potential damage, (b) to compare with field data as available, (c) to develop risk matrix, and (d) to use as guidance for Phase 2 damage evaluation.

Risk Analysis Framework

To assess the potential risk of damages to underground utility facilities, the research team developed a risk analysis framework including risk areas and risk factors as shown in Table 74.

Table 74. Risk Areas and Factors of Preliminary Risk Analysis Framework.

Risk Area	Risk Factor
Overweight vehicles	Gross vehicle weight Axle loads Tire sets Tire type and pressure Frequency of travel
Pavement	Type Structure/depth Integrity/age
Soils	Type
Buried utilities	Depth Age Material Diameter Location <ul style="list-style-type: none">• near roadbed• crossing (angle) Casing (y/n, material)

In Table 74, risk areas are a grouping of risk factors by common subject. The researchers used the risk factors as variables for input in the following sensitivity analysis (see Table 76, Table 77, and Table 78).

Tools for Sensitivity Analysis

The research team reviewed available tools to conduct the sensitivity analysis. Below is summary of the tools reviewed by researchers.

Iowa Formula

In 1941, Spangler developed the original Iowa Formula to calculate the horizontal deflection of a buried flexible pipe structure, combining the elastic ring theory and fill-load hypothesis based on the stress distribution (10). Since its original development, revisions were made by Watkins and Spangler in 1958, and Masada in 2000 to come up with the vertical deflection calculation (11, 12). The modified form is the most widely used in practice for buried pipe design. During this review, the research team incorporated the modified Iowa formula in a Microsoft Excel spreadsheet program to perform calculations of vertical pipe deflections as a function of load magnitude, soil compaction, and pipe geometric and material properties.

2D Finite Element Programs

CANDE, an acronym for Culvert ANALysis and DDesign, is a 2D finite element program developed for the structural design, analysis, and evaluation of buried structures including culverts, underground storage facilities, and storm water chambers (194). CANDE was

originally developed by Katona in 1976 and recently upgraded for analysis and LRFD design of buried structures by Mlynarski et al. in 2008 (195, 194). The research team obtained an executable copy of the program, studied the program, and ran it on selected problems to learn how CANDE may be used for the sensitivity analysis.

During this learning stage, the research team identified a couple of limitations with respect to using CANDE for this purpose:

- The program does not permit simulation of multiple axles to realistically model truck geometries seen on roadways.
- CANDE does not have an automated mesh generation utility, which makes the program harder to use in a sensitivity analysis where geometric conditions such as depth of cover of pipe and pavement layer thickness need to be varied to identify critical conditions.

Another 2D finite element program, which the research team has used in previous projects, is PLAXIS, an acronym for PLasticity AXISymmetric, is a program that is particularly suited for geotechnical structure design and analysis. PLAXIS was used in the National Cooperative Highway Research Program (NCHRP) 647 study to recommend design specifications for live load distribution on buried structures (196). Due to its flexibility in modeling multiple axles and its automated mesh generation capability, researchers made the decision to use PLAXIS for the sensitivity analysis in Phase I of this project. However, there is still the limitation in modeling out-of-plane loads, which is inherent in a 2D finite element analysis. This limitation is handled by using an equivalent load magnitude and geometry to model out-of-plane loads in the 2D analysis.

3D Finite Element Program

Three-dimensional finite element programs have recently been utilized in several research projects to simulate highway and airport pavement response to truck and aircraft traffic loads. These programs offer the most versatility in realistically modeling complicated load configurations. However, application of these programs call for advanced skills in generating the 3D finite element mesh, and applying the appropriate boundary conditions. Three-dimensional finite element programs also require much longer computer running times compared to 2D analysis that is more widely used due to its simplicity. The research team is planning to utilize a 3D finite element program in Phase 2 of this project to perform a limited verification of the 2D analysis results with respect to assessing the risk of damage to buried utility structures subject to superheavy load moves.

Setup of Sensitivity Analysis

Prior to conducting sensitivity analysis using the PLAXIS 2D finite element program, the research team made an attempt to verify its applicability by comparing the program predictions with available field data collected from previous studies. The first verification was made using field data from the experimental program conducted by Watkins and Reeve in 1982 to determine the live load deflection of plastic pipe as a function of soil cover and soil compaction (197). They installed a 24-in. corrugated plastic pipe within sandy clayey silt at 1 to 3 ft depths of cover,

and at compacted backfill densities ranging from 75 to 95 percent of AASHTO T 99. Watkins and Reeve applied an H-20 truck load, simulated by a John Deere tractor (16 kips per wheel for a 32-kip axle load) on the buried pipes and measured the pipe deflections under loading.

Figure 35 compares the test measurements with the predictions from PLAXIS. Overall, the predicted deflections, expressed as percentages of the corresponding nominal pipe diameters, are observed to show good correspondence with the measured values. There is one point (at 1 ft depth of cover and 75 percent soil compaction) where PLAXIS over-predicted the measured deflection by about 0.6 percent. However, for this case, both the prediction and measured value identify a critical condition where the vertical deflection is above the 5 percent tolerance normally allowed in practice.

The trend indicated that the vertical deflection significantly decreased from 1 to 2 ft depth of cover especially in soil compacted at 75 percent of AASHTO T 99. The modified Iowa formula generally overestimated the deflections (at 95 percent soil compaction) compared to test measurements and PLAXIS predictions. The other verification was made using field data taken by Arockiasamy et al. in 2006 (198). In this previous project, researchers installed a 36-in. HDPE 6 ft below the surface, in backfill soil classified as poorly graded sand with silt (SP-SM) compacted at 95 percent of AASHTO standard compaction. Two tandem dump trucks were used to simulate the two-lane traffic. The axle load of each truck was 34.6 kips.

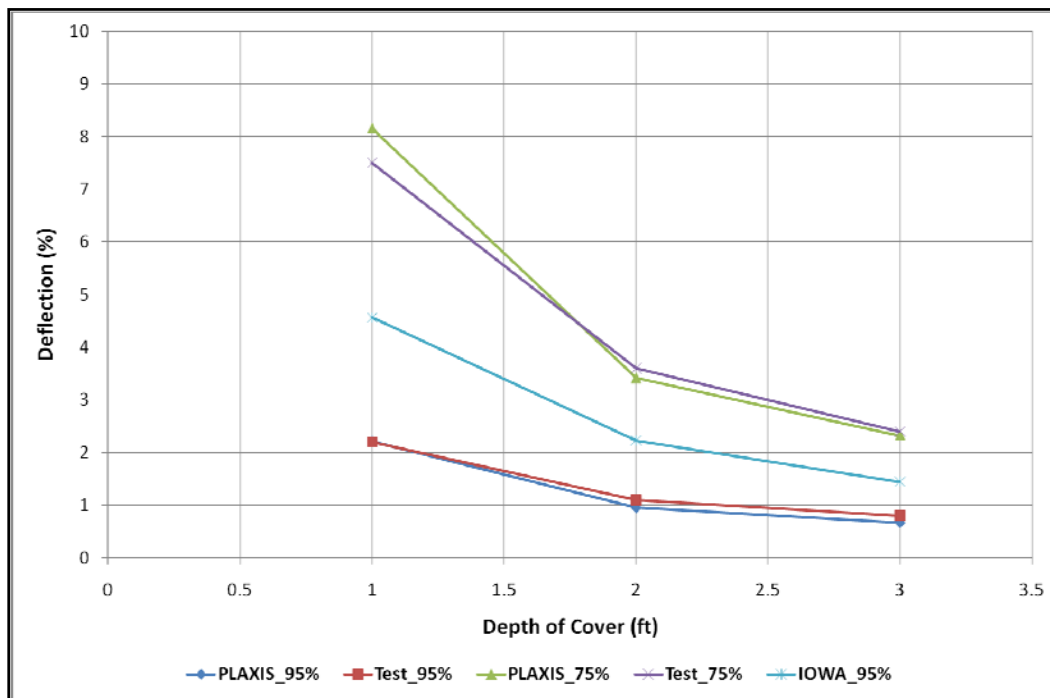


Figure 35. PLAXIS Verification with Field Data from Watkins and Reeve (197).

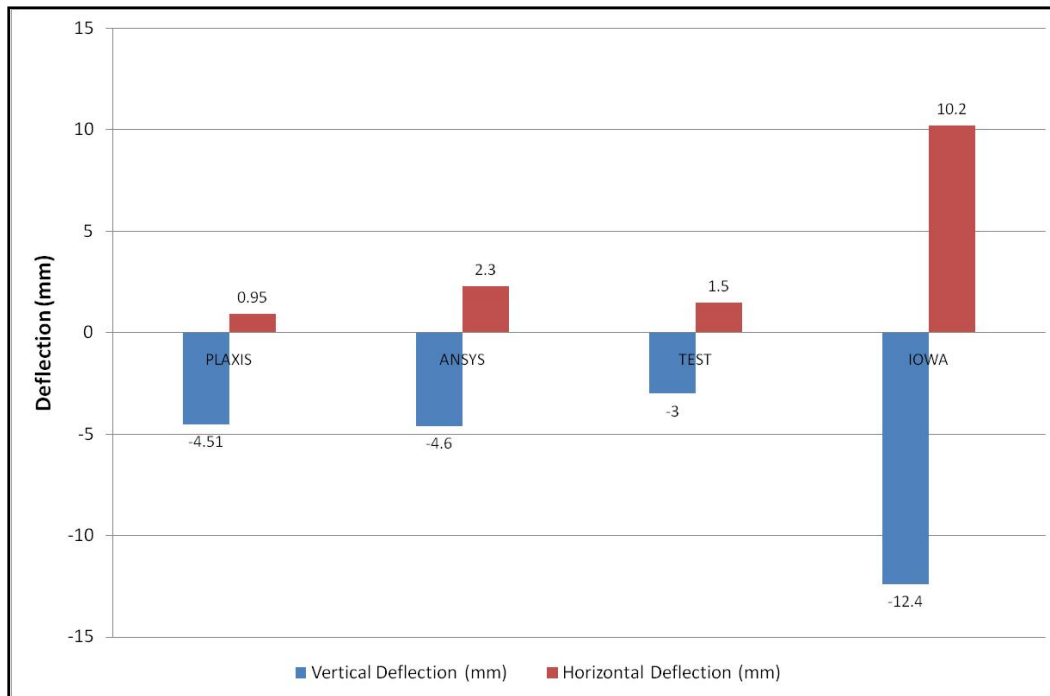


Figure 36. PLAXIS Verification with Field Data from Arockiasamy et al. (198).

Figure 36 compares the predicted vertical pipe deflections with the test measurements. In their project, Arockiasamy et al. used the Analysis System (ANSYS) 3D finite element program to predict the pipe deflections under loading. In this current project, TTI researchers used PLAXIS to predict the vertical deflections. Figure 36 shows that the ANSYS and PLAXIS predictions are generally comparable to each other and to the test measurements. The predicted radial deflection from PLAXIS is smaller than the ANSYS prediction and the test measurement. However, this difference is not considered significant in practice. Again, the modified Iowa formula exhibited significantly conservative predictions compared to the other values. This observation, along with the similar finding from the project done by Watkins and Reeve, indicate that current design procedures based on the modified Iowa formula are rather conservative.

Based on the results from the above verification, the research team decided to proceed with the sensitivity analysis using PLAXIS as the analysis tool. Table 75, Table 76, and Table 77 show the levels of the analysis variables selected by the researchers for this evaluation. These selections are based on the literature review conducted during this project.

Table 75. Variables Considered in Sensitivity Analysis.

Variable	Range
Axle weight (kips)*	32, 40, and 48
Number of axles	1,3, 5, 7, and 9
Depth of cover (ft)	1, 1.5, 2, 3, and 6
Pipe material	PVC, Ductile iron, and Clay pipe
Pavement type	Non-paved (6" base + backfill material + clay subgrade)
Backfill soil type	SW (well graded or gravelly sand)
Backfill soil compaction	85, 90, 95% based on AASHTO standard compaction

*Corresponds to HS-20, HS-25, and HS-30 design loads used in practice.

Table 76. Material Properties of Pipe.

Type	Nominal diameter (in.)	Outer diameter (in.)	Inner diameter (in.)	Wall thickness (in.)	EA* (lb/in.)	EI * (lb in. ² /in.)
PVC	24	24.8	22.5	0.71	284,400	11,981
Ductile Iron	24	25.8	24.7	0.37	8,880,000	101,306
Vitrified Clay	24	25.5	21.0	2.25	13,050,000	5,505,304

*These properties are given per linear foot of pipe.

Table 77. Parameters for Mohr-Coulomb Model of Backfill Material.

Soil Type*	Modulus of Elasticity (psi)	Poisson's ratio	Angle of friction (deg)	Dilatation angle (deg)	Cohesion (psi)
SW95	4100	0.29	48.0	18.0	0.001
SW90	3100	0.25	43.0	13.0	0.001
SW85	2100	0.21	38.0	8.0	0.001

* Well-graded sandy backfill (SW) at corresponding compacted densities of 95, 90 and 85%.

Results of the Sensitivity Analysis

Axle Position

The researchers varied the pipe position to investigate the sensitivity of pipe vertical deflection to the axle position as shown in Figure 37. For the 2D PLAXIS analysis, researchers converted the axle weight load to an equivalent strip load using the procedure from the NCHRP 647 study.

Five axles, each weighing 48 kips and at 4-ft axle spacing, were imposed on the pavement surface. The 48-kip axle weight is based on the HS 30 design truck configuration. The pavement structure in this analysis comprised 6 in. of flexible base over SW85 backfill material over clay subgrade. Researchers selected this pavement structure since an unpaved surface represents a more critical condition relative to pipe design compared to a paved surface with a stabilized stiffer material. The 24-in. PVC pipe was positioned 2 ft below the top of the base layer.

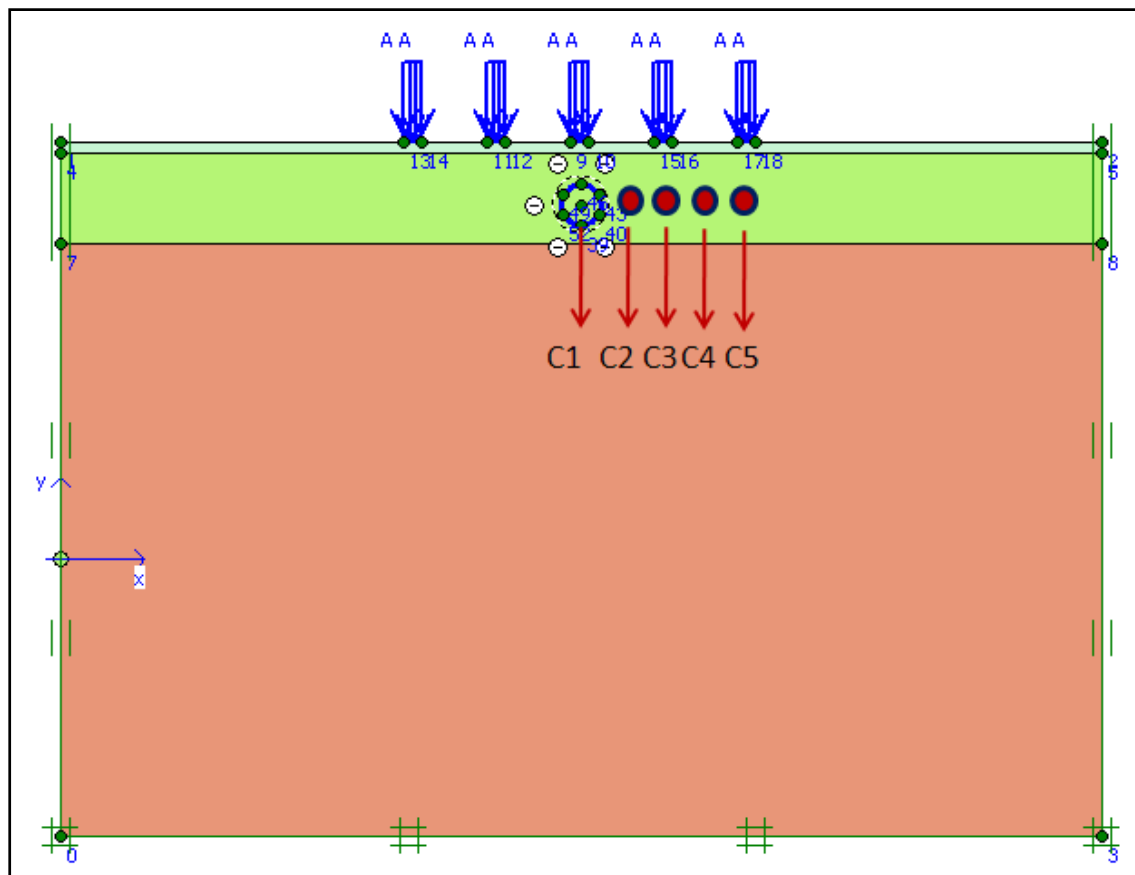


Figure 37. Varied Axle Positions with Respect to Pipe.

As shown in Figure 38, the maximum damage ratio is obtained when the axles are positioned symmetrically with respect to the pipe (denoted by C1). This result is logical since the pipe is expected to detect all axle loads at this position resulting in the most severe case based on pipe vertical deflection. The damage ratio in this sensitivity analysis is defined as the ratio of percent pipe vertical deflection to the 5 percent deflection criterion that is typically adopted in design practice. A damage ratio over 1 indicates the pipe deformed vertically above the 5 percent tolerance. Based on this result, researchers positioned the axles symmetrically with respect to the pipe to take into account the most severe condition.

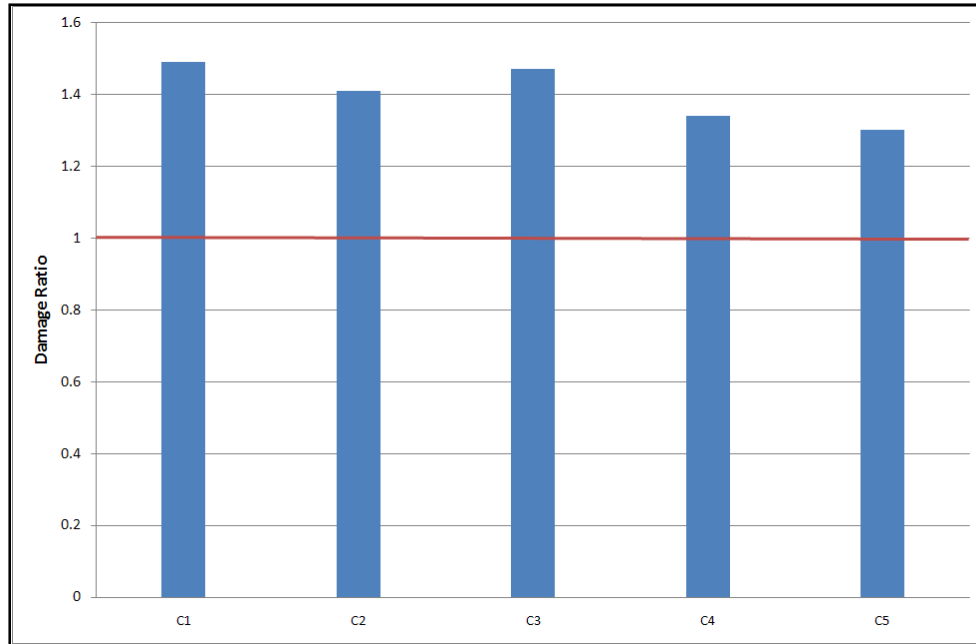


Figure 38. Sensitivity of Damage Ratio to the Axle Position.

Axle Weight

To investigate the sensitivity of pipe vertical deflection to the axle weight, researchers predicted the vertical deflections corresponding to the three levels of axle weight given in Table 75. The axle weights selected correspond to the three HS truck configurations typically considered in pipe design. The same pavement structure (2 ft depth of cover) and axle configuration (5 axles with 4-ft spacing) were used in evaluating the effect of axle weight. Figure 39 shows the results of this analysis. As expected, higher axle weight results in larger damage ratio. Based on this finding, researchers used a 48-kip axle weight in evaluating the effects of the other variables that are presented in the following sections.

Number of Axles

Researchers also investigated the effect of multiple axles on the predicted response of buried utilities to surface loads. For this investigation, researchers predicted the vertical deflections for different numbers of HS-30 design axle weights. Researchers assumed the same pavement structure used in the previous analyses except that the pipe was positioned at 1.5-ft depth of cover. This depth is the shallowest depth stipulated in existing Texas utility accommodation rules.

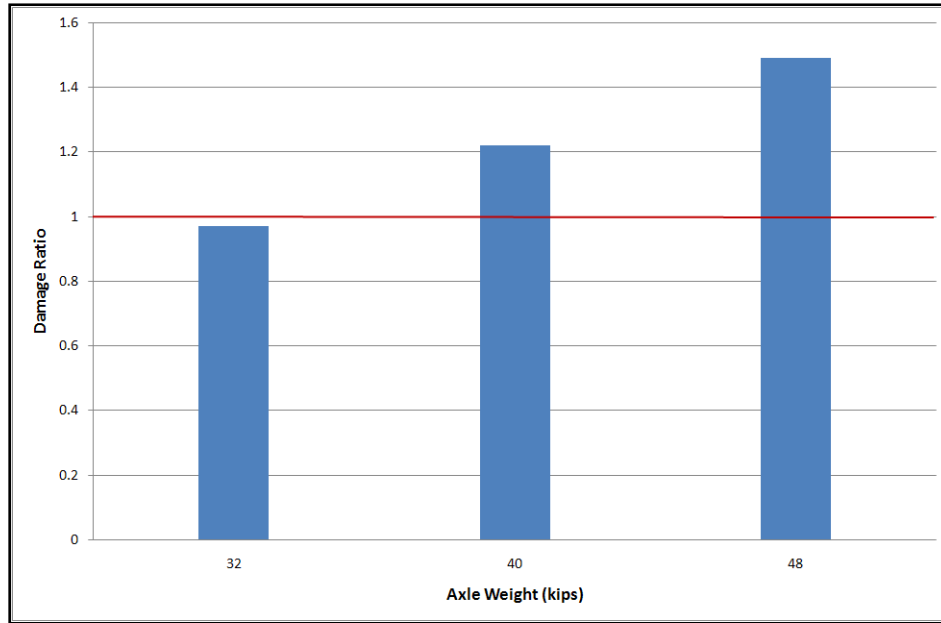


Figure 39. Sensitivity of Damage Ratio to the Axle Weight.

As expected, the damage ratio increased with the number of axles, as shown in Figure 40. The largest increase in the damage ratio occurs when the number of axles was changed from one to three. Figure 40 shows that multiple axles of transport vehicles used on some superheavy load moves need to be considered in estimating the damage potential associated with these moves. Based on the results shown in Figure 40, researchers modeled 9 axles in the remainder of the sensitivity analysis presented herein.

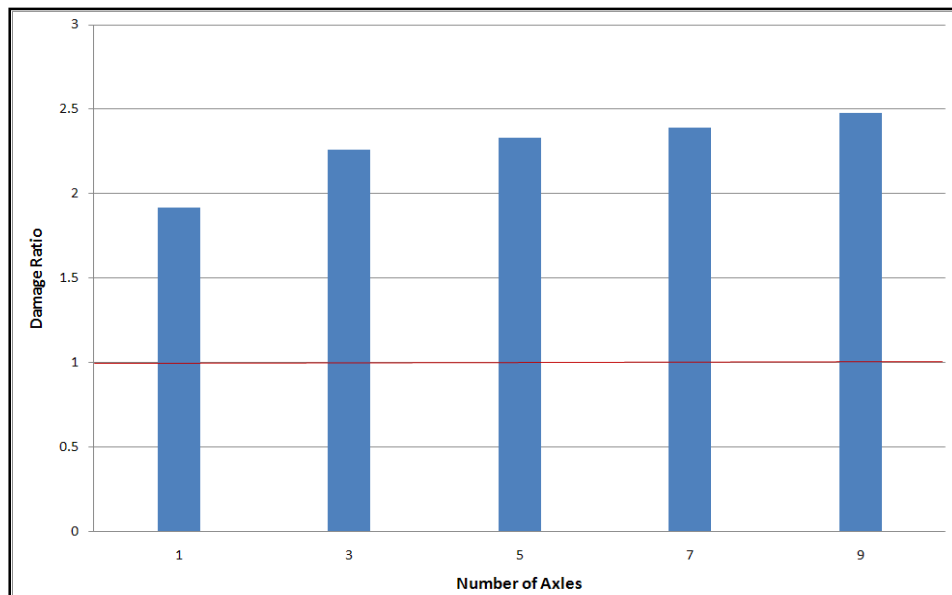


Figure 40. Sensitivity of Damage Ratio to Number of Axles.

Depth of Cover

Five levels of depth of cover (see Table 3) were considered in this analysis. These levels covered the range of depths found from the review of existing specifications. Figure 41 shows the sensitivity of the damage ratio to the depth of cover—the shallower the pipe, the higher the predicted vertical pipe deflection and damage ratio. For the assumptions used in this analysis, which correspond to a critical condition involving 9 axles at 48 kips per axle, 85 percent compaction of backfill, and unpaved surface with just 6 in. of base, the analysis suggests a minimum 3 ft depth of cover to satisfy the 5 percent deflection tolerance typically specified in pipe design. The minimum 3-ft depth of cover is also adopted in practice based on the public works design manual of the City of North Richland Hills and the construction standards of the City of Grapevine. This information was obtained from previous contacts made by the research team with departments of public works.

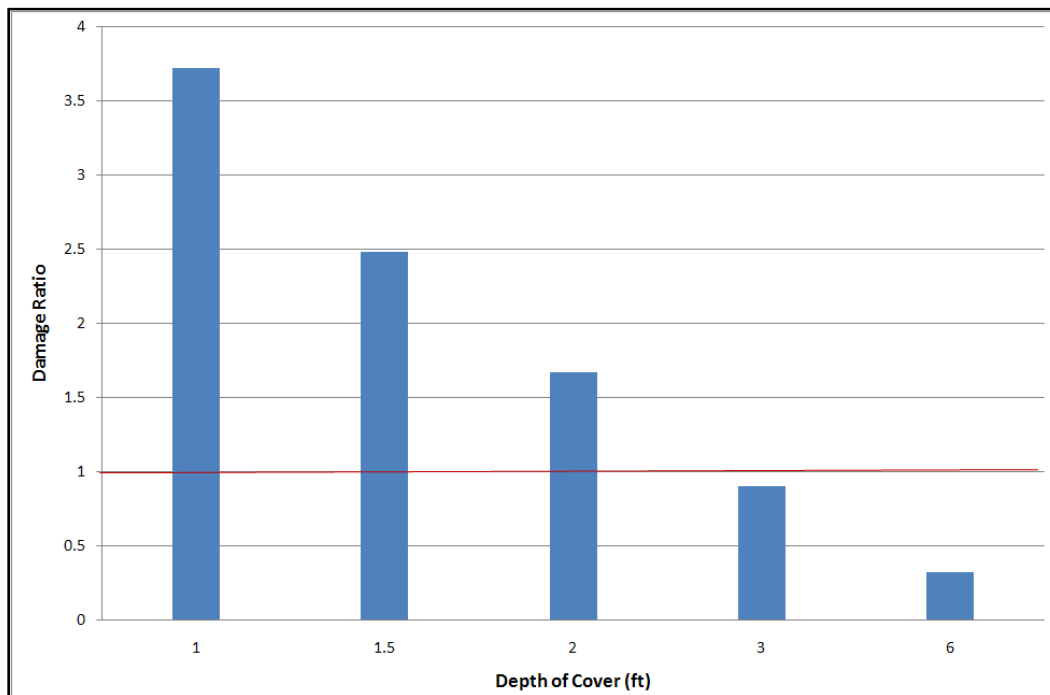


Figure 41. Sensitivity of Damage Ratio to the Depth of Cover.

Pipe Material and Wall Thickness

Three different types of pipe materials were considered. For the comparisons, researchers assumed the same nominal pipe diameter of 24 in., positioned at 2-ft depth from the unpaved surface and subjected to nine HS-30 design axle loads. Figure 42 shows the effect of pipe material on the predicted vertical deflections. For the assumptions used, the predicted damage ratio decreased as the pipe material changed from PVC to ductile iron to vitrified clay. In this analysis, the pipe wall thickness varied between pipe materials according to the design tables used in existing specifications (for the given 24-in. pipe size and pressure rating).

Researchers also considered the effect of pipe wall thickness (assuming the same pipe material and nominal diameter size) to simulate the effect of aging on the predicted pipe vertical

deflection. In this analysis, researchers considered ductile iron pipe, and modeled the effect of potential thinning of the pipe wall due to corrosion as a result of chemical reactions over time. Figure 43 shows slightly higher damage ratio with thinner wall thickness. Overall, the results presented in Figure 42 and Figure 43 indicate less sensitivity of the damage ratio to the pipe material and wall thickness compared to the effects of other factors considered in this sensitivity analysis.

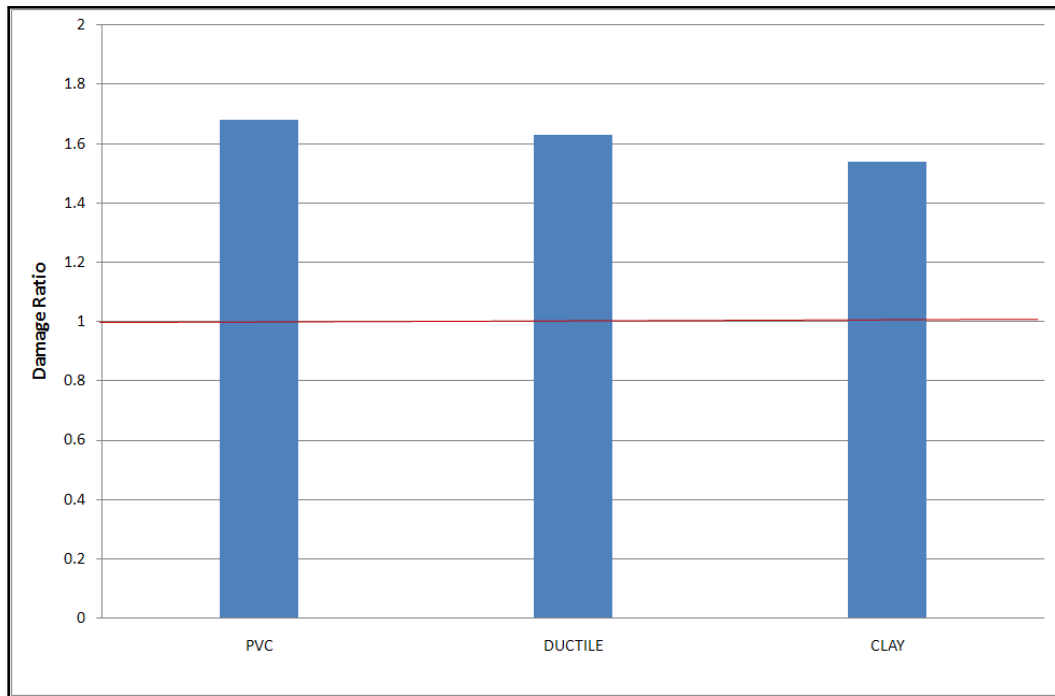


Figure 42. Sensitivity of Damage Ratio to the Pipe Material.

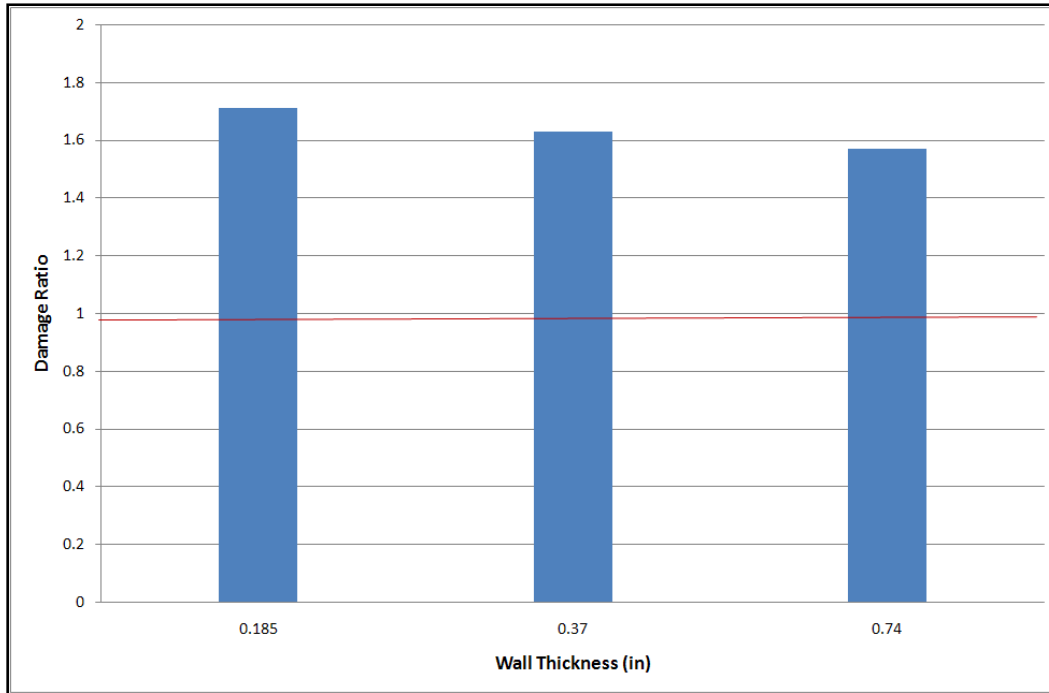


Figure 43. Sensitivity of Damage Ratio to the Pipe Wall Thickness.

Backfill Soil Type

The sensitivity analysis also considered different levels of compaction for the backfill material within which the pipe is buried. Table 77 shows the material properties assumed in this analysis. Researchers predicted the vertical deflections of a 24-in. PVC pipe at 2 ft depth of cover within the same pavement structure, and subjected to the same nine HS-30 design axle loads used in the earlier analyses. As expected, Figure 44 shows higher damage ratio with lower compaction.

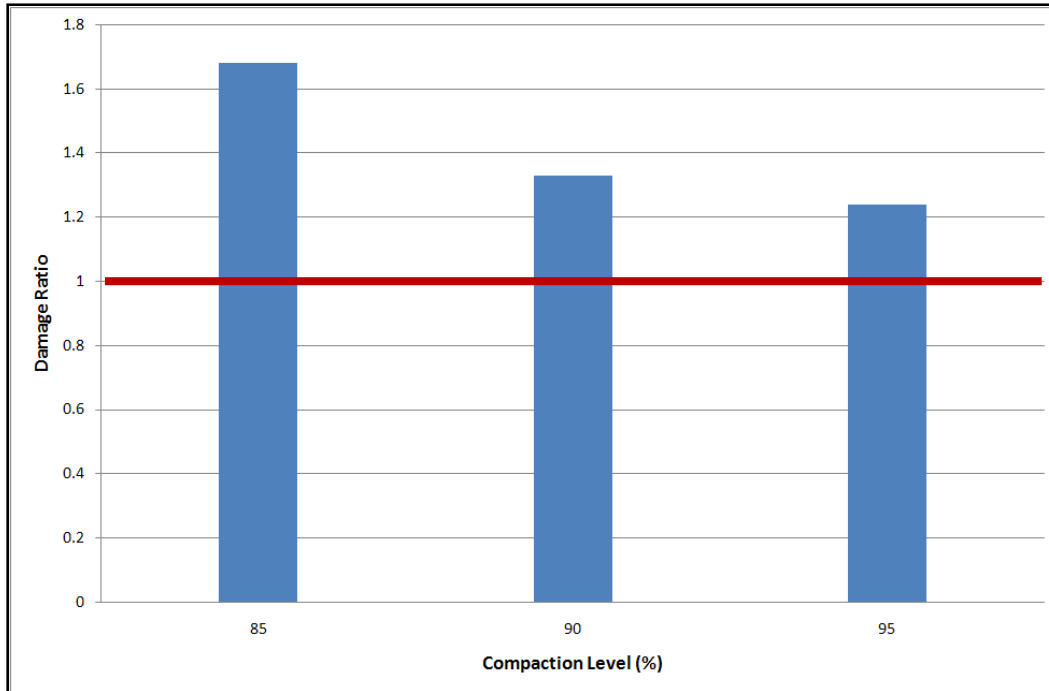


Figure 44. Sensitivity of Damage Ratio to the Compaction Level.

Summary of the Sensitivity Analysis

Based on the results presented, researchers noted the following findings from the sensitivity analysis:

- **Analysis Reliability and Calibration.** The predicted displacements using the PLAXIS 2D finite element program showed reasonable agreement with field test values taken from two previous studies.
- **Axle Positions.** Axles positioned symmetrically about the pipe produced maximum damage ratio based on predicted vertical displacements.
- **Axle Loads.** Higher axle load along with larger number of axles resulted in higher damage ratio.
- **Depth of Cover.** Depth of cover showed the most significant influence to predicted damage ratio.
- **Pipe Material.** The pipe material and wall thickness also influenced the damage ratio but its effect is relatively small compared to the effects of depth of cover, number of axles, and axle load magnitude.
- **Backfill Compaction.** Low compaction level of backfill material exhibited higher damage ratio.

Analysis Limitations

Researchers note that the sensitivity analysis assumed static loading conditions to predict the pipe deflections under varying conditions. The research team recommends that the fatigue behavior associated with repetitive loads should be investigated in the laboratory during Phase 2 of this project.

In addition, while the effect of multiple axles was considered based on typical HS-20, HS-25, and HS-30 truck load configurations used in current pipe design methods, the effect of multiple tires on multiple axles found on some of the transport vehicles used on superheavy load moves was only approximately modeled. For this reason, researchers recommend additional analysis using a 3D finite element program to directly model the load configurations found on multi-wheel superheavy load trailers. This analysis will supplement the findings presented from the sensitivity analysis using PLAXIS.

CHAPTER 7. PRELIMINARY CONCLUSIONS AND RECOMMENDATIONS

SUMMARY OF FINDINGS

The objectives of Phase 1, accomplished during the first year of the project, were to (a) provide a review of technical design and engineering requirements for utility accommodation in Texas, (b) provide a preliminary assessment of potential impact of overweight loads on buried utilities, (c) provide a preliminary assessment of UAR adequacy to deal with overweight loads on buried utilities, (d) provide preliminary recommendations for a business process for TxDOT overweight routing coordination, and (e) provide recommendations for the Phase 2 utility damage evaluation. The following sections provide a summary of the findings of the first year.

Review of Technical Design and Engineering Requirements for Utility Accommodation in Texas

In general, piping materials are classified as flexible or rigid. A flexible pipe is deemed to produce at least 2 percent deflection without regard to structural distress. Materials that do not meet this criterion are generally considered rigid. Rigid pipes are mainly classified into three types based on material type used: asbestos-cement pipe, clay pipe, and concrete pipe. For rigid pipes, strength to resist wall stress due to the internal pressure and external loads is critical in design. Ductile iron (cast iron,) steel, and thermoplastic pipes are usually considered flexible. For flexible pipes, stiffness is a critical factor in resisting ring deflection and buckling. The research team found the following with regard to technical and engineering requirements for utility installations:

- Concrete pipes are often required to be designed and manufactured in accordance with AWWA M 9, AWWA C301-72, AWWA C303-78, and AWWA C303 (8, 20, 19, 38). Reinforced concrete pipe was dominant prior to manufacturing of prestressed concrete pipe. The difference in construction of this pipe from prestressed concrete is that mild steel reinforcement is cast into the wall of the pipe instead of prestressing with high strength wire.
- Asbestos-cement pipes are applicable for both gravity and pressure systems. Asbestos-cement pipe for water systems often conform to ASTM C296 or AWWA C400 (21, 22). However, production of this pipe has been halted in the U.S. because of hazardous risks associated with the material.
- Vitrified clay pipe is manufactured from clay and shale, which are chemically inert. This type of pipe is very corrosion and abrasion resistant but only used for non-pressure applications due to its inherent low strength (2000 to 7000 psi.) Available pipe size ranges from 3 to 42 in. in nominal diameter. Vitrified clay pipes are often used for sewer lines larger than 15 in. in diameter and often use manufacturing standard ASTM C700 (28).

- Ductile iron pipe is very popular and often the preferred material in public works with respect to repair and maintenance of waste water systems. Water distribution line installations are often designed to withstand a working pressure of 150 psi. Typical standards require ductile iron pipes meeting the requirement of AWWA C151/ANSI A21.51 (16). Other popular standards are AWWA C110, AWWA C111, AWWA C150. Ductile iron pipe usually is coated with a cement-mortar lining to improve the hydraulic efficiency and provide some corrosion protection.
- Steel pipes are less frequently used for water installations. If used for water lines, popular standards for steel pipes are AWWA Manual M 11 and AWWA C200 (2, 3). Steel pipe is more frequently used as casing pipe. Steel casing pipe typically conforms to ASME B36.10 and other local special provisions (39).
- Thermoplastic pipes are also widely used in various water systems. There are four principal materials used: polyvinyl chloride (PVC), acrylonitrile-butadiene-styrene (ABS), polyethylene (PE), and polybutylene (PB). Most plastic pressure or sewer pipes are made of PVC. PVC pipe for water lines are often Class 150 conforming to AWWA C900 (23). Pipe for sewer lines is typically larger than 6 in. in diameter and mostly PVC if less than 15 in. in diameter, meeting the requirements of ASTM D 3034 (25). The main advantage of PVC pipe is its high strength-to-weight ratio and resistance to almost all types of corrosion from chemical and electrochemical processes. Thus, any type of lining or coating is not required. However, the performance of PVC pipe is significantly affected by its operating temperature.
- Fiberglass pipe, another material used for flexible pipe systems, is made from glass fiber reinforcements embedded in or surrounded by cured thermosetting resin. Since the 1960s, fiberglass pipe has been used for municipal water and sewage applications due to temperature, chemical, abrasion, and weathering resistance.

In general, piping systems should be designed to perform from 50 to 100 years since both government and private sectors cannot generally afford to replace pipe systems at less than 50-year intervals. The service life is not just a function of pipe material itself, but is mainly tied to the loading or environmental conditions to which the pipe system is subjected.

Preliminary Assessment of UAR Adequacy to Deal with Overweight Loads on Buried Utilities

The review of the historic evolution of the UAR with respect to buried utilities found the following:

- The current version of the UAR is a result of years of rule evolution. The origin of the state utility accommodation policy can be traced to a number of documents that provided early guidelines for the installation of underground utility facilities in the late 1940s and early 1950s. The development of these early specifications was likely subject to county and district engineer opinion and experience, personal bias, and engineering judgment. As a result, when assessing the risk on buried utilities, it is important to consider the age

of the utility facility. Utility facilities installed before 1979 could have been installed using a significantly lower standard than in use today.

- Since the reorganization of the Texas Administrative Code in 1979, the UAR have been amended or otherwise modified 11 times, on average about every three years. In several cases, rules have become stricter over time, requiring greater depth of cover, or removing exceptions for existing installations. Again, it is critical to consider the age of a utility to determine which construction standard applied at the time of construction.
- Anecdotal evidence and feedback from TxDOT and county officials suggest that although standards are in place, they are not always followed by utility contractors. For example, several county officials mentioned problems with communication lines buried with a much lower depth of cover than required, which frequently causes problems during highway maintenance activities. TxDOT officials mentioned a lack of staff and time to adequately monitor and inspect utility construction activities.
- Utility Crossing Highways. Since 1979, all utilities crossing highways in general must be encased, with a structural strength at least equal to drainage culverts. This regulation has essentially not changed over time, but some exceptions exist, such as certain type of gas pipes.
- Backfill Density. Since 1979, the backfill density must be at a minimum equal to the density of the surrounding soil.
- Depth of Cover. Since 1979, the standard depth of cover for most buried utilities was 18 in. (12 in. where conditions permit) or half the diameter of the pipe, whichever greater, under the pavement, and 24 in. under highway ditches (18 in. where conditions permit and for existing lines). Depth of cover requirements were increased for electric lines in 1989, and in 2009 for all other utility types. The 2009 amendments typically removed the 1979 exceptions, and provided higher depth of cover requirements for unencased utility facilities.

The sensitivity analysis found that depth of cover was the most significant factor for predicted damage ratio. Modeling HS-20, HS-25, and HS-30 design trucks typically used for bridge design, the researchers found that typical 24-in. pipes under an unpaved surface require a minimum depth of cover of 36 in. With a depth of cover of 24 in., the damage criterion was exceeded for both HS-25 and HS-30 trucks. The researchers predicted similar results for PVC, ductile iron, and clay pipes. As a result, the current exception for existing water and sewer lines at a depth of 24 in. may not provide sufficient depth of cover to adequately protect the buried utility facility. The current requirement of 30 in. minimum depth of cover below highway ditches may be sufficient for HS-20 and HS-25 axle weights, but is probably insufficient for HS-30 axle weights. Pending the results of additional analysis, it is too early to make a final determination at this point.

The results of the sensitivity analysis confirm the increase of the required depth of cover for new utility installations in 2009 was warranted, and may have to be increased further in the future.

The results also provide that utility facilities installed before 2009 are at a potential risk of damage, and facilities installed before 1979 even more so.

Preliminary Assessment of Potential Impact of Overweight Loads on Buried Utilities

The goal of this assessment was to develop a thorough understanding and documentation of the potential impact of overweight loads on buried utilities to support the development of recommendations with respect to utility accommodation that would minimize this impact. At the beginning of the project, researchers noted that the direction and scope of Phase 2 would largely depend on the findings from Phase 1, particularly with respect to findings from a review of the historical evolution of UARs and design standards for buried utilities, as well as evaluations of candidate case study sites to investigate the impact of overweight loads on utilities buried within the right of way.

With respect to identifying case studies involving damage to buried utilities due to overweight loads, researchers conducted an extensive outreach effort in Phase 1. These outreach efforts included the following:

- A letter from the Right of Way Division to utility stakeholders requesting information about utility lines that were damaged or were suspected to be damaged due to overweight load transports in Texas, disseminated to over 400 utility stakeholders.
- A general review of trade magazines, newspapers, and journals focusing on utilities damaged by overweight transports.
- A review of emergency work authorizations of the Utility Installation Review system and numerous follow-up phone calls to utility representatives.
- Contacting several TxDOT district maintenance directors and maintenance supervisors.
- Contacting water/sewer departments of several major cities including:
 - City of Beaumont Water Utilities Department.
 - City of Port Arthur Water Utilities Department.
 - City of Corpus Christi Water Department.
 - City of Kingsville Water Department.
 - City of Houston Department of Public Works and Engineering.
 - City of Texas City Utilities Department.
 - City of Big Spring Utility Maintenance Department.
 - Trinity River Authority (Northern Region).

This outreach effort did not identify any incidence of damage to buried utilities within the right of way due to overweight loads. Thus, in lieu of case studies, researchers conducted a sensitivity analysis to evaluate the effects of various risk parameters on the potential damage to buried utilities due to overweight loads. This sensitivity analysis used existing design criteria obtained from a review of current specifications. The general finding from this Phase 1 analysis suggests that current design standards appear to be adequate. However, in light of the fact that piping systems are typically designed to perform about 50 to 100 years, some piping systems in place today may have been installed before rules for underground utilities were codified in the Texas Administrative Code in 1979, and thus may have been installed using a lower standard.

Although the outcome of the outreach effort that did not identify any incidence of traffic-associated damage to buried utilities within the right of way implies that current design standards are adequate, it is unclear to what degree these standards protect buried utilities from repetitive overweight loads. Determining the impact of such repetitive loads on buried utilities is subject to the Phase 2 utility damage evaluation in the second year of this project.

Preliminary Recommendations for a Business Process for TxDOT Overweight Routing Coordination

The research team found that currently, there is no organizational unit within TxDOT that could provide data on critical, buried utility infrastructure. Furthermore, the team was thus far unable to identify locations of critical, buried utility infrastructure with the help of utility stakeholders, although the research team took several steps to reach out to the utility community.

The researchers conducted several outreach efforts and research activities to identify cases of buried utilities damaged by overweight loads. However, these efforts did not produce any cases where damage to buried utilities was attributable to overweight loads. Since the research team was unable to find any such cases, there was no opportunity to develop a preliminary business process for TxDOT overweight routing coordination to protect critical buried utility infrastructure. Instead, the research team proposed a modification to the research plan to include the development of this process in the second project year, if needed, as more information from the Phase 2 Utility Damage Evaluation becomes available.

Recommendations for Phase 2 Utility Damage Evaluation

The objectives of Phase 2, which will be accomplished during the second year of the project, are to (a) provide an assessment of overweight load impact on buried utilities based on documented and verified cases of load-associated damage to buried utilities, (b) provide a final assessment of UAR adequacy to deal with overweight loads on buried utilities and recommendations for changes to UAR, and (c) provide a revised business process of overweight permitting to enhance TxDOT coordination.

Researchers presented the findings from the outreach effort and the Phase 1 sensitivity analysis in a project meeting held in Austin in June 2010. While the findings throw a favorable light on current design practice, researchers noted that the sensitivity analysis is based on static loading using the same design load magnitudes and configurations (i.e., HS-20, HS-25, and HS-30) assumed in current practice. In order to obtain necessary data to assess the effect of repetitive loading,

researchers propose to conduct a limited number of laboratory fatigue tests in Phase 2 based on the available FY11 budget.

For these tests, researchers propose to fabricate an 8-ft wide by 8.5-ft high by 10-ft long box within which a pipe will be placed at a selected depth of compacted material. Researchers plan to instrument the pipe with sensors to measure the crown displacement and circumferential stress under repetitive loading. The current plan is to induce a target level of displacement for each load repetition and to record the variation in the load required to produce this target displacement with cumulative repetitions. Researchers will use the data to establish whether and when failure of the pipe has been reached, up to the proposed test limit of 100,000 load repetitions. Specifically, the researchers make the following recommendations for the Phase 2 Utility Damage Evaluation:

- **Laboratory Testing.** Researchers propose to test six specimens: three target displacement levels for two pipe materials (PVC and concrete) using the same depth of cover, soil material (clean sand), and compaction level. Each test is expected to take about five days to instrument the pipe, setup the box, and collect data under cyclic loading. Researchers plan to re-use the box after each test, but will instrument and place a new pipe in the box for each subsequent test. The outcome from the proposed laboratory tests are fatigue data collected under simulated field conditions that can be used to assess the adequacy of existing utility accommodation rules based on potential damage from repetitive overweight loads.
- **Finite Element Sensitivity Analysis.** In addition to the proposed laboratory tests, researchers plan to supplement the Phase 1 sensitivity analysis by evaluating the effect of multiple tires on the response of a buried utility under load. On super heavy load moves where gross vehicle weights are in excess of 1,000,000 lb, it is not unusual to see transport trailers with up to 16 tires per axle or line. While the load per tire on these axles is lower than the tire load used to design pipes in practice, the number of tires on these super heavy transport trailers are much more than the number of tires in the HS-20, HS-25, and HS-30 design load configurations. Thus, in the Phase 2 damage evaluation, researchers plan to conduct further comparative evaluations of these design axle configurations with the multi-tire axle configuration used on some super heavy load moves. For this purpose, researchers will consider using a 3D finite element program to compare the axle configurations.

REFERENCES

1. Moser, A. P. and S. Folkman. *Buried Pipe Design*. 3rd Edition, McGraw-Hill, 2008.
2. American Water Works Association. *Manual: Steel Pipe: A Guide for Design and Installation*. AWWA M11, Denver, CO, 2004.
3. American Water Works Association. *Steel Water Pipe - 6 In. (150 mm) and Larger*. AWWA C200, Denver, CO, 2005.
4. *Ductile Iron Pipe for Wastewater Applications*, Ductile Iron Pipe Research Association, Birmingham, Alabama, 2006.
5. American Water Works Association. AWWA M41. *Ductile-Iron Pipe and Fittings*, Third Edition, 2008.
6. American Water Works Association. *Manual: PVC Pipe - Design and Installation*. AWWA M23, Denver, CO, 2002.
7. American Water Works Association. *Fiberglass Pipe Design*. AWWA M45, Denver, CO, 2008.
8. American Water Works Association. *Manual: Concrete Pressure Pipe*. AWWA M9, Denver, CO, 2008.
9. Marston, A., and Anderson, A.O. *The Theory of Loads on Pipes in Ditches, and Tests of Cement and Clay Drain Tile and Sewer Pipe*. Bulletin No. 31, Iowa Engineering Experiment Station, Ames, Iowa, 1913.
10. Spangler, M.G. *The Structural Design of Flexible Pipe Culverts*, Iowa State College, Bulletin XL (30), 1941.
11. Watkins, R.K., and Spangler, M.G., *Some Characteristics of the Modulus of Passive Resistance of Soil: A Study in Similitude*. Procedures of the 37th Annual Meeting of the Highway Research Board, 1958, pp. 576–583.
12. Masada T., *Modified Iowa Formula for Vertical Deflection of Buried Flexible Pipe*, ASCE Journal of Transportation Engineering, Vol. 126, No. 5, 440–446, 2000.
13. American Association of State Highway and Transportation Officials. AASHTO LRFD Bridge Design Specifications, 2nd ed. Washington, D.C., 1999.
14. McGrath, T.J., *Replacing E' with the Constrained Modulus in Buried Pipe Design*. In *Pipelines in the Constructed Environment*. Edited by J.P. Castronovo and J.A. Clark. Reston, Va., ASCE, 1998.
15. *Construction Details and Standard Drawings*, City of Grapevine, Texas. Obtained from <http://www.grapevinetexas.gov/LinkClick.aspx?fileticket=gvDDScAE7iE%3d&tabid=371&mid=514>, 2006. Accessed August 31, 2010.
16. American Water Works Association. *Ductile-Iron Pipe, Centrifugally Cast, for Water*. AWWA C151/A21.51, Denver, CO, 2009.
17. Standard for Thickness Design of Ductile-Iron Pipe. ANSI/AWWA C150/A21.50, Denver, Colorado.

18. *Ductile Iron Pipe Design for Fire Protection, Water, and Wastewater*. Revised Version No. 2.04, Publication No. BRO-001, U.S. Pipe and Foundry Company, Birmingham, Alabama, 2004. Obtained from <http://www.uspipe.com/Files/20047231412260.001DuctileIronPD.pdf>. Accessed May 27, 2010.
19. *Standard for Reinforced Concrete Water Pipe-Steel Cylinder Type, Pretensioned*. ANSI/AWWA C303-78. Denver, Colorado.
20. *Standard for Pre-stressed Concrete Pressure Pipe-Steel Cylinder Type for Water and Other Liquids*. ANSI/AWWA C301-72. Denver, Colorado.
21. ASTM Standard C296, *Standard Specification for Asbestos-Cement Pressure Pipe*. Philadelphia, PA.: American Society for Testing and Materials.
22. *Standard for Asbestos – Cement Pressure Pipe, 4 in. through 16 in. (100 mm through 400 mm), for Water Distribution Systems*. ANSI/AWWA C400. Denver, Colorado.
23. American Water Works Association. *Polyvinyl Chloride (PVC) Pressure Pipe, and Fabricated Fittings, 4 in through 12 in (100 mm through 300 mm), for Water Distribution*. AWWA C900, Denver, CO, 2008.
24. *Blue Brute™ Class 150 Submittal and Data Sheet*. Obtained from <http://www.jmeagle.com/pdfs/2008%20Submittal%20Data%20Sheets/Blue%20Brute.pdf>. Accessed May 27, 2010.
25. American Society for Testing and Materials. *Standard Specification for Type PSM Poly (Vinyl Chloride) (PVC) Sewer Pipe and Fittings*. ASTM D 3034, West Conshohocken, PA, 2008.
26. *Gasketed PVC Sewer Pipe Datasheet*. PWEagle Waterworks Products, Eugene, OR, 2004. Obtained from <http://www.pwpipe.com/literature/f/mkt-f-750.pdf>. Accessed May 27, 2010.
27. ASTM Standard D2412, *Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading*. Philadelphia, PA.: American Society for Testing and Materials.
28. ASTM Standard C700, *Standard Specification for Vitrified Clay Pipe, Extra Strength, Standard Strength, and Perforated*. Philadelphia, PA.: American Society for Testing and Materials.
29. *Construction Standard*, City of Grapevine, Texas, 2006. Obtained from <http://www.grapevinetexas.gov/LinkClick.aspx?fileticket=HGg4rYsW8is%3d&tabid=371&mid=514>. Accessed August 31, 2010.
30. *Public Works Design Manual*, City of North Richland Hills, Texas, 2009. Obtained from http://www.nrhtx.com/pdf/PW_DesignManual/NRH%202009%20PW%20Design%20Manual.pdf. Accessed August 31, 2010.
31. *Blue Brute™ Class 165, Class 235, and Class 305 Submittal and Data Sheet*. Obtained from www.jmeagle.com/pdfs/2008%20Brochures/Blue%20Brute_web.pdf. Accessed May 27, 2010.
32. Texas Commission on Environmental Quality, Austin, Texas, 2010. Obtained from <http://www.tceq.state.tx.us>. Accessed May 27, 2010.

33. ASTM Standard C76, Standard Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe. Philadelphia, PA.: American Society for Testing and Materials.
34. ASTM Standard D698, Standard test methods for laboratory compaction characteristics of soil using standard effort. Philadelphia, PA.: American Society for Testing and Materials.
35. American Water Works Association. *Ductile-Iron and Gray-Iron Fittings for Water*. AWWA C110/A21.10, Denver, CO, 2008.
36. American Water Works Association. *Rubber-Gasket Joints for Ductile-Iron Pressure Pipe and Fittings*. AWWA C111/A21.11, Denver, CO, 2007.
37. Ductile Iron Concrete and Steel Pipe Specification, City of Fort Worth, Texas, 2004.
38. American Water Works Association. *Concrete Pressure Pipe, Bar-Wrapped, Steel-Cylinder Type*. AWWA C303, Denver, CO, 2008.
39. American Society of Mechanical Engineers. *Welded and Seamless Wrought Steel Pipe*. ASME B36.10M-2004, New York, NY, 2004.
40. American Society for Testing and Materials. *Standard Specification for Seamless Copper Water Tube*. ASTM B88, West Conshohocken, PA, 2009.
41. American Water Works Association. *Underground Service Line Valves and Fittings*. AWWA C800-05, Denver, CO, 2005.
42. American Society for Testing and Materials. *Standard Specification for Poly (Vinyl Chloride) (PVC) Pressure-Rated Pipe (SDR Series)*. ASTM D 2241, West Conshohocken, PA, 2009.
43. American Society for Testing and Materials. *Standard Specification for Poly (Vinyl Chloride) (PVC), Plastic Pipe, Schedules 40, 80, and 120*. ASTM D 1785, West Conshohocken, PA, 2006.
44. American Society for Testing and Materials. *Standard Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Controller Outside Diameter*. ASTM D3035-08, West Conshohocken, PA, 2008.
45. American Water Works Association. *Polyethylene (PE) Pressure Pipe and Tubing, 1/2 in (13mm) through 3 in (76 mm), for Water Service*. AWWA C901, Denver, CO, 2008.
46. American Water Works Association. *Polyethylene (PE) Pressure Pipe and Fittings, 4 in (100 mm) through 63 in, (1,575 mm) for Water Distribution and Transmission*. AWWA C906, Denver, CO, 2007.
47. Unified Facilities Guide Specifications. *Water Distribution*. UFGS-33 11 00, National Institute of Building Sciences, Washington, D.C., 2009.
48. Unified Facilities Criteria. *Water Supply: Water Distribution*. UFC 3-230-10A, U.S. Department of Defense, U.S. Corps of Engineers, Washington, D.C., 2004.
49. Unified Facilities Guide Specifications. *Cathodic Protection by Galvanic Anodes*. UFGS-26 42 13.00 20, National Institute of Building Sciences, Washington, D.C., 2006.
50. American Water Works Association. *Cement-Mortar Lining for Ductile-Iron Pipe and Fittings for Water*. AWWA C104/A21.4, Denver, CO, 2008.
51. American Water Works Association. *Polyethylene Encasement for Ductile-Iron Pipe Systems*. AWWA C105/A21.5, Denver, CO, 2005.

52. American Society for Testing and Materials. *Resistance to Short-Time Hydraulic Failure Pressure of Plastic Pipe, Tubing, and Fittings*. ASTM D 1599, West Conshohocken, PA, 2005.
53. American Society for Testing and Materials. *Filament-Wound "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe*. ASTM D 2996, West Conshohocken, PA, 2007.
54. American Society for Testing and Materials. *Centrifugally Cast "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe*. ASTM D 2997, West Conshohocken, PA, 2007.
55. American Water Works Association. *Fiberglass Pressure Pipe*. AWWA C950, Denver, CO, 2007.
56. American Water Works Association. *Reinforced Concrete Pressure Pipe, Steel-Cylinder Type*. AWWA C300, Denver, CO, 2004.
57. American Water Works Association. *Pre-stressed Concrete Pressure Pipe, Steel-Cylinder Type*. AWWA C301, Denver, CO, 2007.
58. American Water Works Association. *Standard for Liquid Epoxy Coating Systems for the Interior and Exterior of Steel Water Pipelines*. AWWA C210, Denver, CO, 2007.
59. American Water Works Association. *Cement-Mortar Lining of Water Pipelines in Place-4 In. (100 mm) and Larger*. AWWA C602-06, Denver, CO, 2006.
60. American Water Works Association. *Cement-Mortar Protective Lining and Coating for Steel Water Pipe - 4 In. (100 mm) and Larger - Shop Applied*. AWWA C205, Denver, CO, 2007.
61. American Water Works Association. *Coal-Tar Protective Coatings and Linings for Steel Water Pipelines – Enamel and Tape – Hot-Applied*. AWWA C203, Denver, CO, 2008.
62. American Society for Testing and Materials. *Standard Specification for Seamless Copper Pipe, Standard Sizes*. ASTM B 42, West Conshohocken, PA, 2002.
63. American Society of Mechanical Engineers. *Cast Bronze Alloy Threaded Fittings Classes 125 and 250*. ASME B16.15, New York, NY, 2006.
64. American Society of Mechanical Engineers. *Cast Copper Alloy Solder Joint Pressure Fittings*. ASME B16.18, New York, NY, 2005.
65. American Society of Mechanical Engineers. *Standard for Wrought Copper and Copper Alloy Solder Joint Pressure Fittings*. ASME B16.22, New York, NY, 2005.
66. American Society of Mechanical Engineers. *Standard for Cast Copper Alloy Fittings for Flared Copper Tubes*. ASME B16.26, New York, NY, 2006.
67. American Society for Testing and Materials. *Standard Specification for Poly (Vinyl Chloride) (PVC) Plastic Pipe Fittings, Schedule 40*. ASTM D 2466, West Conshohocken, PA, 2006.
68. American Society for Testing and Materials. *Standard Specification for Poly (Vinyl Chloride) (PVC) Plastic Pipe Fittings, Schedule 80*. ASTM D 2467, West Conshohocken, PA, 2006.

69. American Society for Testing and Materials. *Standard Specification for Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe, Schedules 40 and 80*. ASTM D 1527, West Conshohocken, PA, 2005.
70. American Society for Testing and Materials. *Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe (SDR-PR)*. ASTM D 2282, West Conshohocken, PA, 2005.
71. American Society for Testing and Materials. *Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe Fittings, Schedule 40*. ASTM D 2468, West Conshohocken, PA, 1996.
72. American Society for Testing and Materials. *Standard Specification for Solvent Cement for Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe and Fittings*. ASTM D 2235, West Conshohocken, PA, 2004.
73. American Water Works Association. *Molecularly Oriented Polyvinyl Chloride (PVCO) Pressure Pipe, 4 in through 12 in (100 mm through 300 mm), for Water Distribution*. AWWA C909, Denver, CO, 2002.
74. American Society for Testing and Materials. *"Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe Joints Using Flexible Elastomeric Seals*. ASTM D 4161, West Conshohocken, PA, 2005.
75. American Society for Testing and Materials. *Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless*. ASTM A 53, West Conshohocken, PA, 2007.
76. American Society for Testing and Materials. *Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless (Metric)*. ASTM A 53M, West Conshohocken, PA, 2007.
77. American Society of Mechanical Engineers. *Standard for Gray Iron Threaded Fittings; Classes 125 and 250*. ASME B16.4, New York, NY, 2006.
78. American Society of Mechanical Engineers. *Malleable Iron Threaded Fittings, Classes 150 and 300*. ASME B16.3, New York, NY, 2006.
79. American Water Works Association. *Installation of Ductile-Iron Water Mains and Their Appurtenances*. AWWA C600, Denver, CO, 2005.
80. American Society for Testing and Materials. *Laboratory Compaction Characteristics of Soil Using Standard Effort (12,000 ft-lbf/ft³) (600 kNm/m³)*. ASTM D 698, West Conshohocken, PA, 2007.
81. American Society for Testing and Materials. *Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications*. ASTM D 2321, West Conshohocken, PA, 2008.
82. American Society for Testing and Materials. *Soils for Engineering Purposes (Unified Soil Classification System)*. ASTM D 2487, West Conshohocken, PA, 2006.
83. American Society for Testing and Materials. *Standard Specification for Electric-Fusion (ARC)-Welded Steel Pipe (NPS 4 and over)*. ASTM A 139, West Conshohocken, PA, 2004.
84. American Society for Testing and Materials. *Standard Specification for Electric-Fusion (ARC)-Welded Steel Pipe (NPS 4 and over, Metric)*. ASTM A 139M, West Conshohocken, PA, 2004.

85. American Society for Testing and Materials. *Standard Specification for Welded and Seamless Steel Pipe Piles*. ASTM A 252, West Conshohocken, PA, 2007.
86. American Welding Society. *Structural Welding Code – Steel*. AWS D1.1/D1.1M, Miami, FL, 2008.
87. American Society for Testing and Materials. *Standard Specification for Ready-Mixed Concrete*. ASTM C 94, West Conshohocken, PA, 2009.
88. American Society for Testing and Materials. *Standard Specification for Ready-Mixed Concrete (Metric)*. ASTM C 94M, West Conshohocken, PA, 2009.
89. National Fire Protection Association. *Standard for the Installation of Private Fire Service Mains and Their Appurtenances*. NFPA 24, Quincy, MA, 2010.
90. Uni-Bell PVC Pipe Association. *Recommended Practice for the Installation of Polyvinyl Chloride (PVC) Pressure Pipe (Nominal Diameters 4-36 inches)*. UBPPA UNI-B-3, Dallas, TX, 1992.
91. American Water Works Association. *Underground Installation of Polyvinyl Chloride (PVC) Pressure Pipe and Fittings for Water*. AWWA C605, Denver, CO, 2005.
92. American Society for Testing and Materials. *Underground Installation of Thermoplastic Pressure Piping*. ASTM D 2774, West Conshohocken, PA, 2008.
93. American Society for Testing and Materials. *Underground Installation of “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe*. ASTM D 3839, West Conshohocken, PA, 2008.
94. American Water Works Association. *Field Welding of Steel Water Pipe*. AWWA C206-03, Denver, CO, 2005.
95. American Society for Testing and Materials. *Standard Practice for Making Solvent-Cemented Joints with Poly(Vinyl Chloride) (PVC) Pipe and Fittings*. ASTM D2855, West Conshohocken, PA, 2002.
96. American Society for Testing and Materials. *Safe Handling of Solvent Cements, Primers, and Cleaners Used for Joining Thermoplastic Pipe and Fittings*. ASTM F 402, West Conshohocken, PA, 2005.
97. Unified Facilities Guide Specifications. *Sanitary Sewers*. UFGS-33 30 00, National Institute of Building Sciences, Washington, D.C., 2008.
98. Unified Facilities Guide Specifications. *Natural Gas and Liquid Petroleum Piping*. UFGS-33 11 23, National Institute of Building Sciences, Washington, D.C., 2009.
99. American Society of Mechanical Engineers. *Gas Transmission and Distribution Piping Systems*. ASME B31.8-2010, New York, NY, 2010.
100. American Society for Testing and Materials. *Standard Specification for Polyethylene (PE) Gas Pressure Pipe, Tubing, and Fittings*. ASTM D2513, West Conshohocken, PA, 2009.
101. Unified Facilities Guide Specifications. *Earthwork*. UFGS-31 00 00, National Institute of Building Sciences, Washington, D.C., 2008.
102. American Society for Testing and Materials. *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft³) (2700 kNm/m³)*. ASTM D1557, West Conshohocken, PA, 2009.

103. American Association of State Highway and Transportation Officials. *Standard Method of Test for Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in) Drop*. AASHTO T 180, Washington, D.C., 2009.
104. American Association of State Highway and Transportation Officials. *Correction for Coarse Particles in the Soil Compaction Test*. AASHTO T 224, Washington, D.C., 2004.
105. National Clay Pipe Institute. *Clay Pipe Engineering Manual*. Lake Geneva, WI, 1985.
106. American Concrete Pipe Association. *Concrete Pipe Design Manual*. Irving, TX, 1980.
107. American Concrete Pipe Association. *Concrete Pipe Handbook*. Irving, TX, 1980.
108. American Society for Testing and Materials. *Standard Specification for Reinforced Concrete Arch Culvert, Storm Drain, and Sewer Pipe*. ASTM C 506, West Conshohocken, PA, 2009.
109. American Society for Testing and Materials. *Standard Specification for Reinforced Concrete Elliptical Culvert, Storm Drain, and Sewer Pipe*. ASTM C 507, West Conshohocken, PA, 2009.
110. American Society of Civil Engineers. *Design and Construction of Sanitary and Storm Sewers*. ASCE Manual of Engineering Practice No. 37, Reston, VA, 1983.
111. American Society for Testing and Materials. *Standard Specification for Reinforced Concrete Low-Head Pressure Pipe*. ASTM C 361, West Conshohocken, PA, 2008.
112. American Society for Testing and Materials. *Standard Specification for Reinforced Concrete Low-Head Pressure Pipe (Metric)*. ASTM C 361M, West Conshohocken, PA, 2008.
113. American Water Works Association. *Reinforced Concrete Pressure Pipe, Non-cylinder Type*. AWWA C302, Denver, CO, 2004.
114. American Society for Testing and Materials. *Standard Specification for Ductile Iron Gravity Sewer Pipe*. ASTM A 746, West Conshohocken, PA, 2009.
115. American Society for Testing and Materials. *Standard Specification for Mortar for Unit Masonry*. ASTM C 270, West Conshohocken, PA, 2008.
116. American Society for Testing and Materials. *Standard Specification for Portland Cement*. ASTM C 150, West Conshohocken, PA, 2009.
117. American Society for Testing and Materials. *Standard Specification for Portland Cement (Metric)*. ASTM C 150M, West Conshohocken, PA, 2009.
118. American Society for Testing and Materials. *Standard Specification for Air-Entraining Admixtures for Concrete*. ASTM C 260, West Conshohocken, PA, 2006.
119. American Society for Testing and Materials. *Standard Specification for Concrete Aggregates*. ASTM C 33, West Conshohocken, PA, 2008.
120. American Society for Testing and Materials. *Standard Specification for Concrete Aggregates (Metric)*. ASTM C 33M, West Conshohocken, PA, 2008.
121. American Society for Testing and Materials. *Standard Specification for Concrete Sewer, Storm Drain, and Culvert Pipe*. ASTM C 14, West Conshohocken, PA, 2007.

122. American Society for Testing and Materials. *Standard Specification for Concrete Sewer, Storm Drain, and Culvert Pipe (Metric)*. ASTM C 14M, West Conshohocken, PA, 2007.
123. American Society for Testing and Materials. *Standard Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe*. ASTM C 76, West Conshohocken, PA, 2008.
124. American Society for Testing and Materials. *Standard Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe (Metric)*. ASTM C 76M, West Conshohocken, PA, 2008.
125. American Water Works Association. *Flanged Ductile-Iron Pipe with Ductile-Iron or Gray-Iron Threaded Flanges*. AWWA C115/A21.15, Denver, CO, 2005.
126. American Society for Testing and Materials. *Standard Specification for Acrylonitrile-Butadiene-Styrene (ABS) and Poly (Vinyl Chloride) (PVC) Composite Sewer Piping*. ASTM D 2680, West Conshohocken, PA, 2009.
127. American Society for Testing and Materials. *Standard Specification for Acrylonitrile-Butadiene-Styrene (ABS) Sewer Pipe and Fittings*. ASTM D 2751, West Conshohocken, PA, 2005.
128. American Society for Testing and Materials. *Standard Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals*. ASTM D 3212, West Conshohocken, PA, 2007.
129. American Society for Testing and Materials. *Standard Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe*. ASTM F 477, West Conshohocken, PA, 2008.
130. American Society for Testing and Materials. *Poly (Vinyl Chloride) (PVC) Corrugated Sewer Pipe with a Smooth Interior and Fittings*. ASTM F 949, West Conshohocken, PA, 2009.
131. American Society for Testing and Materials. *Standard Specification for Poly (Vinyl Chloride) (PVC) Profile Gravity Sewer Pipe and Fittings Based on Controlled Inside Diameter*. ASTM F 794, West Conshohocken, PA, 2003.
132. American Society for Testing and Materials. *Standard Specification for Rigid Poly (Vinyl Chloride) (PVC) Compounds and Chlorinated Poly (Vinyl Chloride) (CPVC) Compounds*. ASTM D 1784, West Conshohocken, PA, 2008.
133. American Water Works Association. *Ductile-Iron Compact Fittings for Water Service*. AWWA C153/A21.53, Denver, CO, 2006.
134. American Society for Testing and Materials. *Polyethylene (PE) Large Diameter Profile Wall Sewer and Drain Pipe*. ASTM F 894, West Conshohocken, PA, 2007.
135. American Society for Testing and Materials. *Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter*. ASTM F 714, West Conshohocken, PA, 2008.
136. American Society for Testing and Materials. *Polyethylene Plastics Pipe and Fittings Materials*. ASTM D 3350, West Conshohocken, PA, 2008.
137. American Society for Testing and Materials. *"Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer Pipe*. ASTM D 3262, West Conshohocken, PA, 2006.
138. *Utility Accommodation Rules*. Texas Administrative Code, Title 43, Transportation, Part 1, Texas Department of Transportation, Chapter 21, Right of way, Subchapter C.

- Obtained from
[http://info.sos.state.tx.us/pls/pub/readtac\\$ext.ViewTAC?tac_view=5&ti=43&pt=1&ch=21&sch=C&rl=Y](http://info.sos.state.tx.us/pls/pub/readtac$ext.ViewTAC?tac_view=5&ti=43&pt=1&ch=21&sch=C&rl=Y). Accessed October 30, 2009.
139. *National Electrical Safety Code*. C2-2007. Institute of Electrical and Electronics Engineers (IEEE), 2007.
 140. *Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards*. Code of Federal Regulations, Title 49, Part 192. Obtained from http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&tpl=/ecfrbrowse/Title49/49cfr192_main_02.tpl. Accessed April 6, 2010.
 141. *Transportation of Hazardous Liquids by Pipeline*. Code of Federal Regulations, Title 49, Part 195. Obtained from <http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr;sid=401b4eb1be38062dcd29668ef6ee1e09;rgn=div5;view=text;node=49%3A3.1.1.1.7;idno=49;cc=ecfr>. Accessed April 6, 2010.
 142. *Rules and Regulations for Public Water Systems*. Texas Administrative Code, Title 30, Chapter 290, Subchapter D. Obtained from [http://info.sos.state.tx.us/pls/pub/readtac\\$ext.ViewTAC?tac_view=5&ti=30&pt=1&ch=290&sch=D&rl=Y](http://info.sos.state.tx.us/pls/pub/readtac$ext.ViewTAC?tac_view=5&ti=30&pt=1&ch=290&sch=D&rl=Y). Accessed April 6, 2010.
 143. *Utility Policies*. Texas Highway Department. Accessed March 15, 2010. Unpublished document.
 144. *Accommodation of Utilities*. Code of Federal Regulations Title 23, Chapter I, Part 645B. Obtained from <http://www.gpoaccess.gov/cfr/index.html>. Accessed Feb. 4, 2010.
 145. *A Policy on the Accommodation of Utilities within Freeway Right of Way*. American Association of Highway Transportation Officials Technical Committee on Geometric Design. Washington D.C., 2005.
 146. *A Guide for Accommodating Utilities within Highway Right of Way*. American Association of Highway Transportation Officials Technical Committee on Geometric Design. Washington D.C., 2005.
 147. *Highway/Utility Guide*. American Public Works Association and University of Alabama Department of Civil Engineering. Kansas City, 1993.
 148. *RAC Operation Guideline*. Texas Department of State Health Services. Obtained from http://www.dshs.state.tx.us/emstraumasystems/TexasAdministrativeCodes&EMSTraumaSystemRules06_2008.pdf. Accessed Nov. 24, 2009.
 149. *Texas Register*. Special Issue, October 20, 1997. Office of the Secretary of State, Austin, Texas, pp. 38–39.
 150. Texas Administrative Code, Title 43: Transportation, Chapter 21: Right of Way Division. October 1979, pp. 56–82.
 151. *Texas Register* 7. Office of the Secretary of State, Austin, Texas, May 1982, pp. 1952–1953.
 152. *Texas Register* 14(35). Office of the Secretary of State, Austin, Texas, May 1989, pp. 2366–2371.
 153. *Texas Register* 15(49). Office of the Secretary of State, Austin, Texas, June 1996, p. 3751.

154. *Texas Register* 21(48). Office of the Secretary of State, Austin, Texas, December 1996, p. 5980.
155. *Texas Register* 22(27). Office of the Secretary of State, Austin, Texas, December 1997, pp. 3443–3444.
156. *Texas Register* 23(49). Office of the Secretary of State, Austin, Texas, December 1998, pp. 12474–12475.
157. *Texas Register* 24(8). Office of the Secretary of State, Austin, Texas, December 1999, pp. 1220–1221.
158. *Texas Register* 26(10). Office of the Secretary of State, Austin, Texas, December 2001, p. 2055.
159. *Texas Register* 30(10). Office of the Secretary of State, Austin, Texas, December 2005, pp. 1466–1474.
160. *Texas Register*, 33(49). Office of the Secretary of State, Austin, Texas, December 2008, pp. 10066–10068.
161. *Texas Register*, 34(37). Office of the Secretary of State, Austin, Texas, September 2009, pp. 6308–6311.
162. *Texas Register*, 34 (49). Office of the Secretary of State, Austin, Texas, September 2009, pp. 8795–8800.
163. Special Provisions for TxDOT – San Antonio District Utility Permits. Texas Department of Transportation, San Antonio District, San Antonio, Texas, March 2009.
164. Special Provisions for TxDOT – Bryan District Utility Permits. Texas Department of Transportation, Bryan District, Bryan, Texas, April 2007.
165. Minimum Depth of Cover Table (For Underground Utilities on Highway Right of Way). Texas Department of Transportation, Pharr District, Pharr, Texas, October 2009.
166. 23 USC 127. U.S. Code, Title 23, Chapter 1, Sections 127. <http://www.gpoaccess.gov/uscode/>. Accessed March 29, 2010.
167. 23 CFR 657. Code of Federal Regulations, Title 23, Part 657, Certification of Size and Weight Enforcement. http://www.access.gpo.gov/nara/cfr/waisidx_09/23cfr657_09.html. Accessed March 29, 2010.
168. 23 CFR 658. Code of Federal Regulations, Title 23, Part 658, Truck Size and Weight, Route Designations – Length, Width, and Weight Limitations. http://www.access.gpo.gov/nara/cfr/waisidx_09/23cfr658_09.html. Accessed March 29, 2010.
169. 7 TTC 643. Texas Transportation Code. Title 7, Subtitle F, Chapter 643, Motor Carrier Registration. <http://www.statutes.legis.state.tx.us/Docs/TN/htm/TN.643.htm>. Accessed March 29, 2010.
170. 7 TTC 645. Texas Transportation Code. Title 7, Subtitle F, Chapter 645, Single State Registration. <http://www.statutes.legis.state.tx.us/Docs/TN/htm/TN.645.htm>. Accessed March 29, 2010.
171. 7 TTC 646. Texas Transportation Code. Title 7, Subtitle F, Chapter 646, Motor Carrier Brokers. <http://www.statutes.legis.state.tx.us/Docs/TN/htm/TN.646.htm>. Accessed March 29, 2010.

172. 6 TTC 201. Texas Transportation Code. Title 6, Subtitle A, Chapter 201, General Provisions and Administration.
<http://www.statutes.legis.state.tx.us/Docs/TN/htm/TN.201.htm>. Accessed March 29, 2010.
173. 6 TTC 370. Texas Transportation Code. Title 6, Subtitle G, Chapter 370, Regional Mobility Authorities.
<http://www.statutes.legis.state.tx.us/Docs/TN/htm/TN.370.htm><http://www.statutes.legis.state.tx.us/Docs/TN/htm/TN.646.htm> Accessed March 29, 2010.
174. 7 TTC 621. Texas Transportation Code. Title 7, Subtitle E, Chapter 621, General Provisions Relating to Vehicle Size and Weight.
<http://www.statutes.legis.state.tx.us/Docs/TN/htm/TN.621.htm>. Accessed March 29, 2010.
175. 7 TTC 622. Texas Transportation Code. Title 7, Subtitle E, Chapter 622, Special Provisions and Exceptions for Oversize and Overweight Vehicles.
<http://www.statutes.legis.state.tx.us/Docs/TN/htm/TN.622.htm>. Accessed March 29, 2010.
176. 7 TTC 623. Texas Transportation Code. Title 7, Subtitle E, Chapter 623, Permits for Oversize and Overweight Vehicles.
<http://www.statutes.legis.state.tx.us/Docs/TN/htm/TN.623.htm>. Accessed March 29, 2010.
177. 43 TAC 18. Texas Administrative Code. Title 43, Part 1, Chapter 18, Motor Carriers.
[http://info.sos.state.tx.us/pls/pub/readtac\\$ext.ViewTAC?tac_view=4&ti=43&pt=1&ch=18](http://info.sos.state.tx.us/pls/pub/readtac$ext.ViewTAC?tac_view=4&ti=43&pt=1&ch=18). Accessed March 29, 2010.
178. 43 TAC 28. Texas Administrative Code. Title 43, Part 1, Chapter 28, Oversize and Overweight Vehicles and Loads.
[http://info.sos.state.tx.us/pls/pub/readtac\\$ext.ViewTAC?tac_view=4&ti=43&pt=1&ch=28](http://info.sos.state.tx.us/pls/pub/readtac$ext.ViewTAC?tac_view=4&ti=43&pt=1&ch=28). Accessed March 29, 2010.
179. 43 TAC 28.10. Texas Administrative Code. Title 43, Part 1, Chapter 28, Section 28.10, Purpose and Scope.
[http://info.sos.state.tx.us/pls/pub/readtac\\$ext.TacPage?sl=R&app=9&p_dir=&p_rloc=&p_tloc=&p_ploc=&pg=1&p_tac=&ti=43&pt=1&ch=28&rl=10](http://info.sos.state.tx.us/pls/pub/readtac$ext.TacPage?sl=R&app=9&p_dir=&p_rloc=&p_tloc=&p_ploc=&pg=1&p_tac=&ti=43&pt=1&ch=28&rl=10). Accessed March 29, 2010.
180. 7 TTC 502. Texas Transportation Code. Title 7, Subtitle A, Chapter 502, Registration of Vehicles. <http://www.statutes.legis.state.tx.us/Docs/TN/htm/TN.502.htm>. Accessed March 29, 2010.
181. *Permit Officer's Reference Guide*. Motor Carrier Division, Texas Department of Transportation, Austin, Texas, April 2007.
182. *Recommendations of the Overweight/Oversize Work Group*. North & East Texas Maintenance Operations Group, Texas Department of Transportation, Tyler, Texas, November 23, 2006.
183. *LexisNexis Academic and Library Solutions – LexisNexis Academic*. Reed Elsevier Inc. Obtained from <http://academic.lexisnexis.com/online-services/academic/academic-overview.aspx>. Accessed April 10, 2010.
184. *Houston Chronicle*. Obtained from <http://www.chron.com/>. Accessed June 23, 2010.

185. *Corpus Christi Caller-Times*. Obtained from <http://www.caller.com/>. Accessed June 23, 2010.
186. *San Antonio Express-News*. Obtained from <http://www.mysanantonio.com/>. Accessed June 23, 2010.
187. *Fort Worth Star-Telegram*. Obtained from <http://www.star-telegram.com/>. Accessed June 23, 2010.
188. *Abilene Reporter News*. Obtained from <http://www.reporternews.com/>. Accessed June 23, 2010.
189. *Beaumont Enterprise*. Obtained from <http://www.usnpl.com/txnews.php>. Accessed June 23, 2010.
190. *Port Arthur News*. Obtained from <http://panews.com/>. Accessed June 23, 2010.
191. *Underground Focus Magazine*. Obtained from http://www.underspace.com/UFM_files/current_issue.html. Accessed June 23, 2010.
192. *Accident File Archive*. *Underground Focus Magazine*. Obtained from http://www.underspace.com/UFM_files/accident_bulletin/accident.php. Accessed June 23, 2010.
193. *About UIR*. UIR Online Help for Installation Owner Users. Obtained from https://apps.dot.state.tx.us/uirpro/UIR_HELP/UtilityCompany/UIR_Online_Help_System.htm. Accessed June 30, 2010.
194. Mlynarski, M., Katona, M.G., and McGrath, T.J., *Modernize and Upgrade CANDE for Analysis and LRFD Design of Buried Structures*, NCHRP Report 619, 2008. <http://144.171.11.40/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=408>. Accessed October 23, 2009.
195. Katona, M.G., and Smith, J.M., *CANDE User and System Manuals*, Federal Highway Administration Report No. FHWA-RD-77-6, 1976.
196. Peterson, D. L., Nelson, C.R., Li G., McGrath, T.J., and Kitane, Y., *Recommended Design Specifications for Live Load Distribution to Buried Structures*, NCHRP Report 647, 2010.
197. Watkins, R.K., and Reeve, R.C., *Effect of Heavy Loads on Buried Corrugated Polyethylene Pipe*, Advanced Drainage Systems, Inc., Columbus, Ohio, 1982.
198. Arockiasamy, M., Chaallal, O., and Limpeteeprakarn, T., *Full-Scale Field Tests on Flexible Pipes Under Live Load Application*, Journal of Performance of Constructed Facilities, Volume 20., No. 1, ASCE, pp. 21~27, 2006.

**APPENDIX A. COMPARISON OF INSTALLATION SPECIFICATIONS FOR BURIED UTILITY
FACILITIES IN THE 1979 AND 2010 UTILITY ACCOMMODATION RULES**

Table 78. General Rules for Underground Utilities.

Topic	1979 UAR	2010 UAR
Encasement	<ul style="list-style-type: none"> • In general, underground utility line crossings shall be encased. • Encasement shall be as specified for each type of line and shall be composed of materials of satisfactory durability. • The strength of the encasement material shall equal or exceed structural requirements for drainage culverts. • Welded steel pipeline crossings may be without encasement if such pipelines conform to 49 CFR 192 or 49 CFR 195 and provide increased wall thickness and/or higher strength steel, greater depth of cover, and adequate markings. 	<ul style="list-style-type: none"> • Utilities crossing a highway shall be encased by steel, concrete, or plastic pipes. • If horizontal directional drilling is used to place the casing, high-density polyethylene (HDPE) pipe must be used in place of plastic pipe. • The strength of the encasement material shall equal or exceed structural requirements for drainage culverts. • The length of any encasement under the roadway shall be provided from top of backslope to top of backslope for cut sections, 5 ft beyond the toe of slope for fill sections, or 5 ft beyond the face of the curb for curb sections.
Depth	<ul style="list-style-type: none"> • The department shall specify other protection in lieu of the depth required for the particular utility line where placements at the required depths are impractical. 	<p>Additional protection is needed where placements at the required depths are impractical, including encasement or use of a reinforced concrete slab. Reinforced concrete slabs or caps shall meet the following standards:</p> <ul style="list-style-type: none"> • width: 5 ft, or three times the diameter of the pipe, whichever is greater; • thickness: 6 in., at minimum; • reinforcement: #4 bars at 12 in. centers each way or equivalent reinforcement; and • cover: no less than 6 in. of sand or equivalent cushion between the bottom of the slab/cap and the top of the pipe.
Manholes	<ul style="list-style-type: none"> • Manholes should be straight on line installations with a minimum overall width necessary to operate and maintain the enclosed equipment. 	<ul style="list-style-type: none"> • A manhole's dimensions shall be the minimum acceptable by appropriate engineering and safety standards. • Inline manholes are the only type permitted within the right of way. • The width dimensions shall be no larger than necessary to hold equipment involved and to meet safety standards for maintenance personnel. Outside width, the dimension of the manhole perpendicular to the highway, shall not exceed 10 ft. • The outside diameter of the manhole chimney at the ground level shall not exceed 36 in. The district may allow an outside diameter

Topic	1979 UAR	2010 UAR
		<p>of up to 50 in.</p> <ul style="list-style-type: none"> • The top of the roof of the manhole shall be 5 ft or more below ground level. • Manhole rings and covers must be designed for HS-20 loading.
Installation	<ul style="list-style-type: none"> • Lines beneath an existing highway shall be installed by boring or tunneling. Jacking may not be used unless approved by the district. Bore pits should be located: <ul style="list-style-type: none"> ○ at least 30 ft from the edge of the nearest through traffic lane and no less than 20 ft from the edge of pavement on ramps; ○ not less than 10 ft from the edge of pavement or 5 ft from face of curb for low traffic roadways and frontage roads; or ○ if the above requirement cannot be met, additional approved protective devices will be installed for protection of the traveling public. • The use of explosives needs to be permitted by the department. • Where longitudinal trenching is permitted, backfill shall be compacted to densities equal to that of the surrounding soil. Trenching across jointed concrete pavement is not allowed and in no instance shall trenching across continuously reinforced concrete pavement be permitted. 	<ul style="list-style-type: none"> • Lines beneath an existing highway shall be installed by boring or tunneling. Jacking may not be used unless approved in writing by the district. The use of explosives is prohibited. Pipe bursting or fluid/mist jetting may be allowed by the department. • For rural, uncurbed highway crossings, all borings shall extend beneath all travel lanes with the following clearances unless precluded by right of way limitations: <ul style="list-style-type: none"> ○ 30 ft from all freeway mainlanes and other high-speed (>40 mph) highways, ○ 16 ft for high-speed highways with current average daily traffic volumes of 750 vehicles per day or fewer, ○ 16 ft for ramps, or ○ 10 ft for low-speed (40 mph or less) highways. • Annular voids greater than 1 in. between the borehole and carrier line (or casing if used) shall be filled with a slurry grout or other flowable fill. • For curbed highway crossings, all borings shall extend beneath travel and parking lanes and extend beyond the back of curb, plus: <ul style="list-style-type: none"> ○ 30 ft from facilities with speed limits of 40 mph or greater; or ○ 5 ft from facilities with speed limits of 40 mph or less, plus any additional width necessary to clear an existing sidewalk. • When trenching longitudinally, back fill or stabilized sand shall be compacted to densities equal to that of the surrounding soil.
Unsuitable conditions for underground utilities	<p>Conditions not suitable for pipeline crossings:</p> <ul style="list-style-type: none"> • deep cuts; • locations near footings or bridges and retaining walls; • crossing intersections at-grade or ramp terminals; • at cross-drains where flow of water, drift, or stream bedload may be obstructed; • locations within basins or underpasses drained by pump if the 	<p>Conditions unsuitable or undesirable for pipeline crossings:</p> <ul style="list-style-type: none"> • deep cuts; • locations near footings or bridges and retaining walls; • crossing intersections at-grade or ramp terminals; • locations at cross-drains where the flow of water may be obstructed; • locations within basins or underpasses drained by pump if the

Topic	1979 UAR	2010 UAR
	<p>pipeline carries a liquid or liquefied gas; or</p> <ul style="list-style-type: none"> • wet or rocky terrain where minimum depth of cover would be difficult to attain. 	<p>pipeline carries a liquid or liquefied gas; or</p> <ul style="list-style-type: none"> • terrain where minimum depth of cover would be difficult to attain.
Clearances	<ul style="list-style-type: none"> • Vertical and horizontal clearances between a pipeline and a structure or other highway or utility facilities should be sufficient to permit maintenance of the pipeline and the other facilities. 	<ul style="list-style-type: none"> • Except as specified in this subchapter, there shall be a minimum of 12 in. vertical and horizontal clearance between a pipeline and an existing utility. • If an installation of another utility or highway feature cannot take place without disturbing an existing utility, the minimum clearance will be 24 in.

Table 79. Low Pressure Gas and Liquid Petroleum Lines.

Topic	1979 UAR	2010 UAR
Depth of cover	<ul style="list-style-type: none"> • The minimum depth of cover within the right of way and under highway ditches, but outside the pavement structure, shall be 24 in. for either encased or unencased installations. A reduction of 6 in. in the above requirements may be authorized to permit existing lines to remain in place. • Lines shall be a minimum of 18 in. or 1/2 the diameter of the pipe, whichever is greater, beneath the bottom of the pavement structure. Where materials and other conditions justify, a minimum depth under the pavement structure of 12 in. or 1/2 the diameter of the pipe, whichever is greater, may be permitted. 	<p>For crossings:</p> <ul style="list-style-type: none"> • Where materials and other conditions justify, the district may require a minimum depth of cover under the pavement structure of 12 in. or 1/2 the diameter of the pipe, whichever is greater. • The minimum depth of cover for encased low-pressure gas lines: <ul style="list-style-type: none"> ○ 18 in. or 1/2 the diameter of the pipe, whichever is greater, under pavement structure; ○ 24 in. outside pavement structure and under ditches (original unsilted flow line); or ○ 30 in. for unencased sections of encased lines outside of pavement structure. • The minimum depth of cover for unencased low-pressure gas lines: <ul style="list-style-type: none"> ○ 60 in. under the pavement surface or 18 in. under the pavement structure for paved areas; ○ 48 in. outside paved areas and under ditches (original unsilted flow line); or ○ a lesser depth if authorized by the district where a reinforced concrete slab is used to protect the pipeline. <p>For longitudinal installations:</p> <ul style="list-style-type: none"> • The minimum depth of cover shall be 36 in.
Encasement	<ul style="list-style-type: none"> • Lines shall be encased as required for high pressure gas and liquid petroleum lines or they may be placed without encasement if they are of welded steel construction and are protected from corrosion by adequate and approved cathodic protective measure, with specific agreement that the pavement will not be cut for repairs at any time in the future. 	<ul style="list-style-type: none"> • Crossings shall be placed in a steel encasement, unless the line is of welded steel construction and is protected from corrosion.
Plastic lines	<ul style="list-style-type: none"> • Plastic lines may be used provided the internal pressure will not exceed 60 lb per square in., but shall be encased right of way line to right of way line on crossings and have at least 30 in. of cover. • The maximum size of plastic lines shall not exceed 6 in. • Longitudinal plastic lines shall be installed concurrently with a durable metal wire or other means for detection purposes. 	<ul style="list-style-type: none"> • Plastic lines shall be encased within the right of way on crossings, and must have at least 30 in. of cover.

Topic	1979 UAR	2010 UAR
Exceptions to location requirements	<ul style="list-style-type: none"> • In urban areas, existing longitudinal lines that can be maintained without violating access control and that are not under the pavement or shoulder of any proposed roadway or existing roadway that is scheduled for a major improvement may remain in place. 	<ul style="list-style-type: none"> • n/a

Table 80. High Pressure Gas and Liquid Petroleum Lines.

Topic	1979 UAR	2010 UAR
Depth of cover	<p>For encased lines:</p> <ul style="list-style-type: none"> • The minimum total clear depth of cover for casing pipe shall be 30 in. For the portion of the carrier line outside of the casing pipe the minimum depth of cover within right of way shall be 36 in. Exceptions may be authorized to permit existing lines to remain in place with a reduction of 6 in. in the above-specified depths. • All lines normally shall be a minimum of 18 in. or 1/2 the diameter of the pipe, whichever is greater, beneath the bottom of the pavement structure. Where materials and other conditions justify, a minimum depth under the pavement structure of 12 in. or 1/2 the diameter of the pipe, whichever is greater, may be permitted. <p>For unencased lines:</p> <ul style="list-style-type: none"> • The minimum depth of cover shall be 60 in. under the pavement surface or 18 in. under the pavement structure, whichever is greater. Under ditches, the minimum depth of cover shall be 48 in. • A reduction in the specified depths may be authorized where the pipeline is protected by a reinforced concrete slab. 	<p>For crossings:</p> <ul style="list-style-type: none"> • Encased lines. Where materials and other conditions justify, the district may approve a minimum depth of cover under the pavement structure of 12 in. or 1/2 the diameter of the pipe, whichever is greater. Otherwise, the minimum depth of cover shall be: <ul style="list-style-type: none"> ○ the greater of 18 in. or 1/2 the diameter of the pipe, under pavement structures; ○ 30 in. if the line is outside the pavement structure or under a ditch; or ○ 36 in. for unencased sections of encased lines outside the pavement structure. • Unencased lines. Where a reinforced concrete slab is used to protect the pipeline, the district may authorize a reduction in the depths. Otherwise, the minimum depth of cover is as follows: <ul style="list-style-type: none"> ○ 60 in. under the pavement surface or 18 in. under the pavement structure in paved areas; or ○ 48 in. if the line is placed outside the pavement structure or under a ditch. <p>For longitudinal installations:</p> <ul style="list-style-type: none"> • The minimum depth of cover shall be 48 in.
Encasement	<p>Encasement for crossings:</p> <ul style="list-style-type: none"> • Pipelines across highways may be encased or unencased. • When encasement is used, such encasement shall be provided under center medians and from top of backslope to top of backslope for cut sections or 5 ft beyond the toe of slope for fill sections, or face of curve, of all roadways, and 5 ft beyond any overpass or other structure where the line passes under it. • Where encasement is not employed, the welded steel carrier pipe shall provide sufficient strength to withstand the internal design pressure and the dead and live loads of the pavement structure and traffic. Additional protections should include: <ul style="list-style-type: none"> ○ heavier all thickness and/or higher factor of safety in design, 	<ul style="list-style-type: none"> • Casing shall consist of a vented steel pipe. • Where encasement is not employed, the utility shall show that the welded steel carrier pipe will provide sufficient strength. Additional protective measures must include: <ul style="list-style-type: none"> ○ heavier wall thickness, higher factor of safety in design, or both; ○ adequate coating and wrapping; ○ cathodic protection; and ○ the use of Barlow's formula regarding maximum allowable operating pressure and wall thickness, as specified in 49CFR §192.105. • Shallow anode bed types exceeding 48 in. in width shall not be

Topic	1979 UAR	2010 UAR
	<ul style="list-style-type: none"> ○ adequate coating and wrapping, ○ cathodic protection, and ○ other measures as required by 49CFR192 or 49CFR195. ● The minimum length of the above additional protection shall be the same as that required by encasement. ● Existing lines under low volume roads may be permitted to remain in place without encasement or extension of encasement if they are protected by a reinforced concrete slab or equivalent protection or if they are located at a depth of 6 ft under the pavement surface and not less than 4 ft under the roadway ditch. Reinforced concrete slabs should meet the following standards: <ul style="list-style-type: none"> ○ width: three times the diameter of the pipe or 5 ft minimum, whichever is greater, ○ thickness: 6-in. minimum, ○ reinforcement: #4 bars @ 12 in. centers each way or equivalent wire mesh, and ○ cover: the cushion between the bottom of slab and top of pipe shall be not less than 6 in. 	<p>permitted in right of way. All others must have a depth of coverage of at least 36 in. Deep well anode beds of up to 60 in. in diameter are acceptable. Rectifier and meter loop poles shall be placed at or near the right of way line.</p> <ul style="list-style-type: none"> ● The minimum length of the additional protection shall be the same as that required for an encased crossing. ● The district may allow existing lines under low-volume highways to remain in place without encasement or extension of encasement if they are protected by a reinforced concrete slab or equivalent protection or if they are located at a depth of 5 ft under the pavement structure and not less than 4 ft under a highway ditch.
Exceptions to location requirements	<ul style="list-style-type: none"> ● In urban areas, existing longitudinal lines that are not under the pavement or shoulder of any roadway or in the center median of a controlled access highway may be permitted to remain in place. 	<ul style="list-style-type: none"> ● n/a

Table 81. Water Lines and Non-Potable Water Control Facilities.

Topic	1979 UAR	2010 UAR
Water Lines		
Depth of cover	<ul style="list-style-type: none"> The same as required for low pressure gas lines. 	<ul style="list-style-type: none"> The minimum depth of cover shall be 30 in., but not less than 18 in. below the pavement structure for crossings.
Encasement	<ul style="list-style-type: none"> Encasement shall be provided under normal width center medians and from center of ditch to center of ditch for cut sections or 5 ft behind toe of slope for fill sections or face of curb of all roadways. Encasement may be omitted under center medians where their width is appreciably greater than normal rural standards. Encasement under side road entrances may be omitted if conditions allow. Encasement under low traffic roadways may be omitted on existing water lines having an inside diameter of 24 in. or more and on new lines having an inside diameter of 30 in. or more when all other requirements are met. 	<ul style="list-style-type: none"> Unless otherwise approved, water lines crossing under paved highways must be placed in a steel encasement pipe within the limits of right of way. Encasement may be omitted under center medians and outer separations that are more than 76 ft wide. Encasement under side road entrances may be omitted in consideration of traffic volume, condition of highway, maintenance responsibility, or district practice. Existing water lines 24 in. or greater may be allowed to remain unencased under the pavement of new low volume highways.
Lines crossing highway by bore	<ul style="list-style-type: none"> n/a 	<ul style="list-style-type: none"> Lines for customer service that cross the highway may be placed in a HDPE encasement pipe without joints (rolled pipe).
Plastic lines	<ul style="list-style-type: none"> Plastic lines may be used when they have at least 30 in. of cover for both crossing and longitudinal segments. Crossings shall be encased in accordance with §21.42 (Pipelines – General) and §21.43 (High Pressure Gas and Liquid Petroleum Lines). 	<ul style="list-style-type: none"> n/a
Manholes	<ul style="list-style-type: none"> The outside diameter of the manhole chimney at the ground level shall not exceed 36 in. 	<ul style="list-style-type: none"> n/a
Exceptions to location requirements	<ul style="list-style-type: none"> Same as required for low pressure gas lines. 	<ul style="list-style-type: none"> n/a
Irrigation and drainage facilities	<ul style="list-style-type: none"> Irrigation and drainage facilities installed across right of way shall be designed and constructed in accordance with departmental standards for highway culverts or bridges. 	<ul style="list-style-type: none"> n/a

Topic	1979 UAR	2010 UAR
Non-Potable Water Control Facilities		
Depth of cover for buried pipe facilities	<ul style="list-style-type: none"> • n/a 	<ul style="list-style-type: none"> • The minimum depth of cover shall be 30 in., but not less than 18 in. below any pavement structure.
Encasement for buried pipe facilities	<ul style="list-style-type: none"> • n/a 	<ul style="list-style-type: none"> • Unless the district approves another type of encasement, all non-potable water control lines crossing under paved highways within right of way must be placed in a steel encasement pipe. • At the district's discretion, encasement may be omitted under center medians and outer separations that are more than 76 ft wide.

Table 82. Installation Specifications for Buried Utility Facilities – Sanitary Sewer Lines.

Topic	1979 UAR	2010 UAR
Depth of cover	<ul style="list-style-type: none"> The same as required for low pressure gas lines. 	<ul style="list-style-type: none"> The minimum depth of cover shall be 30 in., but not less than 18 in. below any pavement structure.
Encasement	<ul style="list-style-type: none"> Lines to be operated under pressure and those composed of materials not conforming to material or depth of cover requirements shall be encased as prescribed for water lines. 	<ul style="list-style-type: none"> Pressurized line crossings under paved highways within the limits of the right of way shall be placed in a steel encasement pipe. Gravity flow lines not conforming to the minimum depth of cover shall be encased in steel or concrete. At the district's discretion, encasement may be omitted under center medians and outer separations that are more than 76 ft wide.
Materials	<ul style="list-style-type: none"> Sewer line crossings shall be cast iron, with satisfactory joints, or materials and designs that will provide equal strength and resistance to damage from sulfide gases and other corrosive elements. Concrete pipes may be used in those areas where its use has been proven acceptable. New and relocated longitudinal lines and those crossing low traffic roadways may be of any material that has been proven to be of satisfactory strength and durability, provided all other requirements are met. 	<ul style="list-style-type: none"> n/a
Manholes	<ul style="list-style-type: none"> Manholes serving sewer lines up to 12 in. shall have a maximum inside diameter of 4 ft. For any increase in line size greater than 12 in., the manhole diameter may be increased a like amount. Manholes for large interceptor sewers should be specially designed, keeping the overall dimensions to a minimum. The outside diameter of the manhole chimney at the ground level shall not exceed 3ft. 	<ul style="list-style-type: none"> n/a
Exception for existing lines in urban areas	<ul style="list-style-type: none"> The department may approve existing sewer lines in urban areas to remain in place at some locations. 	<ul style="list-style-type: none"> n/a

Table 83. Underground Electric Lines.

Topic	1979 UAR	2010 UAR
Depth of cover	<ul style="list-style-type: none"> The same as required for encased high-pressure gas and liquid petroleum lines. 	<p>All lines may be installed by direct bury at the following minimum depth of cover according to the voltage of electric lines as required by the National Electrical Safety Code:</p> <ul style="list-style-type: none"> 30 in. for electric lines with voltage of 22,000 or less; 36 in. for electric lines with voltage from 22,001 to 40,000; and 42 in. for electric lines with voltage of 40,001 or greater.
Encasement	<ul style="list-style-type: none"> Encasement shall be provided under center medians and from top of backslope to top of backslope for cut sections or 5 ft beyond the toe of slope for fill sections, or face of curb, of all roadways and 5 ft beyond any overpass or other structure where the line passes under it. Encasement may be omitted under center medians where their width is appreciably greater than normal rural standards. Existing lines under low-volume roadways may be permitted to remain in place without encasement or extension of encasement if they are protected by a reinforced concrete slab or equivalent protection or if they are located at a depth of 6 ft under the pavement surface and not less than 4 ft under the roadway ditch. Reinforced concrete slabs should meet the following standards: <ul style="list-style-type: none"> width: 5-ft minimum, thickness: 6-in. minimum, reinforcement: #4 bars @ 12 in. centers each way or equivalent wire mesh, and cover: the cushion between the bottom of slab and top of pipe shall be not less than 6 in. 	<p>Electric lines crossing the roadway shall be:</p> <ul style="list-style-type: none"> encased in steel or comparable material greater than or equal to that of ductile iron, with satisfactory joints, or materials and designs that will provide equal or better protection of the integrity of the highway system and resistance to damage from corrosive elements to which they may be exposed; and buried a minimum of 36 in. under highway ditches, and 60 in. below the pavement structure.
Manholes	<ul style="list-style-type: none"> Straight-line manholes are the only type normally permitted. Overall width dimensions should be no larger than necessary to hold the equipment and for safety standards to be assured. Outside width should not exceed 7 ft, length should be held to be reasonable minimum and the top of the roof should be 5 ft below ground level. The outside diameter of the manhole chimney at the ground level should not exceed 36 in. 	n/a

Table 84. Underground Communication Lines.

Topic	1979 UAR	2010 UAR
Depth of cover for crossings	<ul style="list-style-type: none"> • The minimum depth of cover shall be 24 in. for either encased or unencased installations outside the pavement structure and 18 in. under pavement structure. Where materials and other conditions justify, exceptions may be authorized to permit existing lines to remain in place with a reduction of 6 in. in the above-specified depths. • Crossings should be located at approximate right angles to the highway to the extent feasible and practicable. 	<ul style="list-style-type: none"> • The minimum depth of cover for cable television and copper cable communication lines shall be 24 in. under ditches or 18 in. beneath the bottom of the pavement structure, whichever is greater. • The top of the fiber optic facility shall be placed a minimum of 42 in. below the ditch grade or 18 in. below the pavement structure or 60 in. below the top of the pavement surface, whichever is greater. The department may authorize a minimum depth of cover of not less than 36 in. below the ditch grade or 60 in. below the top of the pavement surface, whichever is greater.
Depth of cover for longitudinal placement	<ul style="list-style-type: none"> • The minimum depth of cover shall be 24 in. for either encased or unencased installations outside the pavement structure and 18 in. under pavement structure. Where materials and other conditions justify, exceptions may be authorized to permit existing lines to remain in place with a reduction of 6 in. in the above-specified depths. 	<ul style="list-style-type: none"> • The minimum depth of cover for cable television and copper cable communications lines shall be 24 in. • The minimum depth of cover for fiber optic facilities shall be 42 in. The minimum depth of cover may be reduced to not less than 36 in. upon approval.
Encasement for crossings	<ul style="list-style-type: none"> • Lines crossing highway do not require encasement except where in the judgment of the district engineer it is necessary. Encasement or other suitable protection should be considered for facilities: <ul style="list-style-type: none"> ◦ with less than minimum bury, ◦ near footings of bridges or other highway structures, or ◦ near other locations where there may be hazards. • If the installation of the line is to be accomplished by boring a hole the same or about the same diameter as the line and pulling it through, then encasement is not necessary. Where such conditions cannot be met, encasement should be provided. The annular void between the drilled hole and the line or casing should be filled with a satisfactory material to prevent settlement of any part of the highway facility over the line or casing. • Encasement may be metallic or nonmetallic material. The strength of the encasement shall equal or exceed structural requirements for drainage culverts. • The length of any encasement shall be under center medians and from top of backslope to of backslope for cut sections or 5 ft beyond the toe of slope for fill sections, or face of curb, of all 	<p>The department may require encasement or other suitable protection when necessary to protect the highway facility when the line is located:</p> <ul style="list-style-type: none"> • at less than the minimum depth; • near the footing of a bridge or other highway structure; or • near another hazardous location.

Topic	1979 UAR	2010 UAR
	<p>roadways.</p> <ul style="list-style-type: none"> • Encasement may be omitted under center medians where their width is appreciably greater than normal rural standards. Where encasement is not installed, specific agreement should be reached with the utility company that the pavement will not be cut for repairs any time in the future. 	
Manholes	<ul style="list-style-type: none"> • Straight-line manholes are the only type normally permitted. • Manholes should not be installed in the pavement or shoulders of high volume roads except at locations on non-controlled access highways in urban areas where necessary for existing lines. • Manholes may remain in place or be installed under traffic lanes of low volume roadways in municipalities provided measures are taken to minimize such installations and to avoid their locations at intersections insofar as possible. • Manhole dimensions should be the minimum acceptable for good engineering and safety standards. Outside width should not exceed 7 ft, with the length to be held to a minimum. • The outside diameter of the manhole chimney at the ground level should not exceed 36 in. or 50 in. when proven necessary. • The top of the roof of the manhole should be 5 ft below ground level. Where such depth cannot be met, sufficient data should be submitted to the department for administrative handling. 	n/a

APPENDIX B. LETTER TO UTILITY STAKEHOLDERS



October 15, 2009

Re: Evaluation of Overweight Load Routing on Buried Utility Plant, TxDOT Research Project 0-6394

Dear Utility Stakeholder:

The Texas Department of Transportation (TxDOT) is asking for your assistance in identifying locations within state highway right of way with known or suspected risk of damage to buried utility infrastructure. The focus of this research is to identify those locations at risk due to frequency and magnitude of overweight load transport activities (not related to highway construction). This information will be used in a two-year TxDOT sponsored research project entitled, "Evaluation of Overweight Load Routing on Buried Utility Plant" being conducted by the Texas Transportation Institute (TTI), part of the Texas A & M University System. The objectives of the project are to:

- Evaluate the adequacy of the Utility Accommodation Rules (which govern utility installations within state highway right of way) with respect to recent increases in overweight load permitting activity on Texas highways, and
- Develop guidelines for better coordination among TxDOT divisions, regional centers and district offices which seek to minimize impact on buried utility infrastructure.

TTI will evaluate utility damage through forensic field investigation including geotechnical and pavement analysis. For locations within state highway right of way with known or suspected damage to buried utilities possibly caused by overweight load transport activity, please contact TTI with as much of the following information as possible.

- Site Location
 - County
 - Roadway name/designation
 - Location description, nearest intersection, milepoint or coordinates
 - Location relative to roadway (e.g., crossing angle, distance from edge of pavement/ROW line)
- Buried Utility Infrastructure Characteristics
 - Depth
 - Casing/conduit properties (diameter, material, strength/fatigue properties if known)
 - Installation date or approximate age
 - Installation method

THE TEXAS PLAN

REDUCE CONGESTION • ENHANCE SAFETY • EXPAND ECONOMIC OPPORTUNITY • IMPROVE AIR QUALITY
INCREASE THE VALUE OF OUR TRANSPORTATION ASSETS

An Equal Opportunity Employer



October 15, 2009

-Other utility information as available

TTI will consider field evaluations for all sites reported until May 1, 2010. Please email (or mail) information to:

Mr. Edgar Kraus, P.E.
Texas Transportation Institute
1100 NW Loop 410, Ste. 400
San Antonio, TX 78213
e-kraus@tamu.edu

Please include your contact information to allow for follow-up and further coordination if needed. For additional questions, please contact the research project supervisor, Mr. Edgar Kraus at 210.731.9938 or the TxDOT project director, Mr. Randy Anderson at 512.416.2953 or via email at (rande0@dot.state.tx.us). Information submitted to TTI will be handled in strict confidence and will only be used for field evaluations of damage to buried utilities in the context of the research project. Any further dissemination of this outreach to interested stakeholders is encouraged.

The Texas Department of Transportation greatly appreciates your involvement and support of this project as it seeks to better protect the investments made by the ratepayers/taxpayers of this state.

Sincerely,

John P. Campbell, P.E.
Director of Right of Way

THE TEXAS PLAN

REDUCE CONGESTION • ENHANCE SAFETY • EXPAND ECONOMIC OPPORTUNITY • IMPROVE AIR QUALITY
INCREASE THE VALUE OF OUR TRANSPORTATION ASSETS

An Equal Opportunity Employer