TxDOT Survey Manual

Revised April 2016

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Manual Notice 2016-1

From: Gus Cannon, CTCM, Right of Way Division Director

Manual: *TxDOT Survey Manual*

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Purpose

To communicate changes and additions to TxDOT's surveying procedures, as well as provide general reference for surveying procedures performed by and for the Texas Department of Transportation (TxDOT).

The further intent of this manual is to incorporate changes in technology and the evolution of surveying methodologies and policies at TxDOT. This manual is for use by TxDOT employees, TxDOT contractors and consultants.

Contents

This manual provides information on the use of surveying technology to perform surveys at the state and district level, including small-scale mapping projects.

This manual also incorporates appropriate reference material for surveying as well as the laws, rules, and regulations adopted by the Texas Board of Professional Land Surveying (TBPLS) to ensure TxDOT's compliance with all applicable laws.

Specific Changes

Chapter 3, Preliminary Surveying

- Re-numbered figures & tables and updated links throughout the chapter.
- Updated Section 4, Photogrammetry to allow the use of airborne GPS to reduce the amount of ground control for aerial mapping projects.

Instructions

Users are encouraged to print this manual double-sided from the PDF. To ensure manual currency, check the publishing date of printed manuals against the manual found on the TxDOT Online Manuals System website.

Contact

Please address your comments, concerns, or questions regarding this manual's information policies, guidelines, procedures, and practices to the TxDOT Committee on Geomatics & Surveying (COGS).

Archives

Past manual notices are available from a pdf archive.

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Chapter 1 — Introduction

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Section 2 — Manual Organization

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Section 4 — Standing Committee on Surveying

Section 1 — General Information Overview

Manual Use

This manual is primarily intended to be accessed online. The online version takes precedence over printed copies, changes, updates, and edits. However, paper copies may be used in the field. Copies should be checked against the online manual version for currency date to insure the latest information. Caution should be taken not to rely entirely on the printed version due to ongoing updates and/or changes.

Some information in this manual is excerpted and/or adapted from other sources, both online and standard text. Users should be aware that information found in this manual may change at the source and therefore should check the sources provided to insure use of the most current information.

The *TxDOT Survey Manual* is intended to provide guidance for planning, executing, and classifying surveys for both TxDOT employees and contractors.

The *TxDOT Survey Manual* contains information governing the operational standards used by Texas Department of Transportation (TxDOT). These standards are the policies and guidelines set forth by TxDOT regarding surveying processes and procedures.

Section 2 of this chapter presents all chapter descriptions.

Information security laws and standards govern the information presented within this manual. Please refer to the *TxDOT Information Security Manual* for specific security information.

Documentation of Authority

The following documents authorize the *TxDOT Survey Manual* and the activities it covers:

- *TxDOT Directive 5-92*, TxDOT Manual System
- *Executive Order 1-89*, Policy and Procedure Communication
- *TxDOT Policy Statement 2-26*, Information Security

Laws and Standards

The *TxDOT Survey Manual* provides the information that TxDOT survey resource users need to comply with applicable legal and policy requirements. Based on federal and state laws, state standards and agency policy, this manual draws upon the following:

- *Texas Government Code*, Section 2203.004, Requirement to Use State Property for State Purposes
- *Texas Government Code*, Section 403.275, Liability for Property Loss.

Administrative Documents

This manual draws upon information contained in the following memos and administrative announcements:

- TxDOT Memorandum, Surveying Operations, Charles W. Heald, March 28, 2000
- TxDOT Administrative Announcement, Professional Land Surveying, Byron C. Blaschke, P.E., September 28, 1990
- TxDOT Memorandum, Survey Datum Designated for Use Within TxDOT, Charles W. Heald, December 7, 1998
- TxDOT Memorandum, TxDOT Surveying Procedures, William Burnett, July 21, 1995.

Section 2 — Manual Organization

Organization of Chapters

Chapters 2-7 are similar in organization and address a general aspect of surveying and related information. Each chapter has:

- numbered sections for major topics
- unnumbered subsections describing concepts and policies relevant to the section topic.

Some chapters also contain procedures and directions for successfully completing tasks related to the section topic.

Subsequent sections are numbered sequentially within each chapter and contain related information associated with the chapter topic. Each chapter's title describes its content.

Subsections contain detailed information that describes concepts, policies, standards, and procedures related to the section topic. Concepts and policies a user needs to know for successfully complete a procedure are presented before the procedure; some procedures are presented in tables with (step/action) directions for completing a task.

This manual is designed to be published and accessed electronically. The manual is divided into an introductory chapter and chapters that address specific surveying topics.

Table 1.1 TxDOT Survey Manual Organization

Element	Purpose
Chapter 1	Identifies and provides manual information and organization. Identifies the authorities, laws and standards that govern the manual. Provides the manual purpose, acknowledgements, and background.
Chapters 2 – 7	Provide TxDOT survey policies and procedures
Appendix A	References
Appendix B	Second Term Calculations
Appendix C	Monumentation
Appendix D	Glossary
Index	Lists of figures, tables, and specific terms within chapters.

Chapter Descriptions

Chapter descriptions are provided for a quick overview of information contained in each chapter.

Chapter 2, General Surveying Procedures

Chapter 2. General surveying procedures and standards, as well as an introduction to surveying is presented in this chapter. Some of the standards and requirements contained and described in this manual are more comprehensive than others found elsewhere. These standards provide a means by which competency may be readily distinguished in the land surveying profession. Accuracy is a prime consideration in surveying and is stressed in this chapter.

Chapter 3, Preliminary Surveying

Chapter 3. This chapter provides information on the many types of surveying and procedures. Detailed information is provided for each survey type. Tables are also included in this chapter to further describe and explain specific information regarding preliminary surveying.

Chapter 4, Design Surveying

Chapter 4 discusses the descriptions and definitions for the types of surveys. It provides detailed information on TxDOT deliverables and differential leveling.

Chapter 5, Right of Way Surveying

Chapter 5 provides the phases of a boundary survey, the rules, and information pertaining to this type of survey is discussed. Instructions for fieldwork are presented, as well as checklists for further accuracy. Right of Way mapping requirements and map components are discussed in detail.

Chapter 6, Aviation Surveying

Chapter 6 discusses the roles and responsibilities of the various entities and individuals involved in aviation surveying. Additionally, aviation easements are presented along with samples for further explanation.

Chapter 7, Construction Surveying

Chapter 7 provides detailed information on survey checks and checklists suggestions. This chapter discusses the types of survey categories involved in construction surveying.

Appendix A, References

Appendix A, References - contains the references for information used in this manual.

Appendix B, Second Term Calculations

Appendix B, Second Term Calculations - contains information from the C&GS Special Publication 252. It contains plane coordinate projection tables: Texas (Lambert) by C&GS, January 1950.

Appendix C, Monumentation

Appendix C, Monumentation - contains information on TxDOT-approved methods of setting monuments in various soil conditions; the methods and illustrations of specific marker disks for each condition.

Appendix D, Glossary

Appendix D, Glossary - contains definitions for terms used in this manual.

Index

The index lists figures, tables, and specific terms.

Section 3 — Manual Overview

Purpose of the TxDOT Survey Manual

This manual is intended to be a general reference for surveying procedures performed by and for the Texas Department of Transportation (TxDOT). This manual is not a step-by-step instruction manual or a surveying textbook. The purpose of its publication is to establish minimum standards, policies, and procedures of surveying for TxDOT. The manual incorporates appropriate reference material for surveying as well as the rules adopted by the Texas Board of Professional Land Surveyors (TBPLS).

Manual Creation

The members of the Standing Committee on Surveying (SCOS) created the TxDOT Survey Manual. SCOS members were appointed to ensure department-wide compliance with all applicable laws, to serve as a liaison between TxDOT and the TBPLS, and to develop a set of procedures to be followed by TxDOT employees, contractors, and consultants performing surveys for TxDOT. As part of the SCOS charter, its members have developed this current *TxDOT Survey Manual* to incorporate changes in technology and the evolution of surveying methodology and policies at TxDOT. This manual will be updated as necessary.

Acknowledgements

The Standing Committee on Surveying (SCOS) would like to thank the following agencies for allowing their publications or portions of their publications to appear in this manual: Texas Board of Professional Land Surveying, and the Texas Society of Professional Surveyors.

The Standing Committee on Surveying would also like to thank the following Texas Department of Transportation Divisions for their contributions to this manual: Aviation Division, Right of Way Division, Technology Services Division, and General Services Division.

How to Get Help

The district survey coordinators are available to answer questions and discuss procedures and specifications outlined in this manual. Additionally, the Technology Services Division provides a helpdesk number, which offers survey help from the Automated Survey Support Unit. Users may access the helpdesk by calling (512) 302-2350, press 3 for engineering support, and then 4 for surveying support.

If there is a need for updates or corrections, please notify the district survey coordinator. TxDOT employees will also be able to find contact information for an area SCOS representative on the Crossroads site under the miscellaneous link, "TxDOT Surveying and Mapping."

Section 4 — Standing Committee on Surveying

Committee Background and Members

The Standing Committee on Surveying (SCOS) was formed from the Metric Surveying Subcommittee, which was created to prepare a surveying guide for metric surveying. The members of the original Metric Surveying Subcommittee were as follows:

Paul W. Maples, RPLS, Chairman, Jack L. Housworth, Jr., RPLS, Charles W. "Sonny" Joseph, RPLS, Franklin C. McCumber, RPLS, Clyde "Roger" Wheat, RPLS, Max A. Farriss, P.E., RPLS, Bobby Benavidez, Charles Davis, Richard Ferguson, Joe Grimes, Cecil Jenkins, Randall Kircher, James Woods.

The current and past members of the Standing Committee on Surveying responsible for this release of the manual are:

Judy B. Skeen, P.E. (Sponsor), W. J. (Joe) Breaux, RPLS (BMT), Mark Caldwell, RPLS (ATL), Jesse Cooper, RPLS (ROW), Jonathon Cox, RPLS (DAL), John Pierce, RPLS (TSPS Liaison), Marcella (Marcy) Saenz, P.E. (DES), Steve Schmidt, CST (TSD), Ivor Walker, RPLS (HOU), James Woods, RPLS (CRP), John Wallis, RPLS (ODA), Darryl Zercher, RPLS (TSD), Randal Kircher, RPLS (CRP), Mike Robbins, RPLS (AMA), Mark Eder (DAL), Brent Hillebrenner, P.E. (DES).

Link to SCOS Information

A link for information concerning the Standing Committee on Surveying (SCOS) is on TxDOT's intranet home page. This link should be used for current membership rosters of the SCOS and updated information about on-line editions of the *TxDOT Survey Manual* and the TxDOT Annual Surveyors' Conference.

SCOS Charter

The roles and missions of the SCOS are to:

- recommend direction for TxDOT survey operations
- maintain the *TxDOT Survey Manual* recommend standard field procedures and associated field tolerances
- recommend standard business practices for TxDOT surveying operations
- provide assistance and support to district / division surveying personnel on technical and contractual issues

- provide assistance to the Technology Services Division (TSD) in the development and implementation of data collection hardware and software
- provide assistance to the Technology Services Division and General Services Division (GSD) in the development of standard specifications for the procurement of surveying hardware
- provide assistance to the Right of Way (ROW) Division on professional land surveying issues
- provide assistance to the Design Division on engineering surveying for design
- serve as TxDOT liaison to the Texas Board of Professional Land Surveying (TBPLS) on TxDOT surveying policy and practices.

Committee Makeup

- 5 Member seats from districts
- 1 Standing seat from ROW, appointed by the director, Right of Way Division
- 1 Standing seat from TSD, appointed by the director, Technology Services Division
- 1 Standing seat (Ex-officio) from DES, appointed by the director, Design Division.

Membership Terms

- regular terms are five years in length
- regular terms begin and end at the SCOS Annual Workshop (in the spring of the year)
- unexpired terms may be completed by a new member
- members may serve more than one, non-consecutive term
- membership should be comprised of both Registered Professional Land Surveyor (RPLS) and non-RPLS members
- members are recommended by the committee membership, with statewide geographic representation desired. Respective district engineers approve members who are confirmed by TxDOT's deputy executive director.

Leadership / Administration

- The director, Technology Services Division sponsors the SCOS committee.
- A chairperson, appointed by a majority vote of the committee membership, leads the committee.
  - The committee chairperson is responsible for scheduling committee meetings and developing the associated agendas.
  - The committee chairperson may serve in this capacity for more than one consecutive year.
- Meetings are conducted on a quarterly basis, or more frequently if needed.

- Meeting summaries are developed to document the business conducted and assignments made during committee meetings.

Chapter 2 — General Surveying Procedures

Contents:

Section 1 — General Surveying Procedures

Section 2 — Standards

Section 3 — Introduction to Surveying

Section 4 — Surveying with GPS

Section 5 — Coordinate Systems

Section 6 — Units and Datum

Section 7 — Metadata

Section 1 — General Surveying Procedures

Standards and Requirements Overview

Information contained in this section is excerpted in its entirety and/or adapted for this manual from the Texas Board of Professional Land Surveying, the Texas Society of Professional Surveyors, and the Texas Administrative Code.

The Standing Committee on Surveying (SCOS) endorses the minimum standards set by the Texas Board of Professional Land Surveying **(**TBPLS**)** and all surveying completed for the Texas Department of Transportation (TxDOT) shall adhere to those standards.

The SCOS also endorses the Texas Society of Professional Surveyors *(TSPS) Manual of Practice* as a guideline for all types of land surveying, either by or for TxDOT.

Where standards and requirements contained and described in this manual are more comprehensive than those found in the Texas Board of Professional Land Surveying Professional and Technical Standards (Texas Administrative Code, Title 22, Part 29, Chapter 663, Subchapter B, Professional And Technical Standards), and the *TSPS Manual of Practice*, it is due to the additional needs and requirements of TxDOT. Note that each district may have standards for individual projects which exceed these minimum recommended standards and requirements.

A glossary of terms is available in Appendix D.

Minimum Standards of Practice (TBPLS)

Following are the minimum standards for Professional Land Surveyor as adopted by the Texas Board of Professional Land Surveying (TBPLS), which are contained in the Texas Administrative Code, Title 22 Examining Boards, Part 29 Texas Board of Professional Land Surveying, Chapter 663 Standards of Responsibility and Rules of Conduct, Subchapter B Professional and Technical Standards.

Any instrument carrying the seal and signature of a Registered Professional Land Surveyor must comply with the Professional Land Surveying Practices Act and Rules adopted by the TBPLS.

22 Texas Administrative Code §663.13. Introduction

The Board establishes these minimum standards of practice to better serve the general public in regulating the practice of professional surveying in Texas. Professional surveying performed in Texas, unless otherwise specifically exempted herein, shall meet or exceed the requirements of

these standards. The Board considers any survey, the purpose of which is to delineate, segregate, separate, or partition any interest in real property of any kind, under these standards.

To better serve the general public in regulating the practice of land surveying in Texas, these minimum standards of practice (Standards) are established. All land surveys performed by a Registered Professional Land Surveyor (RPLS) in Texas shall adhere to these standards by meeting or exceeding the requirements hereof.

22 Texas Administrative Code §663.15. Precision

The actual relative location of corner monuments found or set within:

- **corporate limits** of any cities in Texas shall be reported within a positional tolerance of 1:10,000 + 0.10'
- **extraterritorial jurisdiction** (EJT) of any cities in Texas shall be reported within a positional tolerance of 1:7,500 + 0.10'
- **all rural areas outside extraterritorial jurisdiction areas** of all cities in Texas shall be reported within a positional tolerance of 1:5,000 + 0.10'.

Areas, if reported, shall be produced, recited, and/or shown only to the **least** significant number compatible with the precision of closure.

Survey measurement shall be made with equipment and methods of practice capable of attaining the tolerances specified by these standards. Positional tolerance of any monument is the distance that any monument may be mis-located, in relation to any other monument cited in the survey.

22 Texas Administrative Code §663.16. Boundary Construction

When delineating a property or boundary line as an integral portion of a survey, the surveyor shall respect:

- junior/senior property rights
- footsteps of the original surveyor
- the record, the intent as evidenced by the record
- proper application of the rules of dignity or the priority of calls, and
- applicable statutory and case law of Texas.

Appropriate deeds and/or other documents including those for adjacent parcels shall be relied upon for the location of the boundaries of the subject parcel(s).

A land surveyor, assuming the responsibility of performing a land survey also assumes the responsibility for such research of adequate thoroughness to support the determination of the intended

boundaries of the land parcel surveyed. The land surveyor may rely on record data related to the determination of boundaries furnished for the registrants' use by a qualified provider, provided that the registrant reasonably believes such data to be sufficient and notes, references, or credits the documentation by which it is furnished.

All boundaries shall be connected to identifiable physical monuments of record dignity. In the absence of such monumentation, the surveyor's opinion of the boundary location shall be supported by other appropriate physical evidence, which shall be explained in the surveyor's report.

22 Texas Administrative Code §663.17. Monumentation

(a) All monuments set by a RPLS shall be set at sufficient depth to retain a stable and distinctive location and be of sufficient size to withstand the deteriorating forces of nature and shall be of such material that in the surveyor's judgment will best achieve this goal.

(b) When delineating a property or boundary line as an integral portion of a survey (survey being defined in the Act, §1071.002 subsection (6) or (8), the land surveyor shall set, or leave as found, sufficient, stable and reasonably permanent survey markers to represent or reference the property or boundary corners, angle points, and points of curvature or tangency. **ALL SURVEY MARKERS SHALL BE SHOWN AND DESCRIBED** with sufficient evidence of the location of such markers on the surveyors' plat.

If the land surveyor prepares a written description of the surveyed premise, he/she shall include the following in that written description:

1. reference to a description of the survey markers as shown on the plat, and
2. the seal and signature of a registered or licensed surveyor.

All metes and bounds descriptions prepared for easements shall be tied to physical monuments of record related to the boundary of the affected tract. In addition, the land surveyor may furnish an electronic copy of a written description, provided that the text is verbatim to that of the certified document retained in the land surveyor's file.

Where practical, all monuments set by Professional Land Surveyors to delineate or witness a boundary corner shall be marked in a way that is traceable to the responsible registrant or associated employer.

22 Texas Administrative Code §663.18. Certification

The Registered Professional Land Surveyor (RPLS) shall apply his/her seal to all documents representing professional surveying as defined in the Act.

If the surveyor certifies, or otherwise indicates, that his/her product or service meets a standard of practice in addition to that promulgated by the Texas Board of Professional Land Surveying, then the failure to so meet both standards may be considered by the Board, for disciplinary purposes, to be misleading the public.

22 Texas Administrative Code §663.19. Plat / Description / Report

Preliminary documents released from a land surveyor's control shall identify the purpose of the document, the land surveyor of record, the land surveyor's registration number, and the release date.

Such preliminary documents shall not be signed or sealed and shall bear the following statement in the signature space: "Preliminary, this document shall not be recorded for any purpose."

Preliminary documents released from the land surveyor's control, which include this text in place of the land surveyor's signature, need not comply with the other minimum standards promulgated in this chapter.

A land surveyor shall certify only to factual information that the land surveyor has personal knowledge of or to information within his/her professional expertise as a land surveyor, unless otherwise qualified.

Registered professional land surveyors may certify, using the registrant's signature and official seal, services that are not within the definition of professional land surveying as defined in the Act, provided that such certification does not violate any Texas or federal law.

For the purpose of these rules, the word "report" shall mean any or all of the following:

- survey plat,
- descriptions, or
- separate narratives.

All reports shall delineate the relationship between record monuments and the location of boundaries surveyed; such relationship shall be shown on the survey plat, if a plat is prepared, and/or a separate report and recited in the description with the appropriate record references recited thereon and therein.

Every description prepared for defining boundaries shall provide a definite and unambiguous identification of the location of such boundaries and shall describe all pertinent monuments found or placed.

Every survey plat prepared shall be to a convenient scale, and provide a definite and unambiguous representation of the location of the surveyed land according to its record description. Where mate-

rial discrepancies are found between the record and the condition discovered, the surveyor shall apprise his/her client in the following manner:

- If a plat of survey is prepared, the surveyor shall:
  - make specific reference of the discrepancy on the plat or survey, or
  - make a general reference to the discrepancy on the plat of survey and a specific reference to a report of survey which more specifically describes the discrepancy
- If a survey plat is not prepared, the surveyor shall notify his/her client of any material discrepancy by report of survey or other written notice.

Courses shall be referenced by notation upon the survey plat to an identifiable line for directional control.

The survey plat shall bear the name of the land surveyor responsible for the land survey, his/her official seal, his/her original signature (Rule §661.46), and date surveyed.

Boundary monuments found or placed by the surveyor shall be described upon the survey plat, including those controlling monuments to which the survey may be referenced. The surveyor shall note upon the survey plat, which monuments were found and which monuments were placed because of his/her survey.

A reference shall be cited on the plat to the record instrument, which defines the location of adjoining boundaries.

When appropriate, reference shall be cited in the description prepared to the record instrument, which defines the location of adjoining boundaries.

If any report consists of more than one part, each part shall note the existence of the other part or parts.

If a land surveyor provides a written narrative in lieu of a Plat/sketch/drawing to report the results of a survey, the written narrative shall contain sufficient information to demonstrate the survey was conducted in compliance with the Act and rules of the Board.

Section 2 — Standards

Overview

Information contained within this section is excerpted in its entirety from the Texas Society of Professional Surveyors (TSPS) *Manual of Practice.*

Standards

I. INTRODUCTION

The standards and specifications detailed herein are for voluntary use. The rules and regulations of the Texas Board of Professional Land Surveying (TBPLS) are mandatory and have the effect of law. They are frequently referenced throughout this manual.

A. These professional standards prescribe practices for land surveying in the state of Texas, so as to ensure the completion of the survey in accordance with commonly accepted standards of professional services, prevailing technological progress and current public welfare requirements. The standards further provide a means whereby competence may be readily distinguished in the land surveying profession. It is intended that these standards be commonly accepted as fundamental and necessary, except where a differing federal, state or local law, ordinance or rule may be more restrictive. Also, see the introduction to the TBPLS Professional and Technical (P & T) Standards, found in the General Rules of Procedures and Practices.

B. These standards will be of considerable value to property owners in Texas in obtaining professional surveying services. Further, these standards will assist the County Clerks of Texas in receiving and accepting maps for recordation.

C. It is anticipated that these standards will be of considerable interest and value to the public and to other professions, most notably the legal and real estate professions.

D. Surveys to be filed with the Texas General Land Office are to conform to existing statutes.

E. All professional surveying must be conducted in accordance with the TBPLS General Rules of Procedures and Practices.

II. GENERAL STATEMENT

A. It shall be the duty of each Registered Professional Land Surveyor to counsel with his client or employer to determine the purpose of any surveying service so as to be certain the needs of the client or employer are met. The specific purpose of a survey will determine the Category of service needed, thereby identifying the information required, the work to be done and a sound basis for

cost. Particular attention should be directed toward the client needs regarding the sale or purchase of real property and the probability that title insurance may be issued on the basis of the survey.

B. The land surveyor must provide the professional expertise, trained personnel and equipment necessary to achieve the results promulgated by these standards.

C. Any land survey is greatly influenced by the determination and evaluation of record information as well as field evidence. It is essential therefore, that the land survey be accomplished in substantial compliance with these professional standards to ensure that every land survey is located, described, monumented and mapped in a professional manner.

D. The computations of geometrical closure is seldom an assurance of the degree of accuracy to which a land parcel has been surveyed, but rather a means whereby excessive errors or blunders can be ascertained. Following the correction for the effects of systematic errors, the effects of accidental errors inherent in any linear or angular measurement must be determined by applied mathematical analysis.

III. DEFINITIONS AND APPLICATIONS

A. Accidental Error: An error for which it is equally probable that the sign of the error is a plus or minus value; an error for which there is no proportional change or relationship between monuments, conditions and the sign or magnitude of the error; an error, evident in a series of measurements, which is compensated in total effect.

B. Bearing Source: The source of the bearing (or course) must be related to a monumented line stated in the report, on the map or in any description as: 1) Geodetic Bearing, 2) Grid Bearing of the Texas Coordinate System of 1983 (or 1927), (with the proper zone specified), Sec. 21.071, et seq, Tex. Nat. Res. Code Ann. (Vernon 1978) or 3) A record bearing or the relation thereto.

C. Category: A unit dividing major professional services of a Registered Professional Land Surveyor into defined segments of similar nature, procedure and practice. A Category is comprised of one or several services or products that are closely allied. A Route Survey is a Category. A Land Title Survey is a different Category. Each Category has specific requirements.

D. Closure: A mathematical application whereby a determination is made as to the exactness that a geometrical form is generated or attained within its confined elements of connecting lines and points; a computation method used by a land surveyor to test the quality of field survey measurements and to apply corrections in balancing or adjusting the survey to meet precision specifications.

E. Condition: Each Category is divided into 4 Conditions unless otherwise specified. A Condition is determined by the location of the site to be surveyed in regard to rural, suburban, urban or urban business district areas. Every site within the state will fall into one of the 4 Conditions. A Condition establishes the tolerances required for that survey. The below listed Conditions are intended to provide for the large majority of land boundary surveying assignments. Where doubts exist between

any two or more Conditions as to which sufficiently provides for the total needs of the surveying products, the higher conditions shall be used.

E.l URBAN BUSINESS DISTRICT, CONDITION I: Any land survey made in a downtown business district of any city, town or village shall be known as an Urban Business District Land Survey, Condition I. A Condition I survey may define exterior boundaries, subdivide property, locate or relocate lots or tracts, define routes or rights of way and partition urban business district property for any legal use or purpose. An Urban Business District Land Survey may be made in any geographical area of the state for any appropriate legal purpose including title company insurance requirements for deletion of area and boundary exceptions on any real estate.

E.2 URBAN, CONDITION II: Any land survey made within the corporate limits of any city, town or village, but not in the recognized downtown business district, shall be known as an Urban Land Survey, Condition II. A Condition II survey may determine exterior boundaries, subdivide property for subdivision purposes, locate or relocate individual lots or tracts, define routes or rights of way and partition urban property for any legal use or purpose. An Urban Land Survey may be made in any geographical area of the state except within the downtown, business district of a city, town or village and may be used for any appropriate legal purpose, including title company insurance requirements for deletion of area and boundary exceptions on any real estate in urban, suburban, and rural areas.

E.3 SUBURBAN, CONDITION III: Any land survey that is made out side the corporate limits of any city, town or village but in any area that is or is intended to be primarily used for residential, commercial or industrial purposes or land lying between such residential, commercial or industrial areas whose value is influenced by the presence of such nearby developed real estate shall be known as a Suburban Land Survey, Condition III. A Condition III survey may determine exterior boundaries, subdivide property for subdivision purposes, locate or relocate individual lots, or tracts, define routes or rights of way and partition suburban property for any use or purpose. The Suburban Land Survey may be made in any geographical area of the state except within corporate limits of a city, town, or village and may be used for any appropriate legal purpose including: Title company insurance requirements for deletion of area and boundary exceptions on any real estate in suburban or rural area.

E.4 RURAL, CONDITION IV: All land boundary surveys that are made outside a corporate city, town or village limit or outside a suburban residential, commercial or industrial subdivision to locate boundaries of unimproved or improved lands used for the production of crops, livestock or minerals, including gas, oil or coal (fossil fuels), shall be known as a Rural Land Survey, Condition IV. Partitioning of such land may also be done provided the primary purpose, nature or use of the surveyed land is known to remain unchanged. A Rural Land Survey is intended to locate the boundaries and determine the quantity of improved or unimproved farm, ranch, or quarry lands, define routes or rights of way, or to partition the site for like use, but is not to be used for subdividing into tracts or lots for a different purpose or use.

F. Controlling Monument: A monumented land corner to which a land survey is referenced. Is often a monument of record.

G. Land Survey, Boundary Survey, or Property Survey: A survey performed by a Registered Professional Land Surveyor for the primary purpose of locating, describing, monumenting, and mapping a parcel of land.

H. Land Title Survey: A survey of real property performed by a Registered Professional Land Surveyor to be used by a title insuring agency for purposes of insuring title to said real property.

I. Positional Tolerance: A measure of the accuracy of the position of a monumented boundary corner with respect to its described location without error. Also, see applicable TBPLS rules for this subject.

J. Record: Any documentary material filed in the public records of a city, county or state office that pertains to the location of real property.

K. Shall, Should: "Shall," in this document, is considered obligatory; "should" is considered advised and recommended.

L. The compliance or conformity with essential requirements. Also the equivalent of substantial performance, where inconsequential, trivial variations or omissions are minimized, but may occur.

M. Surveyor, Land Surveyor or Registered Professional Land Surveyor: A person holding a valid license to practice land surveying as a Registered Professional Land Surveyor in the state of Texas, as issued by the Texas Board of Professional Land Surveying.

N. Systematic Error: An error, which, for known changes in measurement conditions, results in proportional changes of values, which remain unchanged, both in magnitude and sign; an error, evident in a series of measurements, which is cumulative in total effect.

O. Tolerance: The allowable imperfection of any value stated or established in a survey. Each Category has 4 Conditions and each Condition has certain tolerances or specifications for values that must be met. The following explanations of tolerance items are to be used with the tolerance chart for each Category.

O.1 Error of closure reflects the precision of the survey and is the result of mathematically determining the latitude and departures and subsequently the misclosure of the traverse. Once this value has been determined and found to be of no lesser quality than required, any suitable adjustment may be made.

O.2 Angular closure for each Condition is expressed as the number of seconds allowable for any angle multiplied by the square root of the number of angles in the traverse. This value should not be exceeded in any loop closure. The basis for this angular value is well documented in standard textbooks on surveying practice and procedures.

O.3 Accuracy of the bearing (or course) in relation to source is the relationship of each bearing as expressed on a map, plat, and/or in a description of the new survey. This shall not exceed the angular relationship of the stated source by more than the following tolerance:

- Sin A = 1/P (approximately) and rounded to nearest 5 seconds
- Where A = ± bearing accuracy in seconds (rounded) and p = the denominator of the allowable error of closure (precision) for the particular Condition (i.e. 5,000; 7,500; 10,000; or 15,000)

O.4 Positional tolerance of any monument is the distance that any monument may be mislocated. This distance can be determined by dividing the length of the course between two monuments by denominator of the appropriate error of closure. The results of this calculation will establish the tolerance or radius around a point. No traverse adjustment shall be made to any distance larger than this positional error. The preceding tolerance calculations shall not apply to distances of 225 feet or less; however, all distances between monuments from 0 through 225 feet shall have a positional error not to exceed 0.03 feet.

O.5 "Calculation of area — accurate and carried to" means that the perimeter courses and distances as shown on a map, plat or drawing representing the survey shall compute to the area stated on the map. The decimal shall be carried only so far as it is compatible with the precision of the survey and not beyond the last significant number. A one acre survey with a precision of 1:5,000 will result in an area calculation of ± value of 0.0002 acre. The acreage should then be carried only to the nearest 0.001 acre. Likewise a survey of a one acre tract with a precision of 1:15,000 will result in an area calculation of ± 3 square feet or about ± .00007 acre. The acreage can then be carried to the nearest 0.1 acre. Similar values can be mathematically applied to any size tract by the formula:

- Ae = A - (e/e+l x A)
- Where Ae = ±
- A = area of tract in square feet, determined from survey
- e = denominator of error of closure for the particular Conditions (5,000; 7,500; 10,000; 15,000)

P. Water Course: A stream of water such as a river, brook, creek, bayou, etc. A visible channel for water such as a ditch, channel or stream bed.

Q. Working Sketch: A map prepared from record data depicting the relationship of the various record tracts, usually in, but not limited to, the immediate vicinity of the parcel being considered or surveyed.

R. Other Definitions: Most terminology used in these standards is common within the profession or is defined herein; or when not defined herein refer to the Definitions of Surveying and Associated Terms (1978), as compiled by the joint committee of the American Society of Civil Engineers (ASCE), and American Congress on Surveying and Mapping (ACSM), Library of Congress Catalog Card No. 72—76807 or to Glossary of the Mapping Sciences published by ASCE, ACSM and the American Society for the Photogrammetry and Remote Sensing (ASPRS), 1994.

IV. RECORDS SEARCH

A. A land surveyor assuming the responsibility of performing a land survey also assumes the responsibility for such research of adequate thoroughness to support the determination of the intended boundaries of the land parcel surveyed.

B. In the absence of sufficient record evidence substantiating the intended boundaries of a parcel of land and the adjoining parcels, the land surveyor shall inform the client of such need and pursue every reasonable opportunity to accrue equivalent evidence through unrecorded sources, such as the testimony of local land owners, government officials, land surveyors, abstracters, real estate brokers, attorneys and any other person or agency which is normally involved in the disposition of real property.

C. The land surveyor may accompany his record search determination and evaluation with a comprehensive field investigation, which may reveal the existence of record monumentation supporting the land parcel description to be surveyed.

V. DESCRIPTIONS

A. Any description written for the purpose of defining land boundaries shall provide a definite and unambiguous identification of the location thereof. Any form of description, regardless of the presence or absence of any or all dimensions, but specifically tying to adjoiner conveyance descriptions, and which fulfills the foregoing conditions, is acceptable; however, such description, in addition to all necessary ties to such adjoiners, shall contain sufficient data of dimension to enable the description to be mapped in accordance with these standards.

B. Every description for a land parcel, prepared by a land surveyor, shall describe all monuments found or placed.

VI. MAPS

A. When a land survey performed by a land surveyor requires a map, it shall be drawn to a convenient scale, and provide a clear and unambiguous representation of the location of the surveyed land parcel by its legal description. Measurements shown upon the map of a land survey shall be in substantial compliance with these standards.

B. Where a surveyed boundary line varies materially in distance and/or bearing from a recorded boundary distance and/or bearing, the land surveyor should apprise his/her client or employer of such. This may be done by 1.) Report of Survey, 2.) Working Sketch, or 3.) Showing and identifying such recorded distance and/or bearing along the mapped boundary line in proximity to the surveyed values, but not so as to cause confusion.

C. Map bearings shall be referenced by notation upon the map to an identifiable, monumented line for directional control.

D. The map shall bear the name, firm name, and address of the land surveyor responsible for the land survey, his official seal, his original signature, date surveyed, and certification required herein.

E. Monuments found, placed, or replaced by the land surveyor shall be described upon the map, including those controlling monuments to which the survey may be referenced. The land surveyor shall note upon the map which monuments were found and which monuments were placed as a result of his/her survey.

VII. MEASUREMENTS

A. Land survey measurements shall be made with equipment and methods of practice capable of attaining the tolerances specified by these standards. Also, see the TBPLS minimum standards requirement.

VIII. MONUMENTS

A. Sufficient corners shall be monumented or witnessed on all completed boundary surveys except where existing monuments (monuments being any significant physical object and/or its physical witness) are found in place. Every land survey performed by a land surveyor shall be monumented or witness monumented at all boundary corner locations. All monuments may (or should) bear the land surveyor's registration number or equivalent identification at or near the top of the monument whenever practical. Also, see the TBPLS minimum standards requirement.

Section 3 — Introduction to Surveying

Overview

The information found within this section is a product of the former Texas Department of Transportation (TxDOT) Metric Surveying Subcommittee and the Standing Committee on Surveying (SCOS).

Types of Surveys

Surveying is the science of determining relative positions of points on or near the earth's surface. The horizontal positions of these points are computed from distances and directions, and vertical positions from differences in elevations which are measured individually or in combination to a specified degree of accuracy, and are in direct relation to a known or determined datum.

Accuracy is a prime consideration in surveying. Instruments for each type of survey are used with prescribed techniques to achieve a designated accuracy.

Less accuracy than specified results in a survey which will prove useless for its intended purpose; more accuracy wastes time and effort, and may not improve the final results.

Surveys are normally divided into two general classes: Geodetic and Plane.

Geodetic Surveys

The mathematical shape of the earth is an oblate spheroid (almost a sphere) with a major diameter at the equator of about 7,920 miles. Distances or areas measured on the surface of the earth are, therefore, not along straight lines or planes, but are on a curved surface. Geodetic surveys that normally extend over long distances and cover large areas must have computations to allow for curvature of the earth.

To accomplish this, the earth's major and minor diameters are computed accurately, and from these a spheroid reference. The position of each geodetic station is related to this spheroid. The positions are expressed as latitudes (angles north or south of the equator) and longitudes (angles east and west of the prime meridian), or as plane coordinates on a rectangular grid system, correlated with the latitude and longitude. In addition, the plumb line deflection and its effect on relative positions of the stations are considered in precision work.

Plane Surveys

When the extent of the survey becomes small (less than 100 square miles in area), and when only limited accuracy is required, the effect of curvature can be ignored. These surveys are treated as if the measurements were made on a plane and are known as plane surveys.

The difference between plane and geodetic surveying can be expressed in terms of plumb lines. In plane surveys, plumb lines are considered parallel, while in geodetic surveys convergence is taken into account.

Highway and railroad surveys, which may extend for hundreds of miles, are usually in a narrow strip and are considered plane surveys. However, a limited computation for the earth's curvature is necessary in this case. On a long traverse survey, an astronomic azimuth is determined at intervals of several miles.

The astronomic azimuth establishes an astronomic north-south line and may be used to obtain the true direction of a survey line. The azimuth values of the lines between astronomic azimuth stations consider the convergence of the meridians. The methods, operations, and measurements in either type of survey are similar; but since the distances between stations are usually much greater in geodetic surveying, more precise equipment and procedures are used.

Surveying Field Work

Field work in surveying consists of making and recording measurements. The operations are as follows:

1. Measuring distances and angles to:
   - establish points and lines of reference for locating details such as boundary lines, roads, buildings, fences, rivers, bridges, and other existing features
   - stake out or locate roads, buildings, utilities, and other construction projects
   - establish lines parallel or at right angles to other lines, measure inaccessible distances as across rivers, extend straight lines beyond obstacles such as buildings and do any work that may require use of geometric or trigonometric principles.
2. Measuring differences in elevations and determining elevations to:
   - establish permanent points of known elevation (bench marks)
   - determine elevations of terrain along a selected line or area for plotting profiles and computing grade lines
   - stake out grades, cuts, and fills for construction projects.
3. Making topographic surveys wherein horizontal and vertical measurements are combined.
4. Recording field notes to provide a permanent record of the field work.

Planning

Planning is probably the most important part of the performance of a control survey utilizing GPS survey measurement techniques. Proper planning will give one added confidence that quality data will be collected. Regardless of the level of the survey, the items listed below should be addressed before the field data collection process begins.

Reconnaissance

Prior to the commencement of any TxDOT survey, all significant aspects of the project should be understood so that the project can be performed effectively and efficiently.

For GPS surveying perform a reconnaissance survey of the site to:

- determine the location and sky visibility of existing and new control stations
- pick the locations for new stations making sure satellites can be recorded in a minimum of three quadrants
- look at logistics of project and determine transportation required
- gain permission to access station(s) on private land
- if applicable, the surveyor should notify law enforcement of their activities; record sky visibility chart data and access requirements for all stations
- look for any objects that could be sources for radio interference
- look for any multipath conditions that may affect data collection.

Factors Affecting Field Work

The surveyor in the field must constantly be alert to the different conditions he or she encounters and the requirements of the survey. The weather, terrain, personnel, purpose, and accuracy of the survey, systematic procedures, and the expected rate of progress are some of the factors that will affect the work.

Physical factors such as terrain and weather will affect each field survey in varying degrees. Measurements using telescopes can be stopped by fog, mist, or dust. Swamps and flood plains under high water can impede taping surveys. Lengths of light-wave distance measurements are reduced in bright sunlight. Generally, reconnaissance will predetermine the conditions and alert the survey party to the best method to use and the rate of progress to be expected.

The status of training of the personnel is another factor that affects field work. Experience in handling the survey instruments and equipment can shorten survey time without introducing errors, which would require resurvey. The personnel factor is a variable that will affect the rate of progress.

The purpose of the survey will determine the needed accuracy, which, in turn, will influence the selection of instruments and procedures. For instance, comparatively rough procedures can be used in measuring for earth-moving, but grade and alignment of a highway must be much more precise, and require more accurate measurements. Each increase in precision also increases the time required to make the measurement, since greater care and more observations must be taken.

Each survey measurement will be in error to the extent that no measurement is ever exact. Besides errors, survey measurements are susceptible to mistakes or blunders. These arise from misunderstanding the problem, poor judgment, confusion on the part of the surveyor, or simply from an oversight. By working out a systematic procedure, the surveyor will often detect a mistake when some operation seems out of place.

Survey speed is not the result of hurrying; it is the result of saving time through the following:

- the skill of the surveyor in handling his field equipment
- the intelligent planning and preparation of the work
- the process of making only those measurements that are consistent with the accuracy requirements.

Satellite Health and Availability for GPS Surveying

Only healthy satellites should be observed during the course of data collection. The satellite health situation can be checked by accessing the latest GPS status message from the USCG website at http://www.navcen.uscg.gov/. This status message can also determine if there were problems after the data collection period is over.

There are times of the day when the numbers of satellites available will vary. Especially with real-time kinematic (RTK) positioning planning a work around for these times greatly increases productivity and the quality of results. Most, if not all, GPS software packages include a utility allowing the user to predict satellite coverage. A minimum of five (5) satellites are to be logged for any GPS work. In order to project satellite availability, the software will require a recent ephemeris file.

One Internet site for obtaining this file is:
http://www.trimble.com/planningsoftware_ts.asp?Nav=Collection-8425

Sky Visibility for GPS Surveying

Prior to data collection, the surveyor should look at each station to determine the extent, if any, of sky visibility obstructions greater than ten (10) degrees above the horizon. This survey should include obstructions in all four (4) quadrants of the sky.

If there are obstructions, the most desirable place for those obstructions to be located is northward of the station to be surveyed because of the design of the satellite constellation. If there is an

obstruction in that area, it could still be a source of multipath at the GPS antenna. Therefore, the obstruction should be located.

Satellite Geometry for GPS Surveying

The geometric quality of a constellation of satellites is measured by Position Dilution of Precision (PDOP). It is also measured by Geometric Dilution of Precision (GDOP). The difference between PDOP and GDOP is that GDOP considers time, where PDOP only considers geometry.

The user should be aware of the manufacturer's recommendations of maximum DOP values for the various types of surveys the user will perform. The vertical component of the GPS position is the most likely component to lack in quality if the DOP values are high. Therefore, if performing a vertical control survey, collect data with conservative DOP values.

One way to ensure that quality data are collected for the vertical is to collect satellite data that includes at least one satellite that is tracked greater than seventy (70) degrees above the horizon. However, a VDOP of less than 4.0 is all that is required. A PDOP of over 6.0 should probably be considered to be too great for usable data, making a PDOP of over 7.0 is unacceptable. Static data during periods of high DOP values should be deleted. Performance of RTK is more demanding and should not be done at PDOP values of 4 or greater.

Field Notes

The field notes of the surveyor must contain a complete record of all measurements made during the survey with sketches and narration, where necessary, to clarify the notes. The best field survey is of little value if the notes are not complete and clear. They are the only record that is left after the field party leaves the survey site.

All field notes should be lettered legibly. Numerals and decimal points should be legible and permit only one interpretation. Notes must be kept in the regular field notebook and not on scraps of paper for later transcription. The field notebook is a permanently bound book (not loose-leaf) for recording measurements made in the field.

Field note recording takes three general forms: tabulations, sketches, and descriptions. Two, or even all three forms, are combined when necessary to make a complete record.

Tabulation — Measurements may be recorded manually in a field book or they may be recorded electronically through a data collector. Electronic data collection has the advantage of eliminating reading and recording errors.

Sketches — Sketches add much to clarify electronic data collection files and should be used as a supplemental record of the survey. They may be drawn to an approximate scale, or important details may be exaggerated for clarity. Measurements may be placed directly onto the sketch or

keyed in some way to the tabular data. A very important requirement of a sketch is legibility. It should be drawn clearly and large enough to be understandable.

Descriptions — Tabulations with or without added sketches can also be supplemented with descriptions. The description may only be one or two words to clarify the recorded measurements, or it may be quite lengthy in order to cover and record pertinent details of the survey.

Note: Erasures are not permitted in field notebooks.

Individual numbers or lines recorded incorrectly shall be lined out and the correct values added. Pages that are to be rejected are crossed out neatly and referenced to the substituted page. This procedure is mandatory since the field notebook is the book of record and it is often used as legal evidence.

Electronic Data

In nearly all cases, field work is automated by the use of computer software and hardware for collecting, reviewing and editing field measurements. A data collector is connected to the instrument (total station, GPS receiver, digital level, etc.) to store the raw measurement data and perform coordinate geometry (COGO) functions while in the field. Original raw data must be saved as a file for retention as matter of record before any data editing is done.

Data Collection

It is recommended that field data in electronic form be collected in the AASHTOWare®, Survey Data Management System® (SDMS) Collector and processed in AASHTOWare® SDMS® Processor. This is software developed by AASHTO and supported by TSD. It is provided gratis to TxDOT consultants under TxDOT's license agreement with AASHTO. Its purpose is to provide a more flexible and user definable method of recording horizontal angles, vertical angles, and slope distances from total stations in a standard format, for use with survey measurement post-processing software.

Radial topographic survey data, traverses, and level runs may all be collected in SDMS® Collector software. The data can then be reduced to coordinates using SDMS® Processor, which uses a least squares type of adjustment. There are a number of useful reports that can be generated in this software.

There are numerous ways to provide connectivity between survey data points. When performing radial topography surveys for a Digital Terrain Model (DTM), points in the same chain such as edge of pavement, centerlines, and ditch lines can be linked together. These survey chains can ultimately be exported to mapping files (2D) or to DTM files (3D) as breaklines. The survey points and breaklines will be used by topographic mapping software to create a Triangular Irregular Net-

work (TIN) and subsequently a DTM. Parcel boundary corners may also be connected with survey chains.

Standard TxDOT feature codes and cells have been developed for use in the field to insure standardization of line weight, color, levels, and symbology. These feature codes also determine whether the points and chains will be exported to a mapping file or a DTM file.

The current list of TxDOT feature codes in Trimble format for TSCe and TSC2 data collectors is the txdotØ6.fcl. This file is available to TxDOT personnel from TSD and consultants may obtain the file from district survey coordinators.

Survey Review and DTM

Three software programs are authorized by TxDOT to view survey results for troubleshooting and preparation for the delivery of a .dgn file. These programs are Autodesk® CAiCE™ Visual® Transportation, Bentley® GEOPAK Survey™, and AASHTOWare® SDMS® Processor. This software will accept the SDMS .cal or .pac files as input and, with the TxDOT feature table attached, will graphically display the project for analysis. Corrections and additions can be made and the DTM can then be created. Photogrammetry files, background maps, macros for visualization and other enhancements may be utilized before 2D or 3D graphics are exported as a DGN file for GEOPAK® / Microstation® use by the designer.

Section 4 — Surveying with GPS

Survey Background Information

All GPS surveying techniques are based upon radio signals from a network of orbiting satellites. These signals are processed to compute station positions by trilateration: the positions of the satellites and computed ranges are used to determine the antenna position.

These positions are computed in an Earth-Centered Earth-Fixed (ECEF) Cartesian coordinate (x, y, z) system, which can be converted to geodetic curvilinear coordinates (latitude, longitude, and ellipsoidal height). With the addition of a geoid height model, orthometric heights can be computed.

Accuracy of a GPS Survey

The accuracy of a GPS survey is dependent upon many complex, interactive factors, including:

- observation technique used, e.g., static vs. kinematic, code vs. phase, etc.
- amount and quality of data acquired
- GPS signal strength and continuity
- ionospheric and tropospheric conditions
- station site stability, obstructions, and multipath
- satellite orbit used, e.g., predicted vs. precise orbits
- satellite geometry, described by the dilution of precision (DOP)
- network design, e.g., baseline length and orientation
- processing methods used, e.g., double vs. triple differencing, etc.

Error Sources in a GPS Survey

Error sources in a GPS survey include the following:

- **reference position errors** - coordinate, monument stability, crustal motion
- **antenna position errors** - equipment setup, phase center variation and offsets
- **satellite position errors** - orbit ephemeris errors
- **timing errors** - satellite or receiver clock errors
- **signal path errors** - atmospheric delay and refraction, multipath
- **signal recording errors** - receiver noise, cycle-slips

- **human errors** - field or office blunders
- **computing errors** - processing and statistical modeling errors.

Operational Procedures

Identify and minimized **all** errors by redundancy, analysis, and careful operational procedures including:

- the repetition of measurements under independent conditions
- make redundant ties to multiple, high-accuracy control stations
- ensure geodetic-grade instrumentation, field procedures, and office procedures are used
- ensure processing with the most accurate station coordinates, satellite ephemerides, and atmospheric and antenna models available.

CAUTION: Be aware that these procedures cannot disclose all problems.

Planning the Survey

Because surveys involving GPS include Geoid models, plane coordinates, projections on the surface and other obstacles matching to older surveys, a plan of action should be set out in the planning stages of new or continued projects.

Project control points will be referenced to the National Spatial Reference System (NSRS) through CORS stations or FBN stations. The static GPS survey is usually the best choice for establishing these points. Project control points should not be more than approximately three (3) miles apart.

Geometry plays an important role in the accuracy of the adjustment in a static survey scenario. TxDOT Levels of Accuracy 1 and 2 apply to the primary project control points (see Table 3.2 TxDOT Level of Survey Accuracy). Boundary work should be done from these stations whenever possible. Additionally, the primary project control points should also include elevation.

From these stations, the next generation of points (secondary control) can be set with slightly less stringent procedures. Secondary control stations are closer together and can be done by traverse or by using FastStatic or RTK procedures if GPS is chosen. TxDOT Level of Accuracy 3 applies here (see Table 3.2 TxDOT Level of Survey Accuracy). Construction work usually dictates that these points be about 1500 feet apart.

Finally, topo work (TxDOT Level of Accuracy 4) is performed from the secondary stations. Secondary stations will be available for occupation with total stations or RTK base receivers.

In planning a survey, if the older coordinate positions must be adhered to, a calibration can be done to the existing control. The software on the data collector usually has a provision for this to be accomplished in the field.

It is imperative that when adherence to older coordinate positions is needed, control points surround the project and work not be done outside the perimeter, otherwise, the cantilever effect of the calibration becomes an objectionable factor. During calibration, if a station exhibits high residuals (does not fit in relation to the others), it should be excluded from the calibration.

Using state plane coordinates throughout the above stages is the best way to maintain integrity between all points. Coordinates of marks surveyed conventionally can be put on the state plane grid by use of a Combined Adjustment Factor (CAF).

Furthermore, by working in plane coordinates, long corridors can be divided into segments of different CAF's to prevent such a growing difference between surface measurements and geodetic positions of NGS stations.

If total station work is to be mixed with GPS work in the same area, it should be considered whether total station traverses would be reduced to the state plane grid or the GPS work be calibrated to the surface values obtained by the total station.

Section 5 — Coordinate Systems

Overview

Many spatial activities, such as navigation, mapping, and surveying, use geographic coordinates to describe the position of objects. Whenever two activities share a common coordinate system, their data can be more readily compared and exchanged.

For this reason, federal and state mapping products are referenced to two standard coordinate systems: the North American Datum of 1983 (NAD 83) for horizontal positions and ellipsoid heights, and the North American Vertical Datum of 1988 (NAVD 88) for orthometric heights. Surveys are referenced to these datums through measurements to control points of the National Spatial Reference System (NSRS).

National Spatial Reference System (NSRS) and Continuously Operating Reference Stations (CORS)

The National Spatial Reference System (NSRS), defined and managed by the National Geodetic Survey (NGS), is a national coordinate system that specifies latitude, longitude, height, scale, gravity, and orientation throughout the Nation, as well as how these values change with time.

The NSRS includes a nationwide network of Continuously Operating Reference Stations (National CORS), statewide Federal & Cooperative Base Networks (FBN/CBN), regional User Densification Networks (UDN), and other historic vertical and horizontal control. Figure 2-1 on the next page illustrates the CORS network stations in Texas, as well as the TxDOT RTK networks in operation.

In Texas, TxDOT operates the majority of CORS stations.

Cooperative CORS Stations

Also noteworthy is the system of Cooperative CORS stations. The main difference between National and Cooperative CORS is that for National CORS sites the public obtains the data from NGS, whereas for Cooperative CORS sites the public obtains the data from site operator.

Links to the data from these stations are available on the NGS Web site. Because of the reduced quality control (QC), limited hours of operation and less permanent nature of these stations, it is important that the surveyor be thoroughly familiar with those stations in their own area before depending on them.

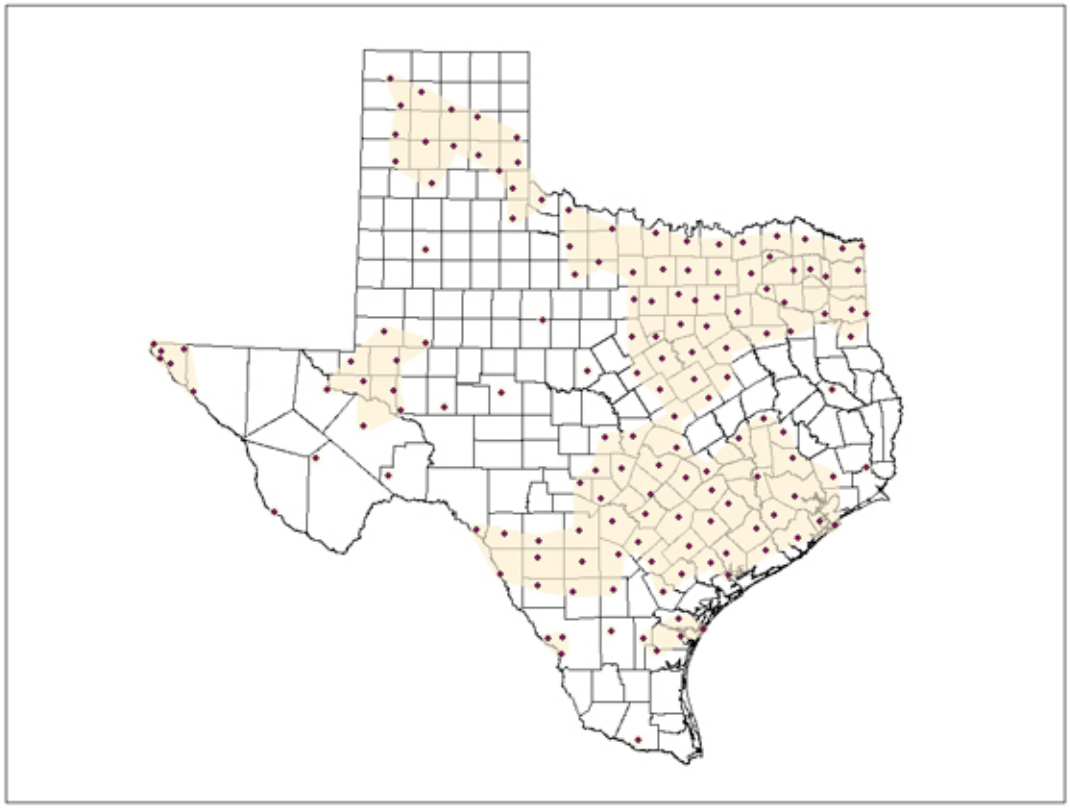

Figure 2-1. CORS Stations and TxDOT RTK Networks.

FBN and CBN

Federal Base Network stations (FBN) (75 to 125 km spacing) or Cooperative Base Network (CBN) stations (25 to 30 km spacings) are B order accuracy and make up the HARN network. These HARN stations have been observed using GPS and have been either used previously as reference stations in the adjustment of the old conventionally surveyed federal monuments or they are newly placed monuments. There are about four hundred of these listed by NGS in Texas.

This manual uses and/or references specific information from the following publications:

- 1989 Federal Geodetic Control Subcommittee (FGCS) document "DRAFT Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques"
- the 1998 NOAA Technical Memorandum "NGS-58, Guidelines for Establishing GPS-Derived Ellipsoid Heights,"
- the May 15, 2000 "Preliminary DRAFT Guidelines for Geodetic Network Surveys Using GPS,"
- and numerous other federal/state guidelines and specifications listed in Appendix A, References.

Section 6 — Units and Datum

Units

Unless otherwise instructed, latitude and longitude will be presented as degrees, minutes, and seconds. Direction indicators N or W will prefix the value and seconds will be carried out five places right of the decimal where accuracy is to approximately .001 feet.

The coordinate system used by TxDOT is the State Plane Coordinate System in NAD83; however, units of length will be in U.S. Survey Feet rather than meters. Horizontal coordinates should be carried out to .001 feet, unless otherwise instructed.

Processing and adjusting GPS data may be done in the metric system but all project data must be delivered in U.S. Survey Feet.

Conversion from meters to U. S. Survey Feet must be made using the following formula:

Meters * 3937/1200 = U. S. Survey Feet

The factor is 3.280833333333 and working with SPC's in the millions, one **must** carry the factor out to 12 places to the right of the decimal as shown.

Datum

All geodetic surveying with GPS will be done in the NAD83 horizontal datum. An adjustment was done in Texas (using GPS), which resulted in the 1993 HARN network. The network was extended to nearly all old, conventionally surveyed federal monumentation. Projects should be referenced to the published HARN coordinates of NGS monumentation.

Elevations will be referenced to the NAVD88 vertical datum.

Surface Coordinates vs. State Plane Grid Coordinates

Depending on how far north or south the project falls in the state plane zone and depending on the elevation of the area; GPS coordinates in the State Plane Coordinate System most likely will need to be adjusted so that lengths measured on the surface will coincide with lengths inversed on the surface projection (state plane grid). An exception to this is when RTK work is done **after** calibrating the equipment to control in already existing surface coordinates.

The TxDOT surveyor or engineer for the project may calculate a combined adjustment factor (CAF) to be used on the project. The surveyor or engineer also might dictate that a standard, county-wide TxDOT Surface Adjustment Factor (SAF) be used or may ask a consultant to calcu-

late their own. It is not important what method is used to arrive at the factor, but it **is** absolutely necessary that the factor used is included in the metadata notes.

The factor should be carried out to eight (8) places in order that all involved parties arrive at the same coordinates to the nearest thousandth of a foot. Seven (7) places will yield only hundredths; the common nine (9) places used by NGS will produce adjusted coordinates to the ten thousandths of a foot.

Highway projects with several CAF's pose no problem when all coordinates can be backed down to SPC's so everything will match. The juncture of two systems; however, needs to be well identified so that all measurements stop or begin at a common point. Stationing must not cross this line without a station equation. Cut and fill volumes can't be calculated across the line. Only State Plane Coordinates can be used seamlessly.

If coordinates have been truncated for easier calculations or for identification, they must be returned to their full configuration before delivery. This is not only for standardization; it is so that the coordinates will work in the seed files for MicroStation as well.

Section 7 — Metadata

Identifying Delivered Coordinates

All coordinates files or lists delivered, whether hard copy or in digital medium, must contain metadata indicating the CAF (or SAF), horizontal datum and adjustment, vertical datum (geoid model if applicable), units of measure and the date of the field work. This would include hard copy drawings, CAD drawings, the data sheets, and each sheet containing coordinates in a report, and ASCII or LandXML files.

Conversions and Transformations

Where design survey accuracy is required, TxDOT will not accept any datum transformations. There is no way to accurately transfer NAD27 coordinates to NAD83 datum. CORPSCON and other conversion software programs are based on NADCON algorithms, which perform a rubber sheeting adjustment that is not accurate.

If a change to the NAD83 project datum is needed for comparison of old surveys, two (2) control points can be resurveyed (GPS or conventional) from references in the new datum. Then, a translation-rotation-scale can be done holding to the two (2) points common to both datum. Or, if original raw GPS data is available, it can be reprocessed holding the new datum coordinates rather than the original datum coordinates.

Both CORPSCON and AASHTOWare SDMS Processor are acceptable software programs for the mathematical conversion of:

1. Metric to US Survey Foot (or visa-versa)
2. SPC zones to adjoining SPC zones
3. UTM to SPC's and
4. Latitude/Longitude to SPC's.

In addition to these strictly mathematical conversions, these software programs provide useable combined adjustment factors (CAF) at the specific location of a point if the elevation is included in the input.

Chapter 3 — Preliminary Surveying

Contents:

Section 1 — Horizontal Control Surveys

Section 2 — Vertical Control Surveys

Section 3 — Investigative Surveys

Section 4 — Photogrammetry

Section 5 — GPS Surveying

Section 6 — Internet Resources

Section 7 — GPS Static Surveying

Section 8 — GPS RTK Surveying

Section 9 — Geodetic Surveying

Section 1 — Horizontal Control Surveys

Overview

Information contained in this section is excerpted in its entirety and/or adapted for this manual from the Texas Society of Professional Surveyors Manual of Practice.

A horizontal control survey is performed for the purpose of placing geographic coordinates of latitude and longitude on permanent monuments for referencing lower levels of surveys. A projection is used to place the coordinates on a plane of northing and easting values for simplified measurements. Scale and elevation factors are applied to make the distance measurements applicable to the exact project location on the working surface and the type of projection chosen is an "equal angle" type.

Justification

The use of assumed coordinates for a new project is not acceptable. Placing all projects on a common coordinate system is more cost effective for the long term. The same control points can be used at a later date on subsequent surveys; a tight network of points can be developed across the area.

Consultants can be instructed to use only these designated points, eliminating the possibility of tying to faulty existing control. With proper use of surface adjustments from the state plane grid, continuity will be maintained from one area to the next, allowing easier detection of blunders and systematic errors. Lost monuments can be replaced to their original location. Work by other agencies, including useful maps and Geographic Information Systems (GIS) data, can be overlaid adding to the overall usefulness and completeness of everyone's efforts.

Resources

Specifications and procedures must adhere to the Texas Society of Professional Surveyors (TSPS) Manual of Practice, Category 7. Federal publications, which define the basic specifications and procedures, include:

Horizontal Control Data Technical Report NOS '88 NGS 19

Manual of Plane Coordinate Systems Special Publication No. 235

Manual of Traverse Computations on the Lambert Grid Special Publication No. 194

Plane Coordinate Projection Tables "Texas" (Lambert) Special Publication No. 252

Standards and Specifications for Geodetic Control Networks by Federal Geodetic Control Committee, 1984

Field Methods

Particularly for horizontal control surveys, GPS is quickly replacing the use of the total station for long distance traversing. The inherent error of each GPS derived baseline (about 5 mm plus 1 part per 1,000,000) will make accuracy at short distances not so attractive. However, using baselines of many miles suddenly becomes phenomenally accurate and cost effective. The distant locations of Continuously Operating Reference Stations (CORS) stations and only scattered high order monuments are not a problem.

A conventional traverse, if using state plane coordinates as the point of beginning (POB), will require every horizontal distance of each leg of the traverse to be multiplied times the CAF of the midpoint of the leg in order to "traverse on the grid." If this is not done, the resulting point will not be positioned correctly on the state plane grid. A technical description of the process, including application of Second Term correction can be found in Chapter 4 of the NOAA Manual NOS NGS 5, State Plane Coordinate System of 1983.

GPS Control

To meet a network or local accuracy level, a GPS project must be connected to sufficiently accurate and well-distributed existing control.

All of the control stations to which the network will be constrained must have positions known on the NAD83 datum. Control of the NGS CORS Network are generally used; however, certain special projects may have a legitimate need for another geodetic reference. Use the appropriate datum adjustment as recommended by the TxDOT district surveyor or survey coordinator.

The minimum number of horizontal and vertical constraints is stated in Table 3.11 Minimum TxDOT Network Design Specifications in this chapter with their location being distributed in different quadrants relative to the center of the project. Where existing NGS or TxDOT horizontal and/or vertical control on a common datum and epoch is available, all such stations lying within a few kilometers of the survey's boundaries should, if possible, be included in the survey if they meet the horizontal accuracy requirements. Second order or better is generally required for vertical.

Rights of Access

As with any survey, permission to enter property must be obtained and arrangements must be made with property owners, tenants, or agents responsible for the property. Depending upon the area, hours of work, and nature of traffic control, local law enforcement officers may need to be notified.

Monuments

Because of the expense and time involved in the accurate determination of position of horizontal monuments, the setting should be permanent and in a location suitable for GPS observation.

The pre-punched, embossed disk for horizontal control is DHT # 164946 and is used for mounting in rock or concrete.

The same face design can be found as a rebar cap with DHT # 164949.

The preferred setting; however, is a rod driven to refusal and protected by a PVC encasement with a flip-lid cover.

Appendix C, "Monumentation," lays out specifications for the three above mentioned methods of monumenting a control point. Whether an aluminum disk or datum point rod is used, the point name should be legibly stamped into the metal surface on the face of the disk, or into the machined surface on the rim of the cover.

Monumentation for New Stations

All monumentation for new Level 1 points are to be in accordance with the following NGS publications:

Concrete Marks, from *NGS Operations Handbook and Manual of Geodetic Triangulation*, S.P. 247.

Setting a Survey Disk in Bedrock or a Structure from NOAA Manual NOS, NGS 1, *Geodetic Bench Marks.*

Setting a NGS 3-D Monument Based on Revised NGS 3-Dimensional (3-D) Rod Mark [Draft Version] by: Curtis L. Smith, *National Geodetic Survey*, July, 1996.

It is recommended that new Level 2 points also follow these construction specifications or they may follow the specifications for the TxDOT datum point rod or the standard poured concrete setting (Type II setting) as found in the TxDOT Survey Manual.

Azimuth Marks

The use of radio masts, church steeples, etc. for azimuth marks is not as practical as it once was. The coordinates that have been used for these intersection stations for years may not be on the same datum or datum adjustment as the newly set monument. As a safeguard, a monument should be placed within about a quarter or half mile of the station and surveyed at the same time. Occasionally, it will be possible to set project control points inter-visible but the terrain may not permit this convenience.

Tolerances

The following tables show tolerances for various conditions for conventional horizontal surveys and for GPS horizontal control surveys. Note that with the use of GPS, there are fewer physical checks and there is more attention paid to the number, location, and quality of reference monuments due to the nature of GPS static surveying.

The following table describes the Texas Society of Professional Surveyors (TSPS) Manual of Practice tolerances for conventional traverse:

Table 3.1 TSPS Tolerances for Conventional Traverse (Category 7)

Condition	I	II	III	
	TSPS 1st Order	TSPS 2nd Order	TSPS 3rd Order	Remarks
Error of Closure	1: 50,000	1:20,000	1:10,000	Loop or between monuments
Allowable Angular Closure	± 3" $\sqrt{N}$	± 8" $\sqrt{N}$	± 15" $\sqrt{N}$	N= number of angles in traverse
* Accuracy of Bearing in Relation to Course	± 04"	± 10"	± 20"	Maximum for any course
Linear Distance Accurate to: (Minimum Length of line)	1: 50,000 (2500 feet)	1: 20,000 (1000 feet)	1: 10,000 (500 feet)	
Positional Tolerance of Any Monument	AC/ 50,000	AC/20,000	AC/10,000	AC = length of any course in traverse
Scale of Maps Sufficient to Show Detail but No Less Than:	1" = 5,000'	1" = 2,000'	1" = 1,000'	
Positional Error in Map Plotting not to Exceed: (applies to original map only)	125 ft.	50 ft.	25 ft.	Generally 1/40” (National Map accuracy calls for 1/50”)
Adjusted Mathematical Closure of Survey No Less Than	1:200,000	1:200,000	1:200,000	

NOTE: *All bearings or angles shall be certified as based on one of the following sources: 1.) Geodetic Bearing, 2.) Grid Bearing of the Texas Coordinate System of 1927 (or 1983), (with the proper zone identified) or 3.) a record bearing or the relation thereto, along a line monumented on the ground as called for in said record.

Accuracy Standards

The new standards support both local and network accuracies:

- The local or relative accuracy of a control point is a value that represents the uncertainty in the coordinates of the control point relative to the coordinates of other directly connected, adjacent control points on the project at the 95-percent (2σ) confidence level.
  - The reported local accuracy is an approximate average of the individual local accuracy values between a control point and other observed control points used to establish the coordinates of the control point (i.e. the adjacent stations directly tied to the control point).
- The **geodetic accuracy** of a control point is a value that represents the uncertainty in the coordinates of the control point with respect to the geodetic datum at the 95-percent confidence level.
- For National Spatial Reference System (NSRS) network accuracy classification, the datum is considered to be best expressed by the geodetic values at the Continuously Operating Reference Stations (CORS) supported by NGS. By this definition, the local and network accuracy values at CORS sites are considered to be infinitesimal, i.e., to approach zero.

Local or relative accuracy is best adapted to check relations between nearby control points; for example, a surveyor checking closure between two NSRS points is most interested in a local accuracy measure.

TxDOT Standard Levels of GPS Accuracy

TxDOT has numerous survey accuracy requirements based on the type of project being surveyed. Listed in the table below are seven levels with typical types of surveys for each. The level of survey accuracy will be used as a standard throughout this manual to define the quality of the survey measurements for a particular application.

The seven levels, of course, are of equal or lesser accuracy than the A and B order federal monuments that could be considered Level 0 in the TxDOT scheme. A Level 0 is shown in some of the charts only to show the relationship of the NGS points to the seven TxDOT levels.

Table 3.2 TxDOT Level of Survey Accuracy

TxDOT Level of Accuracy	Typical Applications
Level 0	CORS, FBN, CBN (this level overseen by NGS)
Level 1	Statewide/district-wide Control Densification, RRP Network Stations (until recognized as NGS CORS), Cooperative CORS sites
Level 2	Primary Project Control, Control for Airborne GPS for Photogrammetry or LiDAR Data Gathering
Level 3	Photogrammetric Control Panels, Boundary Corners, ROW, and Local Control
Level 4	Topography, Stakeout
Level 5	Sub-meter Mapping for GIS (includes inventory and locative surveys)

Table 3.2 TxDOT Level of Survey Accuracy

TxDOT Level of Accuracy	Typical Applications
Level 6	1 – 5 Meter Mapping for GIS (includes inventory and locative surveys)
Level 7	> 5 Meter Mapping for GIS (includes inventory and locative surveys)

The End Product

It must be remembered that if the survey is performed using GPS, the basic results should be state plane coordinates. If a grid to surface adjustment is applied to all coordinates across the board at this point, significant differences over even short distances will accumulate. This is a necessary evil when working on the project surface but for control points to be used again and again on different projects requiring different combined adjustment factors (CAF), the final plane coordinate recorded on a control point data sheet must be a state plane coordinate. Each point must be dealt with individually to assign a surface coordinate to the monumented point.

A separate TxDOT Control Point Data Sheet signed and sealed by a Registered Professional Land Surveyor (RPLS) licensed in Texas for each newly set monument (to be used for control) shall be prepared showing the quality of the point and the monuments used to establish the control point, as well as the usual information associated with control points. The control point data sheet is meant to convey all necessary information for anyone to use this monument at any time without any doubts or further research.

The point naming convention may vary from one district to another by the use of prefixes and suffixes but the base numbering should contain three (3) digits designating the county number, followed by four (4) digits to be used as the discrete control point number (which is not to be duplicated in the county). If allowed by the district, it is also possible to number the points using the U.S. National Grid (USNG) numbering scheme.

No matter which method is used, any printed list, file, or map must indicate the appropriate datum (including datum adjustment), the unit of length, and the state plane zone (if plane coordinates). Further, if the points are project specific (have had a surface-grid adjustment applied), the chosen CAF must be included.

Section 2 — Vertical Control Surveys

Overview

Information contained in this section is excerpted in its entirety and/or adapted for this manual from the TSPS Manual of Practice.

A vertical control survey is performed for accurately determining the orthometric height (elevation) of permanent monuments to be used as bench marks for lower quality leveling. Spirit leveling is the usual method of carrying elevations across the country from "sea level" tidal gauges. However, Global Positioning System (GPS) can be used indirectly but with less accuracy. Height measurements from the ellipsoid (as opposed to the "sea level" geoid) can be determined very accurately with GPS and only with GPS. Trigonometric leveling, with a total station, is not acceptable for vertical control work.

Justification

Due to the federal government's placement of quality bench marks across the county, we have always enjoyed the advantage of having a common vertical datum. With technology as it is today, we can more easily extend elevations to remote areas and minor construction projects. Digital levels and GPS make it practically inexcusable to not have seamless project boundaries. Although construction may only require relative heights (an assumed datum), bringing proper vertical to project areas is advantageous in that bench marks can be used for adjoining projects, saving costs, and errors can more easily be detected having more points in common to check against.

Resources

Specifications and procedures must adhere to the TSPS Manual of Practice, Category 8.

Federal publications that also define procedures and specifications include: USC&GS Special Publication 239 *Manual of Geodetic Leveling;* USC&GS Special Publication 240; *Manual of Leveling Computations and Adjustments;* NOAA Manual NGS 3 *Geodetic Leveling;* and *Control Leveling* NOAA Technical Report NOA 73 NGS 8.

Field Methods

The use of first order leveling is cost prohibitive and unnecessary in most cases for TxDOT operations. Discrepancies between originally run level lines in some cases negate the advantages of the precision of the first order and sometimes second order level runs. The instrument should be treated with care and a peg test should be done often. Level rods are equally critical. Shots should be balanced.

Most digital levels have on-board adjustment programs and/or a memory card that will allow the data to be transferred to a computer for adjustment. The Survey Data Management System® (SDMS) collector, at this point is developed to the extent that it can communicate directly with a level to automatically pull down the information. Manual readings can also be hand entered into the data collector to record the data, warn of out-of-tolerance readings, adjust the point elevations, and compile reports.

A carefully planned GPS network survey can be used to obtain orthometric heights. Since GPS measures heights from the imaginary ellipsoid surface, the data must be converted to usable orthometric heights through a model of interpolated geoid separation measurements.

In order to get the accuracy needed for a vertical control survey, there must be at least 3 or 4 high quality bench marks surrounding the project area (and in 3 or 4 separate quadrants) to better model the area.

This sometimes makes the use of GPS impractical – spirit leveling may be just as cost effective, if the distances are not too great. See Section 7, GPS Static Surveying, and Table 3.11 Minimum TxDOT Network Design Specifications, in this chapter for specific instructions on performing vertical surveys with GPS. Also, see the subsection, Determining Elevations, in this chapter.

Rights of Access

As with any survey, permission to enter private property must be obtained and arrangements must be made with the property owners, with tenants or parties agents in charge. Depending upon the area, hours of work, and nature of traffic control, local law enforcement officers may need to be notified.

Monuments

Because of the expense and time involved in the accurate determination of elevation on a bench mark, the setting should be permanent and in a location suitable for GPS observation. The pre-punched, embossed disk for vertical control is DHT # 164948 for mounting in rock or concrete. The same face design can be found as a rebar cap with DHT # 164947.

However, the preferred setting is a rod driven to refusal and protected by a PVC encasement with a flip-lid cover.

Appendix C, "Monumentation," lays out specifications for the three above mentioned methods of monumenting a vertical control point. Whether an aluminum disk or datum point rod is used, the point name should be legibly stamped on the metal surface on the face of the disk, or into the machined surface on the rim of the cover.

Tolerances

Generally, when a GPS network survey is done, both vertical and horizontal are the end products since processing of data is done using Cartesian coordinates. The tolerances and specifications shown in the tables of the preceding section (Horizontal Control Surveys) include information for the vertical component of the GPS survey.

Table 3.3, available from the *TSPS Manual of Practice for Land Surveying in the State of Texas*, April 2002, shows tolerances for conventional leveling.

Table 3.3 TSPS Tolerances for Conditions (Category 8)

Condition	I	II	III	
	TSPS 1st Order	TSPS 2nd Order	TSPS 3rd Order	Remarks
Error of Closure	4 mm $\sqrt{km}$ 0.017 $\sqrt{m}$	8 mm $\sqrt{km}$ 0.035 $\sqrt{m}$	12 mm $\sqrt{km}$ 0.05 $\sqrt{m}$	Loop or between Control Monuments
Maximum Length of Sight	250 ft.	300 ft.		With good Atmospheric Conditions
Difference in Foresight and Backsight Distance	±10 ft.	±20 ft.	±30 ft.	Per Instrument Set Up
Total Difference in Foresight and Backsight Distances	±20 ft. per sec.	±50 ft. per sec.	±70 ft. per sec.	Per Total Section or Loop
Recommended Length of Section or Loop	2.0 mi.	3.0 mi.	4.0 mi.	Maximum Distance Before Closing or in Loop
Maximum Recommended Distance Between Bench Marks	2000 ft.	2500 ft.	3000 ft.	Permanent or Temporary Bench Marks Set or Observed along the Route
Level Rod Reading	± 0.003 M ± 0.001 ft.	± 0.003 M ± 0.001 ft.	± 0.003 M ± 0.001 ft.	
Recommended Instruments and Leveling Rods	Automatic or Tilting w/Parallel Plate Micrometer Precise Rods	Automatic or Tilting w/ Optical Micrometer Precise Rods	Automatic or Quality Spirit Standard, Quality Rod	When two or more Level rods are used, they should be identically matched
Principal Uses	Broad area control, subsidence or motion studies jig & tool settings	Broad area control, engineer projects basis for subsequent level work	Small area control, drainage studies, some construct and engineer	

GPS Orthometric Height

Requirements for orthometric height constraints are dependent upon geoid slope, project extent, desired accuracy, and the density of the gravity database.

In general, vertical control for Level 1 and Level 2 networks require a minimum of 4, preferably 5 published vertical control stations. They should be situated on the outside corners of the project at a minimum.

In other words, at least one bench mark should be fixed in each of the four (4) quadrants of the survey area, such that nearly all of the newly surveyed stations will fall inside a boundary drawn around the outside bench marks. Additional bench marks inside the perimeter will aid in strengthening the adjustment.

The End Product

The vertical datum in use by TxDOT is the NAVD 88 datum. This datum has replaced the older NGVD 29 datum and shows elevations to be slightly greater in Texas. Since areas between held points in the adjustment are interpolated, there is no mathematical conversion but the National Geodetic Survey (NGS) software VERTCON will give an approximate transformation. Any printed list of coordinates, any file, or any map showing elevations, must indicate the appropriate vertical datum and the unit of length.

The point naming convention may vary from one district to another by the use of prefixes and suffixes but the base numbering should contain three digits designating the county number followed by four digits to be used as the discreet control point number (which is not to be duplicated in the county).

A separate data sheet for each newly set bench mark used for control should be prepared showing the quality of the point and the tie points it was surveyed from as well as the usual information associated with control points. The TxDOT Control Point Data Sheet is meant to convey all necessary information for anyone to recover and use this monument at any time without any doubts or further research.

Section 3 — Investigative Surveys

Overview

An investigative survey is a recording of spatial information at the site of an incident or study involving health, welfare, or environment. Some TxDOT districts still provide an investigative survey at the scene of auto accidents, but primarily the Department of Public Safety has their own equipment and procedures.

Any unforeseen impact of highway construction may require a survey of the area. For example, the effects of water run-off from highway design may require mapping if an archeological sites is threatened.

The TSPS Manual of Practice contains a thorough outlining of this type of survey in the Category 9 specifications.

Section 4 — Photogrammetry

Overview

Photogrammetry mapping projects use targeted, surveyed control points, combined with aerial photography or digital imagery, to produce graphical 2D and 3D maps along with digital ortho-rectified imagery. It is TxDOT policy that a Texas Registered Professional Land Surveyor (RPLS) be directly responsible for the setting and surveying of the ground control targets and an American Society of Photogrammetry and Remote Sensing (ASPRS) Certified Photogrammetrist be directly responsible for aerial mapping.

The following sections address Control Targets, Field Surveys, Aerial Photography, Mapping, Field Checks, Reports and Photogrammetry Deliverables.

Control Targets

I. Target Design

In the past it was necessary for control targets to be large enough to be visible on hard-copy contact prints. Digital or "soft-copy" photogrammetry has made contact prints no longer necessary. Therefore, large targets are no longer necessary for most TxDOT projects. Likewise, "box" targets, used to indicate the beginning and ending of a flight strip, are also no longer necessary.

Figure 3-1 shows the typical target size currently used for a TxDOT project with a film scale of 1"=250' (1:3000) or with a digital Ground Sample Distance (GSD) of 5 centimeters. Target size may vary with different film scales or digital image pixel sizes.

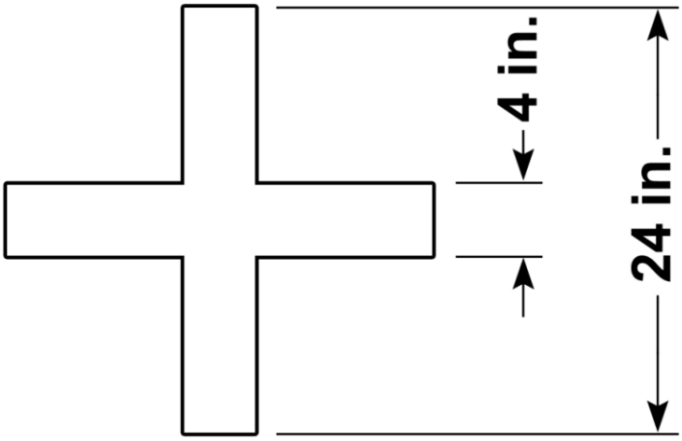

Figure 3-1. Typical target dimensions.

Good contrast between the target and the background surface is important. Therefore, a white target should be used on a dark background. A black target should be used on a light background. Figures 3-2 and 3-3 show the use of background surface and contrasting targets. It is the responsibility of the surveyor to make certain that the target has good contrast with the background surface.

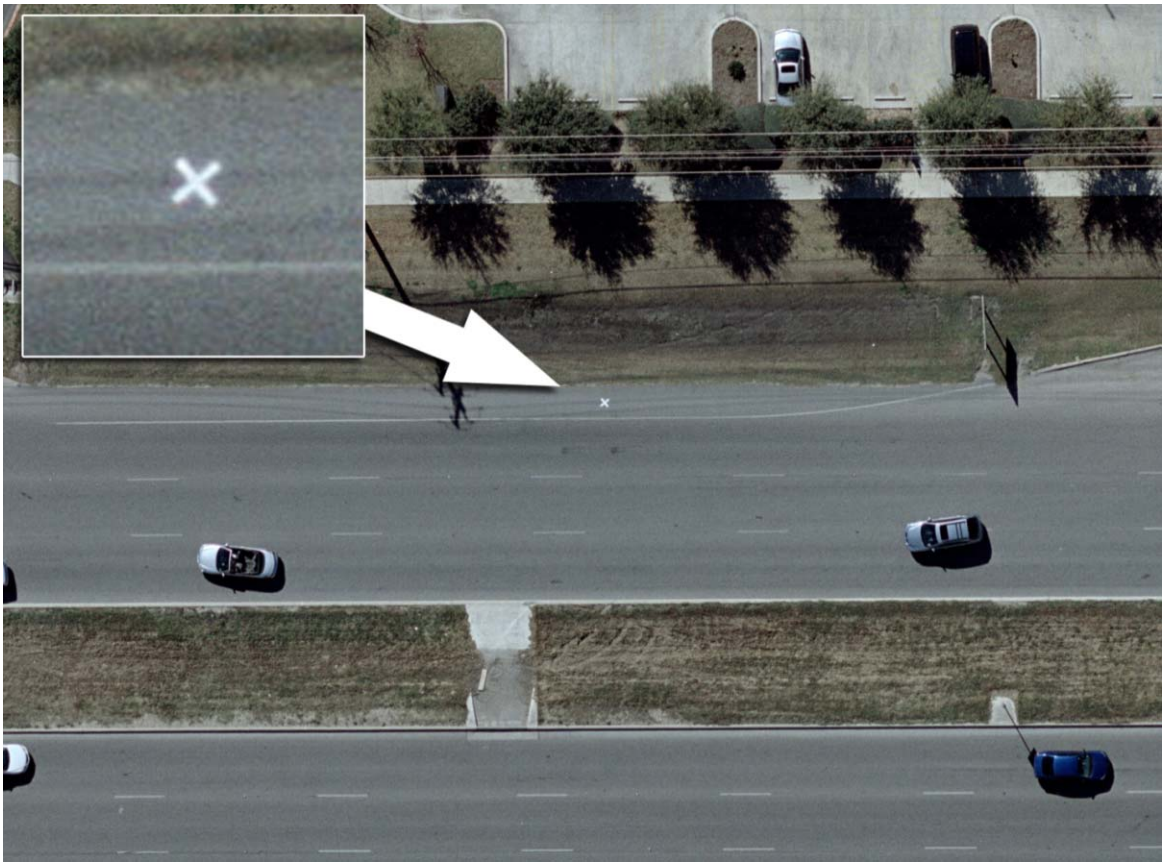

Figure 3-2. White target on dark background surface.

Figure 3-3. Black target on light background surface.

II. Target Location and Placement

The location of control targets is dependent on project conditions including:

- The ability to safely place and maintain the target.
- The size and shape of the project area.
- The accuracy required for the project.
- Project terrain.
- Accessibility to place the target.

TxDOT has developed basic standard configurations to be used as a guideline.

There are two classifications of control network designs: conventional control networks, and control networks supplemented with airborne GPS (ABGPS) data. ABGPS supplemented control networks are preferred because the technique greatly reduces the number of targets required. The use of ABGPS to supplement ground control can improve field crew safety by reducing or eliminating the need to work near busy roadways. However, some projects may require a conventional target layout to serve a dual purpose. For example, targets may be used as aerial control and as con-

trol for construction staking. Guidelines for both type of network (conventional and ABGPS supplemented) are provided in the following paragraphs. Note that the layouts provided must have all three coordinates; a northing, an easting, and an elevation determined by the Surveyor.

III. Conventional Layout

Figure 3-4 shows the legacy conventional control layout used by TxDOT. The layout was developed to combine the needs of aerial mapping with the needs of construction staking. This design was once used frequently but is now considered obsolete.

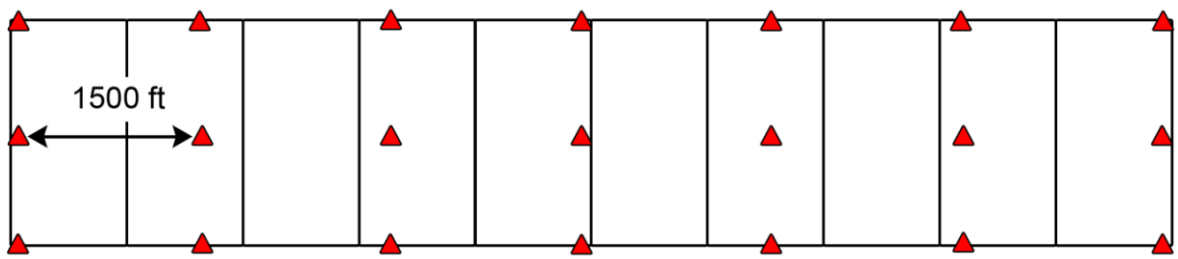

Figure 3-4. Legacy conventional control target layout.

On occasion, there may still be a need to combine control for construction with control for aerial mapping using a 1500 foot spacing of centerline targets. In those situations, a single wing target alternating between the left and right side of the centerline is sufficient. The use of alternating wings reduces the overall number of targets required. An illustration of the alternating wing control layout is shown in Figure 3-5.

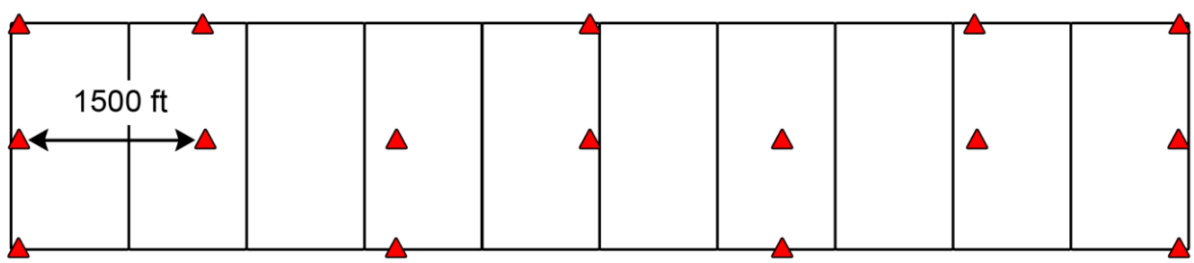

Figure 3-5. Conventional control layout with alternating wing targets.

When aerial mapping control is not being dual purposed, the centerline targets are not necessary--the project can be entirely controlled with wing targets. The spacing between wing targets can be increased to two base distances regardless of the photo scale (film imagery), or pixel size (digital imagery). Figure 3-6 shows the basic conventional control target layout for a TxDOT aerial mapping project when the control is only being used for aerial mapping and ABGPS is not being used. The maximum distance of the target perpendicular to the flight line is the edge of the neat model. In the case of 1"=250' photo scale using film, this perpendicular distance is about 850 feet.

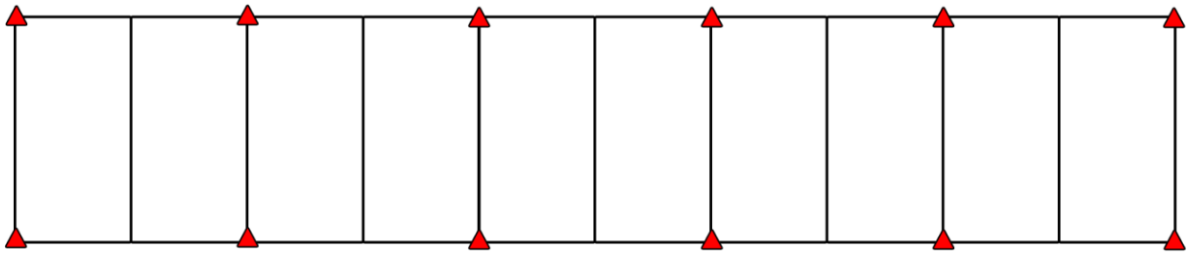

Figure 3-6. Basic conventional control target layout.

Most TxDOT aerial mapping projects are in a strip configuration, with strips of photography aligned along roadways. However, depending on the project, a block configuration may provide a more efficient means to collect aerial photography and to produce aerial mapping. The conventional control layout for a block configuration generally follows along the same lines as the conventional strip configurations. Figure 3-7 shows the typical conventional control layout for a block of aerial photography.

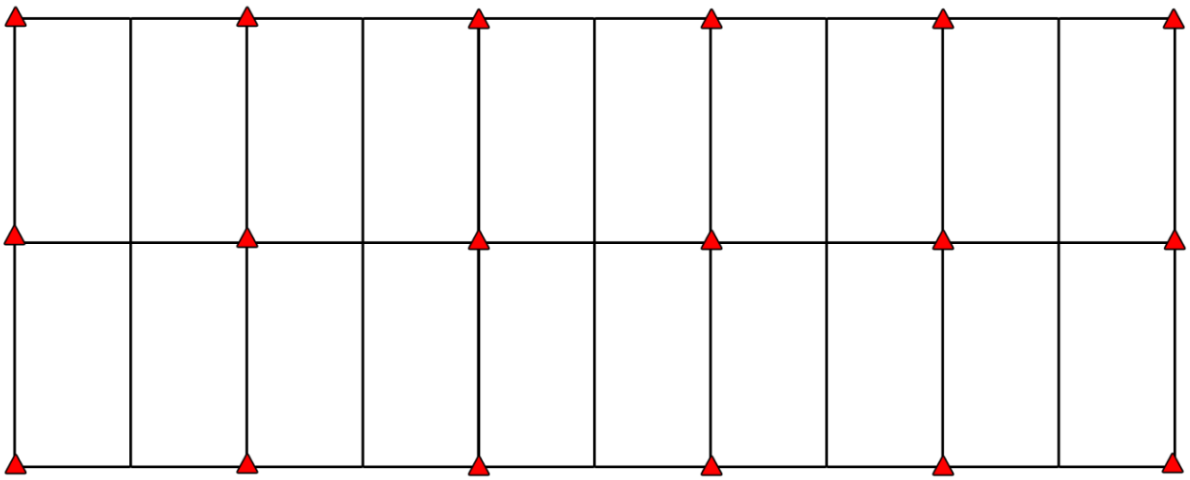

Figure 3-7. Conventionally controlled block layout.

IV. Airborne GPS Supplemented Layout

The basic strip configuration for control targets supplemented with ABGPS data is shown in Figure 3-8. The maximum spacing between pairs of control targets is 6 model bases regardless of the photo scale (film) or pixel size (digital).

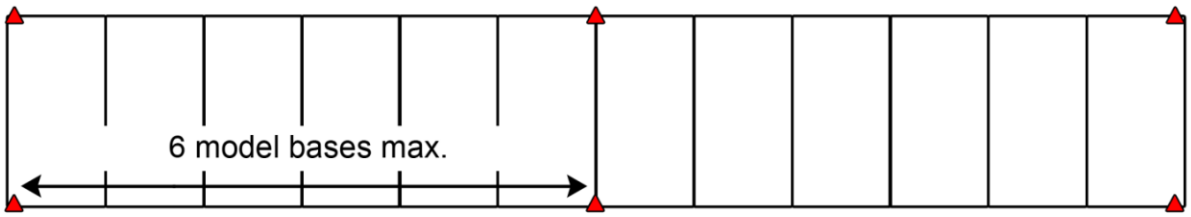

Figure 3-8. ABGPS supplemented ground target layout.

From Figure 3-8, it should be obvious that supplementing ground targets with airborne GPS significantly reduces the number of targets required. However, because there are fewer targets, the exact position of each target becomes more critical to ensure that project requirements are met.

One of the many advantages of using airborne GPS is that it can significantly reduce the number of targets that fall on private property. This is desirable because gaining right-of-entry (ROE) to private property can require considerable time and effort and can significantly increase costs for TxDOT.

When designing a control network it is often the case that a decision has to be made: set one target on private property or set two targets on public land or roadways on either side of the private property. Setting two targets increases the overall number of targets placed in the field and it shortens the distance between pairs of control points. However, in almost every case it is preferable to set the two targets on the public land to avoid the need to enter private property.

Similarly, at the beginning and ending of a photo strip, private property can often be avoided by slightly extending flight lines past the mapping area to include nearby public land or roadways. If there is any question as to using more targets to avoid private property versus obtaining right of entry, the TxDOT District Survey Coordinator should be consulted. In any event, the maximum spacing of 6 model bases between pairs of control targets cannot be exceeded.

Figure 3-9 shows a block configuration using ground control targets supplemented with airborne GPS.

The critical elements of this configuration are:

- the perimeter of the block has a control target at a maximum spacing of 6 model bases,
- a check point is required in the interior of the block a maximum of 8 model bases with a check point between each adjacent strip, and
- the end of each strip is controlled by a pair of control points.

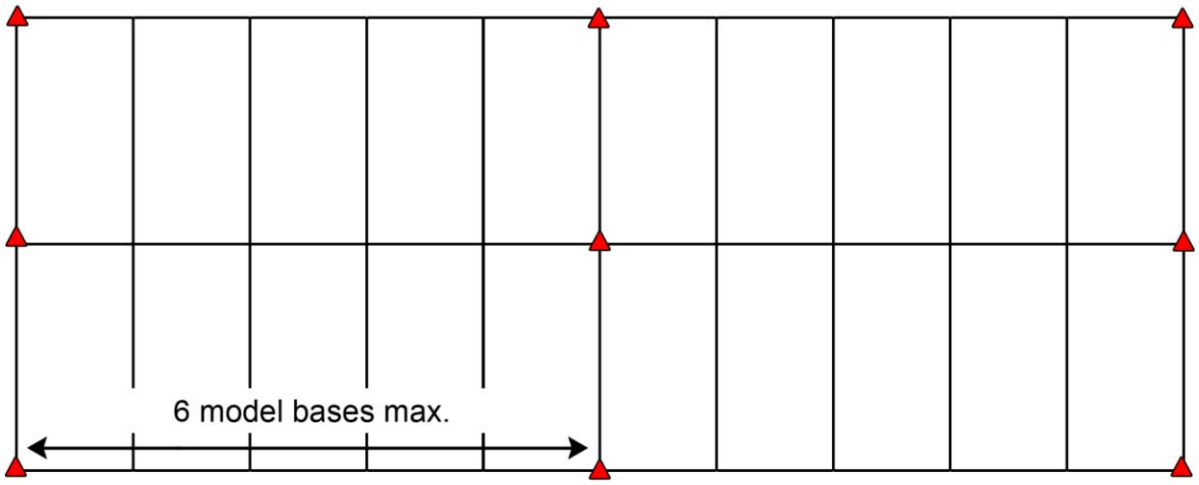

Figure 3-9. Block configuration using ground control targets supplemented with airborne GPS.

In Figure 3-9, notice that the targets located between the strips are shared. If, for some reason, the targets cannot be shared, each strip is required to have two targets at the strip ends.

As mentioned, check points are required in the interior of the block at a maximum spacing of 8 model bases. When the initial analytical solution is performed, the internal points are held out as a check points. The residual values of the check points are evaluated to detect blunders in the solution. The residual values of the check points are recorded and reported in the project Analytical Triangulation Report. For the final analytical solution, the internal points are used as additional control points.

An asymmetrical block is shown in Figure 3-10. Asymmetrical blocks have the same requirements as symmetrical blocks, which includes a pair of control targets at the end of each strip and an internal check point(s) as shown.

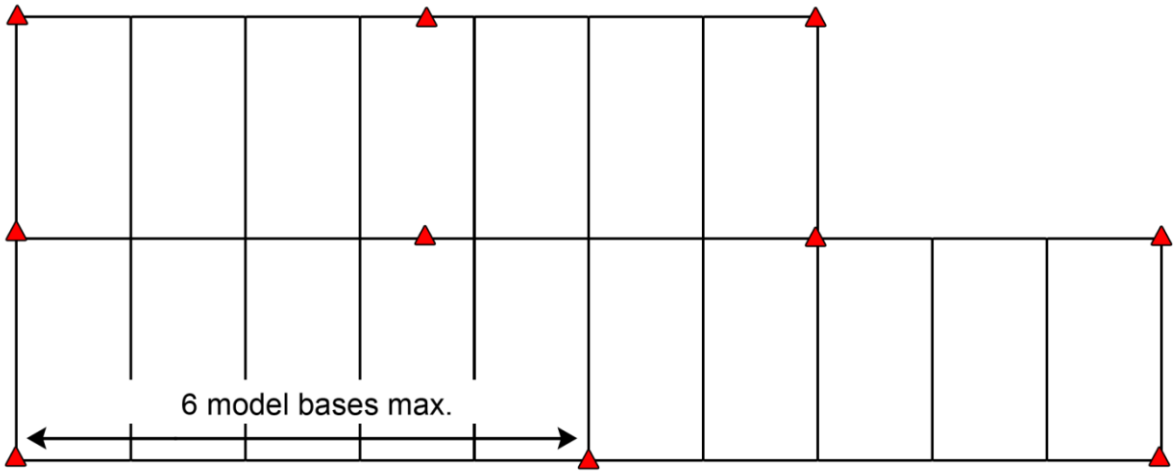

Figure 3-10. Asymmetrical block with airborne GPS supplemented ground control targets.

Note in Figure 3-10, the upper flight strip consists of seven models. This exceeds the 6 model maximum between targets along the perimeter of the block. Therefore, a target has been inserted resulting in a base distance of approximately 3.5 models between targets on the perimeter of the upper strip. Also, note the requirement for a check target interior to the block. A check point is required despite the block having fewer than 8 bases. A least one internal check point is required for every block regardless of the block size.

As an option to placing a pair of control points at the beginning and ending of each strip, it is acceptable to use crossing strips. Crossing strips are commonly used to reduce the overall number of control targets required (particularly in large blocks), or to help avoid areas in which placing a target would be difficult or hazardous. A typical block configuration with crossing strips is shown in Figure 3-11. The requirement for the crossing strip is a pair of control targets at the beginning and ending of the crossing strip and a spacing of no more than 6 base distances between pairs of control points along the crossing strip.

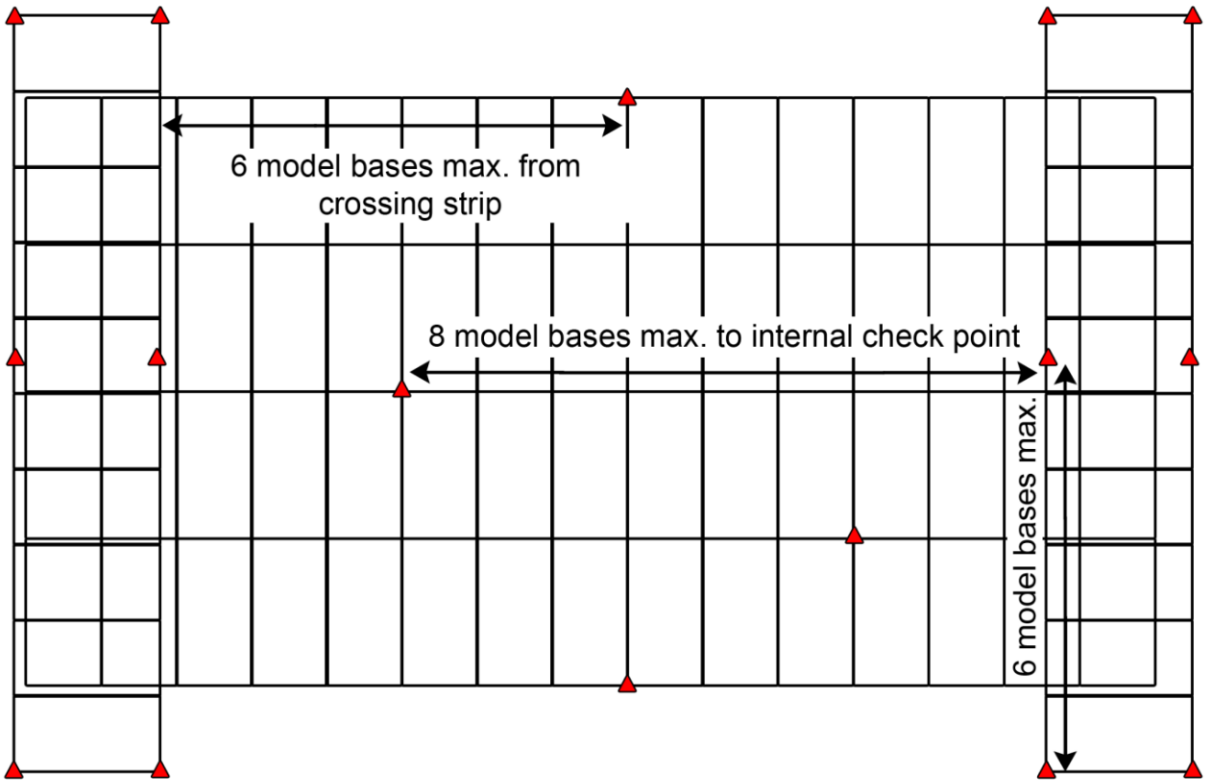

Figure 3-11. Block with crossing strips.

The same 6 model base limitation extends to the exterior strips of the main block from the edge of the crossing strip as shown. Again, internal check points are required at a maximum spacing of 8 model bases within the block between adjacent strips.

V. Strip ties

All photo strips require two control targets at the strip ends. In a block layout, targets can be shared between adjacent strips. For corridor-type projects, a minimum of one control target is required to fall within the overlap area between two overlapping strips to tie the strips together, provided that enough image tie points are passed between the overlapping strips to form a strong tie.

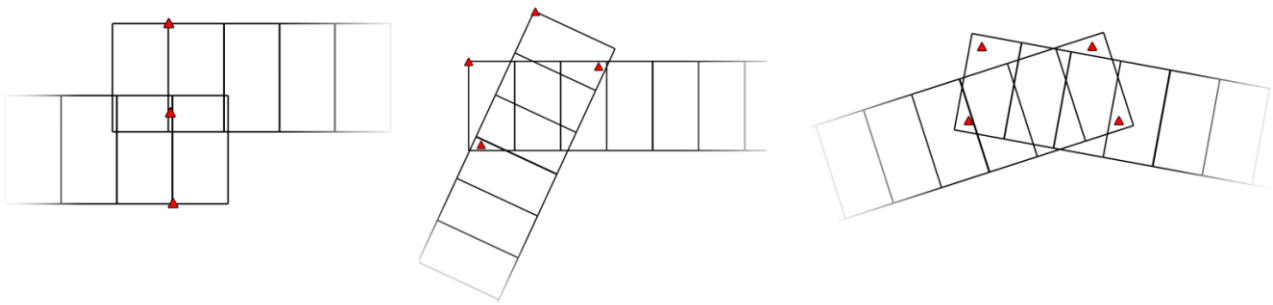

Figure 3-12. Typical strip ties for airborne GPS supplemented ground control.

The target layout diagrams in Figures 3-4 to 3-12 are provided as a general guideline to follow when developing control for TxDOT aerial mapping projects. However, in all circumstances it is the responsibility of the contracted consultant to ensure that the ground control layout is sufficient to meet the accuracy requirements of the project.

VI. Accuracy Requirements

All targets shall have both horizontal and vertical coordinates determined by land surveying. The accuracy requirement for aerial control targets is provided in Section 1.

VII. Additional Requirements

In addition to the requirements provided in the previous paragraphs, the following requirements apply to placement of targets in the field:

- A signed right-of-entry letter with landowners must be obtained prior to entering private property.
- The target shall be clear of any obstruction that may obscure the target on the aerial imagery. When standing on the target there should be a clear view of the sky from 45º above the horizon to zenith.
- The target should be placed flush to the ground. Any vegetation that may grow beneath the target should be removed prior to placing the target.
- Survey measurements are to be made at the center point of the target with the elevation measured on the surface of the target at the center point.
- Targets should not be placed in a shady or shadowed area. It is advisable to inspect potential target locations for shadows that may obscure the target.

- Placing a target beneath overhead wires should be avoided if at all possible. Overhead wires can make three dimensional photogrammetric measurements difficult.
- Targets should be placed on as level an area as possible, and
- Targets placed on private property will be picked up promptly once the aerial flight mission has been approved unless other arrangements have been made with the landowner.

Other considerations affecting the selection of target location and include:

- Selecting a safe work zone, preferably away from vehicular traffic,
- A hard surface on which a target can be painted. A painted target is generally more durable than a cloth target or a target made with other materials, and
- Other project specific situations such as placing a target on a public street to avoid a right-of-entry for private land.

VIII. Documentation and Deliverables

Documentation and deliverables for control targets consists of both textual and graphical information. Textual information shall be submitted using the Ground Control Submission Form (Form 2154). TxDOT contractors should request this form from the TxDOT District Survey Coordinator.

Graphical information shall include a map showing the location of the control targets as placed on the ground. The map shall include a north arrow and scale bar. Each control target shall be labeled with the target number.

Field Surveys

All field surveying activities shall be conducted in accordance with current TxDOT safety requirements relating to land surveying. All targets shall be in place prior to acquisition of aerial photography and shall be checked and maintained until the aerial photography mission is completed.

In general, the RPLS can move a target from the indicated position on the layout map. The distance the target can move depends on the layout (conventional or ABGPS supplemented), and the scale of the photography. For a typical 1:3000 photo scale (film) or 5 cm (digital) ABGPS supplemented project, the target can move from the planned position up to 450 feet parallel to the flight direction. The RPLS should avoid moving the target either further away or closer to the flight line because doing so can result in the target being outside of the photo coverage or can reduce the target's effectiveness.

Aerial Photography

I. General

Metric aerial cameras are required for engineering design level aerial photography. For project photography acquired using a film based aerial camera, a current USGS camera calibration is required. At such time that the USGS approves and accepts in situ calibration, TxDOT will issue guidance on in situ calibration procedures and requirements for reporting in situ calibration results for film based aerial cameras.

For project photography acquired using a digital aerial camera, the camera manufacturer's calibration report or a Statement of Compliance with the manufacturer's calibration and maintenance recommendations is acceptable. At such time that the USGS approves and accepts in situ calibration, TxDOT will issue guidance on in situ calibration procedures and requirements for reporting in situ calibration results for digital aerial cameras.

II. Flight requirements

The aircraft(s) used for aerial photography shall be maintained and operated in accordance with all regulations required by the U.S. Department of Transportation, Federal Aviation Administration (FAA).

The design of the aircraft shall be such that when the camera is mounted with all of its parts within the outer structure of the aircraft, an unobstructed field of view is obtained. The field of view shall be shielded from exhaust gases, oil, effluence, and air turbulence. If a glass port is interposed between the camera lens and the terrain to be photographed, the port shall be of optical quality, free from scratches and blemishes, and shall not degrade the resolution or accuracy of the camera.

Project flights may enter or be within areas of controlled or restricted airspace. All approvals necessary to assure that required clearances are achieved must be obtained prior to the flight mission. When the flight plan and location of any project fall within positive-control airspace, the aircraft must contain the appropriate equipment to operate in such positive-control areas with the purview of the Federal Aviation Regulations. All Military Operation Areas (MOA) shall be identified in advance of the flight and all flight approvals and security clearances obtained from the U.S. Department of Defense.

Aerial photography shall not be taken unless visibility is greater than 10 miles and sustained winds at the surface are less than 20 mph. Wind gusts at the surface shall not exceed 30 mph. Photography will not be acquired when the ground is obscured by snow, haze, smoke, dust, clouds, or cloud shadows.

Flight height shall not be in excess of five (5) percent above or below the required height above mean terrain to achieve the specified film negative scale or digital image ground pixel size.

Exposure overlap along the line of flight shall average sixty (60) percent plus or minus two (2) percent. Side lap between parallel flight strips shall be average thirty (30) percent plus or minus five (5) percent unless otherwise specified.

Crab, as measured from the line of flight and as indicated by the principal points of consecutive photographs, shall not change by more than five (5) degrees between any two consecutive photo frames, and shall not average more than five (5) degrees on any one flight line, nor more than two (2) degrees for the entire project.

Tilt, defined as the departure of the optical axis of the camera from a plumb line, shall not exceed five (5) degrees on any single photograph nor more than one (1) degree for a single flight line. Relative tilt between consecutive photo frames shall not exceed six (6) percent.

III. Film Titling and Digital Image Naming

For projects using aerial film, each photo frame shall be titled. Titling shall be on the left side of the image frame, regardless of the flight direction. The title will include the aerial photo date, the project Service Request Number (SRN), or Control, Section and Job (CSJ) number as directed by the TxDOT District Survey Coordinator, the highway or project name, the photo strip and photo frame number. An example of film titling is shown in Figure 3-13.

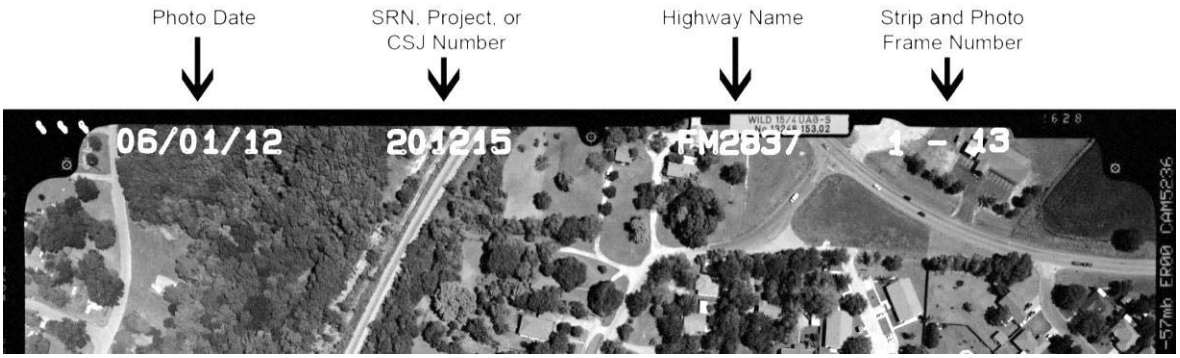

Figure 3-13. Film titling.

For imagery acquired using a digital camera, the same information as found in the film titling will be captured in the digital image file name and on the flight log that accompanies the imagery. The digital image file name will consist of the SRN, Project, or CSJ number, followed by a dash character field separator, the strip number, followed by a dash character field separator, and the photo frame number. An example of a digital image file name is:

201219-2-005.tif

In this example, "201219" is the project SRN, "-" is the first field separator, "2" is the strip number, "-" is the second field separator, and "005" is the photo frame number. The photo frame number shall be padded with leading zeros to match the number of digits in the highest numbered photo frame. For example, if this project were to have a highest numbered photo frame with four digits, then the photo frame number in the example above would be "0005" to match the number of digits in the highest numbered frame.

Aerial photography metadata for both film and digital camera systems shall consist of the flight log filled out by the flight crew during the flight. At a minimal the flight log shall record the date of the aerial photography, the SRN, highway or project name, the aircraft and camera used, and the strip and photo frame numbers for each strip flown.

All imagery, whether film or digital, is the property of TxDOT. Original aerial film is a deliverable and will be archived in the TxDOT film vault located in Austin. Digital imagery is to be delivered to TxDOT on DVD or on a non-returnable solid-state hard-drive for archiving.

Mapping

I. Accuracy standard

The TxDOT map accuracy standards for maps created using aerial photography is the Class 1 of the American Society for Photogrammetry and Remote Sensing (ASPRS) Specifications and Standards Committee Standards for Large-Scale Maps (ASPRS 1990)

Map accuracy depends on all of the individual components that go into the mapping process: ground control accuracy, precision, and spatial geometry; aerial photo acquisition, quality, and processing; analytical triangulation equipment and procedures; and map compilation equipment, procedures, and accuracy. A mapping project can be designed to meet a particular accuracy specification. However, the actual accuracy of the resulting map can only be determined by an independent field check using equipment with a higher order of accuracy than those used to produce the map being checked.

The TxDOT map accuracy standard allows production of photogrammetrically derived maps to adhere to the Class 1 ASPRS standard without the necessity of a field check provided the proper equipment and procedures are used. However, periodically TxDOT may contract or perform field checks to ensure that the required accuracy has been met.

The TxDOT accuracy standard places limits on the root mean square error (RMSE) for individual position components: northing, easting, and elevation. The limiting horizontal RMSE for large scale (1:20,000 or larger) Class 1 maps is 0.01" at the specified map scale. Design level mapping has a limiting RMSE for the X and Y coordinates individually of 0.4 feet. The limiting vertical RMSE for large scale maps is 1/3 of the indicated contour interval for general elevation points and 1/6 of the indicated contour interval for spot elevations on well-defined features. A one foot contour interval is the typical for TxDOT design level mapping unless otherwise specified. A map compiled for a one foot contour interval has a limiting RMSE of 0.33 feet for general terrain and 0.17 feet for well-defined terrain features.

II. Analytical triangulation

A preliminary simultaneous bundle adjustment should be carried out using a minimal amount of control points along the block perimeter. All additional control points should be treated as check points. The results from this minimally controlled adjustment should meet the following criteria:

- The Standard Error of Unit Weight (σ_0) should be less than 1.0. This applies to the individual XYZ residual RSME values on a strip-by-strip and block-wise basis. The σ_0 value is calculated by dividing the RMSE value by the á priori standard deviation. A $\sigma_0 > 1.0$ may indicate an overly optimistic estimate of á priori standard deviations and potentially can hide problem points,
- The residual for any image coordinate should not exceed 15 micrometers,
- The RMS for ground control residuals should not exceed 1/15,000 of the flying height above the average terrain elevation for XY and 1/10,000 of the flying height above the average terrain elevation for Z,
- The maximum residual in any ground control coordinate should not exceed 2.5 times the RMS value for the ground control residuals stated above,
- The RMS of the discrepancy (the difference between the computed coordinate value and the surveyed coordinate value) in check point coordinates should not exceed 1/15,000 of the flying height above the average terrain elevation for XY and 1/10,000 of the flying height above the average terrain elevation for the Z, and
- The discrepancy of an individual check point coordinates should not exceed 2.5 times the RMS for the check point discrepancies stated above.

If the above criteria are met, the preliminary adjustment solution indicates that there are no blunders or gross errors in the photo measurements or ground control measurements. If the last item in the above criteria fails testing, the input data should be checked for blunders.

The final adjustment should be a simultaneous bundle adjustment of the entire project data. All ground control points should be included in the adjustment with no points held out as check points. The final adjustment results should meet the following criteria:

- The Standard Error of Unit Weight (σ_0) should be less than 1.0. This applies to the individual XYZ residual RSME values on a strip-by-strip and block-wise basis. The σ_0 value is calculated by dividing the RMSE value by the á priori standard deviation. A $\sigma_0 > 1.0$ may indicate an overly optimistic estimate of á priori standard deviations and potentially can hide problem points,
- The residual for any image coordinate should not exceed 15 micrometers,
- The RMS for ground control residuals should not exceed 1/15,000 of the flying height above the average terrain elevation for XY and 1/10,000 of the flying height above the average terrain elevation for Z, and
- The maximum residual in any ground control coordinate should not exceed 2.5 times the RMS value for the ground control residuals stated above.

III. Map Compilation

The equipment used in the aerial mapping process is required to be capable of producing maps meeting the ASPRS Class 1 Accuracy Standard.

IV. MicroStation V8i Levels

The following level structure is required for aerial mapping produced for TxDOT:

Table 3.4 Photogrammetric Level Structure.

Ground Feature	Used as a DTM feature?	MicroStation V8i level name	MicroStation V8i level number
Control			
Horizontal control, photo principal point	no	p_control ground ctrl	401
Road			
Paved road, curb	yes	p_road paved, curb	402
Dirt road	yes	p_road dirt	403
Guard rail	no	p_road guard rail	404
Guard fence	no	p_road guard fence	405
Guard posts	no	p_road guard post	406
Concrete barrier	no	p_road conc barrier	407
Paint stripe, solid and dashed	yes	p_road paint stripe	408
Bridge end	yes	p_road bridge end	409
Cattle guard	no	p_road cattle guard	410
Overhead sign	no	p_road overhead sign	411
General road feature	no	p_road general feature	412
Railroad			
Railroad track and ancillary control equipment	no	p_railroad rr control	413
Drainage			
Concrete dam	yes	p_drainage conc dam	414
Concrete drain	yes	p_drainage conc drain	415
Earthen dam	yes	p_drainage earthen dam	416
Riprap	yes	p_drainage riprap	417

Table 3.4 Photogrammetric Level Structure.

Ground Feature	Used as a DTM feature?	MicroStation V8i level name	MicroStation V8i level number
Culvert	yes	p_drainage culvert	418
Inlet	yes	p_drainage inlet	419
Water	yes	p_drainage water	420
Marsh	yes	p_drainage marsh	421
Structure			
Building	no	p_structure building	422
Ruin	no	p_structure ruin	423
Sidewalk	no	p_structure sidewalk	424
Slab	no	p_structure slab	425
Porch, deck	no	p_structure porch	426
Stairs, steps	no	p_structure stairs	427
Fence, gate, fence post	no	p_structure fence	428
Retaining wall	no	p_structure ret wall	429
Wall	no	p_structure wall	430
Cemetery	no	p_structure cemetery	431
Billboard	no	p_structure billboard	432
Sign, sign pole and post	no	p_structure sign	433
Antenna, cellular tower, satellite dish	no	p_structure antenna	434
Windmill	no	p_structure windmill	435
Flag pole	no	p_structure flag pole	436
Pipes, local utility pipe	no	p_structure pipe	437
Tank, large and small oil tank, propane tank	no	p_structure tank	438
Area under construction	no	p_structure constr area	439
General feature, for example soccer or basketball goals, air conditioner units	no	p_structure general	440
Unidentifiable feature	no	p_structure unidentified	441
Utility			

Table 3.4 Photogrammetric Level Structure.

Ground Feature	Used as a DTM feature?	MicroStation V8i level name	MicroStation V8i level number
Fire hydrant	no	p_utility fire hydrant	442
Manhole	no	p_utility manhole	443
Marker, meter, valve	no	p_utility marker	444
Transmission tower, transmission line	no	p_utility trans tower	445
Pipeline, exposed petroleum and gas transmission lines	no	p_utitlity pipeline	446
Utility Poles			
Traffic light, light pole, utility pole with transformer, utility pole	no	p_utility general pole	447
Vegetation			
Woods	no	p_veg woods	448
Tree	no	p_veg tree	449
Tree farm	no	p_veg tree farm	450
Tree orchard	no	p_veg orchard	451
Palm	no	p_veg palm	452
Digital Terrain Model (DTM)			
Breakline	yes	p_dtm breakline	453
General breakline (used for culteral features that affect the DTM but that are not otherwise identified)	yes	p_dtm general breakline	454
Retaining wall breakline	yes	p_dtm retaining wall	455
Sidewalk breakline	yes	p_dtm sidewalk	456
Mass point	yes	p_dtm mass point	457
Water obscured	yes	p_dtm water obscured	458
Obscured area	yes	p_dtm obscured area	459
Pit or fill area	yes	p_dtm pit or fill area	460
Stock pile, gravel stock pile, coal stock pile, etc.	yes	p_dtm stock pile	461

Field Checks

Testing for map accuracy compliance may be performed for any map produced for TxDOT. TxDOT may contract testing to a vendor (typically independent from the aerial mapping vendor) or may conduct testing using state resources. For any testing effort, a written summary of the results of the testing is required.

The written summary will include the project SRN, highway, county, and the date(s) that the field check was performed. A brief summary of the field procedures and equipment used shall be included in the summary.

A table summarizing the results of the field check shall be provided to TxDOT and will include:

- The point number and a description of each check point.
- The XYZ coordinates for each point derived from the photogrammetric map data.
- The XYZ coordinates for each check point determined by field surveying.
- The difference between each of the coordinates and the RMSE value determined from the differences.

A minimum of 20 check points, evenly distributed throughout the project areas, are required for any field check task. This does not include any points withheld from the final quality statistics. For example, points withheld because of field blunders.

Points may be rejected from the statistical analysis resulting from the field check, but the reason for rejecting any check point must be documented. The fact that a point is a statistical outlier is not grounds to automatically reject any check point.

Reports

I. Analytical Triangulation Report

An analytical triangulation report is required for all aerial mapping projects performed for TxDOT. The report is intended to serve as a record of the project from the time of flight planning up until map compilation. At a minimum, the report should include a brief description of the project including the number of flight lines, the number of photo frames, date of analytical triangulation, and key statistics necessary to assess the accuracy and quality of the analytical triangulation processing and adjustment. Additional narrative that would be helpful to more fully explain how the project was processed or how the project progressed should be included in the report.

The analytical triangulation report should be brief and should require only one to two pages. Do not submit voluminous photo-by-photo statistics for the project. Photo-by-photo statistics should be either stored with the project or should be re-creatable if needed later, as would be the case if a problem with the data was to be found.

Key statistics to include in the analytical triangulation report are:

- The sigma value in microns for the block solution.
- The RMS value for the project control for the block solution as individual X, Y, and Z values.
- The maximum ground control residual for the block solution.
- If airborne GPS is being used, the RMS of the photo positions.

II. Airborne GPS Processing Report

The Airborne GPS Processing Report should be a brief summary of the processing of the ABGPS data. At a minimal, the report should identify if the solution is a single baseline solution, a network solution, or a Precise Point Positioning (PPP) solution.

If the solution is PPP, the specific technique used should be identified along with the latency of the precise ephemeris and clock data used.

If a base station(s) is/are used to post-process the GPS data collected by the aircraft, the report should include the distance of the base station(s) to the project site, the base station(s) data collection rate, the use (or non-use) of precise ephemeris and clock data, the processing datum, and geoid used to determine elevations.

The Airborne GPS Processing Report should include information necessary to evaluate the quality of the processing. Typically this will include graphs showing the number of satellites tracked, the PDOP, and, in the case of base station solutions, the forward and reverse processing separation.

If the post-processed data is submitted to TxDOT, it should be noted if the data has aircraft antenna eccentricities removed or a surface adjustment factor applied to the coordinate values. If the antenna eccentricities have not been removed from the data, an antenna eccentricity diagram should be included with the data. If a surface adjustment factor has been applied, the value of the surface factor applied should be noted.

Photogrammetry Deliverables

- If using a film-based aerial camera: film negatives delivered on the film roll. The film is to be delivered to the Information Technology Operations Division (IOD), Photogrammetry Branch.
- If using digital aerial camera: digital image frames delivered on DVD, on a non-returnable solid-state hard drive, or on a non-returnable solid-state flash drive. Delivery on DVD media is limited to projects with less than 40 GB of data. The storage media with images is to be delivered to the Information Technology Operations Division (IOD) Photogrammetry Branch.
- Aerial flight data including a flight map showing the location of flight lines, exposure stations, and control target positions.
- An analytical triangulation report.

- An ABGPS processing report if ABGPS is used.
- Control point documentation (reference Control Targets, VIII. Documentation and Deliverables in this section).
- A MicroStation® two-dimensional (2D) design file containing planimetric features.
- A MicroStation® three-dimensional (3D) design file containing DTM data.
- A GEOPAK® TIN file created using the DTM data.
- Digital (Ortho-Rectified) Orthophotography.
- Any additional deliverable specified by the TxDOT District Survey Coordinator including, but not limited to, hard-copy aerial frame prints, control point diagrams, and field check documentation.

Section 5 — GPS Surveying

General Information

In general, GPS applications can be categorized as follows:

1. **Autonomous** — Immediate positions determined without the aid of post processing or differential corrections. Low-end handheld GPS receivers acquiring only this type of position may be used for finding monuments or rough positions within about 30 feet.
2. **Static** — Long observations establishing long baselines for the purpose of determining survey-grade coordinates for control of projects or intermediate points for extending the National Spatial Reference System. The data from these observations are post-processed in a network which is adjusted using a least squares method.
3. **Fast Static** — Similar to Static with the exception of the length of time of observation. The receivers have the capability of determining (from user set parameters) the time necessary to acquire sufficient data for post processing a position. Time usually ranges from 8 to 20 minutes for an observation. When done with single frequency equipment, this type of survey is usually limited to about 12 kilometers. Even with dual frequency equipment, it should be limited to about 20 kilometers for design grade surveys. Accuracy degrades quickly, but predictably, at longer distances. In a VRS Network, this accuracy will increase.
4. **Post Processed Kinematic** — Used for higher production. Occupation times of well under a minute yet closed loop accuracy when two or more base stations are used. Single frequency data is collected using distances of less than about 10 kilometers.
5. **Real Time Kinematic (RTK)** — Used for topographic surveys, staking out, and other applications, where radial baselines are acceptable. Accuracies of about 2 cm horizontal and 3 cm vertical are attainable at distances of up to about 10 kilometers. Accuracy drops off quickly at longer distances because of atmospheric errors. Many times the communication link between the base station and rover unit will prevent working at these distances. Observation times can be as short as 5 seconds.
6. **Continuous Kinematic** — Used for rapid collection of topo data over large areas not requiring a high degree of accuracy. The rover antenna, usually attached to a vehicle, navigates the roadway or terrain to create trails of points collected at regular intervals without operator intervention. Most often, the driver will follow breaklines or survey chains (top of banks, fences, edge of pavement, etc.).
7. **Airborne GPS** — Used for control for photogrammetry. Airborne GPS reduces the amount of paneling necessary. The system includes receivers at reference stations and rover equipment in the aircraft. The receiver in the aircraft is synchronized with the camera shutter for the geo-positioning of the photos.

8. **Networked RTK (VRS)** — This variation of the standard base-and-rover RTK surveying makes use of a sophisticated network of permanent base stations over a large area at a spacing of approximately 70 kilometers. The stations are connected to a central computer which is accessed by the rover unit (via cellular phone) to communicate a correction to the rover from a "virtual" position within a short distance of the rover. This provides accuracy at the rover that rivals the results of working within a couple of miles of an actual base station.
9. **Code based data collection** — This method of acquiring positions rapidly and with additional attribute information is used for GIS mapping applications where accuracy is not a factor; decimeter to several meters may be considered sufficient. This type of work utilizes code based GPS receivers. The methods of GIS data collection are not addressed in this guide.

TxDOT Levels of Survey Accuracy for GPS

Seven levels of Global Positioning System (GPS) surveying have been established by TxDOT to aid in maintaining standards of accuracy for different types of GPS surveys. The first four of these levels apply to design grade surveying.

The most accurate stations in the state are the Continuously Operating Reference Stations (CORS) of the National Spatial Reference System (NSRS). These stations are overseen by the NGS and their placements are not included in the TxDOT Levels of Surveys. A number of these are maintained by TxDOT and are referred to as regional reference points (see subsection Datum and Project Control within this section).

The following information provides GPS positioning specifications for TxDOT.

Table 3.6 TxDOT GPS Positioning Specifications

	Level 1	**Level 2**	**Level 3**	**Level 4**
Typical job type	RRP's, CORS or major control densification	Primary project control points	Property corners, secondary project control, flight panels	Topo surveys, and non-critical stakeout
Type of GPS	static	static	fast static or RTK	RTK
GPS Positioning Relative to Other Points (Local Accuracy)				
Instrument setup error	2 mm for B order monuments-RRP/ CORS have zero setup errors	2 mm	3 mm	5 mm
Total baseline length error at 2 sigma	8 mm + 1 ppm	8 mm + 1 ppm	12 mm + 1 ppm (see Note1)	20 mm + 1 ppm (see Note 1)

Table 3.6 TxDOT GPS Positioning Specifications

	Level 1	**Level 2**	**Level 3**	**Level 4**
Maximum baseline length for referenc-ing from CORS station	200 km	200 km	N/A	N/A
Maximum baseline lengths between points on a project	100 km	25 km	5 km (no limits within a VRS cell)	5 km (no limits within a VRS cell)
Minimum time per occupation	2 hrs + 1 min per km baseline	1 hr + 1 min per km baseline	180 epochs with rod rotated 180 degrees between observations	3 epochs (see Note 2)
Minimum number of occupations for static network (see Note 3)	2 for B order mon-uments - N/A for RRP/CORS stations	2	2	N/A
Minimum time between occupations	3 hrs	2 hrs	1 hr	N/A
GPS Positioning on the State Plane Grid (Geodetic Accuracy)				
Horizontal accu-racy at 2 sigma	12 mm	20 mm	25 mm	45 mm (see Note 4)
Elevation				
Accuracy at 2 sigma (assuming 100% perfect geoid model	22 mm	25 mm	30 mm	40 mm (see Note 5)

Note 1 - RTK baselines are measured from base station to rover point.

Note 2 - This should not be confused with 3 seconds - depending on conditions, it usually takes approx 5 to 10 seconds for 3 useable epochs.

Note 3 - A complete new setup is required for each occupation.

Note 4 - This should not be confused with project (local) accuracy which is 20 mm + 1 ppm in rela-tion to radius points, traverse points and other secondary control as shown in above “Local Accuracy” specifications.

Note 5 - The vertical component is not acceptable for most stakeout operations.

Level 1 Surveys

The basic purpose of this highest level of GPS surveys is for setting auxiliary points to densify a network of A and B order points that augment the above mentioned CORS stations. This will allow shorter observation times for performing static surveys in placing all lower quality control points. A typical data sheet for one of these points will show the amount of detail and documentation involved. In the usual seven (7) digit station name, the first three (3) digits represent the county number and the last four (4) digits denote the discreet point number assigned by the district. This level of surveys requires the direct supervision of an Registered Professional Land Surveyor (RPLS) and these points are usually set only on an as needed basis for very large projects.

Level 2 Surveys

Intended mainly for project control, these points usually include an azimuth mark for use with conventional surveying equipment. The high degree of accuracy is needed not just in relation to each other (local) but also on the High Accuracy Reference Network (HARN) network so that the same points can be used in subsequent adjoining projects years later. A standard naming convention and data sheets are also commonly used at this level. These surveys require direct RPLS supervision.

Level 3 Surveys

Still sometimes held tightly but can be relaxed enough to use faststatic or kinematic methods with two, or more, higher level reference stations. Appropriate for use mostly for surveying photogrammetric center line panels, property corners and base stations for topographic surveys. RTK will require the use of two or more base stations, or two (2) observations from a networked RTK connection.

Level 4 Surveys

Least stringent design level allowing radial baselines for kinematic surveying. Mainly for topo work, registering data and for continuous kinematic. This level requires use of a temporary base station or a networked RTK connection.

Level 5 Surveys

Level 5a - Includes mapping-grade (GIS) work that is held to 30 cm accuracy. Generally, this level requires a real time correction or post-processing from a base station. Surveys of this level are limited to horizontal accuracy, with vertical positions used for informational purposes only due to their poor accuracy.

Level 5b - Includes mapping-grade (GIS) sub-meter network accuracy. This is probably the most used level of accuracy for GIS work and can be accomplished with the largest variety of equipment.

Surveys of this level are limited to horizontal accuracy, with vertical positions used for informational purposes only due to their poor accuracy.

Level 6 Surveys

This level includes mapping-grade (GIS) work that is held to within a 5 meter accuracy. A Satellite Based Augmentation System (SBAS) is commonly used for this level of accuracy. Surveys of this level are limited to horizontal accuracy. The vertical component is generally of very poor accuracy.

Level 7 Surveys

This category includes locative work for rough positioning using autonomous positions. An accuracy of 10 meters is required, which is achievable with most consumer grade handheld units. This data is limited to horizontal accuracy with vertical positions seldom included.

Data Collection Forms

A sample GPS log sheet is shown on the next page. Please use this form or a similar one. A way to link the form to the data file is important to the processing person. In this case, the form requests the GPS receiver's default file name on the line **8-digit filename**.

A form can be tailored to the needs of the survey crew depending on their experience and proficiency. The collection of weather and meteorological data may be necessary if the project worked on is to be included in the NSRS (bluebooked).

Below is a sample GPS Log Sheet. For a .pdf of the log sheet, click here.

GPS Log Sheet

Operator Name	_____		
Observation Date	_____		
Station Name	_____		
8 digit File Name (if known)	_____		
Antenna Height			
Meters	_____	1st Measurement	_____
Survey Ft.	_____	2nd Measurement	_____
		3rd Measurement	_____

Average _____

Measured to: Bottom of Notch _____ Top of Notch _____ Antenna ref. point _____

Antenna Type _____

Actual Start Time _____

Actual Stop Time _____

4 Digit Receiver # _____

Notes

If adjustable height tripods are used, the height of the antenna above the mark should be measured. This measurement should take place at a minimum of three (3) locations around the ground plane, in two (2) separate units, at the beginning of the observing session, and again at the end of the observing session. The H.I. must be recorded in a field book or on log sheets for every occupation.

Static Observation Field Procedures

All control stations and boundary corners should be occupied a minimum of two times during the course of a survey. Table 3.11 Minimum TxDOT Network Design Specifications, in this chapter outlines how those occupations should be accomplished.

The normal collection rate (epoch) is 5 seconds for static observations, but for long observation times of more than about 3 hours, 15 second epochs are acceptable. For observations of less than half an hour, 5 second epochs are preferable. For fast/rapid static observations, 5 seconds is required. RTK is done at 1 second.

Longer baselines will require longer observations on end points. Minimum observation times for Levels 2 and 3 are listed in Table 3.8 GPS Static Observation Planning. Allowances should be made for difficult setups that may have less satellite visibility or high PDOP.

Level 1 surveys usually involve long distances and will almost always require observation times of 4 to 6 hours and at least two occupations.

The following table illustrates minimum observation times:

Table 3.7 Minimum Observation Times for Survey Levels 2 and 3

Length of Baseline	Minimum observation time *
less than 10 km	45 min
10 to 40 km	1 hr
40 to 100 km	2 hr
100 to 200 km	3 hr
more than 200 km	4 hr or more

* Assuming at least 5 satellites and PDOP of less than 6.0.

RTK Field Procedures

Real-time kinematic (RTK) allows close-in surveying without the requirement of line of sight to the control point. This is very cost effective for Level 4 surveys, and with more stringent requirements RTK can be used for Level 3 surveys.

Set up the base station on a control point with known x, y, z coordinates (all control points must have GPS-static quality horizontal values and differential leveled vertical values). The selection of the base station sites during the project planning phase will greatly affect the success of the RTK observations. If a poor base station site is selected, there will likely be problems throughout the entire survey.

The following information identifies parameters of base station sites:

- Select a site with good sky visibility down to (ten) 10 degrees from the horizon.
- Be aware of high power transmitters, such as microwave, TV stations, military installations, high voltage transmission power lines, etc.
- Be aware of multipath caused by radio wave reflective objects, such as trees, buildings, large signboards, and chain link fences, etc.

If there are no useable control points in the immediate area, or much is to be gained by setting a new control point for the base station, a position can be obtained for the base station setup by means of a calibration from other control points. The survey may be started on just the autonomous position after setting up the base station on the newly placed mark.

With a successful initialization at each of at least three (3) control points, perform a forced coordinate position or **calibration** by keying in the proper coordinates for each point. This will propagate the correct coordinates to the base station. The **calibration** control points must be within about three (3) miles of the base and in at least two (2) separate quadrants.

The calibrated base station coordinates will only be as good as the quality of the chosen **calibration** points and are a poor substitute for the assurance of a pre-surveyed control point.

The surveyor logs the following base station setup into the field notes:

- station name and/or number
- receiver and antenna type
- antenna measurement method (i.e. bottom of notch, bottom of antenna, etc.)
- record antenna H.I. measurements at the beginning and end of each setup
  - if using a fixed height tripod, make and record a measurement to verify that the fixed height has been checked
- record the local time that the base station is started and stopped
- record any problems encountered during the course of the survey with the base station.

The TxDOT UHF transmitters should be two (2) watts. The private sector does not have this 2-watt restriction on their itinerate frequencies. The FCC radio license is for **data** transmissions. This means TxDOT's radios have to stop transmitting when voice transmissions are being made. Be sure the transmitter is equipped with a blocker. Have the proper license and carry a copy with the equipment.

Rover Settings

Configure equipment settings for the type of project to be surveyed. It is a good idea to have all the possible options available while collecting data. In many cases, not every option is used. However, if needed, they will be available.

Some options are to:

- store raw observables at the base to allow for post-processing of the base position should the need arise
- store vector information to allow the RTK data to be adjusted with least squares should the need arise
- set up the survey to allow for post-processed kinematic data should the radio link be lost on a few shots.

Rover Initialization

There are several ways to initialize a kinematic survey. They can include a known baseline; use of an initializer bar; a new point; and an on-the-fly (OTF) initialization.

After the first OTF initialization, observe a point. This can be a temporary mark or a point in the survey. Discard the first OTF initialization and OTF re-initialize with the H.I. changed by more than two feet or move more than forty feet away from the point to be used as a check.

After the new OTF initialization has been accomplished, return to the point being used as a check and re-shoot it. Compare the first and second shots. Are they within an acceptable tolerance?

If the points check, proceed with data collection with the confidence in surveying with a correct initialization. If the error between the two points is beyond the expected error, one or both of the OTF initializations used for a check are incorrect. OTF re-initializations at any of the positions previously used cannot be reused.

The location **must** change by a difference of more than two feet of H.I. or, more likely, move more than forty feet away in a different direction. This will usually provide enough information to identify the OTF initialization that is incorrect. Once the problem is solved begin the survey. This procedure **must** be repeated with any loss of initialization.

Each time a re-initialization is done as a result of a complete loss of lock on satellites, the first station surveyed thereafter must be surveyed a second time with a new initialization from which the survey can continue if the two initializations agree.

NOTE: Contact the local district survey coordinator for a copy of the latest version of the TxDOT Feature Code List.

RTK for Wing Panels

Before starting to survey the panels, use the rover to check into at least one other control point with known x, y, z coordinates (all control points must have GPS-static quality horizontal values and preferably, differential leveled vertical values). These checks should be logged in the field book and in the data collector device. Also make and log checks during the course of the day. If any check shots are greater than 0.10 feet horizontally or 0.12 feet vertically, the problem should be resolved.

Wing panel surveys are in the Level 3 category and must therefore adhere to those requirements including positioning from a second base station.

RTK for Topographical Surveys

Connectivity of survey chains is required for topographical surveys and the use of TxDOT feature codes is mandatory. This TxDOT list is available in Trimble format as **txdot2k.fcl** and in CAiCE format as **txdot2k.ftb**. A printed list of the TxDOT feature codes is available from district survey coordinators.

At no time should the rover exceed a distance of three (3) miles from the base in a topographical survey using radial baselines.

With RTK topographical surveys, any time initialization is lost and reestablished, a previously occupied point should be redone as a check. At least one in every ten (10) points of the survey should be redone with a new initialization at a later time. This would result in a total of at least 10% of the stations receiving a second occupation.

Equipment and Software

TxDOT offers support to its surveyors for Trimble receivers and Trimble processing and adjustment software. Technology Services Division (TSD) maintains a list of recommended equipment and software, in the Procurement and Justification System (PJS), which includes GPS items.

A request for additions can be made on GPS equipment available for TxDOT procurement using the Request for PJS Catalog Add Request Form 2157. This catalogue is accessible to the district information resources administrators.

GPS Receiver

The receivers used for network surveys should record the full-wavelength carrier phase and signal strength of both the L1 and L2 frequencies, and track at least eight (8) satellites simultaneously on parallel channels. L1 only receivers are acceptable only for baselines less than 10 km. Ties to CORS sites should be made with dual-frequency instruments if base lines are longer than 10 km. Receivers should have sufficient memory and battery power to record 6-hours of data at 5-second epochs. Receivers should contain the latest manufacturer's firmware upgrades.

GPS Antenna

The antennas should have stable phase centers and be designed to minimize multipath interference. All antenna models used should undergo antenna calibration by the National Geodetic Survey (NGS). Users should consult user's manual for other specifications.

NGS Geodetic Services Division maintains a GPS Antenna Calibration Web site for calibrating a variety of antennas.

When processing GPS baselines, the user must apply the appropriate GPS antenna phase center offsets. Inappropriate phase center offsets can introduce up to 10 cm of error in the baseline.

GPS antenna ground planes should be utilized according to manufacturer specifications. Ground planes must be utilized for all stations when performing TxDOT Level 1 and Level 2 surveys. For other surveys, a ground plane must be used at the base station and should be utilized in areas where there might be significant multipath. Many new antenna models have built in ground planes.

GPS-RTK Rover Rod

A fixed height rover rod should be used and if possible, it should be the same height as any fixed height tripods on the project; usually 2 meters. Make a physical measurement in the field notes to verify it has been checked. Also, check the level bubble on the rod before and after each project.

Tripods

The tripods must facilitate precise offset measurements between the mark datum point and the antenna reference point (ARP). Fixed-height rods or fixed height tripods are preferable and required for certain surveys due to the decreased potential for antenna centering and height measurement errors. All tripods should be examined for stability with each use. Ensure that hinges, clamps, and feet are secure and in good repair. Test the fixed-height tripods for stability, plumb alignment, and height verification at the start and end of each project.

Tribrachs

Tribrachs and rod levels should be field calibrated before use on each project and should be checked at the end of the project. Any data not bracketed by a successful calibration check are suspect. Professional Tribrach calibration, usually scheduled once a year with regular use is a reasonable interval for maintaining the accuracy of the instrument.

Personnel

All field personnel should be trained in the avoidance of systematic errors during field operations. Field personnel often work alone and must be prepared to make wise, on-the-spot decisions regarding mark identification and stability, equipment use and troubleshooting, and antenna setup. Office personnel should be familiar with geodetic concepts and least squares adjustments. Personnel should participate in any available certification and training activities.

All boundary control survey projects performed for TxDOT will be performed under the charge of a Texas Registered Professional Land Surveyor (RPLS). Personnel requirements for various types of surveys may vary from one TxDOT district to another. The use of certified survey technicians (CST's) is encouraged not to fulfill any requirements, but to aid in the efficiency of operations with the use of goal-oriented employees.

Datum and Project Control

The reference system for horizontal control in the United States is the North American Datum of 1983 (NAD 83). The reference system for vertical control is the North American Vertical Datum of 1988 (NAVD 88). Surveys are referenced to these datums through measurements to control points of the National Spatial Reference System (NSRS).

The NSRS is referenced to a nationwide network of Continuously Operating Reference Stations (CORS). There are approximately 70 of these NSRS stations in Texas. A densification network of A and B order points supplement the network.

Primary project control points should be surveyed in from the CORS stations with ties to additional A and B order points as needed to provide shorter distances and proper geometric network configuration.

It should be noted that HARN coordinates are computed as of the date of the HARN survey (1993). On the other hand, CORS coordinates are computed as of the observation date. As a practical matter, there is not enough movement over time for points in the eastern US to be significant at magnitudes of less than one centimeter accuracy. However, users should examine differences between HARN and CORS coordinates to determine if there has been significant local or regional movement over time.

Primary project control points should be positioned and spaced so that they can be used for both conventional and GPS work. An azimuth mark should be visible from the station for surveys with conventional equipment. A data sheet form to record new control point metadata should be documented for use with new GPS control points. Generally, more reference stations and ties are given than for conventional surveys and an ellipsoid height is added.

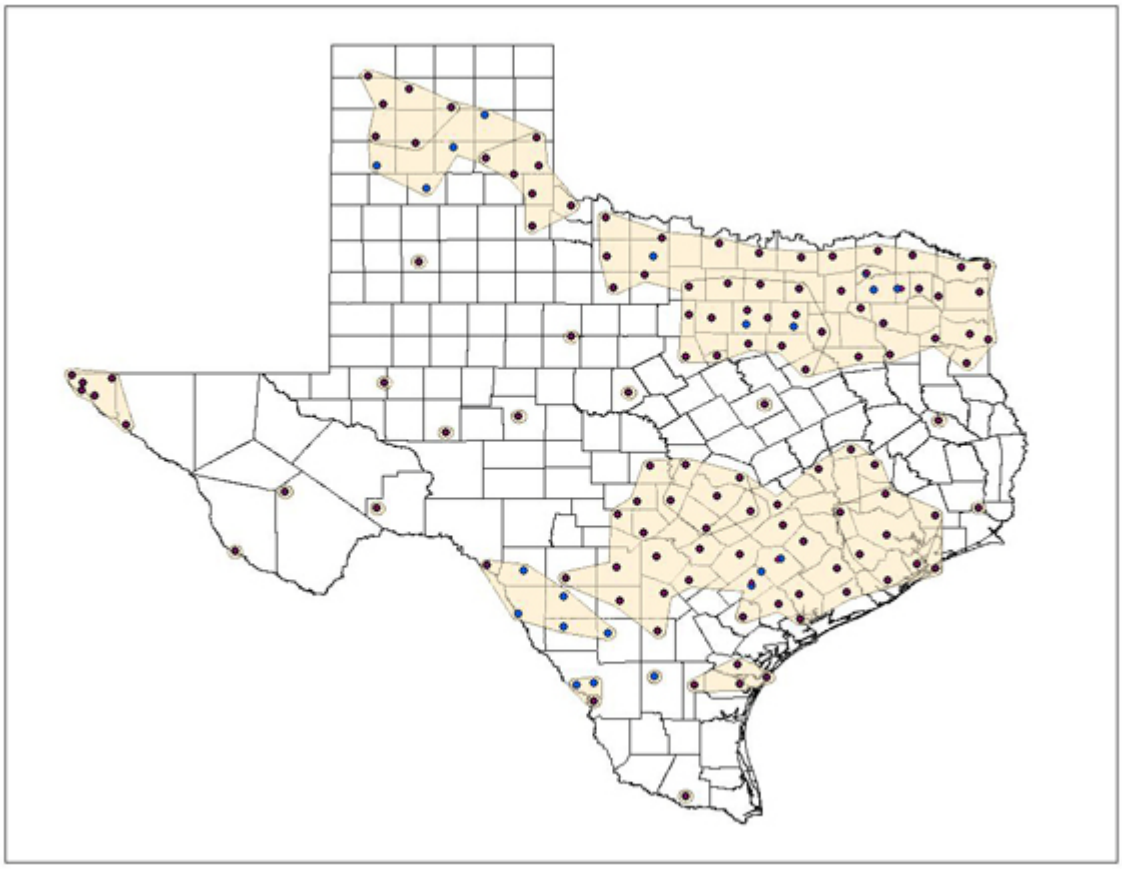

Figure 3-14. TxDOT Regional Reference Points (RRP), January 2010.

Section 6 — Internet Resources

The CORS Site

Using the CORS reference stations insures that all project control points are on a recognized network. It may not seem important at the time, but it also puts the TxDOT project on the NSRS at no extra cost. In fact, it saves sending extra people to the field and buying or renting extra GPS receivers.

For the extra few minutes it takes to download data, the office technician may as well include several additional CORS stations beyond the one or two required by the specifications. Refer to the NGS website www.ngs.noaa.gov under the CORS/OPUS heading for an all-inclusive and current maps.

Retrieving Data from the NGS Site

Retrieve CORS data from NGS from the NGS Web site at: www.ngs.noaa.gov/CORS.

The User Friendly CORS site (UFCORS) allows the user to download all the data desired in just one file containing the number of hours needed from a start time entered on the online form and, at the user's request, can include the coordinates and ephemeris in one simple zipped download. It is not necessary to convert to Universal Time Coordinate (UTC) time or sort through the coded file names. All files available from NGS are in RINEX format.

Should users need to use individual hourly files, a typical NGS RINEX data file from a CORS station appears with this naming convention: {SSSS} {DDD} {H}. {YY} {T}

Where SSSS is the four (4)-character site identifier:

DDD is the day of year

H is a letter that corresponds to an hour-long UTC time block

YY is the year

T is the file type

Example: txan3350.01o

For daily files, the format would be {SSSS}{DDD}0.{YY}{T}.

Obtaining Coordinates from the CORS Site

Coordinates for the station needed can also be found on the NGS Web site by clicking the appropriate site on the map then choosing "coordinates" from the left hand menu. The coordinate data sheet has two sections.

The top section contains the position information for the antenna reference point (ARP) and the bottom section, the information for the L1 phase center of the GPS antenna. It is important to use the ARP coordinates for the held position in processing.

The antenna type at the CORS station (needed during processing) is included in the header of the downloaded file. In addition, each section of the coordinate listing contains the ITRF position and the NAD83 position. Be sure to use the NAD83 position information.

If the PID of a station is known, the coordinates can also be found in the NGS database for the National Spatial Reference System. By starting from the NGS home page, click on "datasheets" in the five selections at the top. Click on the DATASHEETS retrieval link and click on the PIDs. To retrieve the appropriate data sheet, **key** in the PID.

Remember, there may be as many as three (3) separate data sheets associated with a station:

- a data sheet for the monument on the ground (if one exists)
- a data sheet for the L1 phase center of the antenna (the point at which data is actually collected) and finally,
- the ARP (the mounting surface of the antenna).

Each of these points has its own PID.

Retrieving Data from TxDOT

Retrieving CORS data from the original TxDOT maintained stations can be done from the Internet using the following TxDOT web address: http://www.txdot.gov/business/resources/information-technology/gps.html.

TxDOT posts files in both RINEX and Trimble formats. The naming conventions can be found in the "documents" sub-folder.

Files in Trimble format are available in six (6) hour increments or four (4) files per day and files in RINEX format are available hourly. Note that Julian dates are based on Universal Time Coordinate (UTC). There is no provision for combining files before download. Data is kept for thirty (30) days, data older than thirty (30) days must be retrieved from NGS at www.ngs.noaa.gov/CORS.

OPUS

The Online Positioning User Service (OPUS) is the newest addition to NGS' Geodetic Tool Kit. OPUS allows users to submit their GPS data files in RINEX format to NGS, where the data will be processed to determine a position using NGS computers and software. Each RINEX file submitted is processed with respect to three (3) National CORS sites or Cooperative CORS sites.

Any stations in a TxDOT network that contain two (2) or more hours of raw GPS data can be processed at this Web site. The tie sites selected may not be the nearest to the users' site but are selected by distance, number of observations, site stability, etc. Users have the option to select their own CORS sites. The ITRF and NAD83 coordinates, as well as Universal Transverse Mercator (UTM) and SPC Northing and Easting report position data back to the user via e-mail.

TxDOT recommends that users check the results of the processing and adjustment on new points with this NGS service. As a minimum, at least one station should be checked in every network. OPUS positions are usually within one tenth of a foot, horizontally. However, they may be less precise in areas of one-direction-only ties. Additionally, depending on the geoid model this may be several tenths of a foot, vertically.

Use this to verify the NAD83 HARN position and ellipsoid height. Orthometric heights may not tie, based on whether the elevation was established before or after the original Texas HARN network was created.

OPUS-RS is a version of OPUS designed to obtain geodetic quality positioning results from user data sets as short as 15 minutes. The input format on the Web site is very similar to the regular OPUS and accuracies are only slightly less in most cases.

NGS Description of OPUS

The National Geodetic Survey operates the Online Positioning User Service (OPUS) as a means to provide GPS its user's easier access to the National Spatial Reference System (NSRS).

OPUS allows users to submit their GPS data files in RINEX format to NGS, where the data is processed to determine a position using NGS computers and software. Each RINEX file submitted is processed with respect to three (3) CORS sites.

The sites selected may not be the nearest to the users' site but are selected by distance, number of observations, site stability, etc. Users have the option to select their own CORS sites. The position for data will be reported back to the user via e-mail in both ITRF and NAD83 coordinates, as well as UTM and SPC Northing and Easting coordinates.

NGS OPUS Requirements

OPUS is completely automatic. Users are required to enter only a minimal amount of information. OPUS requires the following:

- e-mail address to receive results
- RINEX file that the user wants to process (which may be selected using the browse feature)
- antenna type used to collect this RINEX file (selected from a list of calibrated GPS antennas)
- height of the Antenna Reference Point (ARP) above the monument or mark that user is positioning
- as an option, users may also enter the state plane coordinate code if they want SPC Northing and Easting.

Once the information is completed, click the **upload button** to send the data to NGS. User results will be e-mailed in a few minutes. Upload one RINEX file at a time.

Read through each of the OPUS Help Links. It is important that users understand how to correctly submit their data and how to interpret the results. For inquires or comments, use the OPUS e-mail button.

OPUS is intended for use in the conterminous U.S., Alaska, and Hawaii. It is NGS policy not to publish geodetic coordinates outside the U.S. without the agreement of the affected countries.

Useful Web Sites

Below is a list of website addresses that may be accessed for further information regarding GPS-related activities.

GPS Antenna Information	http://www.ngs.noaa.gov/ANTCAL/index.shtml
GPS Orbital Data	http://www.ngs.noaa.gov/orbits/
GPS Overview	http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html
National Geodetic Survey	http://www.ngs.noaa.gov/
NGS Data Sheets	http://www.ngs.noaa.gov/cgi-bin/datasheet.prl
NGS CORS Data	http://www.ngs.noaa.gov/CORS/
NGS PC Software	http://www.ngs.noaa.gov/PC_PROD/pc_prod.shtml
OPUS	http://www.ngs.noaa.gov/OPUS/
Space Weather	http://www.sec.noaa.gov/today.html
TxDOT RRPdata	ftp.dot.state.tx.us/pub/isd/txdot-info/isd/gps

USCG	http://www.navcen.uscg.gov/

Section 7 — GPS Static Surveying

Overview

Static GPS surveying typically uses a network or multiple baseline approach for positioning. It may consist of multiple receivers, multiple baselines, multiple observational redundancies and multiple sessions. A least squares adjustment of the observations is required. This method provides the highest accuracy achievable and requires the longest observation times; from less than an hour to five hours or longer.

Static positioning is primarily used for ties to the National Spatial Reference System (NSRS) when observing for TxDOT Level 1 and 2 surveys. Project control points are nearly always set using this type of survey.

A variation of the static survey is the faststatic method (also called rapid-static by some manufacturers of GPS equipment). This will allow shorter occupation times (i.e., 8 to 20+ minutes) than static positioning and may use a radial baseline technique, network technique, or a combination of the two. Baseline lengths may not exceed 10 kilometers for L1 only receivers and 20 kilometers for L1/L2 receivers.

Typically, the occupation time is a minimum of 8 minutes for baseline up to 20 km and a minimum of 12 minutes for baselines up to 30 km. Please refer to manufacturers' specifications for minimum occupation times, number of satellites observed, and minimum amount of cycle slip free data collected for this type of data collection method. FastStatic requires a least squares adjustment or other multiple baseline statistical analysis capable of producing a weighted mean average of the observations. More than one base station will be used to provide redundancy for each vector. FastStatic techniques may be used for observing Levels 3 & 4.

Planning

Planning is one of the most important parts of the performance of a control survey utilizing GPS survey measurement techniques.

The following steps will help to ensure the creation of a baseline network, which will produce accurate coordinates on newly placed project points:

Table 3.8 GPS Static Observation Planning

Step	Task
1	Roughly locate both new points and existing control on a map showing roads to use in moving the observers around the project.
2	During field reconnaissance flag and mark points for easy identification by all personnel.

Table 3.8 GPS Static Observation Planning

Step	Task
3	For each session draw independent baselines intended for observation on a map. Move through the project until all points have been included.
4	From an almanac of satellite orbits choose appropriate times for observations to avoid consider space weather – unusually poor conditions caused by solar storms and magnetic disturbances can cause many hours of unusable data. One measure of this activity is the Kp index. An explanation of this scale and daily predictions can be found at http://www.sec.noaa.gov/index.html.
5	When possible, separate redundant observations by 24 hours to consider different atmospheric conditions and then a several hour shift to take advantage of a slightly different satellite constellation.
6	Observing the above suggestions, plan your repeated occupations and observations. Make a schedule understandable to all personnel doing the fieldwork.
The field reconnaissance survey of the site mentioned above should accomplish the following:	
	◆ Determine the location and sky visibility of existing and new control stations ◆ Pick the locations for new stations making sure satellites can be recorded in a minimum of three quadrants ◆ Look at logistics of project and determine transportation required ◆ Gain permission to access station(s) on private land ◆ If applicable, notify law enforcement of your activities ◆ Record sky visibility chart data and access requirements for all stations ◆ Look for any objects that could be sources for radio interference ◆ Look for any multi-path conditions that may affect data collection.

NOTE: All of the control stations selected for reference points must have positions known on the NAD 83 datum. The particular adjustment recommended is the 2003 CORS Adjustment denoted as NAD 83 (CORS).

Fieldwork

The normal collection rate (epoch) is 5 seconds for static observations but for long observation times of more than 3 hours, a collection rate 30 seconds is acceptable.

Longer baselines will require longer total observation times on end points. Typical observation times are listed in the table below. Allowances should be made for difficult situations where there may be less satellite visibility, high PDOP, chance of reflected signal or even solar flares and sunspots.

Table 3.9 Typical Static Observation Times

Length of Baseline	Minimum Observation Time *
less than 10 km	45 minutes

Table 3.9 Typical Static Observation Times

Length of Baseline	Minimum Observation Time *
10 to 40 km	1 hour
40 to 100 km	2 hour
100 to 200 km	3 hour
more than 200 km	4 hour or more

Minimum observation times for surveys Level 2 and lower.

* Assuming at least 5 satellites and PDOP of less than 6.0.

If adjustable height tripods are used, the height of the antenna above the mark should be measured. It is recommended that this be at a minimum of three locations around the ground plane in two separate units at the beginning of the observing session and again at the end of the observing session.

There are certain newer types of antenna where this is not possible; therefore, the manufacturer's recommended measurement should be followed. The H.I. must be recorded in a field book or on log sheets for every occupation. The log sheets may contain other information but their main purpose is to pass on to the processor the H.I. of the setup and match the location to the particular data file.

Some antenna setups will require a diagonal (slope) distance to be measured from the edge of the ground plane to the monument. Follow the equipment manufacturer's instructions and include the type of measurement on the data sheet. For Trimble antennas (with ground plane), the diagonal measurement is made from a notch on the outer perimeter of the antenna and must be noted as such on the log sheet.

There should be one log sheet per observation. At the end of the day or the end of the project, the party chief, knowing the number of observations, must collect all of the completed data sheets. One missing data sheet may require the repeat of an entire session because it is not possible to redo a single missing point since simultaneous occupations must be made.

The elevation mask should not be set at less than 13 degrees – 15 degrees is normally used. Data from satellites lower than that is just about useless for surveying; it is too noisy going through the atmosphere. Anything over 15 degrees may be denying the processor access to useful data that he or she may need in some situations. Usually the processing is done at a cut-off elevation of 15 or 17 degrees.

All observers should be well aware of the scheduled start and stop times for each session and should allow plenty of time to find the monument (which should be well marked and flagged before the day of the observation) and allow enough time to set up the antenna accurately.

In some situations, time can best be utilized by observing the station's azimuth mark (which is usually about a half mile away and visible from the newly placed station) during the long observation time. The azimuth mark generally only requires about 20 to 30 minutes. However, users will probably not be able to safely leave the station setup unattended, unless it is in a secure area such as a fenced in maintenance yard.

FastStatic (Rapid Static) Positioning

The method of FastStatic/rapid static positioning requires shorter occupation times than static positioning (i.e. 8 to 20 + minutes) and may use a radial baseline technique, network technique, or a combination of the two. Baseline lengths may not exceed ten (10) kilometers for L1 only receivers and twenty (20) kilometers for L1/L2 receivers.

Accuracy degrades at a predictable rate with this type of survey; therefore, longer baselines may be used when design survey quality is not needed. Please refer to the manufacturer's specifications for minimum occupation times, number of satellites observed, and minimum amount of cycle slip free data collected for this type of data collection method.

FastStatic requires a least squares adjustment or other multiple baseline statistical analysis capable of producing a weighted mean average of the observations. More than one base station will be used to provide redundancy for each vector.

FastStatic or rapid static techniques could be used for observing Levels 3 & 4 listed in this chapter. It provides baselines that do not exceed the maximum distances stated above in the first paragraph of this subsection.

Downloading the Data

The Trimble program for transferring the raw data files from the receivers to the laptop or PC is called Data Transfer. Microsoft ActiveSync can also be used. One should never leave a project where considerable travel is required before downloading the files and matching the log sheets.

Processing

Trimble software for this purpose is called Trimble Geomatics Office and includes the basic program, plus two additional individually licensed add-ons called "Wave Baseline Processor" and "Trimble Adjustment." When loading the observations into the Processor of TGO, care should be taken that each file includes the correct antenna type, antenna height, and type of measurement. Remember that on CORS and Cooperative CORS stations, the measurement is from the antenna reference point (ARP) – this is also the point of reference for all RINEX files.

The processing will produce a "fixed" or a "float" solution and it could be determined using L1 only or L1/L2. The fixed solution is considered best but for extremely long baselines the float solu-

tion may be the only solution available. For very short (5 km and less) baseline, an "L1 Only" solution will probably be the final solution. However, users should hope for L1/L2 (also called iono-free) on baselines longer than approximately 5 or 10 km.

Table 3.10 Baseline Solution Types

	Up to 5 km	**5 – 10 km**	**10 – 30 km**	**30 – 200 km**	**More than 200 km**
Desirable	L1 fixed	L1 fixed or L1/L2 fixed	L1/L2 fixed	L1/L2 fixed	L1/L2 fixed
Acceptable	L1 only	L1 only	L1 fixed		L1/L2 float

The processing will generate several other quality indicators. The RMS error estimate of the vector is a good indicator - usually not more than 15 millimeters. A high ratio of difference between the two closest solutions of a baseline length indicates that the integer was easily established and so the result is more assured. Finally, the reference variance should be close to 1.00 – this is the ratio of the actual amount of error to the amount of error expected (given the accuracy in centering the antenna over the point and measuring the H.I.).

Performing loop closures on selected vectors will make blunders apparent. It may take a few tries to determine which vector is at fault. Just as with a conventional traverse, a ratio of precision or parts per million is the method of checking the closures.

Troubleshooting Problematic Baselines

A problematic baseline can be defined as a line observed with two carrier-phase GPS receivers, L1 or L1/L2, and the baseline solution does not meet the manufacturer's specification for quality. In most cases, the problematic baseline was observed with enough satellites for a long enough time period, but the quality indicators show the line to be unacceptable.

The first thoughts may be to re-observe the line. However, this should be the user's last resort. There are enough tools available in the baseline processing software to allow users to examine the observational information to detect obvious problems.

The following are suggestions on what to look for when troubleshooting problematic baselines:

- Look at the plot of all satellites during the observing session; there is a plot for each receiver. Software packages differ, but common to most is a plot showing each satellite observed, one below the other.
- What to look for:
  - When a cycle slip occurs, or there is a loss of lock due to obstructions, there will be a break in the line on the graph for that particular satellite.
  - A short break indicates a cycle slip, a longer break; an obstruction.

  - If too many breaks have occurred, eliminate that satellite and try the baseline solution again. In many cases, this solves the problem.
- Look at the plot of satellites for both receivers.
  - Was the start and stop time approximately the same, or did one receiver start or stop too early or too late?
  - Start and stop times can be changed to encompass only common observing times and then re-observe the baseline.
- Satellites with a high signal-to-noise ratio (SNR) can cause problems. In many cases, a high SNR occurs when the satellite is close to the horizon. It is possible to have a satellite low on the horizon for the entire session. In that case, the satellite should be eliminated from the solution, then resolve the baseline.
- Another way to eliminate high SNR on satellites low to the horizon is to raise the elevation mask for the baseline solution.
- If the length of the session is short, perhaps too short, try a baseline solution with a shorter epoch than normal.
  - If the default on the baseline solution is thirty (30) seconds, try fifteen (15) seconds. This will increase the number of single, double, and triple differences needed to resolve the baseline.
- If all the above suggestions fail, resolve the baseline using a more precise ephemeris than was started with.
- As a last resort, the baseline must be re-observed. Be sure to select a time period different from the original observed time. Look at sky plots and select a time with many satellites and an area free of obstructions.

Network Baseline

TxDOT recognizes there are arguments for and against the use of dependent (trivial) baselines in the least squares adjustment of a network. TxDOT recommends not using dependent baselines.

For any given multiple receiver session, there are n(n-1)/2 total vectors possible, where n = the number of GPS receivers observing simultaneously. The number of independent vectors is n-1.

Using only the independent baselines:

- prevents adjusting the same observations more than once and misstating the network degrees of freedom in the least squares adjustment
- makes it easier to troubleshoot and evaluate the network and locate deviant baselines.

Accuracy Standards for Network Baseline

For a station to qualify for an accuracy classification, network or local, it must meet the listed accuracy standards, relative to all other stations in the network and/or datum, whether or not there was a direct connection between them.

The table below outlines requirements for network design.

Table 3.11 Minimum TxDOT Network Design Specifications

Level of Accuracy *	Level 0	Level 1	Level 2	Level 3
Minimum Number of Closest Direct CORS Ties	2	2	1	0
Minimum Number of Total FBN/CBN /CORS Station Ties	4	4	3	2**
Minimum Number of Horizontal Station Ties	4	4 (Level 0 ties)	3 (Level 1 or 0)	2 (Level 0,1, or 2)
Minimum Number of Vertical Ties (2nd order or better)	6	5	4	2
Minimum Number of Occupations Per Station	2	2	2	2
Minimum Number of Repeat BL's (% of all BL's)	50%	40%	30%	20%
Time Offset Between Observations (Occupations ***)	± 4 hrs	± 3 hrs	± 2 hrs	± 1 hr
Minimum Satellite Elevation Mask	15 Degrees	15 Degrees	13 Degrees	13 Degrees
Minimum Number of Quadrants for H Station Ties	4	4	3	2
Minimum Number of Quadrants for V Station Ties	4	4	4	2
Type of Ephemeris Required	precise	precise	rapid or precise	broadcast or better

* Level 4, 5, 6 and 7 surveys are generally not network surveys. Network requirements do not apply.

** These should be at least be indirect ties to CORS, FBN or CBN stations. They may be surveyed from Level 2 stations, which have been directly tied to CORS, FBN or CBN stations

*** To qualify for a new occupation, the observer must remove the GPS receiver at the station and a completely new setup over that station must take place.

FBN and CBN stations are statewide GPS survey networks that form the highest order of monumented control for the NSRS. These are A and B order points. NGS-maintained FBN stations at 100 km station spacing and volunteer-densified CBN points at 25 – 50 km spacing are included in the Table 5.1 and serve as control for regional and local surveys.

Ideally, the time offset between observations should be 24 hours plus 3 – 9 hours before the second observation in order to "see" a completely different satellite constellation. A more practical approach for scheduling observations with a minimum of overlap is to remember that the satellite positions repeat about every 12 hours (actually they advance in position about four minutes a day). Scheduling with this information in mind could result in substantial savings in time and cost. Also, it should be noted that whenever possible, a different receiver should be used at that station for the repeat observation.

Example of a Network Design Procedure

Network Design Example:

1. Roughly locate both new points and existing control on a map showing roads to use in moving the observers around the project.
2. From reconnaissance and mission planning software, determine the best times to observe.
3. For each session, draw the independent baselines chosen to be observed on map. Move through the project until all points have been observed.
4. Observing the rules for time differences, plan the repeated occupations and observations. Consider redundancy requirements.
5. Measure and record antenna height in two different units at the beginning and before the end of each session.
6. Fill out observation sheet each session.
7. Every one moves every session (where practical).

Adjustment

Once vectors have been processed, a least squares adjustment of the network will produce the best possible solution of final coordinates. The first adjustment should hold only one point to known coordinates. The results will indicate how well the GPS derived baselines fit together. If there had been a bad observation, it would show up here as an anomalous vector.

Then after ensuring that only good quality GPS baselines have been produced, the user can proceed holding each known reference station in subsequent iterations of the least squares process. By watching how remaining known points compare, the user will get an idea of how well the control points fit together. At this point, it can be seen how important it is to have additional control points as checks. The user may find that what was thought was a good control point might have to be thrown out.

The user should be aware of standard least squares quality indicators. The final network should pass the chi-square test; the network reference factor should be about 1.00 (plus or minus .10) and the scalar will usually fall between about 5 and 10.

Minimally Constrained Adjustment

A minimally constrained adjustment (MCA) is an adjustment with only one control point held fixed in the survey network. Holding one control point fixed, shifts observations to the correct location within the chosen datum. Not fixing a control point forces the software to perform a free adjustment. A free adjustment is accomplished by minimizing the size of the coordinate shift throughout the network. This equates to a mean coordinate shift of 0 (zero) in all dimensions.

A minimally constrained or free adjustment acts as one quality control check on the network. This adjustment helps to identify bad observations in the network. If an observation does not fit with the rest of the observations, it is highlighted as an outlier. The minimally constrained or free adjustment also checks on how well the observations hold together as a cohesive unit.

All minimally constrained adjustments must be performed in the WGS-84 datum. Since all GPS observations are made on the WGS-84 datum, the adjustment of the observations should be tied closely to the WGS-84 datum. Realistic error estimates for tribrach centering and H.I. measurement should also be factored into the minimally constrained adjustment.

The following minimally constrained adjustments should be done for Level 1 and Level 2 surveys. The required reports and/or spreadsheets are listed.

An MCA to determine network reference accuracy:

- Submit a minimally constrained adjustment holding the closest CORS fixed – use the NAD83 CORS coordinate in latitude, longitude, and ellipsoid height.
- Create a spreadsheet (or select a report) to compare the published CORS coordinates to the coordinates determined in the MCA.

An MCA to determine local HARN relationship if applicable:

- Submit a minimally constrained adjustment holding the highest order (1st priority) and most central to the project (2nd priority) HARN station.

- Create a spreadsheet (or select a report) that shows the comparison between the measured values and the published values of other HARN stations included in the survey.

An MCA to show the relationship of bench marks used in the survey:

- Submit a minimally constrained adjustment holding the highest order (1st priority), highest stability monument (2nd priority), and most central (3rd priority) to the project vertical control stations.
- Create a spreadsheet (or select a report) showing differences between published orthometric heights (elevations) and measured values.

The minimally constrained adjustment is an iterative process. Perform the minimally constrained adjustment to check the observations for internal consistency and estimates errors for all observations.

If bad observations are found, they should appear as outliers in a histogram of standardized residuals. If bad observations are discovered, they should be removed, one at a time, starting with the largest, so that the statistics of the network are not skewed.

An adjustment should then be performed again. Errors are estimated again. In the subsequent adjustments, the estimated error may be rescaled to produce more realistic error estimates.

These procedures should be repeated until the results meet the following conditions:

- all outliers have been removed from the network
- observations have the most accurate error estimates possible; and observations are adjusted such that they fit together well.

During the iteration process, two least squares statistics should be used to gauge progress:

- **Reference factor** – The reference factor shows how well the observations, along with their respective error estimates, are working together. Once the reference factor approaches 1.00, the errors in the observations are properly estimated and all observations have received their appropriate adjustments.
- **Chi-square test** – Typically when the reference factor approaches 1.00, the chi-square test of network error estimates, degrees of freedom, and level of confidence will pass. At this point, there is confidence that the network observations are working together and that there are no large errors remaining in the network.

Once the minimally constrained adjustment has been completed, move on to the fully constrained adjustment to fit the observations to the local control datum.

Fully Constrained Adjustment

The fully constrained adjustment (FCA) transforms the network of observations to the control points in the network. Once the network is fixed to those control points, adjusted coordinates based on the project datum (using the appropriate datum adjustment as recommended by TxDOT) for all other points in the network can then be determined.

Use this step to check that the existing control fits together well. The minimally constrained adjustment (MCA) showed that the observations fit together and a fairly rigid network is defined. It is assumed that if any large errors are present in the fully constrained adjustment, the source is non-homogeneous control points (values). Any ill-fitting control points should not be fixed (constrained).

When designing the network, it is good practice to use a minimum of three (3) horizontal control points and four (4) vertical control points because two (2) horizontal and three (3) vertical control points are required to define transformation parameters. The additional horizontal and vertical control points can be used to check the consistency of the adjustment and defined transformation parameters. Adding additional control points builds more confidence in the calculated parameters. Levels 1 and 2 do require these three (3) horizontal coordinates and four (4) elevations at a minimum.

In the fully constrained adjustment, begin fixing the control values to determine how well the rigid network of observations fit the control. Essentially, the adjustment determines if the network of observations fit the network of fixed control points given some error estimate. These error estimates consist of the error estimates along with the applied scalar and set-up errors. The transformation parameters should then be calculated to allow the observations to fit to the control.

The following fully constrained adjustments (FCA) for Level 1 and Level 2 should be delivered along with the listed spreadsheets or reports.

An FCA to determine local accuracy for horizontal positions only:

- Submit a fully constrained adjustment fixing a minimum of three (3) horizontal stations as noted above.
- Submit a spreadsheet (or select a report) showing the comparison between the MCA above and the FCA for horizontal position.

An FCA to determine local accuracy for orthometric heights (elevations):

- If there are unexpected differences in the MCA and published values for vertical, submit a fully constrained adjustment fixing a minimum of 4 bench marks.
- In many cases, a fully constrained adjustment will not be required for the final elevations of a control survey.

- If the differences between the published and measured values of the MCA holding one benchmark fixed, fall within the acceptable error limits of a particular level of survey, the MCA elevations will be acceptable as the final results of the survey.

Determining Elevations

After the fully constrained adjustment, the user will still only have heights measured from the ellipsoid (sometimes called GPS heights). It is necessary to determine orthometric elevations for use in the field. The use of a geoid model, such as GEOID03, will usually yield orthometric elevations accurate to within a few centimeters in many places but for design survey accuracy it will be necessary to hold known elevations surrounding the project to get results within millimeters in relation to the surrounding marks.

From those ties, the geoid model is interpolated throughout the network to produce elevations on the newly surveyed points. Again, it can be seen why it is important to have more than just a couple of control points; vertical control points should be well spaced and surround the project whenever possible.

When processing the data, there are five (5) steps to follow for estimating GPS-derived orthometric heights:

Table 3.12 Steps in Processing the Data

Step	Action
1	Perform a 3D minimally-constrained, least squares adjustment of the GPS survey project, i.e., constrain one latitude, one longitude, and one orthometric height value.
2	Using the results from the adjustment in procedure 1 above, detect and remove all data outliers. The user should repeat procedures 1 and 2 until all data outliers are removed.
3	Compute differences between the set of GPS-derived orthometric heights from the minimally constrained adjustment (using the latest National geoid model, e.g., GEOID03) from procedure 2 above and the published NAVD 88 bench marks.
4	Using the results from step 3 of this table, determine which bench marks have valid NAVD 88 height values. This is the **most important step** of the procedure. Determining which bench marks have valid heights is critical to computing accurate GPS-derived orthometric heights. The user should include a few extra NAVD 88 bench marks in case some are inconsistent, i.e., are not valid NAVD 88 height values.
5	Using the results from step 4 of this table, perform a fully constrained adjustment holding all valid known values fixed to arrive at the resulting elevations.

The following table provides adjustment analysis information:

Table 3.13 Office Procedure Guidelines

Adjustment Analysis Criteria	1 cm Horizontal 2 cm Vertical *	2 cm Horizontal 5 cm Vertical
Maximum variance of unit weight (1.0 ideal)	1.5	1.5
Minimum degrees of freedom per station	2 degrees of freedom	1 degree of freedom
Standard deviation of observation residuals, cm	.01 cm	0.1 cm
Standard error of baseline components, cm	.01 cm	0.1 cm
Standardized residuals - pass chi square test - pass tau criterion	yes yes	yes yes
Maximum % observations rejected	10%	10%

*Local Network Accuracy

Deliverables

The final list of coordinates from the survey should include all metadata necessary to make the coordinates usable. This would include datum (and adjustment such as HARN), units, state plane or surface adjusted, and if surface adjusted, the adjustment factor is used. Do not truncate coordinates. Coordinates shall include standard TxDOT feature codes. Most often the format desired is: point name, northing, easting, elevation, feature code. Occasionally, designers request LandXML.

As an indicator of the survey quality, a project summary should be printed as supplied by the software. It will indicate the above information about the baseline processing and the adjustment routine. Such things as histograms and bell curves, ratios of precision for each point, etc. are generally available for review. The raw data in RINEX or DAT file format and log sheets must also be preserved for future retrieval.

Section 8 — GPS RTK Surveying

Overview

Real-time kinematic (RTK) positioning is similar to a total station radial survey. RTK does not require post processing of the data to obtain a position solution. This allows for real-time surveying in the field and allows the surveyor to check the quality of measurements without having to process the data.

RTK positioning may be used for Level 3 and 4 surveys as mentioned in Section 5 of this chapter. Level 3 surveys require that a second base station be set up for the purpose of creating a second baseline. Trimble units (and most others) will allow the averaging or adjustment of the two or more baselines while still standing at the point. Level 4 surveys will accept the single radial baseline solution. The surveyor must also follow the manufacturers prescribed methods.

Real-time surveying technology may utilize single or dual-frequency (L1/L2) techniques for initialization, but the subsequent RTK survey is accomplished using only the L1 carrier phase frequency. Therefore, all RTK surveys are currently subject to the limitations of the L1 frequency which is 10 kilometers from the base station. In order to maintain a 2 cm level of accuracy, distances are usually considerably less than this but there may be circumstances where this maximum range may be extended.

Planning

As with static GPS surveying, mission planning is an important step in performing a RTK survey. There are times of the day when the numbers of satellites available will vary. The positions of the satellites at various times of the day are also a factor. Planning your work around these times greatly increases productivity and the quality of your results. Most, if not all, software packages include a utility allowing suers to predict satellite coverage.

The Trimble planning utility supported by Technology Services Division (TSD) is simply called “Planning” and offers charts, graphs, and sky plots to aid in determining the best times for GPS reception and data quality. Number of satellites and PDOP are the most important indicators. A recent almanac (approximately 12 minutes of broadcast ephemeris data collected within the last couple of days) is needed. The surveyor can collect this or download it from several sites on the internet. The Trimble site, www.trimble.com, uses a file extension of .ssf on their daily almanac files.

The selection of the base station sites will also affect the success of the RTK observations. Users who select a poor base stations site will likely have problems throughout the entire survey. Select a site with good sky visibility down to 10 or 15 degrees from the horizon. Be aware of high power

transmitters such as microwave, TV stations, military installations, high voltage transmission power lines, etc.

Multi-path may be caused by radio wave reflective objects such as trees, buildings, large sign-boards, chain link fences, etc. Because of the orbits of the satellites, obstacles to the north of the antenna setup are not as detrimental to reception.

It is worth the effort to get the base stations in optimum locations. A problem at the base is a problem at all rovers. A problem at one rover is only a problem at that one rover.

If possible, users should take part in the selection of any project control points in the beginning stages of a project. This is to insure that the points can be surveyed with GPS and well spaced for project coverage of real-time kinematic (RTK), if GPS is likely to be used. Of course, the primary project control points selected should always be GPS friendly.

Preparing the Data Collector

It is important to have the Feature Code Library or a feature table loaded into the data collector before going to the field. A list of available existing control points that may be available should also be included to prevent having to type in long coordinate values. On the Trimble TSC and ACU data collectors the control file can simply be an ASCII file with the format: point name, northing, easting, elevation, feature and feature code. The extension can be .txt or it can be a .csv file.

The “job” can be created in the office and exported to the data collector or the user can enter the job parameters in the field. Some of the settings involved are datum, projection, scale, and scale factor and measurement units. The Trimble data collection software is called, “Survey Controller.”

A survey “style” is used as a template to repeat settings for a particular type of real-time kinetic (RTK) survey. The style contains dozens of settings to include all the base and rover radio settings, receiver settings, data and accuracy parameters, etc. The software comes with several styles, but the user will eventually want to create their own to accommodate their particular brand of radios, or cell phones. The user’s styles can be created in the “configuration” icon and will be saved under the Trimble Data folder on the hard drive of the data collector.

Setting Up the Base Station

Set the base station at one second collection rate and at 13 degrees elevation mask. It is advisable to use a fixed height tripod (usually 2-meters). It is possible to do the entire survey without ever having to make an H.I. measurement – a considerable advantage over the conventional survey.

Obviously, it will be of little value to have data based on a coordinate system or datum that is unusable. However, control local in NAD 83 datum may sometimes be unavailable within range of the RTK system. Perhaps control points have been destroyed or maybe no control was extended

beyond the several project control points on a large project. In these instances, a proper GPS methods can be used to bring control points to areas suitable for RTK base stations.

There is also the option of starting an RTK survey with an autonomous position for the base. While collecting the RTK data at the rover, have the base station log raw observables for post-processed GPS. After post-processing the data to establish correct coordinates, users can apply the corrected coordinates to edit the base station positions and shift the collected RTK data to its proper positions. Trimble data collectors have a selection for this purpose, which is called a “here” option.

A similar option is to start your base station with an autonomous (here) position but then observe control points and calibrate or localize (manufactures use different terms) to shift the data to the existing control values.

There are drawbacks to using these two approaches. The problems arise from the inaccuracy of the position of the base stations. For each ten meters of error in the base position, introduce an additional 1ppm (1mm per kilometer) error in our baselines. (This rule holds true with all GPS surveying techniques users might choose.)

Even after the base station data is post-processed and the coordinates are determined and shifted, error will remain in the baselines if the 10 meter fault is present. The finding of an autonomous position of more than 10 meters error, especially if baselines of more than a few kilometers were used, may mean a redo of the survey. For this reason, it is strongly recommended that base stations be known control points.

If it is not possible to use a control point, there are different approaches that can be applied to assure that inaccurate base station coordinates are held to a minimum.

1. Use the Wide Area Augmentation System (WAAS) corrected signal (still only accurate to about 7 meters).
2. Use equipment that allows for averaging of code derived autonomous positions.
3. Predetermine position with code equipment using a correction service.

Using an unknown position for the base station in the methods described above is a poor substitute for the practice of occupying a known position.

The Rover

Set the rover receiver at one (1) second collection rate and 15 degrees elevation mask. The rover rod should always be a fixed height. Unlike conventional surveying from a total station, line of sight is not needed – there is no need to raise or lower the rod height. Usually a 2-meter rod is used. Not having to make this measurement eliminates one more chance of error.

Before getting too far away from the base station, check the radio (or cell phone) link to the rover.

The first thing that must be done upon "starting the survey" on the data collector is to initialize the system (resolve the integer ambiguity). Several methods that are acceptable when preformed properly.

- Known point initialization – this is the fastest and safest way to initialize. Where possible and practical this should be the method of choice. The firmware uses the three-dimensional deltas of the relative WGS84 positions of the base stations and the known point occupied by the rover as an aid in solving the integer ambiguities.
- New point initialization – this is a technique that is usually used on equipment that does not have the ability to solve the integer ambiguity on the fly (OTF).
- On-The-Fly (OTF) initialization – this is the most common technique used by most equipment today. There must be care taken when using this method. The possibility of an incorrect initialization may be remote but remains a possibility.

To avoid the possibility of an undetected incorrect initialization use one of the following methods to check the system.

After the OTF initialization, observe a point, this can be a temporary mark or a point in the survey. Discard the first OTF initialization and OTF re-initialize by moving more than forty (40) feet away from the point to be used as check. After the new OTF initialization has been accomplished return to the point being used as a check and re-shoot. Compare the first and second shots to within an acceptable tolerance. If the points check, proceed with data collection with the confidence of surveying with a correct initialization.

If the error between the two points is beyond the expected error one or both of the OTF initializations used for a check are incorrect. The user must change the location by a difference of more than two (2) feet of H.I. or more likely move more than forty (40) feet away in a different direction. This will usually provide enough information to identify the OTF initialization that is incorrect. Once the problem is solved, users can begin the survey. This procedure must be repeated with any loss of initialization.

As with any surveying techniques the user would want to check a known point in the survey before beginning work, apply the same logic to your RTK survey.

The user is now ready to observe points. The amount of time of occupation will vary depending on conditions such as obstruction, multi-path, noise, etc. The user may have to resort to:

- increasing occupation time to a couple of minutes at one second epochs
- a more stable setup (use of a tripod or bipod)
- use of a ground plane when in a multi-path environment

The use of the most recent list of TxDOT feature codes is mandatory. As of November 2003, the "txdot2k" is the most recent. This TxDOT list is available in Trimble format as "txdot2k.fcl" and in

CAiCE ™ format as "txdot2k.ftb." Topographic data should be collected in a manner similar to a conventional topographic survey in that the rover operator(s) must be aware of the fact that they are collecting chains of connected points to create break lines that will not be crossed in the creation of the TIN file.

The selection of feature codes for "as-builts" and various features will also determine what points will or will not be included in a DTM. TxDOT's Technology Services Division (TSD) provides a class on Survey Data Management System® (SDMS) for data collection that would be helpful in understanding the procedures for collecting data with RTK for topo work.

There are two screens associated with each measurement on the Trimble data collector: the "measure" screen and the "attribute" screen. The initial (default) screen is the "measure" screen, which will allow the user to key in the feature code. Before pressing "measure" however, open the "attribute" to answer the prompts such as FG: or GM: or whatever else appears, then make the measurement.

If the user has not checked the "prompt for attributes" box this will not appear. Users can continue shooting points without going back to the attributes screen, until the situation changes when a new figure number, geometry setting, or whatever else the user might want to change is needed.

A good rule of thumb is to reoccupy about 25% of all points requiring the accuracy of a Level 3 survey after a new initialization or about 10% of the points in a topo survey.

Upon successful completion of the user's observations, the user will now have a radial survey. Users must move the base station to a second control point and repeat the process for surveys that will not allow single baseline solutions (Level 3).

If radial lines are permitted, such as on a topographical survey or wing panel locations, it is still a good idea to occupy a second base station if another control point is nearby to randomly check a few of the points already established.

Post Processing

An alternative method of performing a kinematic survey is to collect the data and process it at a later time. This does not require the use of a communications link (i.e. radio or cell phone) and can be combined with RTK to perform infill when the link is temporarily down. Post processed kinematic survey methods provide the surveyor with a technique for high production measurements and can be used in areas with minimal obstructions of the satellites.

PPK uses significantly reduced observation times (i.e. 0.5 to 3 minutes, usually 10-30 seconds per point) compared to static or fast-static/rapid-static observations. This method requires a least squares adjustment or other multiple baseline statistical analysis capable of producing a weighted mean average of the observations. Post processing will allow kinematic surveying to be used for some Level 3 surveys.

Integrating Conventional Measurements

To be added in a later edition.

Using Networked RTK (VRS)

Networked RTK is a new variation of RTK data collection. Rather than setting up a base station on the project, a number of permanent and continuously operating base stations are set up at about a 30 - 40 mile spacing, providing that augmentation to the basic position is determined at the rover.

These stations send GPS data into a central computer that streams the correction data to the Internet. The data can then be accessed by way of a cell phone/cell modem at the rover receiver. The data collector then uses this information to provide real time solutions with the same speed and accuracy as Base Station RTK but without the complication of setting up a receiver and radio on a local control point.

This system yields the same accuracies as the normally accepted three (3) miles of a standard radio-linked base station and rover. TxDOT has installed a number of these RTK networks. Coverage is growing across the state but presently covers the major metropolitan areas and some of the rural districts. Refer to Figure 3-14 in this chapter.

The name virtual reference station (VRS) was coined for this method because a “virtual” base station point is determined by the computer from the network of base stations. The virtual base station is never more than 3 miles from the rover and is automatically redefined when the rover goes beyond that preset distance.

The TxDOT RTK Network uses the VRS technology. A virtual base point near the project is computed by the central computer. The user operating a rover unit dials in to the TxDOT IP address for connection to the system. The data-ready cell phone/modem must then be physically carried by the user to maintain constant communication between the rover and the Internet. For information about this and other features that vary from place to place and time to time, contact your district survey coordinator, who in turn, may contact the administrators of the system at TSD.

Specific cell phone services and connection information should be obtained from the local cell phone service provider.

The same procedures and precautions as outlined for Base Station RTK should be followed using the TxDOT RTK networks. The difference is simply that users are not working from a base station set up by the user for a particular project. Users will not need to occupy the known station with a GPS receiver transmitting correction data to the rover(s). The work will be accomplished from a network of GPS base receivers.

In the case of a Level 3 point, where users would normally occupy a point more than once and from two or more base stations; three to six RRP's are already being used in the coordinate calculation using the networks. The point should still be occupied twice at different times of the day.

There is an option in Survey Controller to do an "Observed Point," which will automatically collect for a specified amount of time; usually three minutes. This gives the mark a special status in the priority of stations in the TGO program.

The TxDOT RTK Network is based on the National Spatial Reference System, which means that all coordinates are in the NAD83 datum and accuracy and compatibility should not be a problem. This however, can work against users when all previous work was done on local coordinates or the area of previous control may carry local biases.

To overcome the clash of coordinate values, the process of "calibrating" to the existing control is used. This was not used as extensively via the base station method where the control point coordinates were the start of subsequent GPS work.

Most RTK network surveys should be done after a calibration to existing control. Even if the horizontal component doesn't require a calibration, consider performing the vertical calibration. GPS solutions require the aid of a geoid model for elevations. In several areas around the state, the geoid model has a difference of more than a tenth of a foot from known elevations. If any known bench marks exist in the area; calibrate to them.

In TxDOT districts with RTK networks, users should apply for a password through their district survey coordinator. This password will allow users to access the system through the Internet.

Consultants with active contracts are allowed to apply for a password through the district survey coordinator but are limited to just TxDOT work with the TxDOT system. The use of a private real time network for TxDOT work by consultants is up to the discretion of the district survey coordinator.

The End Product

When topo data is collected with real-time kinematic (RTK), the output format most often will need to be in Survey Data Management System® (SDMS) format. The TxDOT supported TGO software exports directly to the SDMS® format. There must be point connectivity (break lines) and the standard TxDOT feature codes will insure this. The file is available at district offices in Trimble format for Trimble TSC-1, TSC-e and ACU data collectors. As mentioned above, the file name is "txdot2k.fcl". Conventional data collected on the Trimble data collector using Survey Controller can be included in the same .dc (job file).

The .dc (job file) can be downloaded to the PC with the Trimble Data Transfer program or using Microsoft ActiveSync with a USB connection. By importing into Trimble TGO, the user can see

the work graphically and do some editing if necessary before exporting the final product as an ASCII or SDMS.cal file.

The use of LandXML format is being investigated as an alternative standard of transfer.

If an ASCII file of final coordinates is needed, the most often requested format is: name, northing, easting, elevation, feature code.

NOTE: that all data passing hands should include notes on datum, projection, geoid model, and date of survey. Coordinates should be designated as **state plane coordinates** or surface adjusted coordinates with an accompanying CAF or SAF factor.

Section 9 — Geodetic Surveying

Overview

Unless otherwise instructed, latitude and longitude will be presented as degrees, minutes, and seconds. Direction indicators N or W will prefix the value and seconds will be carried out five (5) places right of the decimal when using published National Geodetic Survey (NGS) latitude/longitude (geographic) values.

Units

The coordinate system used by TxDOT is the State Plane Coordinate System (SPCS) in NAD 83 datum. However, units of length for northings and eastings will be in U.S. Survey Feet, rather than the defining units of length which is in meters. It should be noted that the U.S. Survey Foot is designated by the Texas Legislature to be the state standard, rather than the International Foot, used in some states (Texas Natural Resources Code, Subchapter D, §21.071 – 79). Horizontal coordinates should be carried out to .001 ft. unless otherwise instructed.

Processing and adjusting GPS data may be done in the metric system, but all project data must be converted and delivered in U.S. Survey Feet. Conversion from meters to U.S. Survey Feet must be made using the following formula:

Meters * 3937/1200 = U.S. Survey Feet

The factor is 3.280833333333 and working with state plane coordinates (SPC's) in the millions, one must carry the factor out to 12 places to the right of the decimal just as shown here.

Datums

All geodetic surveying will be done in the NAD 83 horizontal datum. A horizontal datum is defined as an ellipsoid model with a designated reference point. The most recent datum used in Texas, before NAD 83 was the NAD 27. The latitude and longitude coordinates of a particular point on the ground will differ by about one second of arc between NAD 27 and NAD 83, which equates to about 100 ft.

An adjustment, done in Texas (using GPS) resulted in the 1993 High Accuracy Reference Network (HARN). The network was extended to nearly all old, conventionally surveyed federal monumentation monuments. Projects should be referenced to the published HARN coordinates of NGS monumentation monuments.

Elevations will be referenced to the NAVD 88 vertical datum. An older datum, NGVD 29, has been superseded. Differences between the two range from almost none in Southeast Texas to about a foot

in Northwest Texas. NGS data sheets specifically indicate bench mark elevations as 1.) monumented and surveyed in the newer NAVD 88 datum, 2.) re-surveyed to the new datum or 3.) transformed to the new datum by means of an interpolation software called VERTCON.

Where design survey accuracy is required, TxDOT will not accept any datum transformations based upon a single control point. There is no way to transfer NAD 27 coordinates to NAD 83 datum accurately. CORPSWIN and other conversion software are based on NADCON algorithms, which perform a rubber sheeting adjustment, are not at all accurate in most parts of the state.

If a change to the NAD 83 project datum is needed for comparison of old surveys, two control points can be resurveyed (GPS or conventional) from references in the new datum. Then a translation-rotation-scale can be done holding to the two points common to both datum. Alternatively, if original raw GPS data is available, it can be reprocessed holding the new datum coordinates rather that than the original datum coordinates.

There are several programs, such as CORPSWIN, available through the NGS for conversion of geographic coordinates to state plane coordinates. CORPSWIN, one of the best software available is for the mathematical conversion of a.) Metric to U.S. Survey Foot (or visa-versa) b.) SPC zones to adjoining SPC zones c.) UTM to SPC's and d.) Lat/Lon to SPC's.

In addition to these strictly mathematical conversions, CORPSWIN provides useable outputs to determine a combined adjustment factor (CAF) at the specific location of a point, if the elevation is included in the input. Users should note that this is computed using the sea level factor of the NAD 27 datum, and does not utilize the height above ellipsoid (HAE) method of NAD 83. The programs published by NGS use a mean radius of the earth (20,906,000 feet) for the continental U.S. Other commercially published programs, such as Trimble Geomatics Office, compute a CAF for each point using a terrestrial radius computed for the latitude at that point.

State Plane Coordinates

Background. Because surveys are performed on the curved surface of the earth and at different elevations, measurements from different starting points will not mesh nor will the lines be rectilinear. This may not present a problem in a few miles of work, but in order to seamlessly connect survey work over greater distances, a working plane with a rectangular grid must be used. For engineering applications, the State Plane Coordinate System (SPCS) is used most often.

The SPCS was developed in the 1930's and was based on NAD 27. With a few changes, it was adapted to the present day NAD 83 datum. Coordinates from NAD 27 and NAD 83 do not at all resemble each other, however. Differing false eastings and northings were assigned to the two datums to prevent confusion between coordinates computed on each datum.

Coordinates are given as X (east) and Y (north) in meters. The projection used in Texas to project from the earth's curved surface to a developable plane was the Lambert conformal conic projection.

Five plane coordinate projections zones — North (TX4201), North-central (TX4202), Central (TX4203), South-central (TX4204) and South (TX4205) are used.

The State Plane-to-Surface Transition

One of the most troublesome issues often faced when dealing with state plane coordinate systems (SPCSs) is the fact that, except for a few very small areas, a distance measured on the ground (surface) will differ from the inversed distance between SPCS values. Depending on how far north or south the project falls in the state plane zone and depending on the elevation of the area, coordinates in the SPCS most likely will need to be adjusted so that lengths measured on the surface will coincide with lengths inversed on the state plane grid.

One component of the adjustment involves the projected position from the curved surface of the earth to the plane. It is a ratio, which reflects the difference between a length measurements on the grid versus one lengths made computed on the ellipsoid. A factor suitable for a conversion of any position on the surface to a position on the state plane grid can be found in tables or derived by a number of software programs. This is called the scale factor.

The other component of the conversion is a function of a point's elevation. It reflects the fact that a sea level (or ellipsoid-level) distance measured between two lat/lon points is shorter than a surface distance. The elevation factor is computed by the formula:

$$20{,}906{,}000 / (20{,}906{,}000 + n)$$

where n is the orthometric height and 20,906,000 is the mean radius of the earth

For most surveys, this calculation is adequate (the sample calculations beginning on page 56). For extremely accurate work, the difference between the orthometric elevation and height above the ellipsoid should be taken into account.

Since a user would not use one of these factors without the other, they may as well be combined into one. To derive a combined adjustment factor (CAF), we multiply the scale factor by the elevation factor. TxDOT has calculated a very general combination factor for each county in the state. It is the reciprocal value of the CAF meaning that it is multiplied times a state plane baseline length (or coordinate) to arrive at a surface value. This multiplier, known as a surface adjustment factor (SAF) and a list can be obtained from the district surveyor if the use of project specific factors is not required.

The only way of maintaining integrity between points on the surface and the state plane grid over long distances is to apply an individual CAF for each leg of a traverse between two stations of known state plane coordinates. With the size and nature of most of TxDOT's projects, the practice of choosing a single CAF for a project has become common. Just as with the countywide SAF, the factor is applied equally to all project coordinates rather than an individual factor for each baseline length.

Choosing an Appropriate Project CAF

A CAF can be calculated for any individual point. There may be quite a change in elevation from one end of the project to the other, and if the corridor runs north and south, there may be a significant scale change. The factor should be chosen to minimize these influences in surface to grid distances. A CAF for use on the entire project is usually feasible for projects of less than three to five miles. For larger projects or smaller surface to grid differences, the project will have to be broken down into segments and a separate CAF be determined for each segment.

There are several ways to select a single factor for a project or segment of a project. The TxDOT surveyor or engineer may take an average of the CAF's of each control point of a project or simple pick a point central to the project. Using the CAF provided on the NGS datasheet for a station located near the center of the project is an easy way to obtain a useable value.

Another source is one of the software programs that deal with coordinate calculations. CORPSCON, for instance provides the CAF for any latitude, longitude (or state plane coordinate) and elevation given. The value is generally carried out eight decimal places so that others using it will arrive at the same figure to the nearest thousandth of a foot.

An option, if rapidly increasing differences outward of the center of the project is not of much concern, is to use the less precise TxDOT surface adjustment factor assigned for the entire country. It is not important what value is used, but it is absolutely necessary that the value be included in the metadata so that the coordinates can be backed down to state plane coodinates for meshing with adjoining work or for reassigning a preferred CAF at a later date.

Highway projects with several CAF's pose no problem when all coordinates can be taken back to state plane coordinates so that everything will mesh. However, the juncture of two project segments needs to be well identified to ensure that all measurements stop or begin at a common point of that juncture.

Occasionally, surface coordinates may need to be returned to state plane coordinates (SPC's) so that a more accurate CAF or one used by another consultant can be applied. Ideally, if enough care is taken to arrive at accurate CAF's, and if the areas (to which new CAF's are calculated) are kept small enough, there would be very little accumulation of irreconcilable surface/grid difference.

Truncating Coordinates

With NAD 83 SPC's, coordinates have values well into the millions. If an across-the-board CAF is applied to project points in state plane coordinates, the coordinates change by a huge amount. Two coordinate pairs that both represent the same point, could be over 1,000 feet apart. A shift of that magnitude will occur for every coordinate pair to which the factor is applied. The intent was to change the relationship between points by just a few hundredths or tenths but in the process all the

coordinate values were shifted and moved about a thousand feet. Note that the inverse azimuths between the points will not change in this process, only the distances.

When the calculation is done to convert from grid-to-surface or vice versa, the new coordinates can be easily confused with state plane coordinates. In addition, if one truncates the coordinate value – reduce all northings by the same amount and reduce all eastings by another amount – the solution can cause more dilemma than the original inconvenience. Coordinates in this altered state will also not fit the standard TxDOT seed files in MicroStation®. Furthermore, if the truncated amount is not recorded, there will be many more problems later.

Identifying Delivered Coordinates

All coordinates delivered, whether hardcopy or in digital medium, must contain metadata indicating the CAF (or SAF), horizontal datum and adjustment, vertical datum (Geoid model if applicable), units of measure and the date of the fieldwork. This would include hard copy drawings, CAD drawings, the data sheets, and each sheet containing coordinates in a report, and ASCII or LandXML files.

If coordinates have been truncated for easier calculations or for identification, they must be returned to their full configuration before delivery. This is not only for standardization but also so that they will work in the seed files for MicroStation®.

Calculations

Note: Software is available to perform all of the following calculations; however, “by-hand” solutions are used to illustrate the procedures involved.

This section covers most of the different types of calculations that might be encountered when working on the State Plane Coordinate System. With few exceptions, placing a survey on the system will require only conversion of surface distance to grid. On some surveys, it may be necessary to convert a geodetic (“true”) azimuth to grid azimuth. Fortunately, both of these calculations are very simple.

Surface Distance to Geodetic Distance

Before a surface distance can be converted to grid it must first be converted to geodetic (reduced to sea level).

From the figure of surface distance below the following relationship can be derived:

$$\frac{\text{Geodectic Distance}}{\text{Surface Distance}} = \frac{\text{Rm}}{\text{Rm} + \text{Elevation}}$$

$$\text{Geodetic Distance} = \frac{\text{Rm}}{\text{Rm} + \text{Elevation}} \text{ X Surface Distance}$$

where Rm is the mean radius of the earth or 20,906,000 ft.

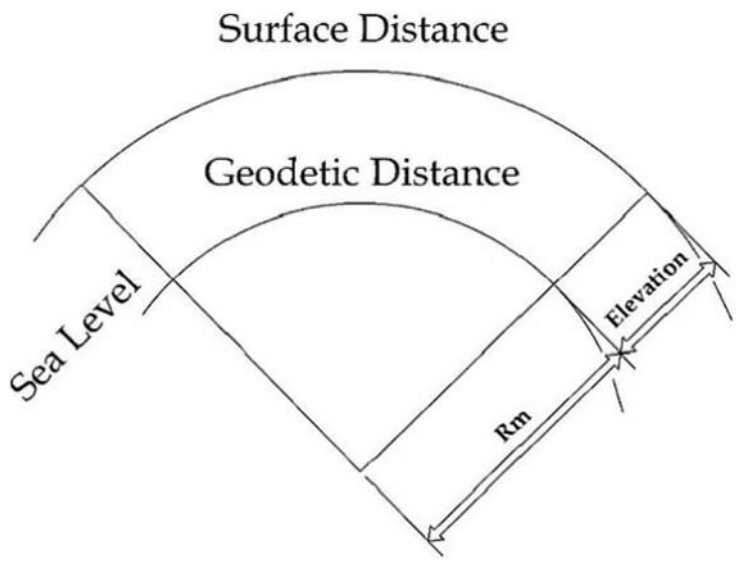

Figure 3-15. Surface Distance to Geodetic Distance.

To be more precise, the ellipsoid (GRS80) does not coincide with sea level by an amount equal to the geoid height (approximately 100 ft. for Texas). Neglecting this difference will result in an error of approximately 1/200,000. If this is significant, then the following equation should be used:

$$\text{Geodetic Distance} = \frac{\text{Rm}}{\text{Rm} + \text{Elev.} + \text{Geoid. Ht.}} \text{ X Surface Distance}$$

The term Rm/(Rm + Elevation) is frequently referred to as the sea level factor. Rm and elevation must be in the same units, either both in feet or both in meters. Depending on survey accuracy requirements and differences in elevation within the project area, the average elevation taken from a USGS quadrangle map is sufficient. For high accuracy requirements, the average elevation of each line should be used. The mean radius of the earth (Rm) is assumed to be 20,906,000 feet.

Geodetic Distance to State Plane Grid Distance

To convert geodetic distance to grid, the projection scale factor (scale ratio) is used where:

$$\text{Scale Factor} = \text{Grid Distance/Geodetic Distance}$$

or

$$\text{Grid Distance} = \text{Geodetic Distance x Scale Factor}$$

Scale factor is a function of latitude and can be obtained from the appropriate projection table. Depending on accuracy requirements and the extent of the project area in a north-south direction, the average latitude as obtained from a quad sheet is sufficient. For high-precision surveys a weighted average of scale factor for each line can be used. But there are usually more important things to worry about—adjustment of optical plummets, ppm correction, baseline calibration, etc. It should be noted that for all practical purposes, scale factors did not change from SPCS 27 to SPCS 83 in Texas.

Surface Distance to State Plane Grid Distance

Converting a surface distance to the state plane grid involves multiplying the distance times both the elevation factor and scale factor.

Grid Distance = Surface distance x Elevation factor

If an average elevation and latitude for the project area is being used, these two factors can be multiplied to obtain a single factor (combined adjustment factor (CAF), which is in turn multiplied times all of the field measured distances, either slope or horizontal.

EXAMPLE:

Given:

Horizontal Distance = 2,640.00 ft.

Average Elevation = 1,400 ft.

Average Latitude = 32° 54'

83 North-central Zone

Solution:

Scale Factor = 0.99987611

(Refer to Appendix B, Second Term Calculations, enter with Latitude = 32° 54')

$$\text{Sea Level Factor} = \frac{20{,}906{,}000}{20{,}906{,}000 + 1{,}400} = 0.9993304$$

Combined Scale Factor (CSF) = 0.99987611 x 0.99993304 = 0.99980916

Grid Distance = 2,640.00 x 0.99980916 = 2,639.50 ft.

EXAMPLE:

Given:

Horizontal Distance = 2,640.00 ft.

Average Elevation = 350 ft.

Average Latitude = 32° 04'

83 Central Zone

Solution:

Scale Factor = 1.00005440

(Refer to Appendix B, Second Term Calculations, enter with Latitude = 32° 04')

$$\text{Sea Level} = \frac{20{,}906{,}000}{20{,}906{,}000 + 350} = 0.99998326$$

Combined Scale Factor = 1.00005440 x 0.99998326 = 1.00003766

Grid Distance = 2,640.00 x 1.00003766 = 2,640.10 ft.

Geodetic Azimuth to Grid Azimuth

To convert geodetic azimuth to grid azimuth the following equation is used:

$$\text{Grid Azimuth} = \text{Geodetic Azimuth} - \gamma + \text{Second Term}$$

The second term can be neglected for most surveys (see Appendix B, for use of second term); therefore, the above equation reduces to:

$$\text{Grid Azimuth} = \text{Geodetic Azimuth} - \gamma$$

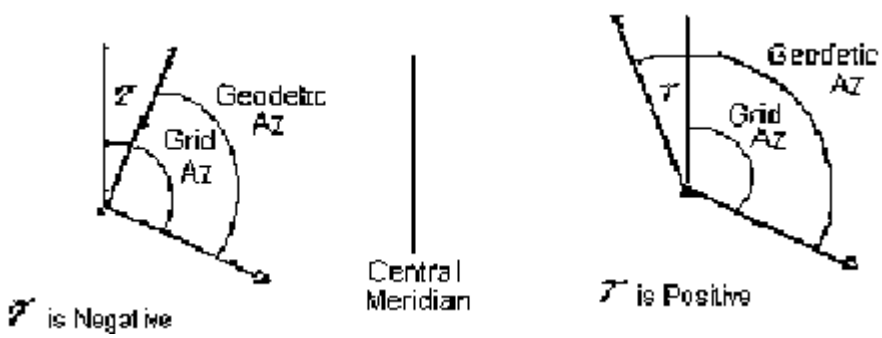

Figure 3-16. Geodetic to Grid Azimuth.

Mapping angle or grid declination is a function of longitude and can be computed from the following equation:

γ = (Longitude of Central Meridian - Longitude of Station) x 1

where Longitude of Central Meridian and l are projection zone constraints. They are listed below as well as in the projection tables found in Appendix B, Second Term Calculations, of this manual.

Table 3.14 State Plane Zones

Zone	LCM	l
83 North	101°30'00"	0.579535862261
83 North-central	98°30'00"	0.545394412971
83 Central	100°20'00"	0.515058882235
83 South-central	99°00"00"	0.489912625143
83 South	98°30'00"	0.454006848165

For most work, the longitude of the beginning point of the survey must be accurately known to convert geodetic azimuth to grid. Since this is usually a triangulation station or other point of known coordinates, the longitude is given or can be computed from the coordinates. Scaling longitude from a USGS quad sheet may be sufficient; however, for Texas a scaling error of 5" of longitude will result in approximately 2" to 3"of error in γ.

EXAMPLE:

Given:

Geod. Az. from Tri Station to Pt. A = 241°12'37"

Long. of Tri Station = 105°10'15"2758

83 Central Zone

Solution:

Long. of Central Meridian = 100°20'00" (Refer to Appendix B, or the above table)

l = 0.515058882235

γ = (100°200'00"–105°10'15"2758)x 0.515058882235

= -2.49164°

= -2°29'30"

Grid Az. = 241°12'37"- (-2°29'30") = 243°42'07"

Given:

Geod. Az. To Backsight = 127°48'36"

Long. of Instrument Station = 94°39'28"

83 South-central Zone

Solution:

Long. of Central Meridian = 99°00'00" (Refer to Appendix B, or the table above)

l = 0.489912625143

= (99°00'00" - 94°39'28") x 0.489912625143

$\gamma = +2.12731°$

= +2°07'38"

Grid Az = 127°48'36" - (+2°07'38") = 125°40'58"

Astronomic Azimuth to Geodetic Azimuth

Astronomic azimuth is based on the true shape and rotation of the earth; whereas, geodetic azimuth is based on the mathematical approximation of the earth's shape. Astronomic azimuth is obtained when making a celestial observation (sun or Polaris). Astronomic azimuth can be converted to geodetic from the following equation:

Geodetic Azimuth = Astronomic Azimuth + Laplace Correction

The Laplace correction is less than 3" for most of Texas and does not exceed 6". If accuracy requires use of the correction, values can be obtained from NGS.

Geodetic Angle to Grid Angle. If the second term is neglected, grid angle is the same as geodetic (grid) angle. Therefore, field angles can be used when computing grid azimuths.

Plane Coordinates to Geographic Coordinates (Lat. and Long.)

To compute latitude and longitude from N and E coordinates, the following equations are used:

$N' = N - N_b$

$E' = E - E_o$

$$\text{Tan}\ \gamma = \frac{E}{R_b - N'}$$

$$\text{Lon.} = \text{Lon. Cent. Meridian} - \gamma / l$$

$$R = \frac{R_b - N'}{\cos\ \gamma}$$

Enter the projection tables with R and interpolate to obtain latitude.

N_b, E_o, R_b and l are constants for the zone. When working on the 83 system, coordinates used in the above equations must be in meters. In solving the above equations, the calculator/computer must be capable of computing to at least 10 digits.

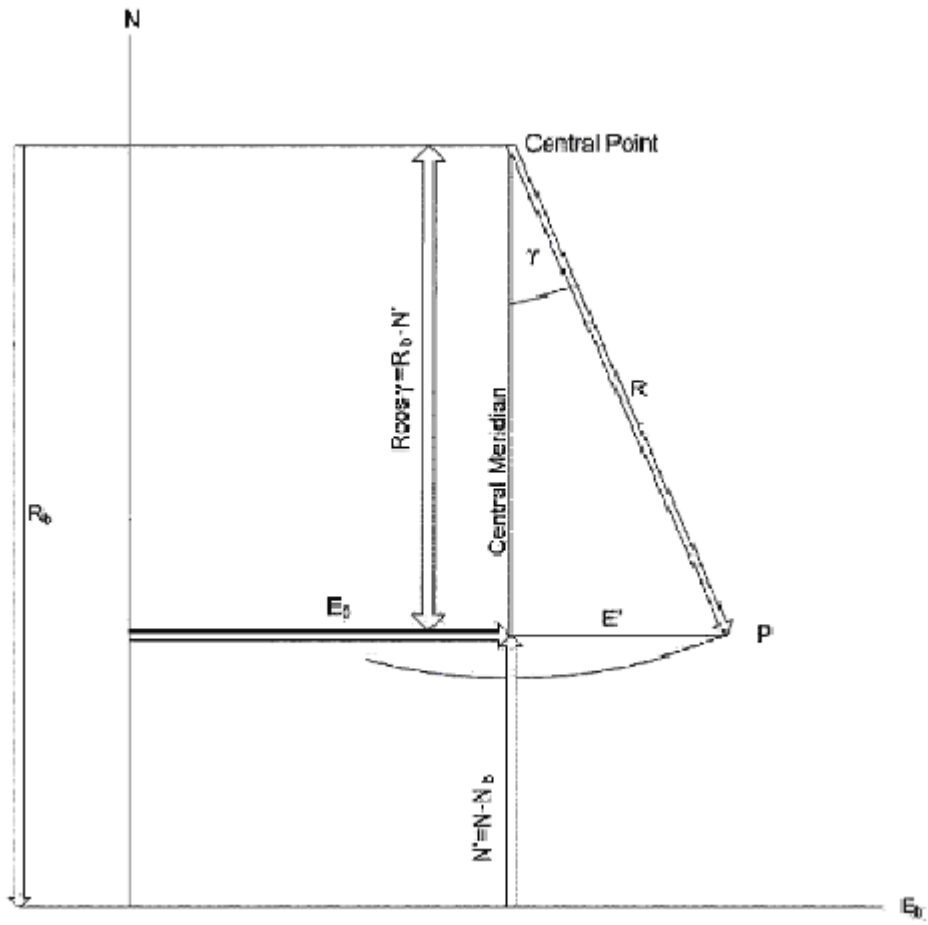

Figure 3-17. Computation Sample. Plane Coordinates to Geographic Coordinates.

EXAMPLE:

Given:

N = 2,256,876.543 m

E = 225,025.678 m

83 North-central Zone

Solution:

N_b = 2,000,000.000 m

E_o = 600,000.000 m

Long. Cent. Meridian = 98° 30'00"

R_b = 9,964,225.7538 m

l = 0.545394412971

N' = 2,256,876.543 - 2,000,000.000 = 256,876.543

E' = 225,025.678 - 600,000,000 = - 374,974.322

R_b – N' = 9,964,225.7538 - 256,876.543 = 9,707,349.2108

Using Equations:

$$\text{Tan } \gamma = \frac{-374{,}974.322}{9{,}707{,}349.2108}$$

$\gamma = -2.2121147004°$

R = 9,707,349.2108

cos (-2.2121147004) = 9,714,588.7428

Or using R - P (for HP: E' in y reg. and R_b-N' in x reg)

R = 9,714,588.7428 (display)

$\gamma = -2.2121147004$(X <>Y)

Long. = 98° 30' 00" - (- 2.2121147004/0.545394412971)

= 98°30'00" - (- 4°03'21".5667)

= 102°33'21".5667

Enter projection tables with R and interpolate for latitude. Computed R is between 33°55' and 33°56'.

R = 9,714,712.237 & diff. = 30.81105 (at lat. = 33°55', Appendix B, Second Term Calculations)

$$\Delta R = 9{,}714{,}712.237 - 9{,}714{,}588.743$$

$$\Delta \text{Lat.} = \frac{123.494}{30.81105} = 4.0081''$$

Lat. = 33°55'04".0081

Enter projection tables with R and interpolate for latitude. Computed R is between 33°55' and 33°56'.

R is obtained from projection tables by entering with latitude and interpolating.

Geographic Coordinates (Lat. and Long.) to Plane Coordinates

To compute N and E coordinates from latitude and longitude, the following equations are used:

$$\gamma = (\text{Lon. Cent. Meridian - Lon.}) \text{ x } l$$

$$N = R_b - R \cos \gamma + N_b$$

$$E = R \text{ Sin } \gamma + E_o$$

N_b, E_o, R_b and l are constants for the zone. When working on the 83 system, coordinates will be in meters. In solving the above equations, the calculator or computer must be capable of computing to at least 10 digits.

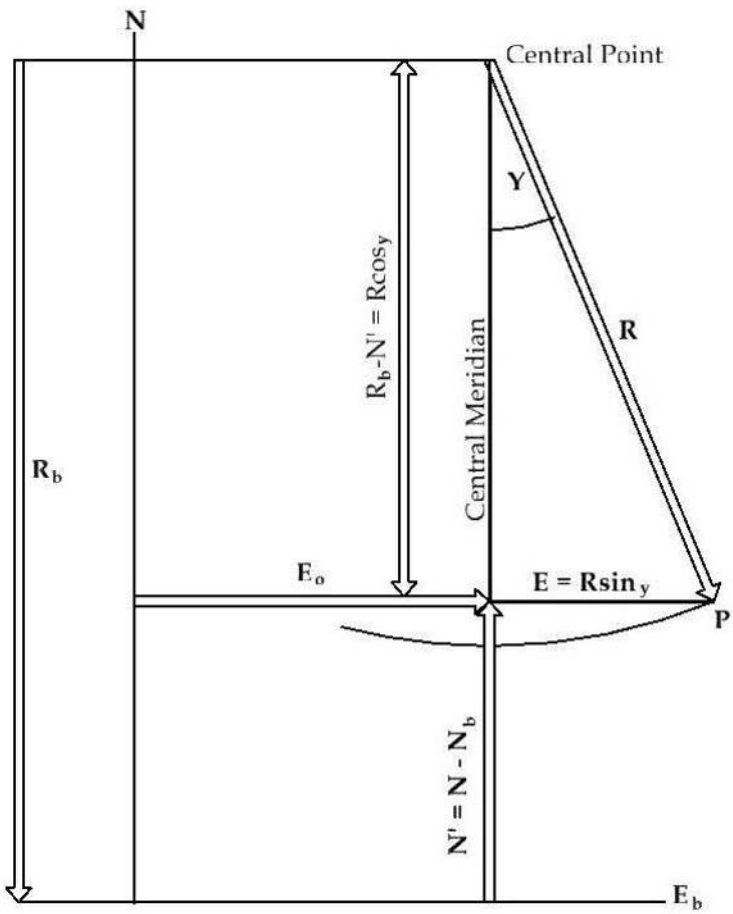

Figure 3-18. Computation Sample. Geographical Coordinates Lat./Lon. to Plane Coordinates.

EXAMPLE:

Given:

Latitude = 29°55'41".2345

Longitude = 94°52'36".5432

83 South-central Zone

Solution:

N_b = 4,000,000.000 m (Appendix B)

E_o = 600,000.000 m (Appendix B)

Long. Cent. Meridian = 99°00'00 (Appendix B)

R_b = 11,523,512.5584 m (Appendix B)

l = 0.489912625143 (Appendix B)

Enter projection tables with latitude

R = 11,292,620.462 & diff. = 30.78941 (For= 29°55', Appendix B)

$\Delta R = 30.78941 \text{ x } 41.2345 \text{ (For} = 29°55', \text{ Appendix B)} = 1{,}269.586$

R = 11,292,620.462 - 1,269.586

=11,291,350.876

$\gamma = (99°00'00'' = 94°5236''.5432) \text{x } 0.489912625143 = 2.0199991353°$

Using Equations

N = 11,523,512.5584 - 11,291,350.876 x cos (2.0199991353) + 4,000,000.000

= 4,239,178.303 m

E = 11,291m350.876 x Sin (2.0199991353) + 600,000.000

= 998,001.292 m

Using P - R (For HP: in y reg. and R in x reg.)

(R_b – N') = 11,284,334.255 (display)

N' = 11,523,512.5584 - 11,284,334.255 + 4,000,000.000 = 4,239,178.303 m

E’ = 398,001.292 (x<>y)

E = 600,000.000 - 398,001.292 =998,001.292 m

Conversion from SPCS 27 to SPCS 83: For all practical purposes, there is no accurate means to convert from NAD 27 to NAD 83. NGS has software available (CORPSCON) to make a rough transformation from one system to the other, but its accuracy is limited to approximately one-half foot.

Example Problems

(1.) Compute state plane coordinates in area.

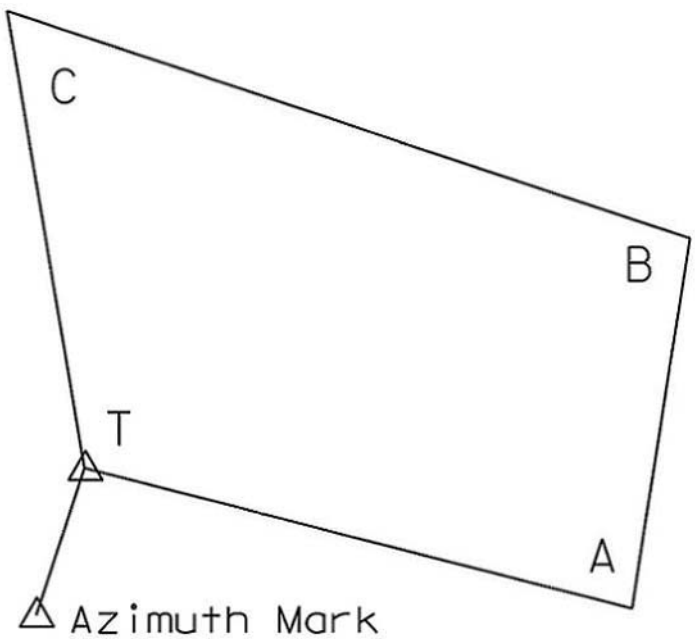

Figure 3-19. Computation Sample: Area.

83 Central Zone Grid Az. to Az. Mark = 195°54'16"

Ave. Lat. = 31°21' N_T =3,190,394.533 m

Ave. Elev. = 2,900' E_T = 420,496.711 m

Convert beginning coordinates to U.S. Survey Feet.

N_T = 3,190,394.533x3937/1200 = 10,467,152.73 ft.

E_T = 420,496.711x3937/1200 = 1,379,579.63 ft.

Combined Scale Factor = 0.99990018 x 20,906,000 / (20,906,000 + 2,900) = 0.99976150

Angle Rt.: Az. Mk/T/A = 268°31'41' (given)

Grid Az. T - A = 195°54'16' + 464°22'57" = 104°22'57"

The following is a listing of computation information:

Table 3.15 Computation Information for Problem 1

Pt.	Adj. Ang. (given)	Grid Az.	Hor. Dist. (given)	Grid D	Lat. (N)	Dep. (E)
T						
		104-25-57	4,163.05'	4,162.06'	-1,037.35'	4,030.71'
A	84-27-11					
		8-54-08	2,769.68	2,769.02	2,735.66	428.50
B	99-37-46					
		288-31-54	5,307.22	5,305.95	1,686.38	-5,030.82
C	64-53-08					
		170-25-02	3,433.23	3.432.41	-3.384.52	571.40
T	114-00-55					
				15,669.44	+0.17	-0.21

Continuation of Table 3.15

Pt.	Adj. Lat.	Adj. Dep.	N	E
T			10,467,152.73'	1,379,579.63'
	-1037.39	4,030.76'		
A			10,466,115.34	1,383,610.39
	2,735.63	428.54		
B			10,468,850.97	1,384,038.98
	1,686.32	-5,030.75		
C			10,470,537.29	1,379,008.18
	-3,384.56	571.45		
T			10,467,152.73	1,379,579.63

Grid Area = 13,767,229 sq. ft. = 316.0521 acres

Surface Area = Grid Area / (Combined Scale Factor)2 = 316.2029 acres

For the above problem, assume azimuth mark cannot be found.

From Polaris observation: Az. T - A = 102° 55'11

$\text{Tan}\ \gamma = E/(R_b - N)$

N_b = 3,000,000.000 m (Appendix B)

E_o = 700,000.000 m (Appendix B)

R_b = 10,770,561.1034 m (Appendix B)

$N' = N - N_b$ = 3,190,394.533 - 3,000,000.000 = 190,394.533

$E' = E - E_o$ = 420,496.711 - 700,000.000 = -279,503.289

$R_b - N'$ = 10,770,561.1034 - 190,394.533 =10,580,166.5704

Using R - P:

$\gamma = -1.51327° = -1°30'48"$

Grid Az. T - A = 102°55'11" - (1°30'48") = 104°25'59"

(2.) Compute state plane coordinates (in meters) for the traverse below.

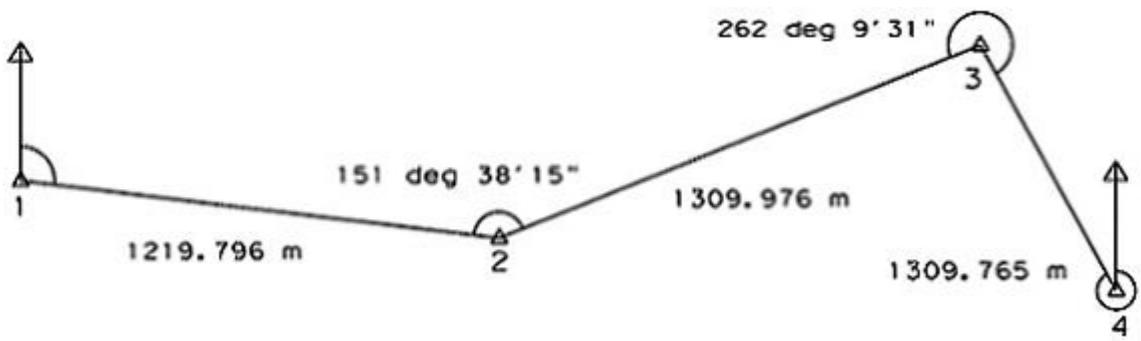

Figure 3-20. Computation Sample: Traverse.

Given:

N_1 = 4,253,992.557 m N_4 = 4,253,195.719 m South-Cent. Zone

E_1 = 734,141.809 m E_4 = 737,212.927 m

Ave. Lat. = 30°07' Ave. Elev. = 700 ft.

From Polaris: Geod. Az. 1 - 2 = 96°45'39" (neglecting Laplace)

Geod. Az. 4 - 3 = 331°13'49"

Solution:

Convert Geod. Az. To Grid Az.

N_b = 4,000,000.000 m

E_o = 600,000.000 m

R_b = 11,523,512.5584 m

At Sta. 1: N' = N - N_b = 253,992.557

E' = E - E_o = 134,141.809

R_b – N' = 11,269,520.001

γ = 0°40'55"

Grid Az = 96°45′39" - (0°40ə55') = 96°04'44"

At Sta. 4: N' = N - N_b = 253,195.719

E'= E - E_o = 137,212.927

R_b = N' = 11,270,316.839

γ = 0°41'51"

Grid Az. =331°13'49" - (0°41'51") = 330°31'58"

CSF = 0.99995611 x (20,906,000 / (20,906,000 + 700)) = 0.99992263

The following is a listing of computation information:

Table 3.16 Traverse Computation for Problem 1

Pts.	Ang. Rt.	Grid Az.	Adj. Az.*	Grid Dist.	Lat.	Dep.
1						
		96-44-04	96-44-06	1,219.700	143.043	1,211.283
2	151-38-15					
		68-22-19	68-22-23	1,309.875	482.770	1,217.664
3	262-09-31					
		150-31-50	150-31056	1,305.675	-1,136.675	642.256
4				3,835.149	796.948	3,071.203

* Az. Closure =150°31'50" - (330°31'58" - 180°) = -08"

Angles measured at four stations: Adj./Sta. = +02"

Computed Closure:

N_4 = 4,253,992.557 - 796.948 = 4,253,195.609

E_4 = 734,141.809 + 3,071.203 = 737,213.012

Error in N (Lat.) = 4,253,195.609 - 4,253,195.719 = -0.110

Error in E (Dep.) = 737,213.012 - 737,212.927 = +0.085

Adjust Lats. and Deps. by compass rule and compute coordinates.

Table 3.17 Adjustments for Problem 2

Pt.	Adj. Lat.	Adj. Dep.	N	E
1			4,253,992.557	734,141.809
	143.008	1,211.256		
2			4,253.849.549	735,353.065
	482.808	1,217.635		
3			4,254,332.357	436,570.700
	-1,136,638	642.227		
4			4,253,195.719	737,212.927

(3.) Convert coordinates and grid azimuth from N.- Cent. to Cent. Zone.

Given:

N = 2,041,990.909 m 83 N.-Cent. Zone

E = 203,858.434 m

Grid Azimuth = 207° 40'32"

Compute:

N, E and Grid Azimuth in 83 Central Zone.

Procedure:

Convert N and E to Lat. and Lon., and Grid Az. to Geod. Az. Using constants and table for 83 North-central Zone. Then convert Lat. and Lon. to N and E, and Geod. Az. to Grid Az. using constants and table for 83 Central Zone.

For 83 North-central Zone:

N_b = 2,000,000.000 m (from Appendix B)

E_o = 600,000.000 m (from Appendix B)

Long. Cent. Meridian = 98°30'00" (from Appendix B)

R_b = 9,964,225.7538 (from Appendix B)

= 0.545394412971 (from Appendix B)

N' = N - N_b = 41,990.909

$E' = E - E_o = -396{,}141.566$

$R_b - N' = 9{,}922{,}234.845$

Using R - P

$R = 9{,}930{,}139.599$

$\gamma = -2.2862986088°$

$\text{Lon.} = 98°30'00'' - \gamma / 1$

$= 98^o30'00'' - (-2.2862986088/0.545394412971)$

$= 102.692009589^o$

Enter tables with R and interpolate for Latitude.

$R = 9{,}930{,}957.217$ & diff = 30.80324 (At = $31^o58'$, from Appendix B)

$\Delta R = 9{,}930{,}957.217 - 9{,}930{,}139.599 = 817.618$

$\Delta \text{Lat.} = 817.618 / 30.80324 = 26.5432''$

$\text{Lat} = 31^o58'\ 26.5432''$

$\text{Geod. Az.} = \text{Grid. Az.} + \gamma$

$= 207^o40'\ 32'' + (-228629861^o)$

$= 205^o\ 23'\ 21''\ 3$

For 83 Central Zone:

$N_b = 3000{,}000.000$ m (from Appendix B)

$E_o = 70{,}000.000$ m (from Appendix B)

Long. Cent. Meridian = $100^o\ 20'\ 00$ (from Appendix B)

$R_b = 10{,}770{,}561.1034$ (from Appendix B)

$l = 0.581899128040$ (from Appendix B)

$\gamma = (100°20'00'' - \text{Lon.}) \text{x}\ 1$

$= (100^o\ 20'\ 00'' - 102.692009589^o) \text{ x } 0.515058882235$

$= 1.21485715596^o$

Enter tables with latitude and interpolate for R.

$R = 10{,}515{,}580.239$ & diff. = 30.80257 (For = $31^o58'$, from Appendix B)

$\Delta R = 30.80257 \times 26.5432'' = 817.599$

$R = 10{,}515{,}580.239 - 817.599 = 10{,}514{,}762.640$

Using P - R

$R_b - N' = 10{,}512{,}399.125$

$N' = 258{,}161.978$

$N = N' + N_b = 3{,}258{,}161.978$ m

$E - E_o = 222{,}930.513$

$E = 477{,}069.487$ m

$\text{Grid.Az.} = \text{Geod.Az.} - \gamma$

$= 205^o\ 23'\ 21''\ 3 - (-1.2148571560^o)$

$= 206^o\ 36'\ 15''$

Summary:

Table 3.18 Converted Coordinates for Grid Azimuth for Problem 3

Zone	N	E	Grid Az.
83 N.-cent.	2,041,990.909 m	203,858.434 m	207°40'32"
83 Cent.	3,258,161.978 m	477,069.487 m	206°36'15"

Latitude = $31^o\ 58'\ 26.5432''$

Longitude = $102^o\ 41'\ 31.2345''$

Chapter 4 — Design Surveying

Contents:

Section 1 — Descriptions and Definitions of Survey Types

Section 2 — Differential Leveling

Section 3 — Trigonometric Leveling

Section 4 — Surveying Vertical Networks with GPS

Section 1 — Descriptions and Definitions of Survey Types

Overview

Information contained in this section is the result of discussions of the Standing Committee on Surveying (SCOS), or is excerpted in its entirety and/or adapted for this manual from the Texas Society of Professional Surveyors, Category 6.

Topographic Survey

A topographic survey is a survey performed to determine the configuration, relief or elevations of a portion of the earth's surface, including the location of natural and/or man made features thereon. A topographic survey is necessary in order to prepare an accurate topographic map and requires the expert skill of a Registered Professional Land Surveyor (RPLS) well versed in maintaining accuracy and precision in detail mapping. Unless noted to the contrary, a topographic survey is not intended as a boundary survey, although some boundaries may necessarily be defined.

Topographic Map

A topographic map is a two-dimensional (2-D) map that presents the horizontal and vertical positions of the features represented; distinguished from a planimetric map by the addition of relief in measurable form. A topographic map usually shows the same features as a planimetric map but uses contours or comparable symbols to show mountains, valleys, and plains.

Planimetric Map

A planimetric map is a map that presents the horizontal positions only for the features represented; distinguished from a topographic map by the omission of relief in a measurable form.

Digital Terrain Model (DTM)

A digital terrain model (DTM) is a mathematical model of a project surface that becomes a three-dimensional representation (3D) of existing and proposed ground surface features. Critical calculations and processes based on the DTM include contouring, cross sections and quantities, drainage models, watersheds, hydraulics, water catchment areas, and cross sections sheets.

A DTM is created through the construction of a Triangulated Irregular Network (TIN) and is based on modeling the terrain surface as a network of triangular facets that are created by simply connecting each data point to its nearest neighboring points. Each data point (having x, y and z coordinates)

is the vertices of 2 or more triangles. The advantage of the TIN method is its mathematical simplicity- all DTM calculations are either linear or planar.

The processes and the resulting DTM offer many advantages over a topographic survey. Field data for a DTM is collected in a way that allows TxDOT to use the latest in automated survey technology. Traditional data collection (for a topographic survey) involves taking cross sections, typically every 100 feet, along a horizontal control line or in a grid pattern. Digital terrain modeling has virtually eliminated this practice.

Data points (shots) are taken at every break in elevation with no particular pattern being required. The emphasis is on identifying all features and changes in elevation within project limits. Data is collected using an electronic data collector with an electronic total station. The data points are assigned feature codes, attributes, descriptions, comments, and connectivity linking codes to add intelligence to a point at the time of data entry into data collector.

Information is downloaded from the data collector to a computer, either in the field or later in an office, and is processed using AASHTOWare® Survey Data Management System® (SDMS) software. A SDMS® calculated file is generated for importation into CAiCE™ or GEOPAK Survey™ for further review. The file is then imported into GEOPAK® for project design.

Route Survey

A route survey is an application of the above described topographic or DTM survey along a determined linear ROW route, either existing or proposed, for a utility or roadway.

Purposes

A topographic survey is made for the purpose of gathering relevant information that will be represented on either a topographic map or in a DTM. Typically, highway planning, engineering design and ROW design are the primary purposes.

Special Note For TxDOT Purposes. When this text discusses procedures or standards relating to either a topographic survey or survey for a digital terrain model, the accuracy, standards, equipment and basic procedural methods employed will be the same. A topographic survey will be performed and a DTM can be used for most all TxDOT applications where route design and engineering are required, whereas a topographic map may be better suited for large area site design and development.

This specification is intended for use in developing a design survey, a digital terrain model, or a topographic survey, with accuracy sufficient to meet TxDOT design needs and requirements.

A 3D model or a DTM may be preferred for purposes such as:

- highway/roadway planning, design

- ROW design
- drainage studies
- site development, planning
- architectural planning, design
- landscape design.

A significant advantage of a DTM is that it offers the ability to view, inspect, and smoothly navigate through, over and across a DTM in a 3D environment for the purposes of locating, editing, and correcting raw field data (points and chains) in 3D.

Considerations - Other Technology

A computer model or a DTM is the ultimate work product of any of these newer methods of data acquisition. Depending on the critical factors of each project, including type, terrain, accuracy, precision required, cost, traffic conditions, and safety, such advanced methods may warrant serious consideration as a compliment to conventional data gathering or as a replacement of common or conventional surveying methods.

While conventional aerial photogrammetry may still be viable; however, as technology continues to advance, existing methods such as photogrammetry with airborne Global Positioning System (GPS) control become more accurate and even more cost effective. Other newer methods of terrain modeling are also available. One such method is airborne Light Detection and Ranging (LiDAR), which is a laser imaging scan done from a helicopter. Another, more advanced method is FLIMAP, or Fast Laser Imaging Mapping and Profiling, which employs laser scanning, incorporated with GPS for navigation and position. A DTM is produced as the deliverable.

Ground based LiDAR is an automated collection of data by reflector-less laser which involves high density scanning of an object or location to collect a “point cloud” of data points. The point cloud of data is further processed into a 3 dimensional computer model image. Typically done from a remote instrument location or multiple locations, 3D Laser scanning is especially good for sites or objects that are difficult to access, have high traffic volumes, involve extreme detail or have other extreme dangers or conditions associated.

This method has also been utilized in place of conventional topographic or digital terrain model (DTM) surveying with much success, especially where high traffic volumes or lane closure issues (safety) were critical factors. Presently the accuracy of the scanned data is said to equal or even exceed that of conventional survey methods, even electronic total station work, with the additional advantage of a greater number of data points all throughout the structure or project. Other methods or technology should be discussed with and approved by the district survey coordinator before use.

Work Product

A DTM or Topographic Survey requires:

- A control survey network, with horizontal and vertical positions on primary control points that are monumented, referenced, and placed near or on the project site.
- Points of secondary control, which are based upon and supplement primary control to facilitate data acquisition within a project.
- A description and location sketch of each control point.

See Chapter 3, Preliminary Surveying, for specifications on horizontal and vertical control networks and information on point descriptions, location sketches, and other pertinent information.

While a topographic map (2 dimensional) may be the typical end product of a topographic survey, for TxDOT purposes a processed computer file for a DTM (3 dimensional) is the primary deliverable product. Even when hard copy maps are specified as a part of the deliverable, electronic graphics files (2D and/or 3D) for the final product must be furnished to TxDOT for each project.

Required files include:

- Computer files of collected raw data, as required by the respective TxDOT office. These computer files should at a minimum, consist of raw, unprocessed data as originally collected in the field by Survey Data Management System® (SDMS) or other approved, TxDOT supported data collection method and software.
- Processed data in a form that is fully compatible and usable in TxDOT supported software programs such as CAiCE™, GEOPAK®, and MicroStation®.

Information Required

The Standing Committee on Surveying (SCOS) has adapted and approved information within this subsection from the Texas Society of Professional Surveyors, Category 6.

Information may be furnished to the surveyor by TxDOT, or the surveyor may be required to research TxDOT files and/or public records, if so directed and agreed upon. Information should include the following:

- project or site location shown on a map
- ROW maps depicting current ROW width(s) and other land, ownership and survey information
- ownership information of adjacent tracts
- intersecting road ROW information, documentation
- construction plans of existing facilities if available

- intended use of the survey and required form of deliverable, files required, etc.
- accuracy required and method of display (contours, spot elevations, etc.)
- horizontal and vertical datum upon which the survey should be based if this varies from the TxDOT standard. Example: match existing project datum instead of NAD 83 or NAVD 88
- availability and need of special data, whether current or historic, which may include: Existing data or mapping from other agencies, county, flood control/drainage district, FEMA, Corps of Engineers, etc.
- for state forces and all consultants, permission must be secured prior to entry on private property to survey outside of state ROW
- research on subject tracts/parcel ownership also includes name(s) of tenants or parties in charge and special conditions or considerations required or requested by the owner
- existing National Geodetic Survey (NGS) and/or United States Geological Survey (USGS) survey control information and data sheets for horizontal and vertical monumentation
- recent aerial photographs (particularly for large sites), USGS quadrangle sheets, or computer files of the same.

Monuments

Reference points and control monuments for a topographic survey may include temporary stakes, hubs, nails in pavement, iron rods, or reinforced concrete monuments.

A wooden hub or stake, nail or iron rod is considered as secondary control (temporary bench mark or control point) which only supplements primary survey control monumentation to facilitate data acquisition.

Primary control points, whether set by GPS or conventional survey methods, shall be of reasonable permanence and should conform to the requirements and specifications shown in Appendix C, “Monumentation” of this manual.

A “datum point” rod or a rock setting is required for GPS Level 1 control points, but the “standard” TxDOT concrete setting can be used for GPS Level 2 surveys. The standard concrete setting was formerly depicted in the old M-92 drawing for Right of Way (ROW) monuments.

Control monuments shall be well referenced, named according to district procedure, indexed in the project data or field notes and identified in the computer file final deliverable. Point names may be furnished for a state-wide or a district monument numbering system by the TxDOT District Survey Coordinator. A location sketch and data sheet for each monument should be furnished to the project manager prior to completion of work.

Example of a monument stamping: 000-0000

where, 000 refers to the County number

and 0000 refers to a discrete monument number for each district and is determined by district surveyor personnel.

Monumentation for New Stations

All monumentation for new Level 1 points are to be in accordance with the following NGS publications:

Concrete Marks, from NGS Operations Handbook and Manual of Geodetic Triangulation, S.P. 247.

Setting a Survey Disk in Bedrock or a Structure from NOAA Manual NOS, NGS 1, Geodetic Bench Marks

Setting a NGS 3-D Monument Based on Revised NGS 3-Dimensional (3-D) Rod Mark [Draft Version] by: Curtis L. Smith, National Geodetic Survey, July, 1996.

It is recommended that new Level 2 points also follow these construction specifications, but the TxDOT surveyor in charge may call for less stringent requirements.

Naming Convention for Level 1 and Level 2 Monuments

The recommended naming convention for Level 1 and Level 2 monuments is as follows:

Example: 1580032

Table 4.1 Naming Convention

Digits	Indication
158	◆ The first three (3) digits indicate the county in which the monument was set. ◆ This is the standard county code used by TxDOT.
0032	◆ The next four digits indicate the point number of this particular monument. ◆ It is specific for this county and there can be no duplicates in the county.

Some districts use variations of this by including a prefix or suffix.

Figures 4-1 and 4-2 are sample data sheets for documenting the monuments likely to be used in the future. There must be a data sheet for all Level 1 and Level 2 monuments. Districts may use their own data sheet form; however, it must contain all the horizontal and vertical geodetic data of these sample data sheets. An RPLS signature and seal is recommended for data sheets for Level 1 and Level 2 GPS monuments.

The following table provides a list of the standard county designator codes used by TxDOT.

Table 4.2 Standard County Designator Codes

County #	County Name	County #	County Name	County #	County Name	County #	County Name
1	Anderson	65	Donley	130	Kaufman	193	Real
2	Andrews	67	Duval	131	Kendall	194	Red River
3	Angelina	68	Eastland	66	Kenedy	195	Reeves
4	Aransas	69	Ector	132	Kent	196	Refugio
5	Archer	70	Edwards	133	Kerr	197	Roberts
6	Armstrong	72	El Paso	134	Kimble	198	Robertson
7	Atascosa	71	Ellis	135	King	199	Rockwall
8	Austin	73	Erath	136	Kinney	200	Runnels
9	Bailey	74	Falls	137	Kleberg	201	Rusk
10	Bandera	75	Fannin	138	Knox	202	Sabine
11	Bastrop	76	Fayette	142	La Salle	203	San Augustine
12	Baylor	77	Fisher	139	Lamar	204	San Jacinto
13	Bee	78	Floyd	140	Lamb	205	San Patricio
14	Bell	79	Foard	141	Lampasas	206	San Saba
15	Bexar	80	Fort Bend	143	Lavaca	207	Schleicher
16	Blanco	81	Franklin	144	Lee	208	Scurry
17	Borden	82	Freestone	145	Leon	209	Shackelford
18	Bosque	83	Frio	146	Liberty	210	Shelby
19	Bowie	84	Gaines	147	Limestone	211	Sherman
20	Brazoria	85	Galveston	148	Lipscomb	212	Smith
21	Brazos	86	Garza	149	Live Oak	213	Somervell
22	Brewster	87	Gillespie	150	Llano	214	Starr
23	Briscoe	88	Glasscock	151	Loving	215	Stephens
24	Brooks	89	Goliad	152	Lubbock	216	Sterling
25	Brown	90	Gonzales	153	Lynn	217	Stonewall
26	Burleson	91	Gray	154	Madison	218	Sutton
27	Burnet	92	Grayson	155	Marion	219	Swisher
28	Caldwell	93	Gregg	156	Martin	220	Tarrant

Table 4.2 Standard County Designator Codes

County #	County Name	County #	County Name	County #	County Name	County #	County Name
29	Calhoun	94	Grimes	157	Mason	221	Taylor
30	Callahan	95	Guadalupe	158	Matagorda	222	Terrell
31	Cameron	96	Hale	159	Maverick	223	Terry
32	Camp	97	Hall	160	McCulloch	224	Throckmorton
33	Carson	98	Hamilton	161	McLennan	225	Titus
34	Cass	99	Hansford	162	McMullen	226	Tom Green
35	Castro	100	Hardeman	163	Medina	227	Travis
36	Chambers	101	Hardin	164	Menard	228	Trinity
37	Cherokee	102	Harris	165	Midland	229	Tyler
38	Childress	103	Harrison	166	Milam	230	Upshur
39	Clay	104	Hartley	167	Mills	231	Upton
40	Cochran	105	Haskell	168	Mitchell	232	Uvalde
41	Coke	106	Hays	169	Montague	233	Val Verde
42	Coleman	107	Hemphill	170	Montgomery	234	Van Zandt
43	Collin	108	Henderson	171	Moore	235	Victoria
44	Colling-sworth	109	Hidalgo	172	Morris	236	Walker
45	Colorado	110	Hill	173	Motley	237	Waller
46	Comal	111	Hockley	174	Nacogdoches	238	Ward
47	Comanche	112	Hood	175	Navarro	239	Washington
48	Concho	113	Hopkins	176	Newton	240	Webb
49	Cooke	114	Houston	177	Nolan	241	Wharton
50	Coryell	115	Howard	178	Nueces	242	Wheeler
51	Cottle	116	Hudspeth	179	Ochiltree	243	Wichita
52	Crane	117	Hunt	180	Oldham	244	Wilbarger
53	Crockett	118	Hutchinson	181	Orange	245	Willacy
54	Crosby	119	Irion	182	Palo Pinto	246	Williamson
55	Culberson	120	Jack	183	Panola	247	Wilson
56	Dallam	121	Jackson	184	Parker	248	Winkler

Table 4.2 Standard County Designator Codes

County #	County Name	County #	County Name	County #	County Name	County #	County Name
57	Dallas	122	Jasper	185	Parmer	249	Wise
58	Dawson	123	Jeff Davis	186	Pecos	250	Wood
62	De Witt	124	Jefferson	187	Polk	251	Yoakum
59	Deaf Smith	125	Jim Hogg	188	Potter	252	Young
60	Delta	126	Jim Wells	189	Presidio	253	Zapata
61	Denton	127	Johnson	190	Rains	254	Zavala
63	Dickens	128	Jones	191	Randall		
64	Dimmit	129	Karnes	192	Reagan		

Texas Department of Transportation

POINT NAME _____ DATE _____

LOCAL NAME (if any) _____ COUNTY _____

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HORIZONTAL***NAD83(93)***
UNITS

Length _____
Angle _____

Geodetic: Latitude _____ Longitude _____
STATE PLANE: Northing _____ Easting _____
State Plane Zone _____ Scale _____
Mapping Angle _____ Combined Factor _____
SURVEYED FROM: a) _____ b) _____ c) _____
INTERVERSIBLE POINT NAME:_____
AZIMUTH & DISTANCE TO INTERVISIBLE POINT: _____
_____

VERTICAL UNITS
NAVD88
ELEVATION: _____

Length _____

[ ] Conventional 3-wire leveling
[ ] GPS from at least three 2nd order or better benches (GEOID___)
[ ] GPS from 3rd order or less benches (GEOID___)

SURVEYED FROM: a) _____ b) _____ c) _____

HISTORY

DATE	ACTIVITY
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____

TYPE OF MARK
Description: _____
Publicly Accessible: [ ] Yes [ ] No GPSable [ ] Yes [ ] Marginally [ ] No

DESCRIPTION

DATE	FROM/TO
_____	_____
_____	_____
_____	_____
_____	_____

Figure 4-1. TxDOT Control Point Data Sheet.

TxDOT GPS CONTROL POINT

Station Name:	Date:	Adjusted Horizontal Control Data	
Monument Type:		Order:	Survey Method GPS __ TRAV __ OTHER __
City:		Combined Adjustment Factor:	
County:	State:	NAD83 (1993) State Plane Grid Data	Coordinates (U.S. Survey Ft) / Convergence
Project:			
Directions from Major Highway Intersection to Control Point		State: Texas	
		Zone:	
		Code:	
		SURFACE DATA	Coordinates (U.S. Survey Ft.) / Surface Adjustment Factor
Azimuth / Grid Azimuth / Distance (Ft)		State: Texas	
SURVEYED FROM USGS/NGS MONUMENTS:			
		GEODETIC DATA	Position / NAD83 (1983) / Elev. (Ft)
			Latitude: / Longitude:
SIGN AND SEAL PLAT		FIELD SKETCH:	
Surveyor:			
Prepared By:	COMPANY NAME, ADDRESS, PHONE #		

Figure 4-2. Sample Project Specifications Control Point.

Conditions

The effect of location, such as rural, suburban, urban, or urban business district, on conditions of a DTM or topographic survey will be minor and will be most dependent upon the purpose of the survey.

The need for appropriate control and tolerances will be the deciding factor when the purpose of the survey is for roadway or ROW design in determining reasonably accurate quantities of construction materials, such as water, spoil, fill, concrete, etc.

For TxDOT needs, the following shall be covered under Condition I regardless of location (rural or urban), unless TxDOT gives directed and prior approval:

- roadway design
- bridge design
- ROW design

- environmental site
- historical site.

Extended area topography (i.e.: drainage area outside of a ROW) may fall under Condition II, but is subject to direction by the TxDOT project manager.

DTM and topographic survey tolerances are typically confined to the Condition I and II.

Field Procedures

DTM or topographic surveys require a reliable horizontal and vertical control system based on acceptably closed and adjusted traverses and level loops. Attention should be given toward developing this control system before any detail work is begun.

Field work shall be performed to achieve the specified or intended accuracy and results as stated in this manual, in accordance with accepted technical methods, i.e.: TxDOT, NGS, or the TSPS Manual of Practice, and as directed by the manufacturer of the surveying instrument(s) or equipment used.

For GPS applications, the Federal Geodetic Control Subcommittee's (FGCS) *Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques* shall be followed.

Field personnel shall be well trained in the technical aspects of surveying as related to their respective duties.

Surveying instruments shall be checked and kept in close adjustment according to their manufacturer's specifications or in compliance with textbook standards.

- Electronic distance measuring devices shall be compared against a standardized baseline at 6 month intervals, however a comparison check should always be done as needed, especially if an instrument has been dropped, damaged or is suspect of the same. A calibrated baseline certified by NGS is the preferred standard.
- This comparison includes electronic total stations or any other electronic measuring instrument, and may be done by more up to date methods as agreed upon by TxDOT.
- Total stations and theodolites shall be compared against a standard known angle at a 6 month interval; however, a comparison check should always be done as needed, especially if an instrument has been dropped, damaged or is suspect of the same.
- Levels, auto or digital should be checked by the "2 peg test" or the reading the elevation difference between two reference points taken from 1.) a middle setup between points and also 2.) from an end setup. Failure to get the same difference of elevation indicates an out of adjustment condition, which usually requires a shop cleaning and adjustment.

- Auxiliary tapes, cloth or fiberglass, shall only be used for rough measurements where precision is not important, such as determining the width of ditches, the location of excavations or other irregular improvements. Tapes of this sort shall not be used to measure distances in excess of 100 feet.

Field measurements of angles and distances shall be performed in such a manner as to attain the closures and tolerances as found in this manual and see Table 4.4 TSPS Manual of Practice Chart for Tolerances for Conditions, at the end of this section.

Surveys for vertical or horizontal monumentation for control of a DTM or a topographic survey shall refer to the following sources:

- TxDOT Survey Manual
- NGS special publications
- NGS standards for horizontal or vertical control monuments that will be registered
- Department of the Army (Corps of Engineers).

Where aerial photogrammetry is to be used to compile the topographic map, the surveyor shall consult with the photogrammetrist as to specific requirements for the photo control and for additional supplemental information required by conditions of a specific project or location.

- Horizontal and vertical photo control (picture points) shall be based on and looped to the control system.
- Identification of photo control (picture points) must be precise and clear since these points will be used to build the network from which the photogrammetrist must work.
- Photo control points, set before the aerial photography is made, shall be located from, and looped to the control system. The density and pattern for paneled picture points shall be determined through consultation and coordination with the photogrammetrist.

For TxDOT purposes, methods that are more modern are normally used such as the DTM survey that incorporates methods described in the section below.

Surveying procedures with electronic total station or with GPS shall incorporate control points that are tied to a primary control system network of an appropriate level of precision and accuracy for the project.

Acquisition of field data may require running secondary control and bench marks that begin and end at points on the primary control system.

The use of open ended legs or “spur” lines should be avoided whenever possible. When such lines are necessary, appropriate checks shall be made on all field data before leaving the vicinity.

Any field notes written in a field book shall be kept in a neat and orderly manner on all control points, primary or secondary. Appropriate annotations on location, description of point and reference to identifying specific features located during the DTM or topographic survey shall be made.

Topographic Features

The perimeter limits of any unique or special features such as historical structures, cemeteries, burial grounds or grave sites known or found within the project limits or adjacent to and which may be affected (existing or proposed ROW) and shall be shown by actual location.

Buildings and improvements, including distance from proposed ROW up to 50'. See Chapter 5, ROW Surveying of this manual and the TxDOT ROW Manual Volume 1 - Procedures Preliminary to Release. The project manager and/or district surveyor may extend this distance in the following ways:

- center lines of dry creeks, gullies or other confined intermittent watercourses
- paths, car trails, pasture roads, etc.
- borders, boundaries - city limits, county line or state line
- additional data points shall be collected along such features, outside of state ROW, as required and directed by TxDOT. These additional features may include:
  - creeks, streams, rivers and water bodies, shown and identified by name. Water levels shall be determined and displayed by elevation, time, and date of observation.
  - drainage areas - field information on drainage area(s) of a project shall be collected in the same manner as other information to the extent as directed by the project manager and/or district surveyor.

Electronic Data

In nearly all cases, field work is automated by the use of computer software and hardware for collecting, reviewing, editing and processing field data. A data collector may be connected to the instrument (total station, GPS receiver, digital level, etc.) to store the raw measurement data and perform coordinated geometry (COGO) functions while in the field. Original raw data must be saved as a file for retention, as a matter of record, before any data editing or processing is done.

Data Collection

Field data in electronic form should be collected in the SDMS® collection form and processed in SDMS® Processor. This software was developed through the American Association of State Highway and Transportation Officials (AASHTO) and supported by TxDOT Technology Services Division. It is provided gratis to TxDOT consultants under TxDOT's license agreement with AASHTO. Its purpose is to provide a more flexible and user definable method of recording horizontal

angle, vertical angle and slope distance from most of the total stations and in a standard format recognized by the survey review or design software.

There are numerous ways to provide connectivity. When performing radial topography surveys for a DTM, points in the same chain such as edge of pavement, centerlines and ditch lines can be linked together. These survey chains can ultimately be ported to mapping files or to DTM files as DTM break lines. Standard TxDOT feature codes and cells have been developed for use in the field to insure standardization of line weight, color, levels, and symbology.

These feature codes also determine where the points and chains will go, either to a mapping file or a DTM file. Topographic surveys, traverses and level runs may be collected in Survey Data Management System® (SDMS) Collector software. The data can then be reduced to coordinates on a desktop PC using SDMS® Processor, which uses a least squares type of adjustment. There are a number of useful reports that can be generated in this software.

Office Analysis

Survey review and DTM - In order to view the results of a survey for troubleshooting and delivery of a .dgn file, pre-design software will be used. TxDOT uses CAiCE™ Visual® Transportation, GEOPAK Survey™, and SDMS® Processor to serve as the tool(s). This software will accept the SDMS .cal file as input with the TxDOT feature table attached, and will graphically display the project for analysis. Corrections and additions can be made and the DTM can then be created. Photogrammetry files, background maps, macros for visualization and other enhancements may be utilized before 2D or 3D graphics are exported as a .dgn file for GEOPAK® / MicroStation® use by the designer.

TxDOT Deliverables - Computer Files, Maps, and Drawings

Printed maps or plan sets of topographic surveys or digital terrain model (DTM) shall be represented by neat, reproducible drawing sheets. These drawing sheets are plotted for **urban** projects at a typical scale of 1" = 50' (Full Size or scale) or 1" = 100'. Half size, scale, or **rural** projects may use a typical scale of 1" = 100' and 1" = 200', unless otherwise approved or directed and shall accurately depict the results and details of the field work, research, and computations as compiled and checked.

For initial submission, plotted drawings may be on paper, in the same sizes listed above, in a size prescribed by TxDOT graphics standards, the *TxDOT ROW Manual Volume 1 - Procedures Preliminary to Release*, or as requested by the TxDOT project manager. Information may also be submitted in electronic form according to district standards.

For the TxDOT final work product, all final drawings shall be plotted on Mylar film medium and other typed documents on a quality bond paper. All drawings and the information shown shall be plotted or printed on standard sizes and shall be according to TxDOT graphics standards, the

TxDOT ROW Manual Volume 1 - Procedures Preliminary to Release, or standards contained in this manual, as may be applicable.

Typically, full size drawings shall be plotted on 22" x 34" medium. Half (½) scale drawings shall be on an 11" x 17"size medium. Bond paper may be used for initial submittal. Mylar shall be used for all final drawings.

No plat, map or drawing shall be made on a sheet size smaller than 8 ½" x 11"

All information, existing topographic features, monuments - ROW or control monuments, or property corners, whether found or set, etc. shall be represented on a map and in the computer file(s), in the proper dimensioned location by using the most current TxDOT cell library (example: TxDOT2K.cel) for symbol standardization. Some projects (i.e.: ROW acquisition) may require that other features are labeled and dimensioned as to size, height, width, or depth and referenced to the nearest ROW or property line. Site maps for architectural design may require other symbology.

All maps or drawings, whether printed, plotted or in a computer file shall have a north arrow and shall be oriented so that north is toward the top of the sheet unless otherwise directed by TxDOT.

The Texas Coordinate System, based upon NAD 83 (HARN), shall be used with the proper zone, adjustment factor, theta angle and reference monument information used shall be noted.

For TxDOT purposes, a statement containing the above information shall be placed on all drawings and/or included with all computer files that provide reference information or “metadata” on the control monumentation, NGS, or other that is used as a basis for all projects.

Title Sheet

A title/cover sheet shall be prepared for each project (examples accessed from *TxDOT ROW Manual Volume 1 - Procedures Preliminary to Release*, and shall show the following items:

- location of the route or project being mapped shall be shown on a title/cover sheet prepared for each project
- appropriate location sketch
- station numbers of the projects beginning and end
- charge numbers (CSJ, both Construction and ROW)
- stated scale of the drawing with a graphic scale
- project description
- survey date
- larger projects, a sheet index may be preferred

- statement of the basis for horizontal and vertical control, including information listed in sections below
- if prepared by a consultant, the company name, address and phone number shall be shown.

Horizontal Control

Horizontal control deliverables shall include the following:

- For TxDOT purposes, the Texas Coordinate System of 1983/93 HARN adjustment shall be used.
- Map coordinates and distances shall be in surface measurements and the combined adjustment factor (CAF) must be indicated to allow for return to state plane coordinates (SPC).
- A statement shall also be made specifying the proper zone, referenced traverse or triangulation station(s), and the published coordinates of the station(s) used along with elevation.
- The appropriate mapping angle (theta angle) for the site shall be shown on the map.

It should be noted that the TxDOT Surface Adjustment Factor (SAF) is the reciprocal of the CAF.

As mentioned, TxDOT works in surface coordinates, but project size/length, number of counties or SPC zones crossed or other factors may justify showing all information in grid coordinates.

Unless otherwise directed by TxDOT, all deliverables shall be fully compatible with CAiCE™ and/or GEOPAK® and be native MicroStation® files. Graphics standards are available from TxDOT.

Vertical Control

Typically, TxDOT elevation basis is either 1.) an existing project (datum specified by project) or 2.) NAVD 88.

A statement of the basis of elevations shall be made in computer files and placed on all map prints similar to one of the following examples:

1. Elevations refer to a BM set near the N. E. corner of the intersection of First St. and Ave. B (Location), an “X” on top of a concrete inlet (description). Elevation is 200.00 ft., and is referenced datum of Project CSJ 0000-00-000.
2. Elevations are based upon NGS bench mark A1422, NAVD 88, Published elevation—326.042 ft. (1988 Adjustment).

Per TxDOT policy (see Contract for Surveying Services) and as agreed to in survey contracts with the state, all original work products become property of the state. A consultant performing work under contract with the state may keep a copy for company records.

Control Point Data Sheets

A data sheet shall be provided for individual Level 1 and Level 2 control points. It should contain, at a minimum, the information noted below:

Table 4.3 Control Point Data Sheets

Established by	contractor company
Date established	date monumented
TxDOT Level of Survey	e.g. Level 2
Horizontal Datum	e.g. NAD83
Horizontal Adjustment	e.g. '93 HARN
State Plane Projection Zone	e.g. Tx South Central 4204
Vertical datum	e.g. NAVD88
Geoid model used	e.g. GEOID03 or GEOID99
Units	US Survey foot
County name	e.g. Bexar
Station name	e.g. 0150102
Latitude	Latitude to 5 decimal places
Longitude	Longitude to 5 decimal places
Northing	three decimal places
Easting	three decimal places
Elevation	two decimal places
Convergence angle	nearest second
Combined Adjustment Factor	eight decimal places
Survey method for vertical	GPS or leveling
General location	e.g. S Loop 1604 W & FM2790
To Reach description	how to get to station from a well known intersection
Type of Mark	iron rod, brass disc, etc.
Stamping	what is actually stamped on the disk
Stations directly tied	list up to three closest stations directly tied

Certification

While TxDOT contract requirements call for supervision and monitoring by a Registered Professional Land Surveyor (RPLS) signing and sealing a topographic survey, a digital terrain model

(DTM) or preliminary design survey is not usually required, but may be called for by district standards.

Right of Way - Descriptions with Plats (Exhibit A) and ROW Maps

If descriptions and plats of parcels become necessary for ROW acquisition, all descriptions and plats (combined as property descriptions and labeled as TxDOT Exhibit A of the ROW Map package), shall be prepared according to Chapter 5, ROW Surveying of this manual and the TxDOT ROW, Volume 1 - Procedures Preliminary to Project Release. Any additional information needed or required by the district shall also be included as directed.

The following chart is excerpted from the *TSPS Manual of Practice*.

Table 4.4 TSPS Manual of Practice Chart for Tolerances for Conditions

Condition	I	II	
	Urban Business, District Urban, Suburban & Industrial	Rural & Broad Area General Mapping	Remarks & Formulae
Error in Traverse Closure	1:10,000	1:7500	System Control Loop
Unadjusted Level Loop Closure (ft.)	$.04\sqrt{M}$	$.08\sqrt{M}$	System Control Loop M=Miles
Secondary Traverse Closure	1:7500	1:5000	Between System Control Points
Secondary Level Loop Closure (ft.)	$.05\sqrt{M}$	$0.2\sqrt{M}$	Between System Control Points
Positional Error of Any Primary Monument (horizontal)	1:15000	1:10000	For monuments used for Triangulation or Radial Surveying in respect to another
Positional Error of Any Primary Monument (vertical)	± .03 ft.	± 0.15 ft.	For permanent bench marks
*Contour Interval	2 ft.	10 ft.	Or as needed by the State
Contour Accuracy	± ½ Contour Interval	± ½ Contour Interval	
Positional error of any Photo Control Point (horizontal and/or vertical)	0.50 ft.	2 ft.	Or as recommended by Photogrammetrist
Location of Improvements, Structures, and Facilities during survey	± 0.05 ft. ± 0.50 ft.	± 0.1 ft. ± 1 ft.	Vertical (inverts, flow lines) Horizontal

Table 4.4 TSPS Manual of Practice Chart for Tolerances for Conditions

Condition	I	II	
Plotted location of Improvements, etc.	± 1/40 in.	± 1/40 in.	Symbols may be used for large scale maps indicating Center point
Scale of maps sufficient to show detail, but no less than	1" – 200'	1" – 2000'	Drawings are to show location of survey monuments and bench marks

Section 2 — Differential Leveling

Overview

Differential leveling is the process of measuring vertical distances from a known elevation point to determine elevations of unknown points. The most common methods to determine elevation are through the use of 1) a compensator type, automatic (engineering level) and level rod(s), and 2) an electronic digital barcode leveling instrument with barcode rod. A thorough knowledge of leveling principles and proper application of methods and equipment will prevent costly delays and generate the needed results and accuracy.

Preferred methods of obtaining elevations (in order of preference/accuracy) are:

- Differential Leveling - control bench marks, cross-sections, point elevations
- Trigonometric Leveling - for Digital Terrain Model (DTM), 3D Model
- Indirect leveling (and location) by measuring horizontal distances and vertical angles
- Three-dimensional coordinates - both horizontal position and elevation are computed by processing the measurements
- GPS survey - given the appropriate equipment, procedure and data collection.

Other forms of leveling are available but are not discussed in this manual as they are not preferred or their use may be limited.

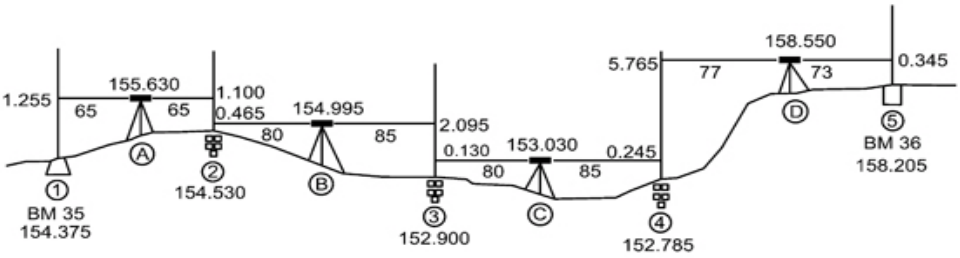

Figure 4-3. Illustration of Differential Leveling.

The method in Figure 4-3 uses the difference in elevation between a known elevation and the height of the instrument, and then the difference in elevation from the height of instrument to an unknown elevation point.

Equipment

- The Rod

- Rods are, in essence, a tape supported vertically, and used to measure the vertical distance (difference of elevation) between a horizontal line of sight and a required point above or below it. The most common types are the Philadelphia rod- a 2 piece rod usually 13' in length, the Frisco rod- a 3 piece rod 12'-15' in length, the Lenker rod- a moveable face, direct reading rod, and the fiberglass-rod- a multi-section, extension rod from 8' - 45' in length. Electronic digital levels use a barcode marked rod. Precision leveling, known as First Order leveling, to extend or establish vertical control over long distances, requires use of invar scale rods.
- All rods should be checked and maintained to ensure consistent readings. Cleaning and adjustment or repair should be done as needed.

◆ The Level

- The compensator type, automatic (engineer) level is made by various manufacturers, and is a precision, self-leveling instrument, equipped with a built-in compensator that automatically maintains a horizontal line of sight and has a telescope with approximately 30-power magnification. The level mounts on a standard surveying tripod, or a fixed-leg tripod for more precise leveling.
- The electronic digital level is also a precision, self-leveling instrument with additional advantages. Advanced capabilities include automatic measurement of height and distance by reading a barcode rod, high precision by employing image processing technology, data display and data recording either internally or to a data collector, installed software for elevation stake-out or other leveling procedures. The digital level offers greater productivity and simplicity in all applications of leveling work.
- All leveling equipment must be checked regularly and properly maintained to ensure that it remains in proper working condition and that systematic errors are eliminated to produce the expected results. This includes daily checks, periodic routine maintenance and yearly cleaning and adjustment by a qualified repair shop.
- Daily - keep the instrument clean by wiping occasionally, especially when used in dusty or wet environment. Operate and adjust the motions. With a compensator type, automatic level, observe the compensator while adjusting level screws to make sure that motion is smooth. If erratic compensator movement is detected, have a qualified repair shop service the instrument.

Instrument Check

On a regular basis and before beginning a leveling project, perform a peg test for collimation error to make sure that readings are consistent. If not, have the instrument serviced.

Anytime an instrument is dropped or severely bumped, or suspected of the same, it should be checked immediately. If questionable, have the instrument serviced before continuing use.

Leveling Methods

- 2nd Order for primary elevation control, extending or establishing bench marks on a project.
- 3rd Order intermediate or temporary bench marks, turning points on a project; aerial photo mapping control; major structures.
- General data collected for a DTM, topographic mapping, cross sections, or other purpose.

Leveling Tolerance

See Table 4.4 TSPS Manual of Practice Chart for Tolerances for Conditions, for specifications and survey conditions.

Datum

The NAVD 88 vertical datum shall be used on all TxDOT projects unless specified by TxDOT prior to the beginning of the survey.

Three-Wire Leveling

Three-wire leveling is the process of reading and recording a rod reading for each of the three horizontal cross-hairs on each shot, then averaging the readings for agreement with the center reading. This method is most accurate as it gives immediate results and a check/confirmation of rod reading. If a difference is detected a check can be done on the spot, before moving on.

An electronic digital level can perform and record this process automatically, after sight of the rod is made. Automated data collection eliminates transposition errors and data is downloaded into a computer for complete analysis.

This is the preferred method for setting or checking control bench marks. Three-wire leveling will be used for all orders of leveling except **general**.

Bench Marks (BM) and Temporary Bench Marks (TBM)

The primary purpose of running a level loop is to establish points of known elevation or bench marks. They are solid, well protected points that can be relied upon to remain undisturbed and unchanged. They should be positioned so as to be usable from a wide area and away from the construction as much a possible so as to remain undisturbed. Consideration should be given to construction activities such as utility re-location proposed within the ROW. It is preferred that bench marks are located in a public ROW, to allow for continued accessibility.

The exact location of the bench mark should be carefully selected, then sketched and recorded in notes, a field book or a data collector.

The numbering or identification system should be consistent with district numbering convention, if any and should be identified with enough detail for another crew to locate the bench mark easily. Bench marks set should always be turned through as part of a closed level loop.

Examples of good bench marks are an iron rod driven to refusal or a TxDOT cap set vertically in a concrete monument (similar to a Type II ROW Monument), a ROW monument, a point or corner of a stable concrete structure, or occasionally a spike set in a large tree or utility pole. It is usually advisable to use a variety of types of bench mark monuments as utility relocation or construction activity may remove objects from a ROW.

The bench marks should not include objects subject to tampering or removal.

Two or more bench marks should be used from the specified reference datum (NAVD 88 unless directed by TxDOT). These bench marks should be identified, confirmed undisturbed, and elevations proved by running a complete level loop between the two, returning to the starting bench mark.

Distance between bench marks should be confirmed with the TxDOT project manager or the district survey coordinator before beginning a project.

Turning Points/Temporary Bench Marks (TP/TBM)

Turning points may be points set either before or during the course of the survey, or natural or man-made points in the area. They must be solid, well defined (or marked) and permanent enough to remain intact until the level loop is finished. Points with a small, sharply defined top are preferred to large flat surfaces.

Turning points should be marked when used so as to insure that the rod is in the exact same place when the backsight and foresight are taken. They are also marked because turning points that are part of a closed level loop are points of known elevation that may have value during future surveys in the area.

Temporary bench marks can be **turning points** that remain or additional intermediate bench marks placed for added convenience.

Temporary bench marks set in trees or power poles should consist of a spike (railroad spike, boat spike, or large nail spike) set horizontally approximately 1 to 2 ft. above ground elevation, also free of above obstructions to the level rod.

General Considerations / Objectives

During the course of running a level loop, choose/set turning points and bench marks to accomplish the required objective and accuracy.

Balance shot distances – The rodman and instrument man must work as a team to balance the backsight and foresight distances. This can be accomplished by use of a digital level, estimating distance by pacing, three-wire stadia difference or, when available, by observing stationing marked on the project. Balanced backsights and foresights, essential in precise leveling, will help eliminate errors caused by refraction, the curvature of the earth and an instrument that is out of adjustment and are an especially necessary procedure when establishing control bench marks.

Maximum sight distance – care should always be given to observe recommended or required distance of sight, depending on the purpose of leveling. See the NGS specifications and Table 4.3 TSPS Manual of Practice Chart for Tolerances for Conditions, found in this chapter, or the manufacturer's recommendations.

Control points and bench marks should always be set to the highest level of accuracy suitable for the project or a higher level if it can be justified.

Section 3 — Trigonometric Leveling

Overview

Calculating the difference in elevation between points is accomplished with trigonometric leveling. Differences in elevations are determined by measuring vertical angles and slope distances. Trigonometric leveling is often used where accurate elevations are not available or when elevation of inaccessible points must be determined. In Texas, most highway surveying does not require this type of leveling.

Trigonometric Leveling Use

The establishment of vertical control using the total station or theodolite is not recommended. The slightest variance of vertical angle on the instrument is amplified over the long distances normally associated with trigonometric leveling. In addition, balancing the shots has no effect in compensating for instrument calibration error. Shots of over approximately 1,000 feet must have curvature and refraction calculations factored in. Spirit leveling with a conventional automatic level or a digital level is normally recommended; there will be few instances in Texas where rugged terrain would require trigonometric leveling for highway surveys.

Elevations for topographical work relative to an occupied control point are perfectly acceptable using the total station. The processing of total station data produces DTM's of adequate quality and in an economic manner. Only topographic surveys and other non-critical work, however, should be performed using data derived from trigonometric calculations.

Section 4 — Surveying Vertical Networks with GPS

Overview

The use of GPS for vertical network surveys requires an understanding of the relationship between conventional and GPS height systems and to the problems unique to the vertical component of a GPS measurement.

Conventional trigonometric, spirit, or compensator leveling measures the relative elevations of points above an undulating equipotential surface called the geoid, which is close to, but not the same as, "mean sea level." The model of this undulated geoid surface, currently in use by TxDOT, is the GEOID03. TxDOT uses the NAVD88 vertical datum for orthometric height (elevation) measurements from this geoid surface (GEOID03) and it has superseded the old NGVD datum of 1929. Elevations measured by conventional leveling are orthometric heights.

Ellipsoid Measurements

In contrast, GPS measures the relative heights of points above a smooth, mathematically simple surface called an ellipsoid. An example of an ellipsoidal reference surface is GRS80, the defining ellipsoid for NAD 83. Elevations derived from GPS measurements are ellipsoidal heights minus the separation between the geoid and ellipsoid.

The ellipsoidal (h) and orthometric (H) heights are closely related by the geoid height (N), the separation between the two reference surfaces, as shown in Figure 4-4 below. Geoid heights can be derived from GPS observations on bench marks, where both the ellipsoidal and orthometric heights have been measured for the same point. A network of GPS bench mark observations, gravity observations, and elevation models are used to develop a geoid model. From this model, geoid heights at other points in the area can be estimated. The accuracy of these geoid heights is dependant upon the accuracies of the various measurements used to construct the model.

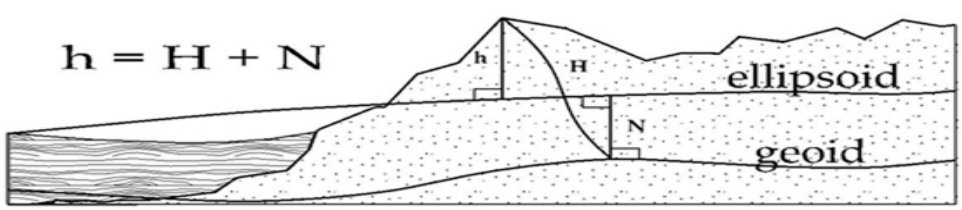

Figure 4-4. Relationship between ellipsoidal (h), orthometric (H), and geoid (N) heights.

Note that in the continental United States the ellipsoid is above the geoid; therefore N in Figure 4-4 is negative. Also, note that the height equation h = H + N is only an approximation as the orthometric height is measured along a curved plumb line normal to the geoid surface, while the ellipsoidal and geoid heights are measured along straight lines normal to the ellipsoid surface. For land survey-

ing applications, the height error associated with this approximation will always be less than one centimeter.

Height Component

The height component of a GPS survey measurement is also affected by relatively poor geometric strength for trilateration, as the earth blocks all satellite signals from the hemisphere below the horizon. This imbalance makes ranging much more critical for determining vertical. Slight ranging errors from multipath or atmospheric conditions are more problematic with this poor geometry.

Accordingly, GPS height accuracies for a survey are typically 1½ - 2 times poorer GPS horizontal accuracies, depending on data quality and baseline length. Increased redundancy of observations under independent conditions is useful for identifying errors.

Because of the need for four (4) or more vertical control points (and in some cases, all four quadrants) to establish good GPS elevations, many times it will be more economical to run conventional level loops.

Chapter 5 — Right of Way Surveying

Contents:

Section 1 — Overview

Section 2 — Phases of a Boundary Survey

Section 3 — Field Work Instructions

Section 4 — ROW Mapping Requirements

Section 5 — ROW Map Components

Section 1 — Overview

Boundary Survey

A property survey is a survey performed to determine the length and direction of boundaries, and to establish or retrace the position of these lines on the ground. The purpose of a property survey is not only to determine the metes and bounds, but most importantly, any conflict in ownership or existing rights of others that affect the ownership of the land.

TxDOT uses property surveys to acquire rights of way, easements, real property for facilities, and lease sites. The property survey is the basis for appraisal and offers to purchase land. The property survey is the basis for **taking** by eminent domain in the event of condemnation.

The majority of TxDOT survey projects will be corridor surveys. These may be limited to surveys of a small extent located inside one or two parent tracts, or they may encompass project limits many miles in length. One project can contain urban, industrial, suburban, and rural properties.

Farmland, pasture, industrial parks, railroads, irrigation canals, rivers, and central business districts can all be crossed in the course of a transportation route survey. The function of the TxDOT surveyor is to provide professional land surveys that are legally defensible and managed in an efficient manner.

Section 2 — Phases of a Boundary Survey

Overview

Information contained within this section is excerpted in its entirety and/or adapted for this manual from the Texas Board of Professional Land Surveying (TBPLS).

Preliminary Research

The foundation of any land survey is record research. According to the current rules of the Texas Board of Professional Land Surveying (TBPLS), the land surveyor must perform research adequate for the assignment.

22 Texas Administrative Code §663.16 (c). Boundary Construction

A land surveyor assuming the responsibility of performing a land survey also assumes the responsibility for such research of adequate thoroughness to support the determination of the location of intended boundaries of the land parcel surveyed. The surveyor may rely on record data related to the determination of boundaries furnished for the registrants' use by a qualified provider, provided the registrant reasonably believes such data to be sufficient and notes, references, or credits the documentation by which it is furnished.

Related Boundary Construction Information

Some sources of record data are:

- Texas General Land Office – Field Notes, Roll Sketches, County Maps, Working Sketches, Correspondence, Survey Reports, Patents
- County Clerk - Deed Records, Plat Records, Commissioner's Court minutes, Patent Records, County Surveyor's Records
- County Central Appraisal District – Tax Parcel Maps
- District Court Clerk
- River Authorities
- Irrigation Districts
- Utility Companies
- Municipal – Planning, Public Works, Engineering, GIS
- Oil Companies, Lumber Companies, Railroads

- Private Surveyors.

An abstract of title or a title run sheet may be of great assistance in determining which conveyances affect the land. The purpose of the title search for the land surveyor is not to determine title from a legal standpoint; it is to retrace the history of the land as it affects the boundaries. The title must be searched back in time sufficiently far enough to uncover all of the pertinent information. In many cases, this will be to the sovereignty of the soil.

After assembling the record information, a working sketch is prepared (*Surveying Wildcat Lease Blocks in Texas*, F.D. Smith, Proceedings of the Third Annual Texas Surveyors Association Short Course, 1954). A working sketch of the patent notes will assist in determining how the original cadastre was formed from the public domain. Careful plotting of the original and corrected field notes will reveal data about junior/senior rights, conflicts and vacancies, original monuments, and other information vital to the retracement of the footsteps of the original surveyor. This is the paramount duty of the modern boundary surveyor.

According to the 22 TAC §663.16 (a), when delineating a property or boundary line as an integral portion of a survey, the surveyor shall respect junior/senior property rights, footsteps of the original surveyor, intent of the parties involved, the proper application of the rules of dignity or the priority of calls, and applicable statutory and case law of Texas.

Draft Deed Record Sketch

In densely populated areas of the state, the original grants have frequently been subdivided into numerous small tracts. It may be necessary to draft a subsequent deed record sketch of the deeds inside each original grant. This plot will contain information similar to the working sketch. The subject tract, description of corners called for in the deed, conflicting elements of the deeds (if any) and easements affecting the subject tract are shown on the deed record sketch.

A preliminary report shall be written analyzing the construction of the working sketches. The preliminary report is a supplement to the graphic depiction and analyses shown in the working sketches. The report will list the sources of the records used to prepare the maps. A summary of the history of surveys affecting the subject lands will generally be best prepared in a chronological sequence. Any potential title problems discovered by the analysis of the records will be emphasized in the report.

Field Work

All fieldwork will be related to the NAD 83 datum through a control network of TxDOT survey points established before the commencement of the boundary survey. Surveys may be performed by GPS techniques, such as real-time kinematic methods in terrain suitable for their employment.

Conventional survey methods may be needed in wooded, urban, or mountainous environments, or a mixture of GPS receivers and conventional total stations. Survey techniques shall comply with the procedures specified in Chapter 3, Preliminary Surveying, of this manual. The surveyor will compute state plane coordinates on the Texas Plane Coordinate System for all survey measurements. Surface coordinates will be computed using methods acceptable to TxDOT.

After the preliminary office research is complete, the surveyor will plan the field work based upon the results of the **preliminary report**. The working sketch will indicate what original corners may be recovered. An original corner that is well known and its use accepted by the local surveying profession is often the most effective beginning point. A careful inspection of the working sketch will frequently reveal the footsteps of the original surveyor that must be retraced for a defensible survey.

The courts have established the duty of the modern boundary surveyor to be the retracement of the footsteps of the original locating surveyor (*Vanishing Footsteps of the Original Surveyor*, Clayton Orn, Report of the Fifth Texas Surveyors Short Course Conference, 1952). The surveyor shall exert every reasonable effort to recover the corners established by the original surveyors of the grants included in the project area.

The question is not where an entirely accurate survey **would** locate the lines, but where **did** the original survey locate such lines (*A Treatise on the Law of Surveying and Boundaries,* F.E. Clark, 1939). This may require multiple visits to the vicinity to search for the best remaining evidence.

The surveyor will begin by locating or retracing as many corners of the original grants as required to construct the boundaries of the lands included in the project for future takings. Subsequent to locating the original grant boundaries and preparing a boundary construction, the surveyor may locate corners and lines of any junior survey interior to the original grants. In this manner, the surveyor will build up a logical scheme of boundary construction.

Final Survey

Upon completion of the retracement survey, a boundary construction map shall be prepared. This map will depict all survey evidence recovered in the survey. The surveyor will prepare a survey map showing the corners recovered, the courses, and distances of the boundaries and areas of lands considered in the project.

A survey report will be written summarizing the findings of the surveyor and particularly the boundary construction of the surveyed properties. Any boundary discrepancies or survey problems found during the survey shall be analyzed and reported. These will also be shown on the survey map.

The survey map will show record and calculated dimensions to facilitate the comparison of deeds with the survey construction. A background map of available aerial photography and digital ortho-

photographs will aid in delineating lines of occupation and natural terrain features having a locative effect.

A final determination of boundaries and construction of surveys in the project area will be made in consultation with the TxDOT surveyor. A **final report** shall be written giving details of the boundary construction of properties involved in the ROW project.

Once the boundary construction of the lands affected by the project has been finalized, the location of the proposed acquisitions may proceed. At this stage, an initial overlay of the proposed takings may point out areas where the proposed right-of-way may be rationalized.

The surveyor will consult with TxDOT staff to minimize uneconomic remainders and the taking of small slivers of land. The cost of acquiring miniscule gores of land from a parent tract can far exceed the value of the property. If possible, these parcels will be eliminated from the final ROW footprint. In addition, the review should examine the mitigation of utility adjustments through possible modification of the proposed ROW.

After the ROW is approved, the surveyor will prepare parcel plats with metes and bounds descriptions. The plats and field notes comprise together the property description. Permanent parcel corners will be set in compliance with TBPLS rules and TxDOT policy.

Aluminum caps stamped “TxDOT ROW” with 1/2" or 5/8" diameter rebar will be set at all property corners, angle points, and points of curvature and tangency. Relative locations of the corner monuments set shall comply with the positional tolerance established by the TBPLS rules. A Preliminary ROW Map will be prepared from the property descriptions.

The Preliminary Right of Way Map will satisfy the requirements of the current edition of the *TxDOT ROW Manual Volume 1 - Procedures Preliminary to Release*. The map will utilize computer graphics software currently required by the department.

The Preliminary Right of Way (ROW) Map is not a survey plat certified by a Registered Professional Land Surveyor (RPLS). It is a graphic representation of ROW conveyances in relation to the proposed roadway alignment.

Appraisers, negotiators, ROW administrators and attorneys and other staff involved in the acquisition of ROW will use the Preliminary ROW Map. The surveyor must take into consideration this fact in the preparation of the ROW map. As such, the ROW map functions not as a survey plat, but as a graphic index map to the parcels to be acquired by the state.

Section 3 — Field Work Instructions

Overview

Information contained within this section is excerpted in its entirety and/or adapted by the Standing Committee on Surveying (SCOS) for this manual from the *TxDOT ROW Manual Volume 1 - Procedures Preliminary to Release*.

Encroachments

An encroachment is defined as any obstruction intruding upon the property of another. An encroachment may indicate the existence of an unwritten right that may evolve into a title right. Under the Texas and United States Constitutions, it is a fundamental duty for TxDOT to determine and compensate the owners for all rights acquired in the taking of property.

Describe and tie all encroachments or possible encroachments in the survey field record.

Exercise special care in observing aerial encroachments such as overhead electric and telephone lines with cross-arms. Record these items in the field record. Other encroachments may include:

- fences
- rock walls
- power poles
- guy wires
- driveways
- buildings or structures
- underground utilities including water, sanitary sewer, communication, electricity, oil and gas pipelines, etc.
- sidewalks
- persons occupying the tract
- clearing in the trees
- disturbed ground.

Roads and driveways crossing the subject tract shall be noted. These roads may be used by adjoining landowners for access to their property. Locate all dirt roads; as they may lead to a cemetery or be ingress and egress to another tract.

All improvements within, along, beside, or up to 50 feet outside the property lines must be located in relation to a property line, identified and dimensioned.

Fence Ties

Property line fences shall be accurately located. Ties will be made as needed. The field survey record will note:

- age of fence
- type of fence
- condition of fence.

The intersection of cross fences with property line fences shall be located. A sketch of cross fences in the interior of a tract shall be made if an aerial photograph is unavailable. Cross fences in the interior of a tract shall not be surveyed unless requested by the RPLS in responsible charge.

Adjoining fences along the property line shall be located in the survey field record. A sketch of such fences will be made if low-level high-resolution aerial photography is unavailable.

Wire fences that meander from tree to tree shall not be located unless they are boundary division fences. When tying tree to tree fences, note in the survey field record as to where the fence begins to go from tree to tree and where the fence ends from tree to tree with periodic ties to fence from a traverse line. Each individual tree does not need to be tied unless required by the RPLS in responsible charge.

Easements

An easement is “an interest in land created by grant or agreement which confers a right upon owners (private or public) to some profit, dominion, or lawful use of the estate of another.”

All surface evidence of utilities corresponding to known easements of record shall be located in the field survey record.

The surveyor will locate all facilities crossing the subject tract to verify the location of the object in relation to the location of a recorded easement.

The surveyor will note:

- new excavations
- pipeline markers
- buried cable route signs
- cleared routes across property

- manholes, and
- any feature that suggests aerial or buried utilities whether or not they were constructed under benefit of an easement of record.

Evidence of all cemeteries or possible cemeteries will be located and noted in the survey field record.

Gates found on the perimeter of the tract shall be located. Apparent frequency of use and condition shall be noted. Sketches of roads entering and exiting the tract shall be made. Aerial photographs may be used as a base map to approximate the location of roads or trails across the property.

Boundary Checklist

The following boundary checklist shall be reviewed before the beginning and end of a boundary survey:

Fences:

- Are all boundary fences located?
- Note fence type, approximate age, type of wire.
- Locate all significant angle points in fences and plot on sketch and/or aerial photographs.
- Prepare detailed sketch of fence at major corners.
- Locate intersection of cross fences at division fences.

Utilities

- locate serial electric, telephone and cable TV lines (unless previously located by topographic survey)
- locate all utilities flagged by one call system
- note the number of wires and brief description of cross bar poles
- locate all guy wires and down guys
- locate all sanitary sewer manholes, water valves, and fire hydrants
- locate all inlets
- locate all underground pipelines, communication and electric lines (locate route signing and vents of underground utilities)
- locate all above ground pipeline and oil or gas well appurtenances such as valves, cathodic protection facilities, tank batteries, pumps, etc., if not previously surveyed.

Property Corners

- locate all monuments on points of curvature and points of intersection of ROW fronting tract
- locate sufficient monuments of ROW adjacent to and on either side of tract, and across public roadways, to determine location of tract to adjoining tracts of ROW taking
- prepare detailed description of property corners located and survey control points set (1/2" IRON ROD FOUND, 1" IRON PIPE FOUND, 2 X 2 HUB AND TACK SET, 3/8" IRON ROD IN ROCK MOUND FOUND, etc.); it is essential to note and markings of found monuments
- set survey control points in places that will be undisturbed in the future
- ensure there is sufficient information from deed plot or subdivision plats to tie in to adjoining property.

Locate Structures in Interior of Parcel near Proposed Taking

- barns
- concrete slabs and foundations
- houses or any permanent structures
- water wells.

Locate Natural Features Referred to in Deeds

- drainage features
- ridge lines or summits
- wooded mottes or woods / prairie boundaries.

Locate Roadways Entering and Exiting the Property

- any dirt or gravel roads or driveways being used for access to adjacent properties
- any abandoned roadways.

Flag All Survey Points

- guard stake and lath set on property corners of the subject parcel
- control points
- survey control points shall be set in such locations to facilitate setting calculated corners in the near future to complete the boundary survey.

TSPS Survey Categories

Information in this subsection is excerpted and/or adapted for this manual from the Texas Society of Professional Surveyors (TSPS) Manual of Practice.

The Texas Society of Professional Surveyors (TSPS) has published the Manual of Practice for many years. Although aimed at the surveyor in the private sector, this manual contains much information useful to the TxDOT surveyor. In particular, the "Chart for Tolerances of Conditions" (which appears below) may be appended to a "Work Authorization" as a survey specification. The manual contains categories of surveys and tolerances, or specifications, for each category of survey. The categories are further subdivided into **conditions**.

Category 1A provides specifications for a Land Title Survey. It is designed to fulfill the normal requirements of all title insuring agencies.

Category 1B is specified as a Standard Land Survey. A Standard Land Survey is not intended to support title insurance activities. Category 1B surveys will be used to locate real property, write legal descriptions, or for platting.

Category 2 is defined as a Route Survey. This type of survey is used for the planning of the location and the acquisition of property for rights of way.

The following chart is excerpted from the *TSPS Manual of Practice*:

Table 5.1 Chart of Tolerances for Conditions

Conditions	**IV**	**III**	**II**	**I**	
	Rural	**Suburban**	**Urban**	**Urban Business District**	**Remarks and Formulae**
Error of Closure	1:5,000	1:7,500	1:10,000	1:15,000	Loop or between Control Monuments
Angular Closure	$30' \sqrt{N}$	$25'' \sqrt{N}$	$15'' \sqrt{N}$	$10'' \sqrt{N}$	N = Number of Angles in Traverse
* Accuracy of Bearing in Relation to Source	40 sec.	30 sec.	20 sec.	15 sec.	Sin α = denominator in Error of Closure Divided into 1 (approx.)
Linear Distances Accurate to:	0.2 ft. per 1,000 ft.	0.15 ft. per 1,000 ft.	0.1 ft. per 1,000 ft.	0.05 ft. per 1,000 ft.	Sin α x 1000 (approx.) where ± = Accuracy of Bearing
Positional Error of Any Monument	AC 5,000	AC 7500	AC 10,000	AC 15,000	AC = Length of Any Course in traverse

Table 5.1 Chart of Tolerances for Conditions

Conditions	IV	III	II	I	
	Rural	**Suburban**	**Urban**	**Urban Business District**	**Remarks and Formulae**
Calculation of Area —Accurate and Carried to:	0.001 .01 .1 .3	0.001 .01 .1 .2	0.0001 .001 .01 .1	0.0001 .001 .01 .1	To 1 acre To 10 acres To 100 acres To 1000 acres
Elevations for Boundaries by Tides, Contours, Rivers, etc. Accurate to	0.2 ft.	0.1 ft.	0.05 ft.	0.03 ft.	Based on sea level datum
Location of Improvements Structures, Paving, etc.	1.0 ft.	0.5 ft.	0.2 ft.	0.1 ft.	Tie Measurements
Scale of Maps Sufficient to Show Detail but no less than	1"= 2,000'	1"= 1,000'	1"=400'	1"=200'	
Positional Error in Map Plotting not to Exceed: (Applies to Original only)	50 ft. 1"=2,000'	25 ft. 1"=1,000'	10 ft. 1"=400'	5 ft. 1"=200'	Generally 1/40th inch (National Map accuracy calls for 1/50th inch)
Adjusted Mathematical Closure of Survey no less than	1:50,000	1:50,000	1:50,000	1:50,000	

NOTE: *TxDOT policy requires all bearings or angles be based on the following source: Grid bearing of the Texas Coordinate System of 1983, with the proper zone and epoch specified.

Information Provided by the State for ROW Mapping

- work authorization to begin work
- copy of the department's *Survey Crew Safety* handbook **to the surveyor**
- an example of a ROW map, traverse closure sheet, and property description
- existing horizontal control information **to the surveyor**
- existing applicable Rights of Way maps of the project area if available **to the surveyor**
- a planimetric map in "MicroStation® compatible" media showing existing topography if available **to the surveyor**

- authorization for TxDOT bronze disk (Type II ROW marker to monument ROW) and TxDOT aluminum rod caps (monument new/proposed ROW parcel)
- inspect and approve surveys, property descriptions, and ROW maps
- pay the surveyor for work performed and accepted.

Section 4 — ROW Mapping Requirements

Overview

Information in this section has been excerpted in its entirety and/or adapted and modified by the Standing Committee on Surveying (SCOS) from the TxDOT Right of Way Division's *ROW Manual Volume 1 - Procedures Preliminary to Release*.

The TxDOT Right of Way (ROW) Division has published procedures for right of way surveying in its Right of Way Manual Collection. The *Volume 1, Procedures Preliminary to Release*, contains the updated policies and requirements of ROW surveying for TxDOT. The current requirements for ROW mapping and surveying are available on-line.

Surveying for ROW Acquisition

Necessity for Correct Property Descriptions. Property descriptions prepared with the intent to convey title to the state must define adequately and clearly the location of the property. State law stipulates that any property description prepared with the intent to convey title to the state constitutes a boundary survey, falling under the jurisdiction of the Texas Board of Professional Land Surveying (TBPLS).

Surveying for ROW Acquisition. Right of entry must be obtained from each landowner before performing any type of surveying on private property. TxDOT will provide standard right of entry forms that should be signed by each landowner before entry is attempted. A verbal right of entry may be obtained but every attempt shall be made to secure a written right of entry before the survey is completed.

All surveying necessary for ROW acquisition must be performed under the supervision of an RPLS. All surveying must conform to all applicable surveying laws and the Professional Land Surveying Practices Act and must follow the *General Rules of Procedures and Practices* of the TBPLS. The Texas Society of Professional Land Surveyors Manual of Practice may be used as a guide in determining accuracy requirements and specifications in the preparation of the survey.

Texas State Plane Coordinate System

All projects must be tied to the Texas State Plane Coordinate System and must be located relative to all adjoining projects. The Technology Services Division has a published set of standard electronic graphics seed files with the correct map projection parameters for a particular area of the state.

Metadata, including the state plane zone, combined adjustment factor (CAF), mapping angle (theta angle) horizontal datum and adjustment, and (if CORS stations were used for a GPS tie) the epoch

date shall be shown on the **title sheet** of the ROW map. A **control sheet** of the ROW map showing survey control stations, coordinate values, and type of adjustment used for the survey may be prepared.

General ROW Map Requirements

A ROW map is a compilation of engineering data, property descriptions, parcel plats, appraisal information, and improvements related to a transportation project. All ROW maps must be prepared under the supervision of an Registered Professional Land Surveyor (RPLS). Under an agreement between TxDOT and the Texas Board of Professional Land Surveyors (TBPLS), ROW maps are not required to be signed and sealed by an RPLS. ROW maps are recognized as internal engineering plans and asset management documents. ROW maps are not considered to be survey plats.

- Preparation of ROW maps normally begins after obtaining schematic design approval.
- During schematic design, the design engineer determines the amount of ROW needed to accommodate the proposed transportation facility.
- The surveyor is responsible for the boundary analysis of the proposed ROW parcels and preparation of the property descriptions (parcel plats and metes and bounds descriptions), ROW maps, and surveyor's reports.

All ROW maps are reviewed and approved for technical completeness, compliance with TxDOT guidelines and adherence to the Professional Land Surveyors Practices Act by the district. The ROW Division will conduct an administrative review of all maps and advise the district of any deficiencies found. Sample ROW map sheets and title sheets are available as guides for preparing maps.

All ROW map sheets for a project must be uniform in size, form and arrangement. The uniformity must conform to TxDOT standards and guidelines and include similar font styles and sizes for each map sheet, as well as a neat and legible arrangement of data on each sheet. The entire ROW map will be bound by the left margin of each sheet.

All ROW projects are authorized by the Texas Transportation Commission and include defined limits. If the Commission authorization for a project does not cover continuous procurement of new ROW, then the map must show both existing and new ROW.

All sheets will consist of double matte, 4-mil Mylar sheets measuring 22 inches by 34 inches. The border shall be positioned ½ inch from the top, bottom, and right edge, and 2 inches from the left edge of the sheet.

Sufficient topography shall be reflected on either side of the centerline of the highway to show the required ROW parcel and the parent tract of land from which the parcel is to be acquired or a distance of 600 feet, whichever is lesser. Details of all improvements bisected by or within 50 feet of

the ROW line not reflected on topographic information furnished by the state shall be shown on the drawings.

All utility easements within or crossing the proposed ROW shall be shown or identified. Proposed roadway planimetric details shall be shaded and shown on each plan sheet.

The surveys, along with their abstract numbers, shall be shown and identified throughout the entire project. Portions of existing subdivisions along the route shall be shown to clearly and accurately reflect the required ROW parcels. The name of the subdivision and intersecting streets, together with lot and block numbers, shall be appropriately shown on the drawing. Each tract of land required for highway ROW purposes shall be identified by a parcel number, by ownership, by amount of required land (in acres for rural land and in square feet for urban land), and the approximate amount remaining in the parent tract of land.

ROW maps may contain the following sheets:

- Title Sheet.
- Parcel Index Sheet - Shows an overall view of project parcels and plan sheets. This sheet may be omitted if all applicable data can be placed on individual map sheets.
- Control Sheet - Shows an overall view of the project and the relationship of monumentation and control. Alternatively, this information may be included on the Parcel Index sheet.
- Plan Sheets.

For additional references for preparation of ROW maps and general surveying, see the following publications:

Table 5.2 Reference Publications for ROW Map Preparation

Publication	Author
TxDOT ROW Manual Vol. 1- Procedures Preliminary to Release	TxDOT ROW Division
TSPS Manual of Practice	Texas Society of Professional Surveyors
Professional Land Surveyors Practices Act Rules and Regulations	Texas Board of Professional Land Surveyors

ROW Parcel Numbering

General Objectives in Parcel Numbering. The methodology of numbering ROW parcels must be correct and consistent to avoid problems in the appraisal process or with record maintenance through the ROW information system. Anyone preparing ROW maps must communicate regularly with the district for uniformity of methodology.

There are specifics of parcel numbering which may be unknown by surveyors or district design engineers. For example, on an urban project one or more contiguous properties may be under common ownership. If the preliminary data shows contiguous properties have a unity of use, then two or more properties may be combined into one marketable unit having one parcel number.

If the appraisal data shows contiguous ownership, but the properties do not have unity of use, then assign each property a separate parcel number, and compute a separate value for each.

Rural projects are usually handled the same as urban projects, with the focus being placed on the parent tract. A parent tract is simply defined as a single property not divided by a public way or platted as a subdivision.

However, a parent tract may be defined by several smaller purchases that comprise one large tract of land under a single ownership. If an undivided tract has common ownership but discrete land uses, then each land use area must be partitioned into separate parcels with a unique number. Parcel numbering does not necessarily have a one-to-one correspondence to property boundaries.

In addition, one parcel may be composed of more than one part. For additional guidance, see the examples in Table 5.3 Parcel Numbering System of this chapter.

Usually, properties divided by existing public ways or by separate ownership are considered separate parcels, although they may have common ownership. However, sometimes the unity of use supports combining parcels. In this case, assign the whole property one parcel number, with each divided property being an associated part.

TxDOT uses the term “parcel” to denote a real property acquired by the state, whether through purchase, donation, or exchange. In the event TxDOT sells or exchanges state land, the term “tract” is used to describe the land unit. The terms should not be used interchangeably. Careful use of these definitions allows the instant identification of the ownership of a property adjoining a state ROW.

Standard Numbering System for ROW Parcels. Number ROW parcels from left to right on each ROW map sheet, based on ownership and land use data available when the preliminary map is prepared. Parcel numbering should begin with number 1 and continue in sequence throughout the limits of the project.

If practical, the stationing should increase from south to north and west to east; or, it should match stationing on the schematic.

This system is typically easier to use on rural projects than on urban projects, because rural parcels are often comprised mainly of larger tracts having the same ownership for many years.

Variation of the number sequencing is sometimes acceptable due to hardship acquisitions or protective buying.

The following are examples and explanations to clarify the standard parcel numbering system and are also found in the *TxDOT ROW Manual Volume 1 - Procedures Preliminary to Release*. Figure numbers in this manual differ slightly from the above ROW manual.

NOTE: Links to figures 5-1 through 5-11 are provided on page 5-19 in this section.

Table 5.3 Parcel Numbering System

Example	Parcel No.	Explanation
1	1, 3, 4, etc.	Normal parcel numbers. See Figures 5-1, 5-3, 5-4, 5-5, and 5-7.
2	58(E)	Usual outfall or channel easement. Easements of this type are located outside of actual ROW and differ from ROW easements sometimes acquired on County/City acquisition projects which are shown as normal ROW parcels. See Figure 5-2.
3	2-Part 1 Part 2	One parcel composed of two parts. Both parts will be included in a single appraisal report, only one value will show on value forms, and only one deed and one title policy or title certificate is to be obtained. See Figure 5-6.
4	3(E)-Part 1 Part 2	Two channel or outfall easements from one tract. Same as Example 3 except that a channel or outfall easement is involved rather than a ROW parcel. See Figure 5-3.
5	2 2(E)	Normal parcel with one outfall or channel easement. See Figure 5-1.
6	3 3(E)-Part 1 Part 2	Normal parcel with two channel or outfall easements. Each appraiser will make one report setting out separate values for the ROW parcel and the easements. Values for both easements will be combined into one value on value forms. One deed and one title policy or title certificate will be obtained for the ROW parcel and only one instrument of conveyance and one title policy or title certificate (State Acquisition Projects) will be secured for the channel easements. See Figure 5-3.
7	2A 2B	Normal Parcel No. 2 divided into two parcels. Could be caused by error in original numbering or due to part of original parcel having been sold since ROW map was prepared. See Figure 5-8. The original Parcel No. 2 cannot be used alone again.
8	2A(E) 2B(E)	Usual outfall or channel easement divided when parcel as in Example 6 is divided. See Figure 5-8.
9	2A 2A(E) 2B 2B(E)-Part 1 Part 2	Parcel divided with one easement with one parcel and two easements with second parcel. See Figure 5-9.

Table 5.3 Parcel Numbering System

Example	Parcel No.	Explanation
10	26-Part 1 Part 2	Figure 5-10 shows parent tract in two counties and two projects with one parcel number divided into parts. Only one appraisal but has division of values. This is applicable to both state and LPA acquisition projects and also to a combination involving both state and LPA acquisition on a project.
11	33(RR)	Crossings held in joint use with a railroad (operating a railroad ROW) by joint use agreements, license, or permit should be numbered in the same manner as a regular parcel of land with the addition of the designator "RR" (e.g., parcel 1RR). To be used for crossings only.
12	34(JUA)	Joint Use Agreement - Joint use of TxDOT right of way with others.
13	57(W)	Wetlands - used for property that is acquired for wetland mitigation.
14	30(X)	Overlooked Improvement - Used when a parcel has been acquired and an overlooked improvement (e.g., private water, water well, root cellar, etc.) is found on the parcel that still needs to be removed.
15	16(TE)	Temporary easements acquired through the normal acquisition process.
16	28(M)	Mitigation: Environmental mitigation, except wetlands.
17	1(AC)	Access rights only. NO ROW TO BE ACQUIRED! See Figure 5-11.
18	71(OAS)	Outdoor Advertising Sign Only - NO LAND ACQUISITION!
19	1AAQ	Advance Acquisition Parcel - Acquired in advance of ROW project release.
20	Tract 4UR	An uneconomic remainder parcel.
21	U1	A number assigned to uniquely identify a utility facility; does not involve land.

Land taken for widening projects that adjoin existing parcels are best numbered with the original parcel numbers but with an alphabetic letter added after the number.

Sample figures are available from the TxDOT ROW ftp site:

Figure #	Sample Name with Link
Figure 5-1	ROW Parcel Numbering Convention (ftp://ftp/dot.state.tx.us/pub/txdot-info/row/manuals/parc1.pdf)
Figure 5-2	ROW Parcel Numbering Convention (ftp://ftp/dot.state.tx.us/pub/txdot-info/row/manuals/parc1a.pdf)
Figure 5-3	ROW Parcel Numbering Convention (ftp://ftp/dot.state.tx.us/pub/txdot-info/row/manuals/parc2.pdf)
Figure 5-4	ROW Parcel Numbering Convention (ftp://ftp/dot.state.tx.us/pub/txdot-info/row/manuals/parc3.pdf)
Figure 5-5	ROW Parcel Numbering Convention (ftp://ftp/dot.state.tx.us/pub/txdot-info/row/manuals/parc4.pdf)
Figure 5-6	ROW Parcel Numbering Convention (ftp://ftp/dot.state.tx.us/pub/txdot-info/row/manuals/parc5.pdf)
Figure 5-7	ROW Parcel Numbering Convention (ftp://ftp/dot.state.tx.us/pub/txdot-info/row/manuals/parc5a.pdf)
Figure 5-8	ROW Parcel Numbering Convention (ftp://ftp/dot.state.tx.us/pub/txdot-info/row/manuals/parc6.pdf)
Figure 5-9	ROW Parcel Numbering Convention (ftp://ftp/dot.state.tx.us/pub/txdot-info/row/manuals/parc7.pdf)
Figure 5-10	ROW Parcel Numbering Convention (ftp://ftp/dot.state.tx.us/pub/txdot-info/row/manuals/parc8.pdf)
Figure 5-11	ROW Parcel Numbering Convention (ftp://ftp/dot.state.tx.us/pub/txdot-info/row/manuals/parc9.pdf)

Section 5 — ROW Map Components

Overview

Information contained within this section is excerpted in its entirety and/or adapted and modified by the Standing Committee on Surveying (SCOS) for this manual from the *TxDOT ROW Manual Volume 1 - Procedures Preliminary to Release*.

Title Sheet

Include the following on the title sheet:

- Layout map large enough to show project location and nearest major collectors
- Highway numbers
- County or counties
- Federal project number (if applicable)
- Construction CSJ number(s). If there is more than one CSJ, tabulate the numbers in the heading with the lowest number shown first, and show CSJ and station numbers at break points with arrow indicators
- ROW CSJ number
- Vicinity map
- Authorized ROW project limits
- Project length
- Scale of the layout map
- North arrow
- Station numbers for the beginning and ending of the project, and station equations
- Reference to previous ROW projects in the same location if applicable
- Datum statement including the basis of bearings and coordinates, adjustment factor used for converting from grid coordinates to surface coordinates and theta (true-to- grid rotation) angle if applicable
- Signatures of appropriate signing authorities
    - For initial submission: The district surveyor or ROW administrator will sign recommending acquisition after a technical review for compliance with TxDOT procedures and Texas Board of Professional Land Surveying rules is completed.

- For initial submission: The area engineer or design engineer will sign recommending acquisition after a review for conformance with the design schematic and verifying the proposed acquisition is adequate to build the proposed transportation facility.
- For final ROW map submission: The district engineer or designee will sign for final approval verifying ROW activities are complete as shown on the final ROW map.

Electronic copies of standard title sheets are available at each district and should be used.

Standard TxDOT symbols shall be used to the greatest extent possible. Any variation from these standardized symbols shall be approved by the district ROW section. The advent of graphics software for preparing construction plans and ROW maps now make it necessary to utilize the TxDOT2K downloadable cell library for symbol standardization.

Follow this link to access an example of a title sheet (ftp://ftp/dot.state.tx.us/pub/txdot-info/row/manuals/title_sheet.pdf).

At the bottom center of the title sheet, directly under the note on station equations, include a statement labeled "NO EXCEPTIONS". Normally, there will be no exceptions on a ROW project. If there are areas where no new ROW will be purchased, insert a note on the title sheet stating that "NO ADDITIONAL ROW WILL BE REQUIRED FROM STATION ____ TO STATION _____."

Parcel Index Sheet

For larger projects containing four (4) or more plan sheets, this sheet will show map sheets and parcels as a large-scale overview of the project. The sheet may also include a chart identifying parcel numbers, land owners, and plan sheet numbers where parcels may be easily located.

Control Sheet

The control sheet may be used to identify the primary control used in preparation of the project. Include the following: the basis of datum, any monuments set for control, the baseline data throughout the project, and any other relevant metadata (i.e., history data).

Plan Sheets

The most important factor in preparing a plan sheet is legibility and clarity of information, even to a person with limited surveying or engineering experience.

Plan sheets shall be drafted at a scale of 1" = 100' (rural) or 1" = 50' (urban), unless a different scale is required for legibility. A planimetric plan sheet developed from aerial photography may be used for the base map of a ROW plan sheet. Plan sheets shall depict existing ROW, adjacent properties, and proposed parcels.

Existing Information

The following shall be shown on each plan sheet:

- existing ROW (by bearing and distance) through the entire project length, even in areas where no new ROW is needed. In areas where new ROW is only needed on one side, the ROW on both sides of the new facility shall be delineated and monuments set.
- existing ROW monuments
- record ownership data of adjacent properties
- points of curvature, points of tangency, and points of intersection (show and label)
- existing utility lines and easements (deed reference, if known)
- existing improvements such as buildings and fences, etc.
- potential obstructions and/or encroachments. (Locate any improvements within 25 feet of the new ROW line. This will assist appraisers in determining damages to the remainders of properties.)
- parent survey lines (show and label)
- city limit lines (show and label)
- county lines (show and label)
- existing public roads, streets and alleys (including recorded plat or deed reference)
- existing drainage or channel easements (include recorded plat or deed reference)
- whole property relative to existing and proposed ROW. If the whole property is too large to fit on the map sheet at the sheet scale, draw an inset at a smaller scale or not to scale with a note stating "N.T.S."

Proposed Information

On each plan sheet, show the following:

- new ROW lines
- new ROW markers
- portions of the proposed design. Although a ROW map is not to be used to construct a highway, the following proposed items or additional topography information shall be shown by either a single line or shading:
  - frontage roads
  - main lanes
  - connecting ramps.

When control of access is used, it should be described in a recorded deed. Limits of denied access should be staked on the ground. The control of access clauses may be included in the property descriptions of a parcel or as a separate instrument. If a metes and bounds description is prepared to describe a controlled access line, it must be signed and sealed by a Registered Professional Land Surveyor (RPLS).

Parcel Information

For each ROW parcel acquired, show the following information:

- property owner name
- parcel number
- parent tract
- type of conveyance (e.g., deed, judgment) - for final ROW map
- recording information (after acquisition) - for final ROW map
- station to station
- area in acres and/or square feet (utilize the TSPS Manual of Practice to determine the accuracy used for calculating square footing based on the category and condition of survey); limits and offset to new ROW line
- area of remainder (calculated from deed)
- property lines, (show and define by bearing and distance relative to existing and new ROW lines); reference only)
- bearing and distance to a monument found or set at a corner outside the area to be acquired. If the corner is defined as a point of commencement (POC) in a property description, then show the letters POC on the map to reference the corner.

Follow the link to access a detailed sample map sheet (ftp://ftp/dot/state.tx.us/pub/txdot-info/row/manuals/plan_sheets.pdf).

Differences between an English title sheet and a metric sheet are stationing and presence of dual units on the metric sheets. For example, show an English unit station as 276+13.70, and show a metric station as 4+754.880. When using dual units, show project length in meters and kilometers, with the equivalent feet and miles shown in parentheses. An example of dual units follows:

NET LENGTH OF PROJECT = 1,981 Meters (6,500 feet) = 1.981 Kilometers (1.231 miles)

At the bottom center of the title sheet, directly under the note on station equations include a statement labeled “NO EXCEPTIONS”. Normally, there will be no exceptions on a ROW project. If there are areas where no new ROW will be purchased, insert a note on the title sheet stating that

"NO ADDITIONAL ROW WILL BE REQUIRED FROM STATION _____ TO STATION ____ ____."

A metric project map must contain the same detailed existing and proposed information as an English project map. Use the following information when preparing a metric map.

- For urban projects, use a scale of 1:200 or 1:500
- For rural projects, use a scale of 1:1000
- Survey stationing increasing from west to east and south to north. The 100-foot station will be replaced with the 1-kilometer station.

1 station = 1,000 m = 1 km

EXAMPLE: 1+000.000 (1+00.00 English)

Normal station intervals are 20 meters; however; 50-meter intervals are acceptable if more practical.

- Show dimensions and areas on metric ROW maps in dual units. Show the metric unit first, followed by the English equivalent in parentheses. If the recorded English equivalent is different from the survey-analyzed English dimension, then show the recorded dimension in brackets. This means that some property lines or existing ROW lines may need to show as many as three distances for one line.
- Show area tabulations in dual units, with the metric unit first followed by the English equivalent in parentheses. Insert a note on the map sheet stating that English units are provided for information only.

ROW Maps for Utility Relocation Projects

Projects that require only utility relocations without parcel or easement acquisition may be submitted with only a ROW map title sheet.

Property Descriptions

In contrast to ROW maps being an internal departmental document, property descriptions (including parcel plats) are prepared as exhibits for the conveyance of a property interest. The property descriptions and parcel plats reflect a boundary survey and must be signed and sealed by an RPLS. Property descriptions prepared for ROW projects consist of a heading with TxDOT identification items with a metes and bounds description and parcel plats prepared on letter size (8 ½" x 11") sheets. Letter size sheets allow the descriptions and plats to be filed with the County Clerk's office without reducing copies. In addition, letter size is the standard file size for TxDOT. Examples of property descriptions and parcel plats are available. See *the TxDOT ROW Manual Volume 1 - ROW Procedures Preliminary to Release*.

NOTE: Use a one-inch border on all sides.

Items to be included on property descriptions and parcel plats, in addition to TBPLS standards, include:

- All property descriptions and parcel plats must be tied to the Texas State Plane Coordinate System, and reference metadata used in preparing the survey.
  - A Texas plane coordinate should be given for at least one point on the plat. This practice is optional for the metes and bounds description.
  - Ownership information shall specify the type of public record referenced, i.e. deed records, official records, real property records, plat records, etc., as well as the volume and page citation.
- Parcel plats are required for all property descriptions
- For all partial acquisitions, at least one reference tie must be made to an established corner outside the parcel area.
  - It is acceptable to use a set corner on the remainder or adjoiner in cases where no found corners exist, although the surveyor may be assuming liability for the remainder as well as for the adjoiner tract.
  - This outside tie should be made to a boundary corner monument that will remain after construction.
- Centerline station ties may, or may not, be of value to the property description, but may be a convenient reference.
  - A station and offset tie at the beginning and end of each parcel is of value to engineers and designers for the construction of a centerline or survey baseline.
  - Station and offset ties in a parcel description, ROW map, and parcel data should identify the source of the stationing.
- If the parcel is located in more than one county or land grant survey, show the land area in each county or land grant.
- Control of access lines.

Parcels consisting of more than one part must include a summary at the end of the property description as follows.

Summary:

Part 1 = 4.333 Acres (188745 square feet)

Part 2 = 2.667 Acres (116174 square feet)

Total = 7.000 Acres (304919 square feet)

Acreages will normally be carried out to three (3) decimal places. However, on large rural parcels that may have lengthy boundary segments, it is acceptable to truncate acreage figures to two (2) decimal places, which better reflects the accuracy of the surveyed line.

Metric Requirements for Existing Projects

On August 26, 1998, the TxDOT executive director issued a memorandum to district engineers concerning the reversion from metric units of measurement mandated by the Federal government, back to English units. The memorandum stated that under TEA-21, the conversion to metric units of measurement on projects is optional.

Projects started in metric that cannot be economically converted to English units may be completed in metric.

Common conversions from English to metric units are:

1 meter (m) = 39.37 /12 (U.S. Survey Foot) or

1 meter (m) = 3.2808333 feet (U.S. Survey Foot)

1 hectare (ha) = 10,000 m^2

1 station = 1 km (Example: 5+000.000)

Stationing intervals (to be shown on map) = 20 m.

Property descriptions covering more than one page should read:

"Page___of____Pages." Include the parcel plats as part of the entire document. For example, when there are three (3) pages of a property description and three pages of a parcel plat, identify each as being one of six (6) pages, and read "Page __ of 6 Pages."

At the end of each property description, add a sentence stating "This property description is accompanied by a separate plat." All property descriptions must be signed and sealed by an RPLS, and must include a statement that the survey was performed on the ground under his/her supervision and must include the day, month and year of the survey.

Sequentially number each call on a property description beginning with number 1. Calls are numbered for clarity and ease in preparing control of access clauses on applicable projects. Numbered calls also make it easier for a reviewer to designate problems. An example of this would be: "The bearing in call number 4 should read N 89°5900" E."

Certification and Monuments

Refer to 22 TAC §663.11 of the General Rules of Procedures and Practices of the TBPLS Act for certification and monumentation of surveys.

Each parcel corner on a ROW project must have a survey marker on the ground to represent that corner. A brass TxDOT ROW monument, DHT# 32147, shall be placed in concrete flush with the ground at all points of curvature, points of tangency, angle points, and at points having a maximum interval of 1500 feet along tangent segments of the ROW. A 5/8" diameter rebar or 3/4" sectional rod with a 2" diameter aluminum cap stamped “Property Corner,” DHT# 164950, shall be placed at the intersections of the new ROW line and individual property lines.

All monuments must be set under the supervision of a Registered Professional Land Surveyor (RPLS) pre-certified by TxDOT. If the district wishes to postpone the establishment permanent monuments until construction is complete, then the following language may be used: “This monument may be replaced by a TxDOT Type II right-of-way upon the completion of the highway construction project under the supervision of a RPLS either employed or retained by TxDOT.”

Examples of property descriptions are given below. The TxDOT ROW Division instituted a change of terminology from “Control of Access” to “Denial of Access” to better define access management of the ROW. The monument itself is stamped with the word “POINT” indicating that denial will be left or right of the point.

ROW Sample Plat Parcel Exhibit A

EXHIBIT “A”

County:	**Collin**	**Page 1 of 4 Pages**
Highway:	**State Highway 289**	**DATE/REVISION DATE**
RCSJ:	0091-04-YYY	
CCSJ:	0091-04-ZZZ	

Description for Parcel 1

BEING 22,731 square feet of land, more or less, in the German Emigration Company Survey, Abstract Number 358, City of Frisco, Collin County, Texas, and being part of a tract of land conveyed by deed to 183 Land Corporation, a Texas corporation, as recorded in County Clerk’s Number 97-0083361, Volume 4009, Page 2535, Deed Records Collin County, Texas; said 22,731 square feet of land being more particularly described by the metes-and-bounds as follows:

COMMENCING at a found ¼ inch iron rod at the Northeast corner of a tract of land conveyed by deed to Frisco Enterprises Limited Partnership, a Michigan limited partnership, as recorded in County Clerk’s Number 92-0007195, Deed Records Collin County, Texas, and the Southeast corner of a tract of land conveyed by deed to Blue Stars Land, L. P., a Texas limited partnership, as recorded in County Clerk’s Number 99-0081760, Volume 4448, Page 1857, Deed Records Collin County, Texas, and in Collin County Road Number 26, and being in the existing Western ROW line of State Highway Number 289;

THENCE North 00 degrees 28 minutes 32 seconds West along the existing Western ROW line of State Highway Number 289 for a distance of 753.46 feet to an angle point;

THENCE North 00 degrees 29 minutes 32 seconds West along the existing Western ROW line of State Highway Number 289 for a distance of 298.08 feet to the Northeast corner of said Blue Stars Land tract of land and the Southeast corner of said 183 Land Corporation tract of land, and being the POINT OF BEGINNING;

THENCE South 85 degrees 02 minutes 17 seconds West along the common line of said 183 Land Corporation tract of land and said Blue Stars Land tract of land for a distance of 72.30 feet to an 5/8 inch iron rod with TxDOT aluminum cap set in the new Western ROW line of State Highway Number 289 and also being the beginning of a Denial of Access Line;

THENCE North 04 degrees 46 minutes 35 seconds West along the new Western ROW line of State Highway Number 289, also being a Denial of Access Line, for a distance of 119.12 feet to an 5/8 inch iron rod with cap set at an angle point, and also being the end of this Denial of Access Line; **

THENCE North 08 degrees 06 minutes 37 seconds East along the new Western ROW line of State Highway Number 289 for a distance of 341.74 feet to an 5/8 inch iron rod with TxDOT aluminum cap set in the existing Western ROW line of State Highway 289;**

Exhibit A, Page 1 of 4

Description for Parcel 1

THENCE South 05 degrees 42 minutes 32 seconds East along the existing Western ROW line of State Highway Number 289 for a distance of 328.48 feet to an angle point from which a found wooden dome post bears South 78 degrees 30 minutes 21 seconds West a distance of 1.77 feet;

THENCE South 00 degrees 29 minutes 32 seconds East along the existing Western ROW line of State Highway Number 289 as conveyed by deed to the State of Texas as recorded in Volume 401, Page 99, Deed Records Collin County, Texas, for a distance of 123.92 feet to the POINT OF BEGINNING and containing 22,731 square feet [0.5218 acres] of land, more or less.

** The monument described and set in this call, if destroyed during construction, may be replaced with a TxDOT Type II ROW Marker upon the completion of the highway construction project under the supervision of a RPLS, either employed or retained by TxDOT.

Access is prohibited across the “Denial of Access Line” to the highway facility from the remainder of the abutting property.

All bearings are based on the Texas Coordinate System of 1983 (1993 Adj.), North Central Zone. All coordinates shown are surface and may be converted to grid by dividing by the TxDOT conversion factor of 1.000152710.

_____

John R. Doe, R.P.L.S. Date

Texas Registration No. 0000

RPLS SEAL

Super Survey Company Inc.

0000 W. Survey Ave

Anytown, Texas 00000

Ph. 000-000-0000

Exhibit A, Page 2 of 4

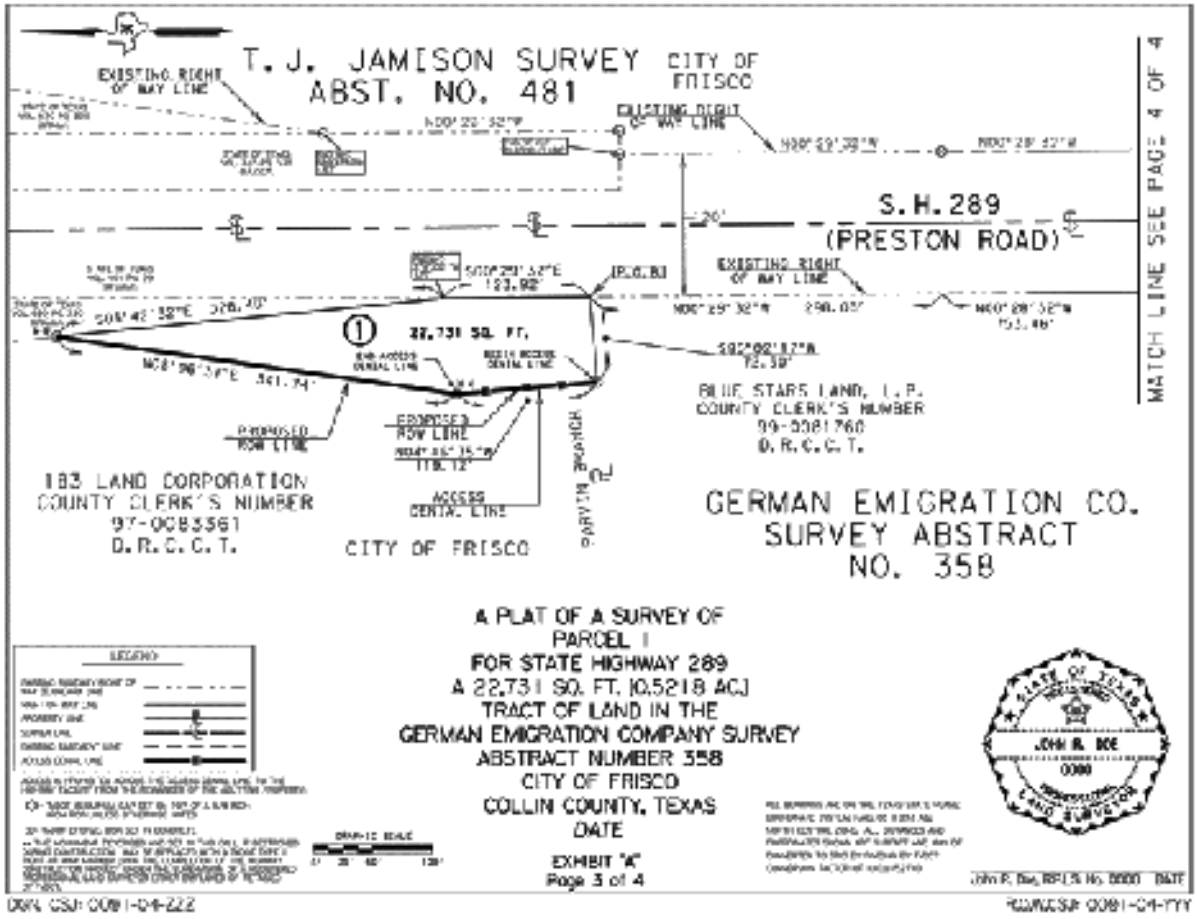

Figure 5-1. Sample Plat Exhibit A.

Exhibit A, Page 3 of 4

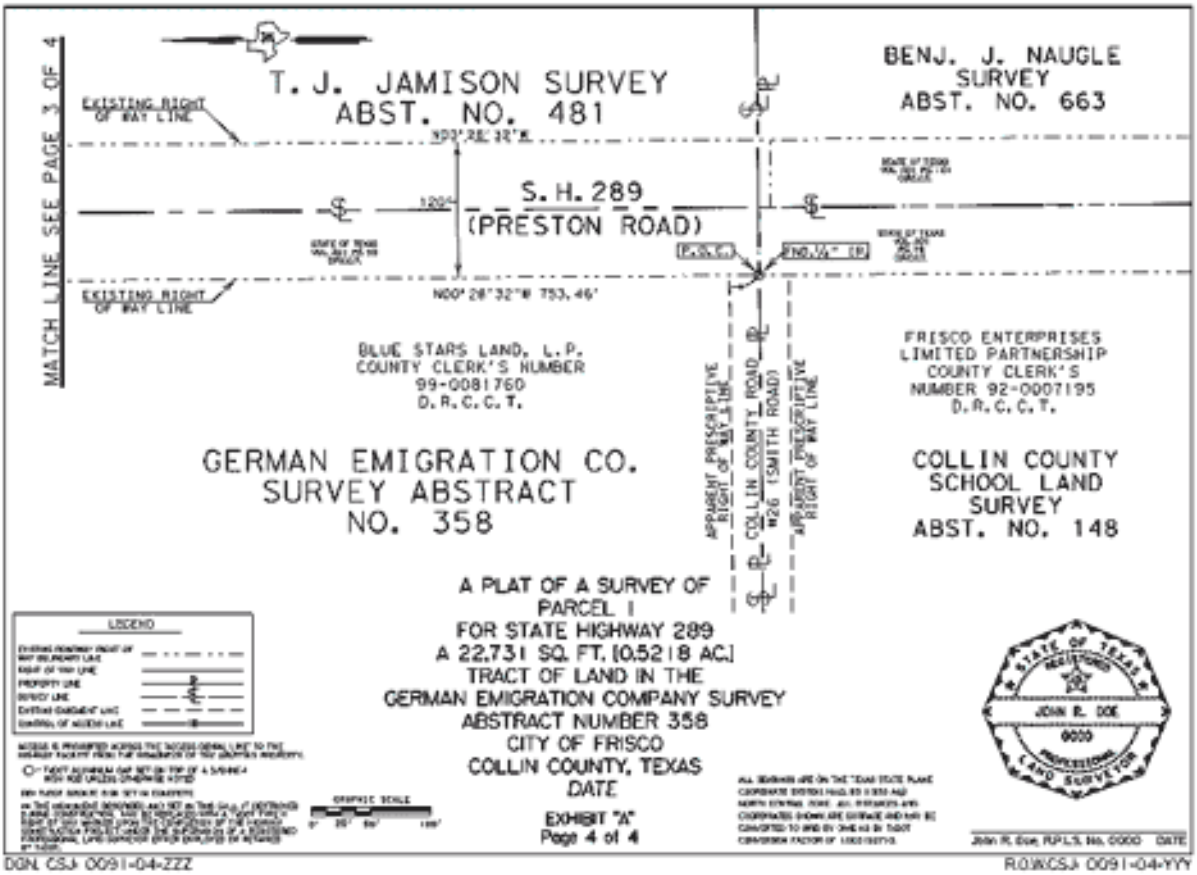

Figure 5-2. Sample Plat Exhibit A.

Exhibit A, Page 4 of 4

ROW Sample Plat Parcel Exhibit B

EXHIBIT "B"

County:	**Collin**	**Page 1 of 3 Pages**
Highway:	**State Highway 289**	**DATE/REVISION DATE**
RCSJ:	0091-04-YYY	
CCSJ:	0091-04-ZZZ	

Description for Parcel 2

BEING 25,637 square feet of land, more or less, in the German Emigration Company Survey, Abstract Number 358, City of Frisco, Collin County, Texas, and being part of a tract of land conveyed by deed to Blue Stars Land, L.P., a Texas limited partnership, as recorded in County Clerk's

Number 99-0081760, Volume 4448, Page 1857, Deed Records Collin County, Texas; said 25,637 square feet of land being more particularly described by the metes and bounds as follows:

COMMENCING at a ¼ inch iron rod found at the Northeast corner of a tract of land conveyed by deed to Frisco Enterprises Limited Partnership, a Michigan limited partnership, as recorded in County Clerk's Number 92-0007195, Deed Records Collin County, Texas, and the Southeast corner of said Blue Stars Land tract of land and in the Collin County Road Number 26, and being in the existing Western ROW line of State Highway Number 289;

THENCE North 00 degrees 28 minutes 32 seconds West along the existing Western ROW line of State Highway Number 289 for a distance of 444.14 feet to a 5/8 inch iron rod with TxDOT aluminum cap set in the new Western ROW line of State Highway Number 289 at the POINT OF BEGINNING;**

THENCE North 09 degrees 27 minutes 49 seconds West along the new Western ROW line of State Highway Number 289 for a distance of 328.44 feet to a 5/8 inch iron rod with TxDOT aluminum cap set at an angle point;**

THENCE North 04 degrees 46 minutes 35 seconds West along the new Western ROW line of State Highway Number 289 for a distance of 278.12 feet to a 5/8 inch iron rod with TxDOT aluminum cap set in the common line of said Blue Stars Land tract of land and a tract of land conveyed by deed to 183 Land Corporation, a Texas corporation, as recorded in County Clerk's Number 97-0083361, Volume 4009, Page 2535, Deed Records Collin County, Texas;

THENCE North 85 degrees 02 minutes 17 seconds East along the common line of said Blue Stars Land tract of land, and said 183 Land Corporation tract of land for a distance of 72.30 feet to the Southeast corner of said 183 Land Corporation tract of land and the Northeast corner of said Blue Stars Land tract of land and being in the existing Western ROW line of State Highway Number 289;

Exhibit B, Page 1 of 3

Description for Parcel 2

THENCE South 00 degrees 29 minutes 32 seconds East along the existing Western ROW line of State Highway Number 289 for a distance of 298.08 feet to an angle point;

THENCE South 00 degrees 28 minutes 32 seconds East along the existing Western ROW line of State Highway Number 289 for a distance of 309.32 feet to the POINT OF BEGINNING and containing 25,637 square feet [0.5886 Acres] of land, more or less.

** The monument described and set in this call, if destroyed during construction, may be replaced with a TxDOT Type II ROW Marker upon the completion of the highway construction project under the supervision of a RPLS, either employed or retained by TxDOT.

Access is allowed to the highway facility from the remainder of the abutting property.

All bearings are based on the Texas Coordinate System of 1983 (1993 Adj.), North Central Zone. All coordinates shown are surface and may be converted to grid by dividing by the TxDOT conversion factor of 1.000152710.

_____

John R. Doe, R.P.L.S. Date

Texas Registration No. 0000

RPLS SEAL

Super Survey Company Inc.

0000 W. Survey Ave

Anytown, Texas 00000

Ph. 000-000-0000

Exhibit B, Page 2 of 3

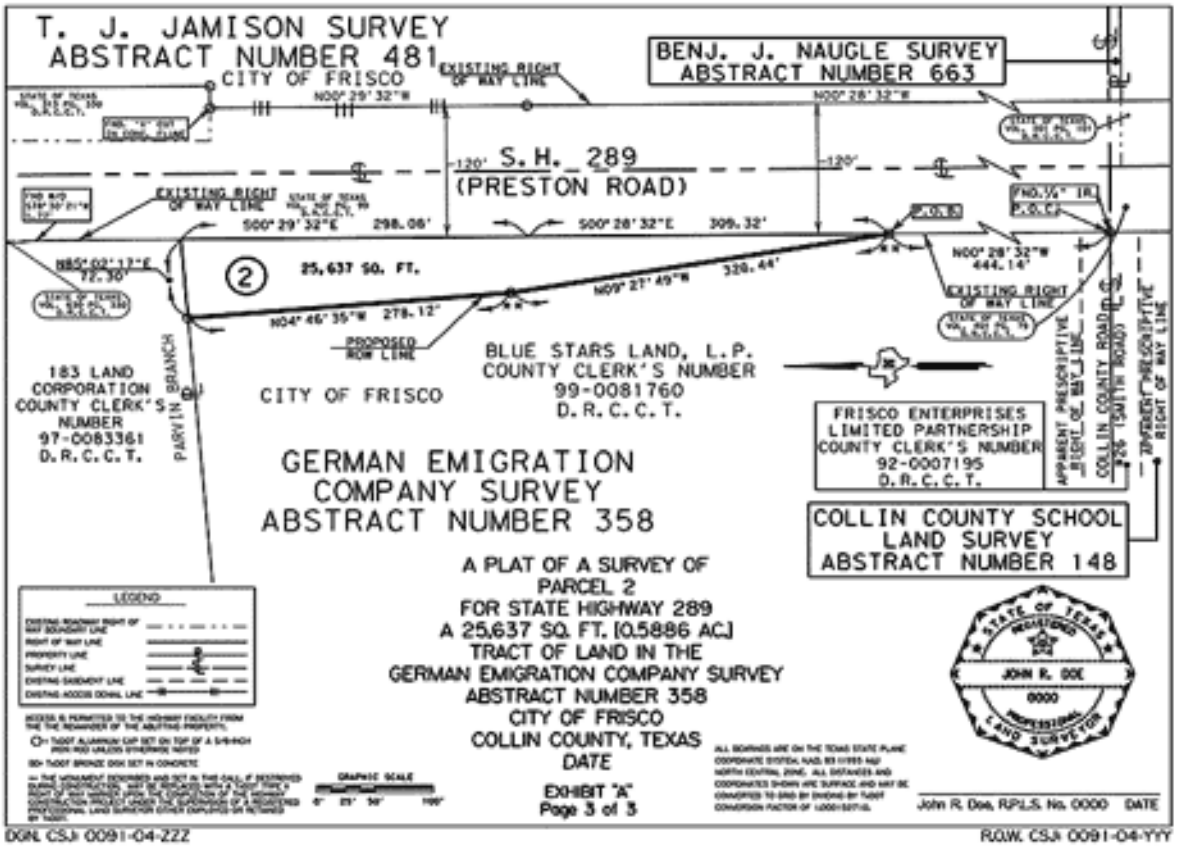

Figure 5-3. Sample Plat Exhibit B.

Exhibit B, Page 3 of 3

ROW Sample Plat Parcel Exhibit C

EXHIBIT "C"

County:	**Collin**	**Page 1 of 3 Pages**
Highway:	**State Highway 289**	**DATE/REVISION DATE**
RCSJ:	0091-04-YYY	
CCSJ:	0091-04-ZZZ	

Description for Parcel 3AC

BEING a Denial of Access Line delineating a denial of access to the transportation facility from the adjacent property along the common boundary of State Highway 289 as conveyed by deed to the State of Texas, as recorded in Volume 313, Page 330, Deed Records of Collin County, Texas, and a tract of land conveyed by deed to Preston 380/153 Venture, as recorded in County Clerk's Number 98-0005379, and in Volume 4082, Page 0073, Deed Records of Collin County, Texas, and being

located in the T. J. Jamison Survey, Abstract Number 481, Collin County, Texas; said Denial of Access Line being more particularly described by the metes and bounds as follows:

COMMENCING at a 3/4 inch iron rod found at the Western most Northwest corner of said Preston 380/153 Venture tract of land and the Southwest corner of a tract of land conveyed by deed to Bear Trap Partnership Fund, LTD., as recorded in County Clerk's Number 97-0025472, and in Volume 3882, Page 500, Deed Records of Collin County, Texas, and in the existing Eastern ROW line of State Highway Number 289;

THENCE South 02 degrees 58 minutes 28 seconds West along the existing Eastern ROW line of said State Highway Number 289 for a distance of 401.83 feet to a 5/8 inch iron rod with TxDOT aluminum cap set at an angle point in the existing Eastern ROW line of State Highway Number 289;**

THENCE South 00 degrees 29 minutes 32 seconds East along the existing Eastern ROW line of State Highway Number 289 for a distance of 130.00 feet to a 5/8 inch iron rod set at the POINT OF BEGINNING of the Denial of Access Line;

THENCE South 00 degrees 29 minutes 32 seconds East along the existing Eastern ROW line of State Highway Number 289 (140.00 feet wide ROW) and along the Denial of Access Line for a distance of 120.00 feet to a 5/8 inch iron rod with TxDOT aluminum cap set at the end of this Denial of Access Line and being an angle point in the existing Eastern ROW line of State Highway Number 289 from which a found "X" cut in concrete bears South 89 degrees 30 minutes 28 seconds West a distance of 20.00 feet;**

Exhibit C, Page 1 of 3

** The monument described and set in this call, if destroyed during construction, may be replaced with a TxDOT Type II ROW Marker upon the completion of the highway construction project under the supervision of a RPLS, either employed or retained by TxDOT.

Access is prohibited across the "Denial of Access Line" to the highway facility from the remainder of the abutting property.

All bearings are based on the Texas State Plane Coordinate System, N.A.D. 83 (1993 Adj.), North Central Zone. All coordinates shown are surface and may be converted to grid by dividing by the TxDOT conversion factor of 1.000152710.

_____

John R. Doe, R.P.L.S. Date

Texas Registration No. 0000

RPLS SEAL

Super Survey Company Inc.

0000 W. Survey Ave

Anytown, Texas 00000

Ph. 000-000-0000

Exhibit C, Page 2 of 3

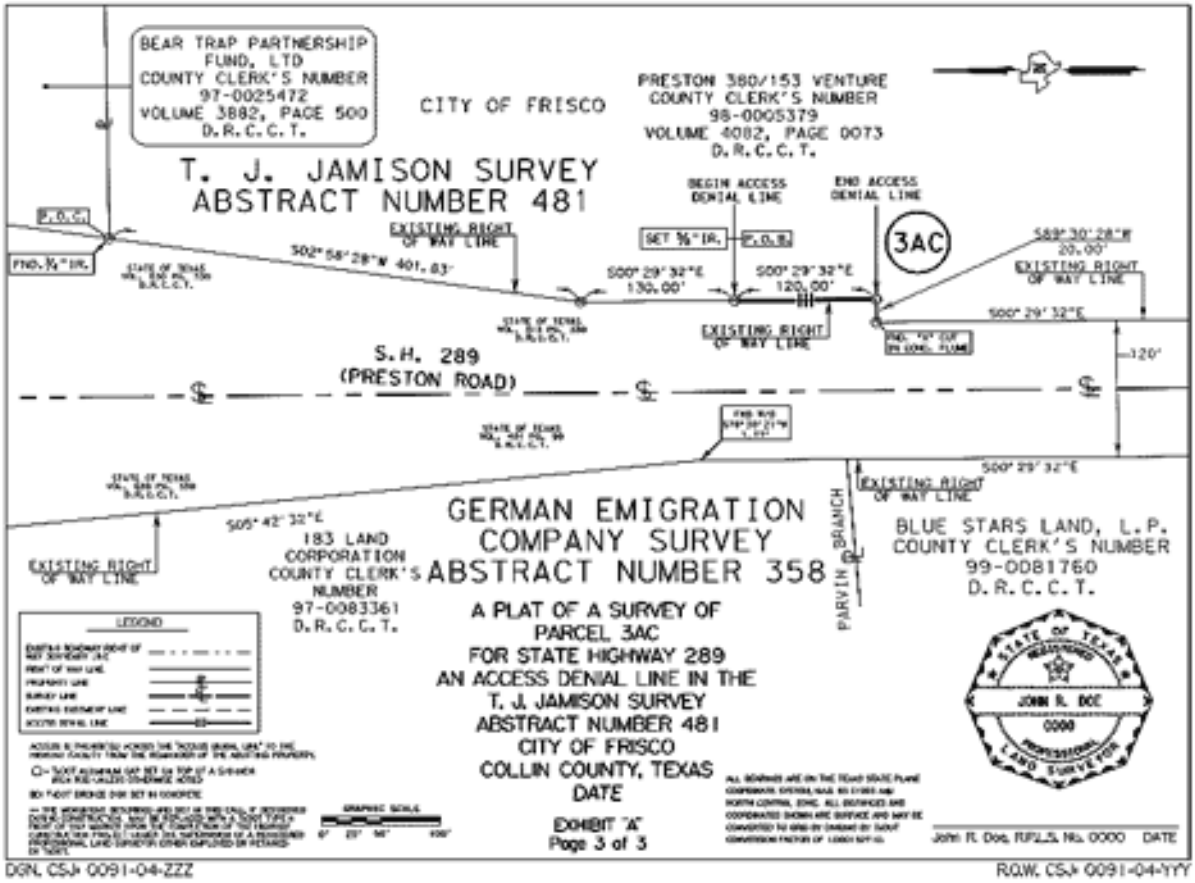

Figure 5-4. Sample Plat Exhibit C.

Exhibit C, Page 3 of 3

RCSJ: 0248-02-058 (ROW)

Property Description for Parcel 10

BEING 6.4792 acres of land situated in both the Gordon Dees Survey, Abstract No. 38, Camp County, Texas, and being out of that certain called 40 acre and 32 acre tracts or parcels of land described in a deed from Woodrow W. Stodghill and wife, Willie M. Stodghill to Ersel N. Young and wife, Dorothy A. Young dated October 8, 1979, and recorded in Volume 178, Page 106 of the

Deed Records of Camp County, Texas, and also being West of and adjacent to a certain called 2.55 acre tract or parcel of land described in a deed to the State of Texas recorded in Volume 94, Page 288, of the Deed Records of Camp County, Texas, said 6.4792 acre tract to be more particularly described by metes and bounds as follows:

BEGINNING at a Type II Concrete ROW Monument with Bronze Disk Set for the Northwest corner of the herein described tract, located on the East boundary line of a certain called 6.0 acre tract or parcel of land described in a deed to Ersel N. Young and wife, Dorothy A. Young, and recorded in Volume 188, Page 715, of the Deed Records of Camp County, Texas, the existing South right-of-way line of County Road 2116, and the proposed West right-of-way line of U.S. Highway 271, said point of beginning being located North 23° 06' 08" West, a distance of 345.19 feet from a Fence Corner Found for the Southeast corner of said called 6.0 acre Young tract, and also being located 784.92 feet left of and at a right angle from the proposed survey centerline of U.S. Highway 271, hereinafter referred to as the "Survey Centerline", at Survey Centerline Station 579+49.70, being located at the coordinates of 7,086,794.7529 feet North and 3,051,741.6186 feet East;

Exhibit D, Page 1 of 5

ROW Sample Plat Parcel Exhibit D

THENCE North 68° 17' 10" East, along the most northerly North boundary line of said called 40 acre Young tract, and the existing South right-of-way line of County Road 2116, a distance of 406.70 feet to a ½" Iron Rod Set, with a yellow cap stamped "BWR", being the Point of Curvature of a curve to the left;

THENCE in a Northeasterly direction, along the existing South right-of-way line of said County Road 2116, also being the most northerly North boundary line of said called 40 acre Young tract, an arc distance 89.52 feet with the above mentioned curve to the left, whose radius is 839.62 feet, whose central angle is 06° 06' 32", and whose long chord is North 65° 13' 54" East, a distance of 89.48 feet, to a ½" Iron Rod Set, with a yellow cap stamped "BWR", being the Point of Curvature of a curve to the right;

THENCE in a Northeasterly direction, along the existing South right-of-way line of said County Road 2116, also being the most Northerly North boundary line of said called 40 acre Young tract, an arc distance 47.99 feet with the above mentioned curve to the right, whose radius is 332.30 feet, whose central angle is 08° 16' 29", and whose long chord is North 66° 18' 52" east, a distance of 47.95 feet, to a ½" Iron Rod Set, with a yellow cap stamped "BWR";

THENCE North 70° 27' 07" east, along the most northerly North boundary line of said called 40 acre Young tract, a distance of 184.13 feet, to the intersection of the existing South right-of-way line of said County Road 2116 and the existing West right-of-way line of U.S. Highway 271, to a ½" Iron Rod Set, with a yellow cap stamped "BWR", being 61.28 feet left of Survey Centerline Station 580+27.51;

THENCE South 11° 37' 05" east, along the existing West right-of-way line of U.S. Highway 271 and the east boundary line of said called 40 acre Young tract, a distance of 423.57 feet to a Type I Concrete ROW Monument Found, being 90.42 feet left of Survey Centerline Station 576+05.26;

THENCE South 13° 19' 05" east, along the existing West right-of-way line of U.S. Highway 271 and the east boundary line of said called 40 acre Young tract and the east boundary line of said called 32 acre Young tract, a distance of 1000.80 feet, to a Type I Concrete ROW Monument Found;

Exhibit D, Page 2 of 5

THENCE South 18° 52' 0" east, along the existing West right-of-way line of U.S. Highway 271 and the east boundary line of said called 32 acre Young tract, a distance of 667.95 feet to a ½" Iron Rod Set, with a yellow cap stamped "BWR", at the Southwest corner of said called 32 acre Young tract and the Northeast corner of a certain called 100.00 acre tract or parcel of land described in a deed to Forrest G. Rodgers, dated April 21, 1965, and recorded in Volume 91, Page 354, of the Deed Records of Camp County, Texas, being 92.15 feet left of Survey Centerline Station 559+38.38;

THENCE South 57° 39' 43' West, along the South boundary line of said called 32 acre Young tract and the North boundary line of said called 100.00 acre Rodgers tract, a distance of 13.41 feet to a ½" Iron Rod with a yellow cap stamped "BWR" Set on the proposed West ROW line and "Denial of Access Line" of US 271, being 105.00 feet left of Survey Centerline Station 559+34.52;

THENCE North 15° 35' 55" West, along the proposed West right-of-way line and "Denial of Access Line" of U.S. Highway 271, a distance of 65.48 feet to a Type II Concrete ROW Monument with Bronze Disk Set, being 105.00 feet left of Survey Centerline Station 560+00.00;

THENCE North 21° 52' 34" West, along the proposed West right-of-way line and "Denial of Access Line" of U.S. Highway 271, a distance of 503.02 feet to a Type II Concrete ROW Monument with Bronze Disk Set, being 160.00 feet left of Survey Centerline Station 565+00.00;

THENCE North 16° 04' 34" West, along the proposed West right-of-way line and "Denial of Access Line" of U.S. Highway 271, a distance of 600.02 feet to a Type II Concrete ROW Monument with Bronze Disk Set, being 165.00 feet left of Survey Centerline Station 571+00.00;

THENCE North 39° 25' 41" West, along the proposed West right-of-way line and "Denial of Access Line" of U.S. Highway 271, a distance of 655.92 feet to a Type II Concrete ROW Monument with Bronze Disk Set, being 430.00 feet left of Survey Centerline Station 577+00.00;

THENCE North 14° 10' 00" West, along the proposed West right-of-way line and "Denial of Access Line" of U.S. Highway 271, a distance of 200.06 feet to a Type II Concrete ROW Monument with Bronze Disk Set, being 425.00 feet left of Survey Centerline Station 579+00.00;

THENCE South 82° 26' 04" West, along the proposed West right-of-way line of U.S. Highway 271, a distance of 363.47 feet to the PLACE OF BEGINNING and containing 6.4792 acres of land.

Exhibit D, Page 3 of 5

Notes:

All bearings and coordinates shown are surface coordinates based on the Texas Coordinate System of 1983 (NAD 83 HARN), North Central Zone 4202, as provided by TxDOT, and can be converted to grid coordinates by dividing by a combined scale factor of 1.000145.

All referenced property distances and areas were taken from deed records acquired from the Camp County Real Property Records.

Access is prohibited across the "Denial of Access Line" to the transportation facility from the adjacent property.

I,_____, RPLS, do hereby certify that this boundary description represents the results of a survey made on the ground from October 2003 to November 2003.

NAME	**RPLS 0000**	**DATE**
Company		
701 East Main Street		
Atlanta, Texas 75551-1210	Phone:	

Exhibit D, Page 4 of 5

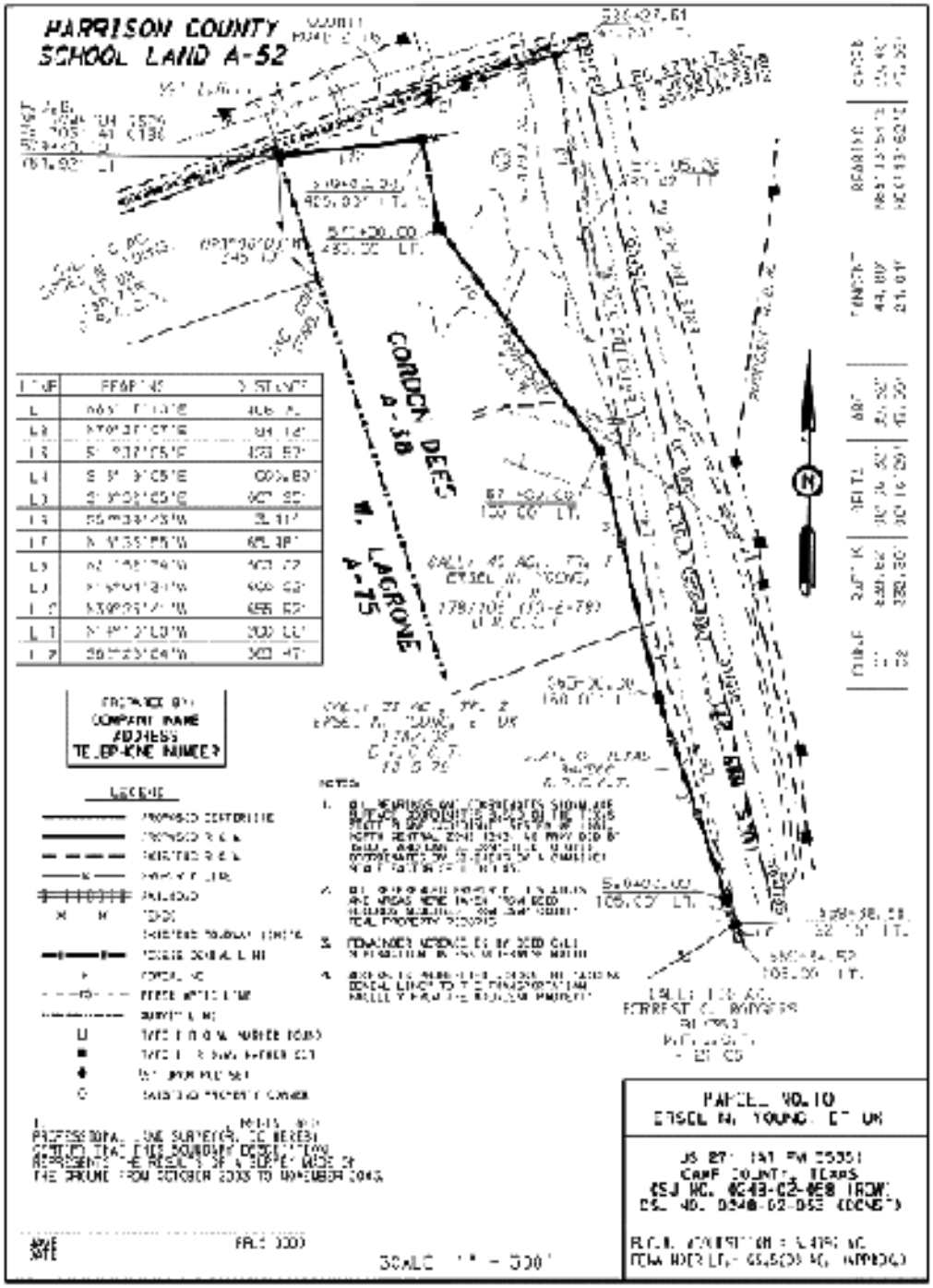

Figure 5-5. Sample Plat Exhibit D.

Exhibit D, Page 5 of 5

Public Roads and Alleys

Existing public roads or alleys that abut or pass through a ROW parcel need to be investigated carefully to determine the source of title. If a recorded instrument such as a ROW deed, dedication by subdivision plat or donation deed can be found, this title should be shown on the ROW map and parcel plats.

If no record can be located, a note should be added stating the existing ROW shown was determined by occupation. If included in the adjacent landowner's deed, the existing ROW should be included in the parcel area but cannot be included for payment.

For existing roadway, areas that do not appear in any conveyance to a public entity or adjacent property owner, a quitclaim deed from the local public agency occupying the facility should be obtained and filed with the County Clerk.

Original Submission to a District

The surveyor should complete and submit preliminary maps, parcel plats, and property descriptions, surveyor reports, and closure sheets to the district for review. The district will determine the size, type, and number of submittals to be used for review purposes. These maps shall be prominently marked as PRELIMINARY.

The district surveyor or appropriate personnel must review the submission for compliance with TxDOT policy and Texas Board of Professional Land Surveyors (TBPLS) standards. The design engineer or appropriate personnel must review the map for compliance with the design schematic and to verify that the area to be acquired and all easements are adequate to build the transportation facility.

Finalizing Maps after Project Acquisition

Once ROW map revisions are complete, all new ROW is acquired, and all documents are recorded, send a half-size original of the ROW map marked "FINAL MAP" on bond paper and a completed electronic graphics file (if available), including all revisions, to the ROW Division for the permanent file. For the final map to be complete, it must contain:

- all project numbers
- grantors' names
- areas of acquired parcels
- recording information
- "U" number assigned for utility adjustments and a table on the **title sheet** listing all utilities in the project and a cross-reference to the parcel where they occur.

- if the utility is reimbursable the utility easement or ROW record citation shall be given with volume and page

- names of the utility owner(s) and graphic depiction of the easement or ROW on the ROW Map Plan Sheet
- all signature blocks completed and
- graphics file (if available) including all revisions.

ROW Maps for Off-System Projects

The need for ROW maps on off-system projects will be determined by the complexity of the project and will be at the district's discretion. Property descriptions must be prepared based on the Texas State Plane Coordinate System and as described in the property descriptions section of this chapter. Submission of ROW maps for off-system projects to the ROW Division is not required since they will not be added to the state highway system.

Standardized MicroStation Graphic Files

See the *TxDOT ROW Manual Volume 1 - Procedures Preliminary to Release* for specific ROW mapping graphic standards.

Due to the multitude of formats used in the consulting industry, TxDOT has recognized a need for standardization in the creation and manipulation of MicroStation Graphic Files. The following guidelines should be used to assist MicroStation® users in the development of graphic files that are compatible with TxDOT's MicroStation® files.

1. BASE FILES — All geometry and line work is done in this file. Points, property lines, centerline information, etc. should be done on assigned levels as shown on the level map. Any text/labels in this file should be for the users own use on separate levels from the line work so that they may be turned off when the base file is used as a reference file for a sheet (map sheet) file.
2. TOPO FILES — No work may be done in these files. The user may turn on or off any level as required in a topographic file when it is used as a reference file. When used as a reference file all line work should be shown as zero line weight, dotted line symbology and white or gray in color.
3. SHEET FILES (MAP SHEETS) — These are the files where the drafting work is done. Text/Labels, whole property sketches, enlarged details, north arrow, and bar scale are shown here. The base file and topographic file are referenced to the sheet file. In addition, other appropriate files showing new buildings and/or utilities shall be referenced. Then the appropriate levels are turned on or off in both of these reference files to show the line work and topographic features that will appear on the finished plan sheet. A TxDOT standard size plan sheet (22" X 34") must be used to define the working area. The sheet cell may be moved or rotated as required. DO NOT MOVE, ROTATE, COPY OR IN ANY WAY ALTER THE ATTACHED REFER-

ENCED BASE OR TOPOGRAPHIC FILES FOR USE IN YOUR SHEET FILES. (Users may, for their own use, rotate the view that they are working in.) After a TxDOT standard size plan sheet cell has been positioned to show the appropriate area, north arrow, bar scale, text and labeling are added along with any whole property sketches and/or enlarged details as required. When numbering map sheets always begin with number 2, as sheet number 1 is reserved for the title sheet (see ROW Mapping above). The map sheet is "finished" by fencing the appropriate area and performing a clip boundary operation on the reference base and topographic files.

4. TITLE SHEET FILES — A standard TxDOT title sheet cell must be used. This sheet contains the following information: Data entry fields for County name; Highway number; Project number (if needed); Construction and ROW C.S.J. number(s); Project limits description; length in feet and miles; a legend of standard utility and mapping symbols; Utility Table; and, when appropriate, a Vicinity map. The title sheet will always be numbered as sheet one of the set of maps (see ROW map title sheet).
5. CELLS — A cell library containing TxDOT standard cells is available on request for users. The cell library must be used to ensure compatibility with TxDOT graphic standards.
6. TEXT/LABELS — See the *TxDOT ROW Manual Volume 1 - Procedures Preliminary to Release* for TxDOT standard size, font, line spacing and weight for text and labels.
7. LINE WEIGHT and LINE SYMBOLOGY — See the TxDOT ROW Manual Volume 1 - Procedures Preliminary to Release for a chart of TxDOT standard line weight and line symbology.
8. WHOLE PROPERTY SKETCHES AND ENLARGED DETAILS — These should always be created as "saved views," referenced from the base file to the sheet file. This will ensure that any changes or updates made in the base file will always be accurately reflected in the saved view(s). All labeling on the saved view(s) should be done in the appropriate sheet file.
9. LEVEL MAP — See the TxDOT ROW Manual Volume 1 - Procedures Preliminary to Release for information on TxDOT standard levels for horizontal alignment, proposed and existing ROW lines, property lines, found points, survey lines, county lines, city limit lines, text/labels, easements, platted/subdivision properties, etc. Any level not designated for use on the level map sheet may be used at the MicroStation® user's discretion.

NOTE: A copy of your completed project level map sheet must accompany any electronic file sent to TxDOT.

Chapter 6 — Aviation Surveying

Contents:

Section 1 — Roles and Responsibilities

Section 2 — Avigation Easements - Various Samples

Section 1 — Roles and Responsibilities

Fee Simple Parcels and Avigation Easements on Texas Airport Improvement Projects

Land surveys needed for the acquisition of easements and fee simple property in conjunction with airport improvement projects should be in accordance with the following guidelines.

Aviation Division's Role

- Set up meeting with district personnel to review all pertinent information needed to create an extension to existing runway.
- Supply all pertinent information needed for the improvement project, showing the proposed areas to be acquired, easements, and/or fee simple parcels.
- Answer questions that arise during the surveying process.
- Supply runway end elevation, latitude, and longitude if available.
- Provide preliminary title commitment information with deeds of parent tract.
- Provide Right-of-Entry Permission forms from the property owner(s) involved.

TxDOT District's Role

- Prepare and provide an executed **work order** with the surveyor to the Aviation Division.
- Oversee survey work for the Aviation Division.
- Supply surveyor with any needed information and/or guidance.

Services to be Provided by Surveyor

- Tie latitude and longitude, if available, to NAD 83 Datum.
- Use equipment capable of meeting or exceeding the accuracy standards in the current TSPS "Manual of Practice for Land Surveying in Texas," in addition to the normally required devices for surveying.
- Prepare all parcel surveys to conform to Category 1A, Condition IV (Rural), suitable for title insurance.
- Create work roll for field crew and office technicians to begin analysis.
- Tie surveys into the appropriate runway end.
- Set monuments for all parcels and easements on the ground (legal descriptions/sketches will reference the monuments set or found to conform to Category 1A suitable for title insurance).

- Include extended centerline of runway with elevations at grade breaks and every 100-foot station on profiles (as shown on attached examples).
- Show Plan & Profiles on survey sketch for avigation easements (see examples: Figure 6-1 and the Sample Format Legal Description in Section 2), with heights of trees, natural ground and proposed height limits of easements.
- Determine mean sea level elevations for the avigation easement imaginary plane and shown on the plat in plan and profile view for each avigation easement parcel.
- Show the size of any remainder tract created when surveying a partial acquisition.
  - This area may be calculated using deed information and the actual field data.
  - An additional sketch will depict the physical relationship of the partial acquisition to the parent tract.
- Use a scale that will allow presentation on an 8 ½” x 14” paper, unless another size is required for legibility.
  - There must be mutual agreement prior to using a larger paper size.
- Furnish four (4) original certified field note descriptions and sketches for each parcel and easement, along with one (1) copy of a traverse closure sheet for each.

Legal Descriptions of Survey Sketches

See examples for legal descriptions of survey sketches of avigation easements and easement forms in the next section.

Section 2 — Avigation Easements - Various Samples

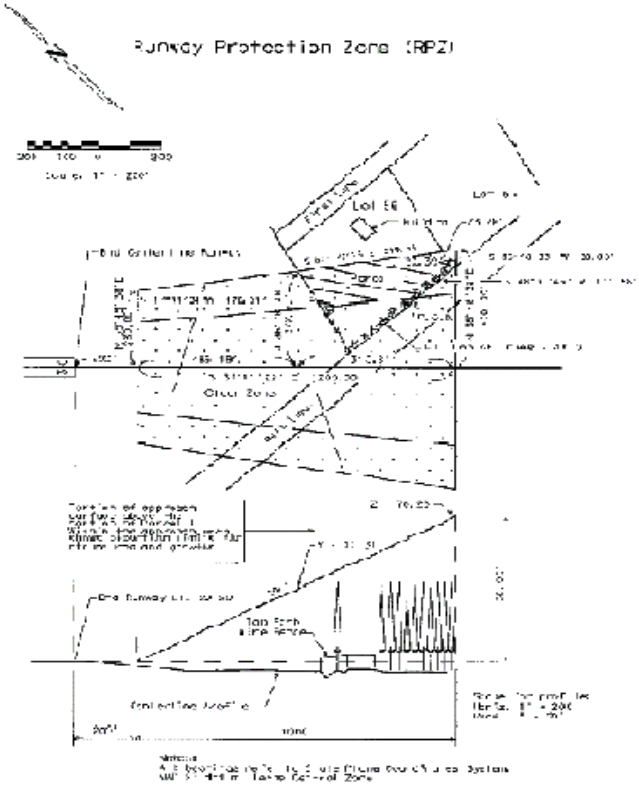

Figure 6-1. Sample Avigation Easement.

Legal Description of Survey Sketch

SAMPLE FORMAT

AVIGATION EASMENT STATE OF TEXAS KNOW	)(	ALL BY THE PRESENTS
COUNTRY OF _____	)(	

WHEREAS:_____*name*_____of the County of _____, State of Texas, hereinafter referred to as Grantors, whether one or more, are the legal owners in fee of that certain parcel of land more particularly described as follows:

See Attached Exhibit “A” (Legal Description)

NOW THEREFORE, in consideration of the total sum of _____ dollars ($x,xxx.xx) and other good and valuable consideration in hand paid, the receipt and sufficiency of which is hereby acknowledged, the Grantors, for themselves, their heirs, administrators, executors, successors and assigns, do hereby grant, bargain, sell and convey unto *City/County of * hereinafter referred to as Grantee, its successors and assigns, for the use and benefit of the public, as easement and right of way, appurtenant to *name airport*, hereinafter referred to as Airport, for the unobstructed use and passage of all types of aircraft whether now in existence or hereafter manufactured and developed, to include, but not be limited to, jet aircraft, propeller driven aircraft, civil aircraft, military aircraft, commercial aircraft, helicopters and all types of aircraft or vehicles now in existence or hereafter developed, regardless of existing of future noise levels, for the purpose of transporting persons or property through the air by whomsoever owned or operated, in and through the air space above Grantors property above an imaginary plane rising and extending in a generally _____ direction over Grantors property, said imaginary plane running from approximately _____ feet Mean Sea level above Point _____ on Exhibit _____ at the rate of one foot vertically for each _____ feet horizontally to approximately feet Mean Sea level above point _____ on Exhibit _____, to an infinite height above said imaginary plane, to an infinite height above Grantors property, as well as in the vicinity of Grantors property, with such use and passage to be unlimited as to frequency, type of aircraft and proximity.

Said easement shall be appurtenant to and for the benefit of the Airport, including any additions thereto wherever located, hereafter made by Grantee or its successors and assigns, guests, and invites, including any and all persons, firms or corporations operating aircraft to or from the Airport.

Said easement and burden, together with all things which may be alleged to be incident to or resulting from the use and enjoyment of said easement, including, but not limited to, the right to cause in all air space above or in the vicinity of the surface of Grantors property such noise, vibrations, flume, deposits or dust or other particulate matter; fuel particles (which are incidental to the normal operation of said aircraft), fear interference with sleep and communication, and d any and all other effects that may be alleged to be incident to or caused by the operation of aircraft over or in the vicinity of Grantors property or in landing at or taking off from, or operating at or in said Airport; and Grantors do hereby fully waive remise and release any right or cause of action which they may now have or which they may have in the future against Grantee, its successor and assigns, due to such noise vibrations, fumes, dust, fuel particles and all other effects that may be caused or may have been caused by the operation of aircraft landing at, or taking off from, or operating at or on said Airport.

The easement and right of way hereby granted includes the continuing right of Grantee to prevent the erection or growth upon Grantors property of any buildings structure, tree or other object extending into the air space above the aforesaid imaginary plane; and to remove from said air space, or at the sole option of Grantee, as an alternative, to mark and light as obstructions to air navigation, any such building, structure, tree or other objects now upon, or which in the future may

be upon Grantors property, together with the right of ingress and egress over Grantors remaining property for the above purpose.

TO HAVE AND TO HOLD said easement and right of way, and all rights appertaining thereto unto Grantee, its successors and assigns, until said Airport shall be abandoned and shall cease to be used for the consideration herein above set forth, the Grantors for themselves, their heirs, administrators, executors, successors and assigns, do hereby agree that for and during the life of said easement and right of way, Grantors will not hereafter erect, permit the erection or growth of; or permit or suffer to remain upon Grantors property any building, structure, tree or other object extending into the aforesaid prohibited air space, and that they shall not hereafter use or permit or suffer the use of Grantors property in such a manner as to create electrical interference with radio communications between any installation upon said Airport and aircraft, or as to make it difficult for flyers to distinguish between airport lights and others, or to permit any use of the Grantors land that causes a discharge of fumes, dust or smoke so as to impair visibility in the vicinity of the Airport or as otherwise to endanger the landing, taking off or maneuvering of aircraft. Grantors further waive all damages and claims for damages caused or alleged to be caused by or incidental to such activities.r public purposes.

IN WITNESS WHEREOF Grantors have set their hands and seals this _____ day of _____, 20

_____
(owner signs on line)

_____
(owner name printed/typed on this line)

(add lines for each additional owner as required)

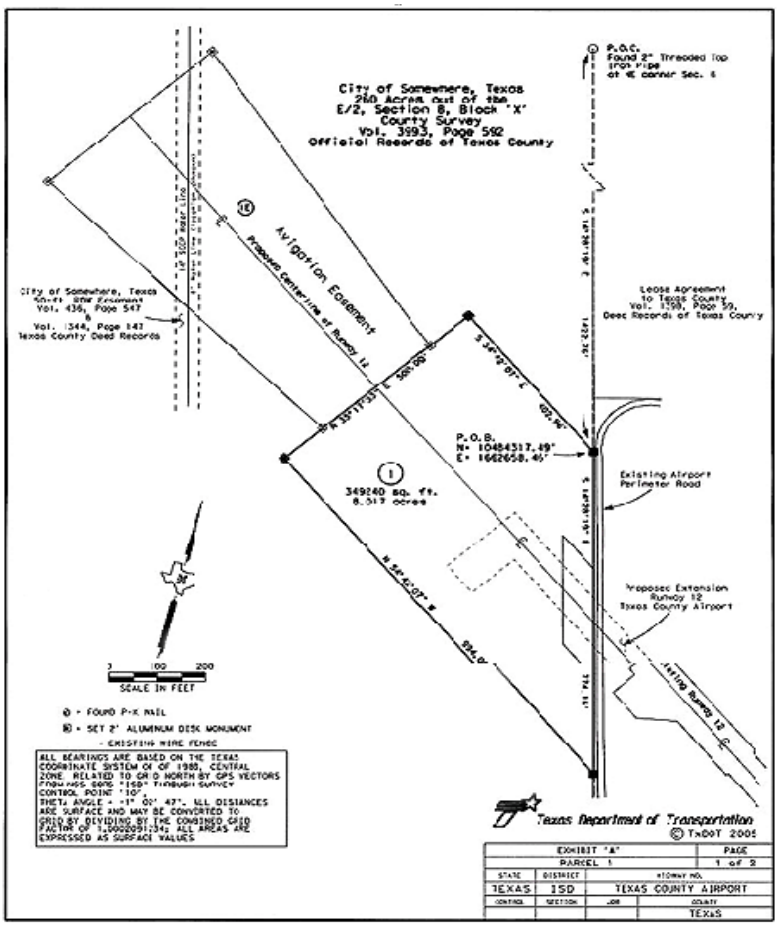

Figure 6-2. Sample Avigation Easement.

Field Notes

CLINTON AVIGATION EASEMENT

FIELD NOTES

DESCRIBING THE BOUNDARIES OF AN AVIGATION EASEMENT UPON AND ACROSS A 260(±) ACRE TRACT OF LAND OUT OF THE A.B. FRIENDS SURVEY, DESCRIBED AS TRACT 1 IN A DEED TO CLINTON RECORDED IN VOLUME 222, PAGE 666 OF THE TEXAS COUNTY DEED RECORDS; SAID EASEMENT BEING MORE PARTICULARLY DESCRIBED AS FOLLOWS:

BEGINNING for reference at an iron rod set at the Northeast corner of the aforesaid 260 acre tract;

THENCE S 16° 21' 23 W, 4,118.13' to an iron rod set in the East line of said 260 acre tract at the POINT OF BEGINNING of the herein described 16.23 acre easement;

THENCE S 16° 21' 23" WI a distance of 1,314.39' to an iron rod set;

THENCE N 82° 07' 43" W, a distance of 544.02' to an iron rod set;

THENCE N 16° 24' 08" 5, a distance of 1,381.96' to an iron rod set;

THENCE S 07° 52' 17" v a distance of 66.67' to an iron rod set;

THENCE S 82° 07' 43" E, a distance of 532.96' to the POINT OF BEGINNING, containing 16.23 acres, more or less.

TIM SURVEYOR

Registered Professional Land Surveyor # XXXX

Date: 6/1/2004

<RPLS SEAL>

Avigation Easement

TIM SURVEYOR

Registered Professional Land Surveyor

P. O. Box 123 Somewhere, Texas 12345

(555) 555-5555

EXHIBIT A

PARCEL NUMBER 4I

AVIGATION EASEMENT

RAILROAD COMPANY SURVEY, A-1

TEXAS COUNTY, TEXAS

Being a 0.871 acre (37956.9 sq. if) avigation easement situated in a 2.869 acre tract of land which was conveyed to Laura Ingalls and Herman Melville as recorded in Volume 555, Page 999, Texas County Deed Records (TCDR), and being situated in the SW 1/4 of Section 7, Block "B" East of the Big Winding River, Railroad Company Survey, A-1, Texas County, Texas, said 0.871 acre avigation easement being more particularly described by metes and bounds as follows;

COMMENCING FOR REFERENCE at a fence corner post found at the northeast corner of the above mentioned 2.869 acre tract, same being the southeast corner of a 0.5 acre tract which was conveyed from Ronald Reagan to Donald Trump, by an instrument recorded in Volume 222, Page 111, TCDR, said fence corner post also being on the west boundary line of a 6.69 acre tract which was conveyed from Walter Mondale, et ux to George Bush, et ux by an instrument recorded in Volume 222, Page 444, TCDR

THENCE N 89° 23' 08" W, along the common line between said Ingalls and Trump tracts, 37.02 feet to a 1/2" iron rod set, and the PLACE OF BEGINNING of the herein described tract;

THENCE S 6° 18' 00" W, a distance of 304.39 feet to a 1/2" iron rod set for corner, on the south boundary line of said 2.869 acre tact, same being the north boundary line of a called 2 acre tract which was conveyed from Forrest Gump, et ux to Jimmy Carter, et ux by an instrument recorded in Volume 888, Page 333, TCDR, a fence corner post found at the southeast corner of said 2.869 acre tract bears, N 89° 54' 23" E, 65.76 feet,

THENCE S 89° 54' 23" W, along the common line between said Ingalls and Carter tracts, 125.16 feet to a 1/2" iron rod set for corner;

THENCE S 89° 54' 23" W, along the common line between said Ingalls and Carter tracts, 125.16 feet to a 1/2" iron rod set for corner;

THENCE N 6° 18, 00" E, a distance of 305.94 feet to a 1/2" iron rod set for corner on the north boundary line of said 2.869 acre tract, same being the south boundary line of a 0.5 acre tract which was conveyed from Karl Malone, et ux by an instrument recorded in Volume 535, Page 888, TCDR, same being the north boundary line of said Ingalls 2.869 acre tract;

THENCE S 89º 23' 08" E along the south boundary line of said Malone tract, at 55.50 feet pass a fence corner post found at Malone's southeast corner, and continuing now along the south boundary line of the aforementioned Trump 0.5 acre tract, for a total distance of 124.39 feet to the PLACE OF BEGINNING and containing 0.871 acres (37956.9 sq. ft.) of land.

The bearings herein recited are based on the bearing of runway 13-31 as shown on a plan entitled "Airport Layout Plan" by Big Engineering Consulting Engineers dated June 2003.

To all parties interested in title to the premises surveyed, I do hereby certify that the above legal description and corresponding plat were prepared from public records and from an actual survey made on the ground under my supervision on April 20-24, 2004, and that same correctly reflects the facts as found at the time of said survey.

TIM SURVEYOR

Registered Professional Land Surveyor # XXXX

Date: 5/1/2004

<RPLS SEAL>

Avigation Easement

July 18, 1994

CITY OF SOMEWHERE

2.51 ACRES OF LAND (Revised 8/18/94)

PROPOSED AVIGATION EASEMENT

A. LOTTALAND GRANT, A-2

TEXAS COUNTY, TEXAS

All that certain lot, tract or parcel of laud being situated in the A. Lottaland Grant, A- 2, Texas County, Texas and being a part of the A. N. Smith tract as recorded in Volume 222, Page 555, Deed Records, Texas County, Texas and being more particularly described as follows;

BEGINNING at the SEC of a 2.371 acre tract deeded to the City of Somewhere as recorded in Volume 481, Page 93. Deed Records, said 2.371 acres being out of the Somewhere Industrial Foundation 20.571 acre tract recorded in Vol. 485, Page 420, and being on the NBL of the Thomas Jefferson tract;

THENCE N 88 deg. 50' 02" E along the SBL, of the 2.371 acre tract and the NBL of the Jefferson tract, a distance of 266.36 feet to this NEC and POINT OF BEGINNING and being the NWC of the Thomas Jefferson tract as recorded in Vol. 444, Page 666;

THENCE S 00 deg. 42' 20" E, a distance of 572.49 feet along this EBL and the WBL of said Jefferson tract;

THENCE N 89 deg. 45' 33" W, a distance of 220.61 feet;

THENCE N 05 deg. 57 03" E, a distance of 602.73 feet to this NWC, being on the SBL of Tract I, deeded to the City of Somewhere from A. N. Smith, recorded in Vol. 444, Page 111;

THENCE S 79 deg. 50' 02" E, along the SBL of the above referenced Tract I, a distance of 153.55 feet to the SEC of said Tract I and the SWC of the 2.371 acre tract, referenced above and the POINT OF BEGINNING, containing 2.51 acres.

I, Tim A. Surveyor, hereby certify this description was prepared from a survey made on the ground under my direction, in February and June, 2004, and accurately represents the results of said survey.

Witness my hand and seal this the 18th day of July 2004

TIM SURVEYOR

Registered Professional Land Surveyor # XXXX

<RPLS SEAL>

Field Notes

TIM SURVEYOR

Registered Professional Land Surveyor

P. O. Box 123 Somewhere, Texas 12345

(555) 555-5555

FIELD NOTES 2.493 ACRE TRACT

PROPOSED AVIGATION EASEMENT

All that certain 2.523 acre tract of land situated in the A. FIRST SURVEY, 4-3 of Texas County, Texas and being a part of a called 513.9 acre tract described in deed to A. N. Smith as recorded in Volume 936 Page 6532 of the Texas County, Deed Records, said tract being further described as follows;

BEGINNING at a bent 1 inch galvanized flat iron found on the East line of said called 513.9 acre tract and being called to be S 00º 33' 43" E 253.43 feet and S 01° 12' 46' E 283.56 feet from the Northeast corner of said 513.9 acre tract and being the Southeast corner of a called 4,212 acre tract described as the First Tract in deed from A.N. Smith to the City of Somewhere as recorded in Volume 234 Page 637 and being the Northwest corner of a called 25.636 acre tract described in deed to Thomas William Smith, et ux Linda F. Smith as recorded in Volume 234 Page 452 and being the Southwest corner of a called 5.245 acre tract described in deed to the City of Somewhere as recorded in Volume 525 Page 42 of the Deed Records, of Texas County, Texas;

THENCE S 10º 36' 24' E (bearing by solar observation) along the East line of said called 513.9 acre tract 284.52 feet to a 3/8 inch steel rod set for a corner;

THENCE N 35º 26' 52" W into said 513.9 acre tract 629.62 feet to a 3/8 inch steel rod set for corner;

THENCE N 05º 22' 49" E 625.35 feet to a 3/8 inch steel rod set on the South line or said called 4,212 acre tract;

THENCE S 82º 28' 35" E along the South line of said 4,212 acre tract 126.35 feet to the point of beginning and containing 2.523 acres of land.

I do hereby certify these held notes to be true and correct and to represent a ground survey completed March 5, 2005.

TIM SURVEYOR

Registered Professional Land Surveyor # XXXX

Date: 4/1/2005

<RPLS SEAL>

Chapter 7 — Construction Surveying

Contents:

Section 1 — Survey Checks

Section 2 — Locative and Construction Surveys

Section 1 — Survey Checks

Overview

It is not the intent of the Standing Committee on Surveying (SCOS) to develop a strict guideline of policy and procedures for project engineers, project managers, and construction inspectors to follow in the area of construction surveying. The SCOS is confident that each project (through the area engineer's office) within each of the 25 districts is being thoroughly managed and the committee does not intend to interfere.

Surveying Suggestions

The SCOS would like to offer a few suggestions that may aid a project manager/inspector in the management of his/her project, from a surveying perspective.

- The horizontal and vertical control for **ANY** project should be established by TxDOT surveying personnel or consulting surveying contracts within an individual district. The surveyors working for the subsequent construction contractor should be required to utilize that control to establish his/her own baselines/secondary control for the particular project.
- Periodic spot-checks of the contractor's completed surveying should be maintained. This should be accomplished by TxDOT surveyors or by an independent existing consulting surveyor under contract with TxDOT in that particular area within the district. These spot-checks are an excellent method of checking the contractor's work and alleviating undue pressure on the project manager/inspector.

The following checklist contains suggested checks to be utilized by the project manager to review a contractor's work:

Table 7.1 Checklist

Item	Minimum Frequency	Remarks
Bench Marks	All	Includes all BMs and TBMs set by contractor.
Culverts & Storm Sewers		
Flow Lines	50%	Both U.S. and D.S. flow lines should be checked. This check should include two of the first three lines the contractor places. There should also be intermediate checks on long structures.
Alignment	25%	This includes station location and placement angle.
Inlets & Manholes		

Table 7.1 Checklist

Item	Minimum Frequency	Remarks
Grade	25%	This includes checking calculations at each end of curb inlet to assure proper alignment with curb. Top grades and flow lines of manholes and drop inlets should be checked.
Location	25%	Includes station and offset.
Bridges		
Alignment	100%	Check Contractor's control points.
Deck Grades	50%	At least ½ of the bridge overhangs should be checked at 50 ft. intervals.
Drilled Shafts and Piling	100%	Check distance between shafts or piling.
Columns	100%	Check plumb before placing concrete.
Caps (Bearing Seats)	50%	Check for location and elevation prior to placing concrete.
Caps (Dowel Bars)	100%	Visually check location and projection.
Roadway		
Grade	10%	Independent check of blue tops on all sub-grade and base courses.
Width	1 per 2000'	Includes sub-grade, base course, and finished roadway
Retaining Walls		
Height	1 per section	The first footing and wall the contractor forms should be checked.
Footing Elevations	1 per wall	

Notes:

- In all cases, a record should be made of the survey checks and the corrections made. A daily report form may be used.
- If the contractor demonstrates a propensity for erroneous surveying, the frequency of checks should be inversely proportionate to the quality of the contractor's work product so far.
- Checks by state personnel are not intended to relieve the contractor of his/her responsibility for accuracy. All survey checks should be random and independent.

Section 2 — Locative and Construction Surveys

Locative Survey

For locative survey specifications, refer to the Category 3 section in the TSPS Manual of Practice for Land Surveying in the State of Texas, available at www.tsps.org.

Construction Survey

For construction survey specifications, refer to the Category 5 section in the TSPS Manual of Practice for Land Surveying in the State of Texas, available at www.tsps.org.

Appendix A — References

Introduction

These references are a listing of authors and works associated with the information found within this manual. This appendix provides users with information for further reading.

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Appendix B — Second Term Calculations

Overview

Some information contained within this appendix has been excerpted from the Coast and Geodetic Survey's (C&GS) publication, Plane Coordinate Projection Tables: "Texas" (Lambert) Special Publication No. 252, and the National Geodetic Surveying (NGS) guidelines and specifications information for latitude and longitude, second term equations.

Second Term

A straight line on the spheroid, when projected by a conformal projection, will result in a curved line on the grid or vice versa (see Figure 1).

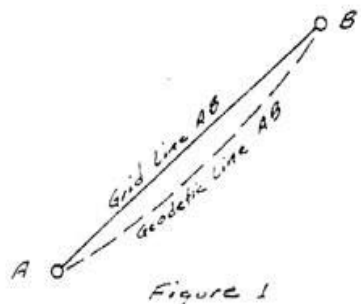

Figure 1

For a Lambert conformal projection this projected line will curve away from the east-west center line of the zone (Y_o or N_o) with the amount of curvature increasing with distance from this line and difference in X (or E) coordinates (see Figure 2).

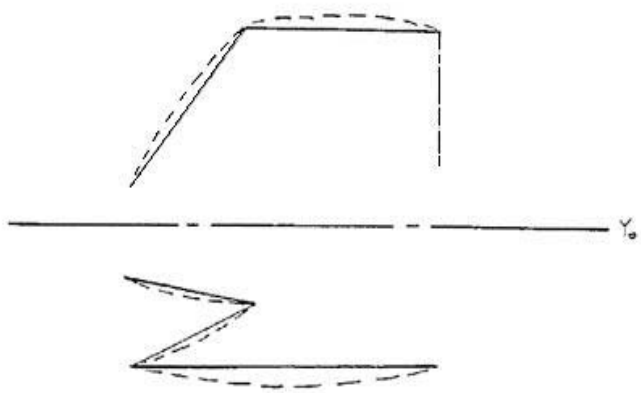

Figure 2

The angle between the grid line and the tangent of the projected curved line at a point is called the second term (J or "t-T"), hence the equation for grid azimuth (see Figure 3):

Grid Az. = Geodetic Az. - δ - second term

Figure B-1. Second Term.

Approximate Equation

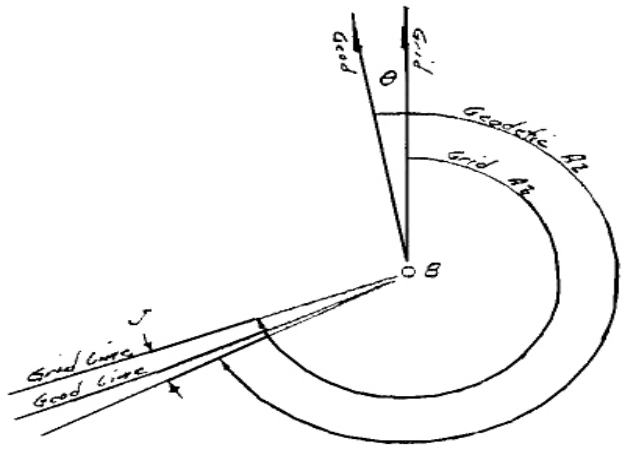

Figure B-2. Approximate Equations.

A very good approximate equation for the second term is:

second term (in seconds of arc) = 2.36 x ΔX x ΔY x 10^{-10}

where: $\Delta X = X_2 - X_1$ in feet

$\Delta Y = Y_1 - Y_0$ in feet

or

second term (seconds of arc) 25.4 ΔE x ΔN x 10^{-10}

where: $\Delta E = E_2 - E_1$ in meters

$\Delta N = N_2 - N_0$ in meters

For most surveys the coordinate values for the above equations can be rounded to the nearest 1000 feet or 500 meters.

The magnitude of the second term is small and can be neglected, except for high accuracy surveys with long lines. The table below, listing values for the second term, illustrates this magnitude.

X_2 - X_1 (in feet)	**Y_1 - Y_0 (in feet)**			
	100,000	300,000	600,000	900,000
5,000	0.1"	0.4"	0.7"	1.1"
10,000	0.2	0.7	1.4	2.1

20,000	0.5	1.4	2.8	4.2
30,000	0.7	2.1	4.2	6.4
40,000	0.9	2.8	5.7	8.5
50,000	1.2	3.5	7.1	10.6

Calculations

Example Problem:

Given: Geodetic Az AB = 110° 27' 32" 5	
θ = + 3° 01' 39" 5°	Y_o = 596,000 feet
X_A = 3,105,000 feet	Y_A = 205,000 feet
X_B = 3,124,000 feet	Y_B = 198,000 feet

Solution:

$\Delta X = X_B - X_A = +19{,}000$

$\Delta Y = Y_A - Y_O = -391{,}000$

second term	= 2.36 x (+19,000) x (-391,000) x 10^{-10}
	= -1" 8
Grid Az	= 110° 27' 32" 5
	= 107° 25' 51" 2

The second term is usually considered to be an azimuth correction; however, for traverse work it is easier to apply second terms to geodetic angles converting them to grid angles. These grid angles are then used to compute grid azimuths using the normal traverse calculation procedures.

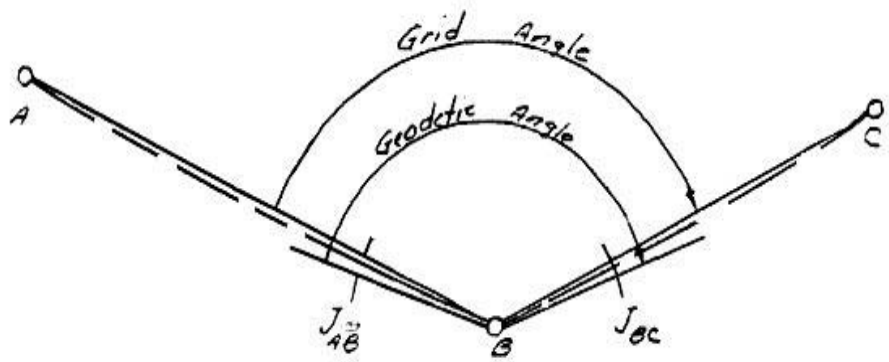

Figure B-3. Calculations.

Second Term Corrections

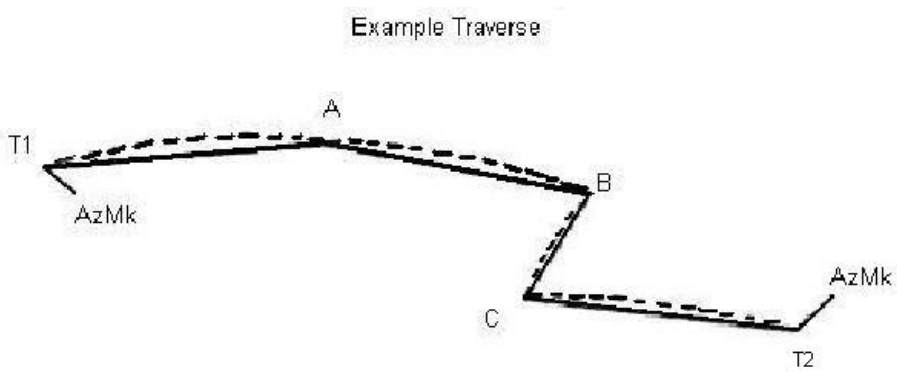

Figure B-4. Second Term Corrections.

27 South Zone

Y_o = 596,000 feet

Line	**Grid Az (from south)**		
T1 - Az Mk	301° 22' 07" 0		
T2 - Az Mk	332° 35' 21" 0		

Compute second term corrections. (Assume approximate coordinates of traverse stations have been computed or scaled from quad sheet.)

Pt.	**X**	**Y**	**Δ X**	**Δ Y**	**Second Term**
AzMk					0" 0
T1	3,186,426.41'	825,155.41'			
			+25,000'	+229,000'	+1.4
A	3,211,000	830,000			
			+19,000	+234,000	+1.0
B	3,230,000	820,000			
			-11,000	+224,000	+0.6
C	301,000				
			+27,000	+206,000	+1.3
T2	3,246,101.74	758,914.15			
					0.0
AzMk					
* $\Delta Y = Y_1 - Y_o$					

Pt.	**Geodetic Angle**	**Second Term (BS)**	**Cor. (FS)**	**Grid Angle**	**Grid Az**
AzMk					
					301° 22' 07".0
T1	318° 02' 26"	0" 0	+1" 4	318° 02' 27" 4	
			-25,000'	-229,000'	79° 24' 34" 4
A	219° 14' 37"	+1" 4	+1" 0	219° 14 ' 39" 4	
					118° 39' 13" 8
B	273° 43' 06"	+1" 0	-0" 6	273° 43' 06" 4	

Pt.	**Geodetic Angle**	**Second Term (BS)**	**Cor. (FS)**	**Grid Angle**	**Grid Az**
					212° 22' 20" 2
C	64° 52' 41"	-0" 6	+1" 3	64° 52' 41" 7	
					97° 15' 01" 9
T2	135° 20' 16"	+1" 3	0" 0	135° 20' 17" 3	
					52° 35' 19" 2
AzMk					

Converting closing azimuth to azimuth from south:

Az = 52° 35' 19" 2 + 108°

= 232° 35' 19" 2

Closing error = 232° 35' 19" 2 - 232° 35' 21" 0 - 232° 35' 21" 0

= 1" 8

Plane Coordinate Projection Tables Texas North Zone

Lambert conformal conic projection with two standard parallels
Plane coordinate projection tables

DATUM: NAD 83
The projection is TEXAS NORTH

Ellipsoidal constants

a = 6378137 m
f = 1/298.25722210

Defining constants

ϕ_b = 34° 0' (latitude of grid origin)
λ_{CM} = 101 30 (longitude of origin and Central Meridian, CM)
ϕ_s = 34 39 (southern standard parallel)
ϕ_n = 36 11 (northern standard parallel)
E_o = 200000.0000 m (easting coordinate of origin)
N_b =1000000.0000 m (northing coordinate of origin)

Derived constants

ℓ = 0.579535862261 = sin(ϕ_o)
K = 13145417.7356 m (mapping radius at the equator)
R_b = 9135570.8896 m (mapping radius at grid origin)

Lambert coordinates (N,E) from geodetic positions (ϕ,λ)

γ = (λ_{CM} - λ) sin(ϕ_o) (γ is the meridional convergence)
E = R sin(γ) + E_o (R from table)
N = R_b - R cos(γ) + N_b

Station	Latitude Longitude	R γ	sin(γ) cos(γ)	E N
sample 1	35 25 0.00000 102 0 0.00000	8978410.692 m -0 17 23.16455	-0.0050573829 0.9999872114	154592.739 m 1157275.019 m

Geodetic positions from Lambert coordinates

tan(γ) = (E - E_o)/((R_b -(N - N_b))
R = (R_b - (N - N_b))/cos(γ)
λ = λ_{CM} - γ/ℓ
ϕ from table using R

Station	E N	E - E_o R_b-(N - N_b)	R γ	Latitude Longitude
sample 2	250000.000 m 1160000.000 m	50000.000 m 8975570.890 m	8975710.1554 m 0 19 9.02258	35 36 27.6335 100 56 57.3400

WARNING: Use sufficient significant digits for trig.functions

Figure B-5. Texas North Zone Plane Coordinate Projection Tables.

Projection Tables

Lambert Conformal Conic Projection Tables

Texas North			
Lat	R (meters)	tab diff.	k
34 0'	9135570.390	30.81830	1.00021397
34 1	9133721.792	30.81317	1.00020691
34 2	9131872.702	30.81804	1.00019993
34 3	9130023.619	30.81791	1.00019303
34 4	9128174.545	30.81778	1.00018621
34 5	9126325.478	30.81766	1.00017948
34 6	9124476.418	30.81754	1.00017283
34 7	9122627.366	30.81742	1.00016626
34 8	9120778.320	30.81731	1.00015978
34 9	9118929.282	30.81720	1.00015337
34 10	9117080.250	30.81709	1.00014706
34 11	9115231.224	30.81699	1.00014082
34 12	9113382.206	30.81688	1.00013467
34 13	9111533.193	30.81677	1.00012860
34 14	9109684.187	30.81668	1.00012261
34 15	9107835.186	30.21658	1.00011671
34 16	9105986.191	30.81648	1.00011089
34 17	9104137.202	30.21639	1.00010515
34 18	9102288.219	30.81630	1.00009950
34 19	9100439.240	30.81622	1.00009393
34 20	9098590.267	30.81613	1.00008844
34 21	9096741.299	30.81605	1.00008304
34 22	9094892.336	30.81597	1.00007772
34 23	9093043.378	30.21590	1.00007248
34 24	9091194.424	30.31582	1.00006732
34 25	9089345.474	30.81575	1.00006225
34 26	9087496.529	30.81569	1.00005726

Lambert Conformal Conic Projection Tables

Texas North			
34 27	9085647.528	30.81562	1.00005236
34 23	9083798.651	30.81556	1.00004754
34 29	9081949.717	20.81550	1.00004280
34 30	9080100.738	20.81544	1.00003814
34 31	9078251.861	30.81533	1.00003357
34 32	9076402.938	30.81533	1.00002908
34 33	9074554.018	30.81528	1.00002468
34 34	9072705.102	30.81523	1.00002036
34 35	9070856.188	30.81519	1.00001612
34 36	9069007.276	30.31514	1.00001196
34 37	9067158.368	30.31511	1.00000789
34 38	9065309.461	30.31507	1.00000390
34 39	9063460.557	30.31503	1.00000000

Projection Tables

Lambert Conformal Conic Projection Tables

Texas North			
Lat	R (meters)	tab diff.	k
34 40'	9061611.655	30.81500	0.99999618
34 41	9059762.755	30.81497	0.99999244
34 42	9057913.557	30.81494	0.99998879
34 43	9056064.960	30.81492	0.99998522
34 44	9054216.065	30.81490	0.99998173
34 45	9052367.171	30.81488	0.99997833
34 46	9050518.278	30.81486	0.99997501
34 47	9048669.387	30.81485	0.99997177
34 48	9046820.496	30.81484	0.99996862
34 49	9044971.605	30.81483	0.99996555
34 50	9043122.716	30.81482	0.99996256
34 51	9041273.826	30.81482	0.99995966
34 52	9039424.937	30.81482	0.99995684
34 53	9037576.048	30.81482	0.99995411
34 54	9035727.159	30.81482	0.99995146
34 55	9033878.269	30.61483	0.99994889
34 56	9032029.379	20.81484	0.99994641
34 57	9030180.489	30.81485	0.99994401
34 58	9028331.598	30.81487	0.99994169
34 59	9026482.706	30.81488	0.99993946
35 0	9024633.813	30.81490	0.99993731
35 1	9022784.918	30.81493	0.99993524
33 2	9020936.023	30.31495	0.99993326
35 3	9019087.126	30.81498	0.99993137
33 4	9017232.227	30.81501	0.99992955
23 3	5015389.326	30.81504	0.99992782
35 6	9013540.424	30.81508	0.99992613

Lambert Conformal Conic Projection Tables

Texas North			
35 7	9011691.319	30.81512	0.99992462
35 2	9009842.612	30.81516	0.99992314
35 9	9007993.702	20.81520	0.99992175
35 10	9006144.790	30.81525	0.99992044
35 11	9004295.376	30.31529	0.99991921
35 12	9002446.958	30.81535	0.99991807
35 13	9000598.037	30.31540	0.99991701
25 14	8998749.113	30.31546	0.99991604
35 15	8996900.186	30.81551	0.99991515
35 16	8995051.255	30.81558	0.99991434
35 17	8993202.320	30.81364	0.99991362
35 18	9991353.382	30.81371	0.99991296
35 19	3989504.440	30.81573	0.99991243

Projection Tables

Lambert Conformal Conic Projection Tables

Texas North			
Lat	R (meters)	tab diff.	k
35 20'	8987655.493	30.81585	0.99991196
35 21	8985806.542	30.81592	0.99991157
35 22	8983957.587	30.81600	0.99991127
35 23	8982108.627	30.81608	0.99991106
35 24	8980259.662	30.21616	0-99991092
35 25	8978410.692	30.81625	0.99991088
35 26	8976561.717	30.81634	0.99991091
35 27	8974712.737	30.81643	0.99991103
35 28	8972863.752	30.81652	0.99991124
35 29	8971014.761	30.81661	0.99991152
35 30	8969165.764	30.81671	0.99991190
35 31	8967316.761	30.81681	0.99991236
35 22	8965467.752	30.81692	0.99991290
35 33	8963618.737	30.81702	0.99991352
35 34	8961769.716	30.81713	0.99991423
35 35	8959920.682	30.31724	0.99991503
35 36	8958071.654	30.31736	0.99991591
35 37	8956222.612	30.81747	0.99991687
35 38	8954373.564	30.31759	0.99991792
35 39	8952524.509	30.81771	0.99991903
35 40	8950675.446	30.81734	0.99992027
35 41	8948826.376	30.81796	0.99992157
35 42	8946977.298	30.81809	0.99992296
35 43	8945128.212	30.81823	0.99992443
35 44	8943279.119	30.31836	0.99992598
35 45	8941430.017	30.31850	0.99992762
35 46	8939580.907	30.31864	0.99992935

Lambert Conformal Conic Projection Tables

Texas North			
35 47	8937731.789	30.31878	0.99993115
35 48	8935882.662	30.31893	0.99993305
35 49	8934033.527	30.81907	0.99993503
35 50	8932184.382	30.81922	0.99993709
33 51	8930335.229	30.81938	0.99993924
35 52	8928486.066	30.81953	0.99994147
35 53	8926636.894	30.81969	0.99994379
35 54	3924787.713	30.31985	0.99994619
35 55	3922938.522	30.82002	0.99994867
35 56	3921089.321	30.82018	0.99995124
35 57	8919240.110	30.82035	0.99995390
35 58	3917390.889	30.82052	0.99995664
35 59	3915541.657	30.82070	0.99995947

Projection Tables

Lambert Conformal Conic Projection Tables

Texas North			
Lat	R (meters)	tab diff.	k
36 0'	8913692.415	30.82087	0.99996238
36 2	8911843.163	30.82105	0.99996537
36 2	8909993.900	30.82124	0.99996845
36 3	8908144.626	30.82142	0.99997162
36 4	8906295.340	30.82161	0.99997487
36 5	8904446.044	30.82180	0.99997820
36 6	8902596.736	30.82199	0.99998162
35 7	8900747.417	30.82219	0.99998513
36 8	8898898.086	30.82238	0.99998872
36 9	8897048.743	30.82258	0.99999239
36 10	8895199.388	30.82279	0.99999615
36 11	8893350.020	30.82299	1.00000000
36 12	8891500.641	30.82320	1.00000393
36 13	8889651.249	30.82341	1.00000795
36 14	8887801.844	30.82363	1.00001203
36 15	8885952.426	30.82384	1.00001623
36 16	8884102.996	30.52406	1.00002050
36 17	8882253.352	30.82428	1.00002486
36 18	8380404.095	30.82451	1.00002930
36 19	8872554.625	20.82473	1.00003383
36 20	3876705.140	30.32496	1.00003844
36 21	8874855.643	30.32320	1.00004314
36 22	8873006.131	30.82543	1.00004792
36 3	8871156.605	30.82567	1.00005279
36 24	3269307.065	30.32591	1.00005774
36 25	8867457.510	30.32615	1.00006278
36 26	8865607.941	30.22640	1.00006790

Lambert Conformal Conic Projection Tables

Texas North			
36 27	8863758.357	30.82665	1.00007311
36 28	8861908.753	30.32690	1.00007841
36 29	8860059.145	30.32715	1.00003379
36 30	8858209.516	30.82741	1.00008925
36 31	3856359.371	30.82767	1.00009480
36 32	8854510.211	30.82793	1.00010044
36 33	8852660.536	30.82819	1.00010616
36 34	8850810.344	30.32846	1.00011197
36 35	8848961.137	30.32873	1.00011786
36 36	3847111.413	30.82900	1.00012384
36 37	2845261.673	30.32927	1.00012991
36 38	8843411.917	30.32955	1.00013606
36 39	8841562.144	30.32983	1.00014229

Projection Tables

Lambert Conformal Conic Projection Tables

Texas North			
Lat	R (meters)	tab diff.	k
36 40”	8839712.354	30.83011	1.00014861
36 41	8837862.547	30.33040	1.00015502
36 42	8836012.723	30.53069	1.00016151
36 43	8834162.882	30.83098	1.00016809
36 44	8832313.024	30.83127	1.00017476
36 45	8330463.147	30.83157	1.00018151
36 46	8828613.233	30.83187	1.00018834
36 47	8826763.341	30.83217	1.00019526
36 48	8324913.411	30.83247	1.00020227
36 49	8823063.463	30.83278	1.00020936
36 50	8821213.497	30.83309	1.00021654

Plane Coordinate Projection Tables Texas North Central Zone 1983

Lambert conformal conic projection with two standard parallels
Plane coordinate projection tables

DATUM: NAD 83
The projection is TEXAS NORTH

Ellipsoidal constants

a = 6378137 m
f = 1/298.25722210

Defining constants

ϕ_b = 34° 0' (latitude of grid origin)
λ_{CM} = 101 30 (longitude of origin and Central Meridian, CM)
ϕ_s = 34 39 (southern standard parallel)
ϕ_n = 36 11 (northern standard parallel)
E_o = 200000.0000 m (easting coordinate of origin)
N_b =1000000.0000 m (northing coordinate of origin)

Derived constants

ℓ = 0.579535862261 = sin(ϕ_o)
K = 13145417.7356 m (mapping radius at the equator)
R_b = 9135570.8896 m (mapping radius at grid origin)

Lambert coordinates (N,E) from geodetic positions (ϕ,λ)

$\gamma = (\lambda_{CM} - \lambda)\sin(\phi_o)$ (γ is the meridional convergence)
$E = R\sin(\gamma) + E_o$ (R from table)
$N = R_b - R\cos(\gamma) + N_b$

Station	Latitude Longitude	R γ	sin(γ) cos(γ)	E N
sample 1	35 25 0.00000 102 0 0.00000	8978410.692 m -0 17 23.16455	-0.0050573829 0.9999872114	154592.739 m 1157275.019 m

Geodetic positions from Lambert coordinates

$\tan(\gamma) = (E - E_o)/((R_b - (N - N_b))$
$R = (R_b - (N - N_b))/\cos(\gamma)$
$\lambda = \lambda_{CM} - \gamma/\ell$
ϕ from table using R

Station	E N	E - E_o R_b-(N - N_b)	R γ	Latitude Longitude
sample 2	250000.000 m 1160000.000 m	50000.000 m 8975570.890 m	8975710.1554 m 0 19 9.02258	35 36 27.6335 100 56 57.3400

WARNING: Use sufficient significant digits for trig.functions

Figure B-6. Texas North-Central Zone Plane Coordinate Projection Tables.

Projection Tables

Lambert Conformal Conic Projection Tables

Texas North - Central			
Lat	R (meters)	tab diff.	k
31 40'	9964225.754	30.80520	1.00016189
31 41	9962377.442	30.80506	1.00015498
31 42	9960529.138	30.80494	1.00014816
31 43	9958680.842	30.80481	1.00014142
31 44	9956832.553	30.80469	1.00013477
31 45	9954984.272	30.80457	1.00012820
31 46	9953135.998	30.80445	1.00012171
31 47	9951287.731	30.80433	1.00011530
31 48	9949439.471	30.80422	1.00010898
31 49	9947591.218	30.80411	1.00010274
31 50	9945742.971	30.80400	1.00009658
31 51	9943894.731	30.80390	1.00009051
31 52	9942046.497	30.80380	1.00008452
31 53	9940198.269	30.80370	1.00007861
31 54	9938330.047	30.80360	1.00007279
31 55	9936501.331	30.80351	1.00006705
31 56	9934653.621	30.80341	1.00006139
31 57	9932805.416	30.80332	1.00005582
31 58	9930957.217	30.80324	1.00005033
31 59	9929109.022	30.80313	1.00004492
32 0	9927260.833	30.30307	1.00003960
32 1	9925412.649	30.30299	1.00003435
32 2	9923564.469	30.80292	1.00002920
32 3	9921716.295	30.30284	1.00002412
22 4	9919868.124	30.80277	1.00001913
32 5	9918019.958	30.80270	1.00001422
32 6	9916171.796	30.80263	1.00000940

Lambert Conformal Conic Projection Tables

Texas North - Central			
32 7	9914323.638	30.80257	1.00000466
32 8	9912475.483	30.30251	1.00000000
32 9	9910627.333	30.80245	0.99999543
32 10	9908779.186	30.80240	0.99999093
32 11	9906931.042	30.80234	0.99998653
32 12	9905082.901	30.80229	0.99998220
32 13	9903234.764	30.80224	0.99997796
32 14	9901386.629	30.80220	0.99997380
32 13	9899538.497	30.30216	0.99996973
32 16	9897690.368	30.80212	0.99996574
32 17	9895842.241	30.80208	0.99996183
32 13	9893994.115	30.30204	0.99995801
32 19	9892145.994	30.30201	0.99993427

Projection Tables

Lambert Conformal Conic Projection Tables

Texas North - Central			
Lat	R (meters)	tab diff.	k
32 20'	9890297.873	30.80198	0.99995061
32 21	9888449.754	30.80195	0.99994704
32 22	9886601.627	30.80193	0.99994355
32 23	9884753.521	30.80191	0.99994015
32 24	9882905.407	30.60189	0.99993632
32 25	9881057.294	30.80187	0.99993359
32 26	9879209.181	30.80186	0.99993043
32 27	9877361.070	30.80184	0.99992736
32 28	9875512.959	30.80184	0.99992437
32 29	9873664.849	30.20183	0.99992147
32 30	9871816.740	30.80182	0.99991865
32 31	9869968.630	30.80182	0.99991591
32 32	9868120.521	30.80182	0.99991326
32 33	9866272.411	30.80183	0.99991069
32 34	9664424.201	30.80184	0.99990820
32 33	9862576.191	30.80184	0.99990580
32 36	9860728.081	30.80186	0.99990348
32 37	9858879.969	30.80187	0.99990125
32 38	9857031.857	30.80189	0.99989910
32 39	9855183.744	20.80191	0.99989703
32 40	9853335.529	30.60193	0.99989505
32 41	9851437.514	30.60195	0.99989315
32 42	9849639.296	30.80198	0.99989134
32 43	9847791.277	30.80201	0.99988961
32 44	9845943.157	30.30204	0.99988796
32 45	9844095.034	30.60208	0.99988640
32 46	9842246.909	30.80212	0.99988492

Lambert Conformal Conic Projection Tables

Texas North - Central			
32 47	9840398.782	30.80216	0.99988352
32 48	9838550.653	30.80220	0.99988221
32 49	9836702.521	30.80225	0.99988098
22 50	9834854.386	30.80229	0.99987984
32 51	9833006.249	30.80234	0.99937878
22 52	9831158.108	30.80240	0.99937730
32 53	9829309.964	30.80245	0.99987691
32 54	9827461.217	30.80251	0.99987611
32 55	9825613.666	30.80257	0.99987538
32 56	9823765.512	30.80264	0.99987474
32 57	9821917.353	30.80270	0.99987419
32 58	9820069.191	30.80277	0.99987372
22 59	9813221.325	30.80285	0.99987333

Projection Tables

Lambert Conformal Conic Projection Tables

Texas North - Central			
Lat	R (meters)	tab diff.	k
33 0'	9816372.854	30.80292	0.99987303
33 1	9814524.679	30.80300	0.99987281
33 2	9812676.499	30.80308	0.99987267
33 3	9810828.314	30.80316	0.99987262
33 4	9808980.125	30.80324	0.99987266
33 5	9807131.930	30.80333	0.99987278
33 6	9805283.730	30.80342	0.99987298
33 7	9803435.525	30.80351	0.99987326
33 8	9801587.314	30.80361	0.99987363
33 9	9799739.098	30.80371	0.99987409
33 10	9797890.876	30.80331	0.99987463
33 11	9796042.647	30.80391	0.99987525
33 12	9794194.413	30.80402	0.99987596
33 13	9792346.172	30.80412	0.99987675
33 14	9790497.924	30.80423	0.99987763
33 13	9788649.670	30.80435	0.99987859
33 16	9786801.409	30.80446	0.99987964
33 17	9784933.141	30.80453	0.99988077
33 18	9783104.866	30.80471	0.99988198
33 19	9781256.584	30.80433	0.99983328
33 20	9779403.294	30.30496	0.99988466
33 21	9777559.997	20.80509	0.99988613
33 22	9775711.692	30.80522	0.99988769
33 23	9773863.379	30.80535	0.99988932
33 24	9772013.058	30.80549	0.99989104
33 25	9770166.728	30.80563	0.99989285
33 26	9768318.391	30.80577	0.99989474

Lambert Conformal Conic Projection Tables

Texas North - Central			
33 27	9766470.044	30.80592	0.99989672
33 28	9764621.689	30.30606	0.99989878
33 29	9762773.326	30.80621	0.99990092
33 30	9760924.953	30.30637	0.99990315
33 31	9759076.571	30.80652	0.99990546
33 22	9757223.179	30.80668	0.99990786
33 33	9755379.778	30.80684	0.99991034
33 34	9753531.368	30.80701	0.99991291
33 35	9751682.948	30.80717	0.99991556
33 36	9749834.517	30.80734	0.99991830
33 37	9747986.077	30.30751	0.99992112
33 38	9746137.526	30.30769	0.99992403
33 39	9744289.165	30.30786	0.99992702

Projection Tables

Lambert Conformal Conic Projection Tables

Texas North - Central			
Lat	R (meters)	tab diff.	k
33 40'	9742440.693	30.80804	0.99993010
33 41	9740592.211	30.80822	0.99993326
33 42	9738743.717	30.80841	0.99993651
33 43	9736895.213	30.80860	0.99993984
33 44	9735046.697	30.80879	0.99994325
33 45	9733198.170	30.80898	0.99994675
33 46	9731349.631	30.80917	0.99995034
33 47	9729501.081	30.80937	0.99995401
33 48	9727652.519	30.80957	0.99995777
33 49	9725803.944	30.80977	0.99996161
33 50	9723955.358	30.80998	0.99996553
33 51	9722106.759	30.81019	0.99996954
33 52	9720258.148	30.81040	0.99997364
23 53	9718409.324	30.31061	0.99997782
33 54	9716560.887	30.81083	0.99998209
23 55	9714712.237	30.81103	0.99998644
23 56	9712363.574	30.81127	0.99999087
23 57	9711014.898	30.31149	0.99999539
33 58	9709166.209	30.81172	1.00000000
35 59	9707317.505	30.31195	1.00000469
34 0	9705468.788	30.31215	1.00000947
34 1	9703620.057	30.31242	1.00001433
34 2	9701771.312	20.21265	1.00001928
34 3	9699922.553	30.31289	1.00002431
34 4	9698073.779	30.61214	1.00002943
34 3	9696224.991	20.31338	1.00003463
34 6	9694376.188	30.81363	1.00003992

Lambert Conformal Conic Projection Tables

Texas North - Central			
34 7	9692527.370	30.81388	1.00004529
34 3	9690678.338	30.31413	1.00005075
34 9	9688829.690	30.31439	1.00005629
34 10	9686980.326	30.81465	1.00006192
34 11	9685131.947	30.81491	1.00006764
34 12	9683283.053	30.81517	1.00007344
34 13	9681434.142	30.81544	1.00007933
34 14	9679585.216	30.81371	1.00003530
34 15	9677736.273	30.31598	1.00009135
34 16	9675887.314	30.91626	1.00009750
34 17	9674033.339	33.81653	1.00010272
34 18	9672139.247	33.31681	1.00011004
34 19	9670340.338	33.31710	1.00011644

Projection Tables

Lambert Conformal Conic Projection Tables

Texas North - Central			
Lat	R (meters)	tab diff.	k
34 20'	9668491.312	30.81738	1.00012292
34 21	9666642.269	30.81767	1.00012949
34 22	9664793.209	30.81796	1.00013615
34 23	9662944.132	30.81825	1.00014289
34 24	9561095.037	30.81855	1.00014971
34 25	9659245.924	30.81885	1.00015663
34 26	9657396.793	30.81915	1.00016352
34 27	9655547.644	30.81945	1.00017071
34 28	9653698.477	30.81976	1.00017788
34 29	9651849.292	30.82007	1.00018513
34 30	9650000.088	30.82038	1.00019247

Plane Coordinate Projection Tables Texas Central Zone 1983

Lambert conformal conic projection with two standard parallels
Plane coordinate projection tables

DATUM: NAD 83
The projection is TEXAS NORTH-CENTRAL

Ellipsoidal constants

a = 6378137 m
f = 1/298.25722210

Defining constants

ϕ_o = 31° 40' (latitude of grid origin)
λ_{CM} = 98 30 (longitude of origin and Central Meridian, CM)
ϕ_s = 32 8 (southern standard parallel)
ϕ_n = 33 58 (northern standard parallel)
E_o = 600000.0000 m (easting coordinate of origin)
N_o =2000000.0000 m (northing coordinate of origin)

Derived constants

ℓ = 0.545394412971 = sin(ϕ_o)
K = 13669256.3042 m (mapping radius at the equator)
R_o = 9964225.7538 m (mapping radius at grid origin)

Lambert coordinates (N,E) from geodetic positions (ϕ,λ)

γ = (λ_{CM} - λ) sin(ϕ_o) (γ is the meridional convergence)
E = R sin(γ) + E_o (R from table)
N = R_o - R cos(γ) + N_o

Station	Latitude Longitude	R γ	sin(γ) cos(γ)	E N
sample 1	33 3 0.00000 99 0 0.00000	9810828.314 m -0 16 21.70994	-0.0047594461 0.9999886738	553305.891 m 2153508.559 m

Geodetic positions from Lambert coordinates

tan(γ) = (E - E_o)/((R_o -(N - N_o))
R = (R_o - (N - N_o))/cos(γ)
λ = λ_{CM} - γ/ℓ
ϕ from table using R

Station	E N	E - E_o R_o-(N - N_o)	R γ	Latitude Longitude
sample 2	650000.000 m 2160000.000 m	50000.000 m 9804225.754 m	9804353.2490 m 0 17 31.90875	33 6 30.2071 97 57 51.2880

WARNING: Use sufficient significant digits for trig.functions

Figure B-7. Plane Coordinate Projection Tables Texas Central Zone 1983.

Projection Tables

Lambert Conformal Conic Projection Tables

Texas Central			
Lat	R (meters)	tab diff.	k
29 40'	10770561.103	30.79536	1.00015050
29 41	10768713.382	30.79523	1.00014384
29 42	10766865.668	30.79511	1.00013727
29 43	10765017.961	30.79499	1.00013078
29 44	10763170.262	30.79487	1.00012437
29 45	10761322.570	30.79476	1.00011805
29 46	10759474.884	30.79464	1.00011181
29 47	10757627.206	30.79453	1.00010565
29 48	10755779.534	30.79442	1.00009958
29 49	10753931.868	30.79432	1.00009359
29 50	10752084.209	30.79422	1.00008768
29 51	10750236.556	30.79411	1.00008186
29 52	10748358.910	30.79402	1.00007612
29 53	10746541.269	30.79392	1.00007046
29 54	10744693.633	30.79383	1.00006488
29 55	10742846.003	30.79374	1.00005939
29 56	10740998.379	30.79365	1.00005399
29 57	10739150.760	30.79357	1.00004866
29 58	10737303.146	30.79349	1.00004342
29 59	10735455.537	30.79341	1.00003826
30 0	10733607.932	30.79333	1.00003319
30 1	10731750.333	30.79325	1.00002826
30 2	10729912.737	30.79318	1.00002329
30 3	10728065.146	30.79311	1.00001846
30 4	10726217.560	30.79305	1.00001372
30 5	10724369.977	30.79298	1.00000906
30 6	10722522.398	30.79292	1.00000449

Lambert Conformal Conic Projection Tables

Texas Central			
30 7	10720674.822	30.79286	1.00000000
30 8	10718827.251	30.79231	0.99999559
30 9	10716979.682	30.79275	0.99999127
30 10	10715132.117	30.79270	0.99998703
30 11	10713284.555	30.79265	0.99998287
30 12	10711436.996	30.79261	0.99997880
30 13	10709589.439	30.79256	0.99997481
30 14	10707741.285	30.79252	0.99997090
30 15	10705894.334	30.79249	0.99996708
30 16	10704045.785	30.79245	0.99996334
30 17	10702199.238	30.79242	0.99995969
30 18	10700351.693	30.79229	0.99995611
30 19	10698504.149	30.79236	0.99995262

Projection Tables

Lambert Conformal Conic Projection Tables

Texas Central			
Lat	R (meters)	tab diff.	k
30 20'	10696656.608	30.79234	0.99994922
30 21	10694809.068	30.79231	0.99994590
30 22	10692961.529	30.79229	0.99994266
30 23	10691113.991	30.79228	0.99993951
30 24	10689266.455	30.19226	0.99993644
30 25	10687415.919	30.79225	0.99993345
30 26	10685571.384	30.79224	0.99993055
30 27	10683723.850	30.79223	0.99992773
30 28	10681876.316	30.79223	0.99992499
30 29	10680028.782	30.79223	0.99992234
30 30	10678181.243	30.79223	0.99991977
30 31	10676333.715	30.79223	0.99991729
30 32	10674486.131	30.79224	0.99991489
30 33	10672633.647	20.79225	0.99991257
30 34	10670791.112	30.79226	0.99991034
30 35	10668943.576	30.79227	0.99990819
30 36	10667096.040	30.79229	0.99990612
30 37	10665248.503	30.79231	0.99990414
30 38	10663400.964	30.79233	0.99990225
30 39	10661553.424	30.79235	0.99990043
30 40	10659705.283	30.79238	0.99989870
30 41	10657858.340	30.79241	0.99989706
30 42	10656010.795	30.79244	0.99989549
30 43	10654163.249-	30.79242	0.99989402
30 44	10652315.700	30.79252	0.99989262
30 45	10650462.149	30.79256	0.99989131
30 46	10648620.596	30.79260	0.99989009

Lambert Conformal Conic Projection Tables

Texas Central			
30 47	10646773.040	30.79264	0.99988894
30 48	10644925.481	30.79269	0.99988789
30 49	10643077.920	30.79274	0.99988691
30 50	10641230.255	30.79280	0.99988602
30 51	10639382.787	30.79285	0.99988521
30 52	10637535.216	30.79291	0.99988449
30 53	10635637.642	30.79297	0.99988385
30 54	10633840.063	30.79303	0.99988330
30 55	10631992.431	30.79310	0.99988233
30 36	10630144.895	30.79317	0.99988245
30 57	10623297.305	20.79324	0.99988214
30 58	10626449.711	30.79332	0.99988193
30 59	10624602.112	30.79339	0.99988179

Projection Tables

Lambert Conformal Conic Projection Tables

Texas Central			
Lat	R (meters)	tab diff.	k
31 0'	10622754.508	30.79347	0.99988174
31 1	10620906.900	30.79355	0.99938178
31 2	10619059.287	30.79364	0.99988190
31 3	10617211.668	30.79373	0.99988210
31 4	10615364.045	30.79382	0.99988239
31 5	10613516.416	30.79391	0.99988276
31 6	10611668.782	30.79400	0.99988322
31 7	10609821.141	30.79410	0.99988376
31 3	10607973.495	30.79420	0.99988438
31 9	10606125.843	30.79430	0.99988509
31 10	10604278.185	30.79441	0.99988589
31 11	10602430.521	30.79452	0.99988676
31 12	10600582.850	30.79463	0.99988773
31 13	10598735.172	30.79474	0.99988877
31 14	10596387.437	30.79486	0.99988990
31 15	10595039.796	30.79492	0.99989112
31 16	10593192.097	20.79510	0.99989242
31 17	10591344.391	30.79522	0.99939380
31 18	10589496.678	30.79535	0.99989527
31 19	10587648.957	30.79548	0.99989682
31 20	10585801.229	30.79561	0.99989846
31 21	10583953.492	30.79574	0.99990018
31 22	10582105.748	30.79588	0.99990199
31 23	10580257.995	30.79602	0.99990388
31 24	10572410.234	30.79616	0.99990586
31 5	10576562.464	30.79631	0.99990792
31 26	10574714.685	30.79645	0.99991006

Lambert Conformal Conic Projection Tables

Texas Central			
31 27	10572866.898	30.79660	0.99991229
31 28	10571019.102	30.79676	0.99991460
31 29	10569171.296	30.79691	0.99991700
31 30	10567323.432	30.79707	0.99991949
31 31	10565475.637	30.79723	0.99992205
21 32	10563627.823	30.79740	0.99992471
31 33	10561779.980	20.79756	0.99992744
31 34	10559932.126	30.79773	0.99993027
31 35	10558084.262	30.79790	0.99993317
31 36	10556236.388	30.79808	0.99993616
31 37	10554333.504	30.79825	0.99993924
31 38	10552540.608	30.79843	0.99994240
31 39	10550692.703	30.79861	0.99994565

Projection Tables

Lambert Conformal Conic Projection Tables

Texas Central			
Lat	R (meters)	tab diff.	k
31 40'	10548844.786	30.79820	0.95994898
31 41	10546996.858	30.79898	0.99995239
31 42	10545148.919	30.79917	0.99995539
31 43	10543300.969	30.79937	0.99995948
31 44	10541453.007	30.79956	0.99996315
31 45	10539605.033	30.79976	0.99996690
31 46	10537757.047	30.79996	0.99997074
31 47	10535909.050	30.80016	0.99997467
31 48	10534061.040	30.80037	0.99997868
31 49	10532213.018	30.80058	0.99998277
31 50	10530364.984	30.80079	0.99998695
31 51	10528516.936	30.80100	0.99999122
31 52	10526668.876	30.80122	0.99999557
31 53	10524820.303	30.80143	1.00000000
31 54	10522972.717	30.80166	1.00000452
31 55	10521124.618	30.80188	1.00000912
21 56	10519276.505	30.80211	1.00001381
31 57	10517428.379	30.80234	1.00001859
31 58	10515580.239	30.80257	1.00002345
31 59	10513732.085	30.80280	1.00002839
32 0	10511383.916	30.80304	1.00003342
32 1	10510035.734	30.80328	1.00003854
32 2	10508137.537	30.80352	1.00004374
32 3	10506339.326	30.80377	1.00004903
324	10504491.100	30.20402	1.00005440
32 5	10502642.859	30.30427	1.00005925
32 6	10500794.603	30.80452	1.00006539

Lambert Conformal Conic Projection Tables

Texas Central			
32 7	10498946.332	30.80478	1.00007102
32 8	10497098.045	30.80503	1.00007673
32 9	10495249.743	30.80529	1.00008253
32 10	10493401.425	30.80556	1.00008841
32 11	10491553.092	30.80582	1.00009438
32 12	10489704.742	30.80609	1.00010044
22 13	10487256.377	30.80637	1.00010657
32 14	10486007.995	30.80664	1.00011280
32 15	10484159.596	30.80692	1.00011911
32 16	10482311.181	30.80720	1.00012550
32 17	10480462.750	30.80748	1.00013198
32 18	10478614.301	30.80776	1.00013355
32 19	10476765.335	30.30805	1.00014520

Projection Tables

Lambert Conformal Conic Projection Tables

Texas Central			
Lat	R (meters)	tab diff.	k
32 20'	10474917.352	30.80334	1.00015194
32 21	10473063.851	30.80864	1.00015876
32 22	10471220.333	30.80893	1.00016567
32 23	10469371.797	30.80923	1.00017266
32 24	10467523.244	30.80953	1.00017974
32 25	10465674.672	30.80983	1.00018691
32 26	10463826.082	30.81014	1.00019416
32 27	10461977.473	30.81045	1.00020149
32 28	10460128.846	30.81076	1.00020891
32 29	10458280.201	30.81108	1.00021642
32 30	10456431.536	30.81139	1.00022402
32 31	10454582.353	30.81171	1.00023169
22 32	10452734.150	30.81203	1.00023946
32 33	10450835.428	30.81236	1.00024731
32 34	10449036.686	30.81269	1.00025525
32 35	10447187.925	30.81302	1.00026327
32 36	10445339.144	30.81335	1.00027138
32 37	10443490.343	30.81369	1.00027957
32 38	10441641.522	30.81402	1.00028785
32 39	10439792.681	30.81436	1.00029621
32 40	10437943.315	30.81471	1.00030466

Plane Coordinate Projection Tables Texas South Central Zone 1983

Lambert conformal conic projection with two standard parallels
Plane coordinate projection tables

DATUM: NAD 83
The projection is TEXAS CENTRAL

Ellipsoidal constants

a = 6378137 m
f = 1/298.25722210

Defining constants

ϕ_b = 29°40' (latitude of grid origin)
λ_{CM} = 100 20 (longitude of origin and Central Meridian, CM)
ϕ_s = 30 7 (southern standard parallel)
ϕ_n = 31 53 (northern standard parallel)
E_o = 700000.0000 m (easting coordinate of origin)
N_b =3000000.0000 m (northing coordinate of origin)

Derived constants

ℓ = 0.515058882235 = sin(ϕ_o)
K = 14219009.8813 m (mapping radius at the equator)
R_b = 10770561.1034 m (mapping radius at grid origin)

Lambert coordinates (N,E) from geodetic positions (ϕ,λ)

γ = (λ_{CM} - λ) sin(ϕ_o) (γ is the meridional convergence)
E = R sin(γ) + E_o (R from table)
N = R_b - R cos(γ) + N_b

Station	Latitude Longitude	R γ	sin(γ) cos(γ)	E N
sample 1	31 0 0.00000 100 50 0.00000	10622754.508 m -0 15 27.10599	-0.0044947215 0.9999898987	652253.677 m 3147913.899 m

Geodetic positions from Lambert coordinates

tan(γ) = (E - E_o)/((R_b -(N - N_b))
R = (R_b - (N - N_b))/cos(γ)
λ = λ_{CM} - γ/ℓ
ϕ from table using R

Station	E N	E - E_o R_b-(N - N_b)	R γ	Latitude Longitude
sample 2	750000.000 m 3150000.000 m	50000.000 m 10620561.103 m	10620678.7990 m 0 16 11.05643	31 1 7.4074 99 48 34.6691

WARNING: Use sufficient significant digits for trig.functions

Figure B-8. Texas South-Central Plane Coordinate Projection.

Projection Tables

Lambert Conformal Conic Projection Tables

Texas South - Central			
Lat	R (meters)	tab diff.	k
27 50'	11523512.553	30.78861	1.00020323
27 51	11521665.242	30.78846	1.00019574
27 52	11519817.934	30.78831	1.00018834
27 53	11517970.636	30.78816	1.00018101
27 54	11516123.346	30.78801	1.00017377
27 55	11514276.066	30.78786	1.00016662
27 56	11512428.794	30.78772	1.00015954
27 57	11510581.530	30.78758	1.00015255
27 58	11508734.275	30.78745	1.00014564
27 59	11506887.029	30.78731	1.00013882
28 0	11505039.790	30.78718	1.00013208
28 1	11503192.559	30.78705	1.00012542
28 2	11501345.336	30.78693	1.00011884
28 3	11499498.120	30.78680	1.00011235
28 4	11497650.912	30.78668	1.00010594
28 5	11495303.711	30.78656	1.00009962
28 5	11493956.518	30.78645	1.00009337
28 7	11492109.331	30.78633	1.00008721
28 3	11490262.151	30.78622	1.00008114
28 9	11488414.978	30.78611	1.00007515
28 20	11486567.311	30.78601	1.00006924
28 11	11484720.650	30.78590	1.00006341
28 12	11482873.496	30.78580	1.00005767
28 13	11481026.348	30.78571	1.00005201
28 14	11479179.205	30.78561	1.00004643
28 15	11477332.069	30.78552	1.00004094
28 16	11475484.938	30.73543	1.00003533

Lambert Conformal Conic Projection Tables

Texas South - Central			
28 17	11473637.812	30.73534	1.00003020
28 18	11471790.692	30.78526	1.00002496
28 19	11469943.576	30.78517	1.00001980
28 20	11468096.466	30.73509	1.00001473
28 21	11466249.360	30.78502	1.00000973
28 22	11464402.259	30.78494	1.00000483
28 23	11462555.163	30.78487	1.00000000
28 24	11460708.071	30.73480	0.99999526
28 25	11458860.982	30.78473	0.99999060
28 26	11457013.898	30.78467	0.99998602
28 27	11455166.818	30.73461	0.99998153
28 28	11453319.742	30.73455	0.99997712
28 29	11451472.669	30.78449	0.99997230

Projection Tables

Lambert Conformal Conic Projection Tables

Texas South - Central			
Lat	R (meters)	tab diff.	k
28 30'	11449625.599	30.78444	0.99996856
28 31	11447778.533	30.78439	0.99996440
28 32	11445931.470	30.78434	0.99996033
28 33	11444084.409	30.78429	0.99995633
28 34	11442237.352	30.78425	0.99995243
28 35	11440390.297	30.78421	0.99994860
28 36	11438543.244	30.78417	0.99994486
28 37	11436696.194	30.78414	0.99994121
28 38	11434849.146	30.78410	0.99993764
28 39	11433002.099	30.78407	0.99993415
28 40	11431155.055	30.78404	0.99993074
28 41	11429308.012	30.78402	0.99992742
28 42	11427460.971	30.78400	0.99992418
28 43	11425613.931	30.72398	0.99992103
28 44	11423766.893	30.72396	0.99991795
28 45	11421919.855	30.78395	0.99991497
28 46	11420072.219	30.78393	0.99991206
28 47	11418225.783	30.78392	0.99990924
28 48	11416378.747	30.78392	0.99990651
28 49	11414531.712	30.78391	0.99990336
28 50	11412684.577	30.78391	0.99990129
28 51	11410837.643	30.78391	0.99999880
28 52	11408990.608	30.73391	0.99989640
28 53	11407143.573	30.78392	0.99989408
28 54	11405296.580	30.78393	0.99989185
28 55	11403449.502	30.78394	0.99988970
28 56	11401602.466	30.78396	0.99988764

Lambert Conformal Conic Projection Tables

Texas South - Central			
28 57	11399755.428	30.78397	0.99988565
28 58	11397908.390	30.72399	0.99988376
28 59	11396061.351	30.78401	0.99988194
29 0	11394214.310	30.78404	0.99988021
29 1	11392367.268	30.78406	0.99987857
29 2	11390520.224	30.78409	0.99987700
29 3	11388673.178	30.78413	0.99987552
29 4	11386826.131	30.78416	0.99987413
29 5	11384979.081	30.78420	0.99987282
29 6	11383132.029	30.78424	0.99987159
29 7	11381284.975	30.78428	0.99987045
29 8	11379437.918	30.78433	0.99986939
29 9	11377590.358	30.73437	0.99986842

Projection Tables

Lambert Conformal Conic Projection Tables

Texas South - Central			
Lat	R (meters)	tab diff.	k
29 10'	11375743.796	30.78442	0.99986753
29 11	11373896.730	30.78448	0.99986672
29 12	11372049.662	30.78453	0.99986600
29 13	11370202.590	30.78459	0.99986536
29 14	11368355.514	30.78465	0.99986480
29 15	11366508.425	30.78472	0.99986433
29 16	11364661.352	30.78478	0.99986395
29 17	11362814.265	30.78485	0.99986365
29 18	11360967.174	30.78492	0.99986343
29 19	11359120.079	30.78500	0.99986329
29 20	11357272.979	30.78507	0.99986324
29 21	11355425.874	30.78515	0.99956328
29 22	11353578.765	30.78524	0.99986340
29 23	11351731.651	30.78532	0.99986360
29 24	11349884.532	30.78541	0.99986389
29 25	11348037.407	30.73550	0.99986426
29 26	11346190.278	30.78559	0.99986471
29 27	11344343.142	30.78568	0.99986525
29 28	11342496.001	30.73573	0.99986588
29 29	11340648.854	30.75588	0.99986659
29 30	11338801.701	30.73598	0.99986733
29 31	11336954.542	30.78609	0.99986326
23 32	11335107.377	30.78620	0.99986922
29 33	11333260.205	30.78631	0.99987025
29 34	11331413.026	30.73642	0.99987139
29 35	11329563.841	30.78654	0.99987261
29 36	11327718.649	30.78666	0.99987391

Lambert Conformal Conic Projection Tables

Texas South - Central			
29 37	11325871.449	30.78678	0.99987529
29 38	11324024.243	30.78690	0.99987676
29 39	11322177.028	30.78703	0.99987831
29 40	11320329.807	30.78716	0.99987995
29 41	11318482.577	30.78729	0.99988167
29 42	11316635.340	30.78742	0.99988347
29 43	11314788.094	30.78756	0.99988536
29 44	11312940.841	30.78770	0.99988734
29 45	12311093.578	30.78784	0.99988939
29 46	11309246.308	30.78799	0.99989154
29 47	11307399.029	20.73814	0.99989377
29 48	11305551.740	30.78329	0.99989608
29 49	11303704.443	30.78844	0.99989848

Projection Tables

Lambert Conformal Conic Projection Tables

Texas South - Central			
Lat	R (meters)	tab diff.	k
29 50	11301857.137	30.78859	0.99990096
29 51	11300009.821	30.78875	0.99990352
29 52	11298162.496	30.78891	0.99990618
29 53	11296315.161	30.78908	0.99990891
29 54	11294467.517	30.78924	0.99991173
29 55	11292620.462	30.78941	0.99991464
29 56	11290773.097	30.73958	0.99991763
29 57	11238925.722	30.78976	0.99992070
29 53	11287078.337	30.78993	0.99992386
29 59	11285230.941	30.79011	0.99992710
30 0	11283383.534	30.79029	0.99993043
30 1	11281536.116	30.79048	0.99993385
30 2	11279688.688	30.79067	0.99993734
30 3	11277841.248	30.79086	0.99994093
30 4	11275993.796	30.79105	0.99994459
30 5	11274146.334	30.79124	0.99994835
30 6	11272298.859	30.79144	0.99995218
30 7	11270451.373	30.79164	0.99995611
30 8	11268603.874	30.79184	0.99996011
20 9	11266756.363	30.79205	0.99996421
30 10	11264903.841	20.79226	0.99996333
30 11	11253061.305	30.79247	0.99997264
30 12	11261213.757	30.79268	0.99997699
30 13	11259366.196	30.79290	0.99998142
30 14	11257518.622	30.79312	0.99998594
30 15	11255671.035	30.79334	0.99999054
30 16	11253823.435	30.79356	0.99999523

Lambert Conformal Conic Projection Tables

Texas South - Central			
30 17	11251975.821	30.79379	1.00000000
30 13	11250128.194	30.79402	1.00000486
30 19	11248280.553	30.79425	1.00000980
30 20	11246432.898	30.79449	1.00001433
30 21	11244585.228	30.79472	1.00001994
30 22	11242737.545	30.79496	1.00002513
30 23	11240889.547	30.79521	1.00003042
30 24	11239042.135	30.79545	1.00003578
30 25	11237194.408	30.79570	1.00004124
30 26	11235346.666	30.79595	1.00004673
20 27	11233498.909	30.79620	1.00005240
30 28	11231651.137	30.79646	1.00005811
30 29	11229803.350	30.79672	1.00006390

Projection Tables

Lambert Conformal Conic Projection Tables

Texas South - Central			
Lat	R (meters)	tab diff.	k
30 30'	11227955.547	30.79698	1.00006978
30 31	11226107.728	30.79724	1.00007574
30 32	11224259.894	30.79751	1.00008179
30 33	11222412.043	30.79778	1.00008793
30 34	11220564.176	30.79805	1.00009415
30 35	11218716.294	30.79832	1.00010045
30 36	11216868.394	30.79860	1.00010684
30 37	11215020.478	30.79888	1.00011332
30 38	11213172.545	30.79916	1.00011988
30 39	11211324.596	30.79945	1.00012653
30 40	11209476.629	30.79974	1.00013326
30 41	11207628.645	30.80003	1.00014007
30 42	11205780.643	30.80032	1.00014698
30 43	11203932.624	30.80061	1.00015397
30 44	11202084.537	30.80091	1.00016104
3045	11200236.532	30.80121	1.00016820
30 46	11198388.460	30.80152	1.00017544
30 47	11196540.369	30.80182	1.00018277
30 48	11194692.259	30.80213	1.00019019
30 49	11192344.131	30.80244	1.00019769
30 50	11190993.985	30.80276	1.00020528

Plane Coordinate Projection Tables Texas South Zone 1983

Lambert conformal conic projection with two standard parallels

Plane coordinate projection tables

DATUM: NAD 83

The projection is TEXAS SOUTH

Ellipsoidal constants

a = 6378137 m

f = 1/298.25722210

Defining constants

ϕ_b = 25° 40' (latitude of grid origin)
λ_{CM} = 98 30 (longitude of origin and Central Meridian, CM)
ϕ_s = 26 10 (southern standard parallel)
ϕ_n = 27 50 (northern standard parallel)
E_b = 300000.0000 m (easting coordinate of origin)
N_b =5000000.0000 m (northing coordinate of origin)

Derived constants

ℓ = 0.454006848165 = sin(ϕ_s)
K = 15621596.5270 m (mapping radius at the equator)
R_b = 12672396.4573 m (mapping radius at grid origin)

Lambert coordinates (N,E) from geodetic positions (ϕ,λ)

γ = (λ_{CM} − λ) sin(ϕ_s) (γ is the meridional convergence)
E = R sin(γ) + E_b (R from table)
N = R_b − R cos(γ) + N_b

Station	Latitude Longitude	R γ	sin(γ) cos(γ)	E N
sample 1	27 0 0.00000 99 0 0.00000	12524674.541 m -0 13 37.21233	-0.0039619468 0.9999921515	250377.906 m 5147820.217 m

Geodetic positions from Lambert coordinates

tan(γ) = (E − E_b)/((R_b −(N − N_b))
R = (R_b − (N − N_b))/cos(γ)
λ = λ_{CM} − γ/ℓ
ϕ from table using R

Station	E N	E − E_b R_b−(N − N_b)	R γ	Latitude Longitude
sample 2	350000.000m 5150000.000m	50000.000 m 12522396.457 m	12522496.2781 m 0 13 43.57922	27 1 10.7790 97 59 45.9762

WARNING: Use sufficient significant digits for trig.functions

Figure B-9. South Zone Texas Plane Coordinate Projection.

Projection Tables

Lambert Conformal Conic Projection Tables

Texas South			
Lat	R (meters)	tab diff.	k
25 40'	12672396.457	30.77799	1.00016350
25 41	12670549.778	30.77786	1.00015684
25 42	12668703.106	30.77773	1.00015027
25 43	12666856.442	30.77760	1.00014377
25 44	12665009.786	30.77748	1.00013737
25 45	12663163.137	30.77735	1.00013104
25 46	12661316.495	30.77723	1.00012480
25 47	12659469.862	30.77712	1.00011864
25 48	12657623.235	30.77700	1.00011256
25 49	12655776.615	30.77689	1.00010657
25 50	12653930.002	30.77678	1.00010066
25 31	12652083.395	30.77667	1.00009484
25 52	12650236.195	20.77657	1.00008909
25 53	12648390.201	30.77646	1.00008343
25 54	12646543.612	30.77636	1.00007786
25 55	12644697.031	30.77627	1.09007237
25 56	12642850.455	30.77617	1.00006696
25 57	12641003.885	30.77608	1.00006163
25 58	12639157.320	30.77599	1.00005639
25 59	12637310.761	30.77591	1.00005123
26 0	12635464.206	30.77582	1.00004616
26 1	12633617.657	30.77574	1.00004117
26 2	12631771.113	30.77566	1.00003626
26 2	12629924.373	30.77558	1.00003143
26 4	12628078.033	30.77551	1.00002669
26 5	12626231.507	30.77544	1.00002203
26 6	12624384.981	30.77537	1.00001746

Lambert Conformal Conic Projection Tables

Texas South			
26 7	12622538.459	30.77531	1.00001297
26 8	12620691.940	30.77524	1.00000856
26 9	12618845.426	30.77518	1.00000424
26 10	12616998.915	30.77512	1.00000000
26 11	12615152.407	30.77507	0.99999584
26 12	12613305.903	30.77502	0.99999177
26 13	12611459.402	30.77497	0.99998778
26 14	12609612.904	30.77492	0.99998388
26 15	12607766.409	30.77487	0.99998005
26 16	12605919.916	30.77483	0.99997632
26 17	12604073.426	30.77479	0.99997266
26 18	12602226.939	30.77475	0.99996909
26 19	12600380.454	30.77472	0.99996560

Projection Tables

Lambert Conformal Conic Projection Tables

Texas South			
Lat	R (meters)	tab diff.	k
26 20'	12598533.970	30.77469	0.99996220
26 21	12596687.489	30.77466	0.99995838
26 22	12594841.010	30.77463	0.99995564
26 23	12592994.532	30.77461	0.99995249
26 24	12591148.055	30.77459	0.99994942
26 25	12589301.580	30.77437	0.99994644
26 26	12587455.106	30.77455	0.99994354
26 27	12585608.633	30.77454	0.99994072
26 28	12583762.160	30.77453	0.99993798
26 29	12581915.689	30.77452	0.99993533
26 30	12580069.218	30.77451	0.99993277
26 31	12578222.747	30.77451	0.99993029
26 32	12576376.276	30.77451	0.99992789
26 33	12574529.806	30.77451	0.99992537
26 34	12572683.335	30.77452	0.99992334
26 35	12570836.854	30.77452	0.99992119
26 36	12568990.393	30.77453	0.99991913
26 37	12567143.921	30.77455	0.99991715
26 38	12565297.448	30.77456	0.99991525
26 39	12563450.974	30.77458	0.99991344
26 40	32561604.500	30.77460	0.99991171
26 41	12559758.024	30.77462	0.99991007
26 42	12557911.346	30.77465	0.99990851
25 43	12556063.063	30.77468	0.99990703
26 44	12554218.587	30.77472	3.99990564
25 45	12352372.105	30.77474	0.99990433
26 46	12550525.620	30.77473	0.99990311

Lambert Conformal Conic Projection Tables

Texas South			
26 47	12548679.134	30.77481	0.99990197
26 48	12546332.645	30.77486	0.99990091
26 49	12544986.154	20.77490	3.99989994
25 50	12543139.660	30.77495	0.99989905
26 51	12541293.163	30.77499	0.99989825
26 52	12539446.663	30.77505	0.99989753
26 53	12537600.161	30.77510	0.99989689
26 54	12535753.654	30.77516	0.99959634
26 55	12533907.145	30.77522	0.99989587
26 56	12532060.632	30.77528	0.99989549
25 57	12530214.115	30.77534	0.99989519
26 58	32528367.595	30.77541	0.99989497
26 59	12526521.070	30.77549	0.99989484

Projection Tables

Lambert Conformal Conic Projection Tables

Texas South			
Lat	R (meters)	tab diff.	k
27 0'	12324674.541	30.77555	0.99989479
27 1	12522828.008	30.77563	0.99989483
27 2	12520981.470	30.77571	0.99989495
27 3	12319134.928	30.77579	0.99989516
27 4	12517288.380	30.77587	0.99989545
27 5	12515441.828	30.77595	0.99989522
27 6	12513595.271	30.77605	0.99989628
27 7	12511748.708	30.77614	0.99989682
27 3	12509902.140	30.77623	0.99989745
27 9	12508055.566	30.77633	0.99989816
27 10	12506208.986	30.77643	0.99989895

Texas South			
27 11	12504362.401	30.77653	0.99989983
27 12	12502515.809	30.77663	0.99990079
27 13	12500669.211	30.77674	0.99990184
27 14	12498822.607	30.77685	0.99990297
27 15	12496975.996	30.77696	0.99990419
27 15	12495129.379	30.77707	0.99990549
27 17	12493232.754	30.77719	0.99990688
27 16	12491436.123	30.77731	0.99990834
27 19	12489589.434	30.77743	0.99990990
27 20	12487742.338	30.77756	0.99991154
27 21	12435896.135	30.77769	0.99991326
27 22	12484049.523	30.77782	0.99991507
27 23	12482202.354	30.77795	0.99991696
27 24	12480356.177	30.77809	0.99991893
27 25	12478509.492	30.77822	0.99992099
27 26	12476662.799	30.77336	0.99992314
27 27	12474816.097	30.77851	0.99992537
27 23	12472969.386	30.77865	0.99992768
27 29	12471122.667	30.77880	0.99993008
27 30	12469275.939	30.77895	0.99993256
27 31	12467429.202	30.77911	0.99993513
2732	12465582.455	30.77927	0.99993778
27 33	12463735.699	30.77943	0.99994052
27 34	12461828.934	30.77959	0.99994334
27 35	12460042.158	30.77975	0.99994625
27 36	12453195.372	30.77992	0.99994924
27 37	12456348.578	30.73009	0.99995231
27 33	12454501.773	30.73026	0.99995547
27 39	12452654.957	30.79044	0.99995872

Appendix C — Monumentation

Overview

Introduction

Appendix C provides the TxDOT-approved methods of setting monuments in various soil conditions.

Each disk has an assigned DHT number and may be ordered from TxDOT warehouses. The use of various settings and disks is determined by the district survey coordinator. Each district may have specific markers to fit particular area needs. DHT numbers for statewide distribution of disks will be given only to the standard disks listed here or new configurations approved by SCOS.

The following marker disks are depicted:

1. ROW markers
2. Survey Control Points, horizontal/vertical stations
3. Bench marks
4. Property corners
5. Denial of access markers.

Markers and Methods

ROW Marker

This bronze Right-of-Way marker has remained unchanged for many years. Only slight changes to the embossed face of this disk will be noticed. The marker is a 4 inch domed-top disk with an open area for a punch mark. Usually, it is set in a poured concrete post and previously referred to as a Type II monument.

EXAMPLE:

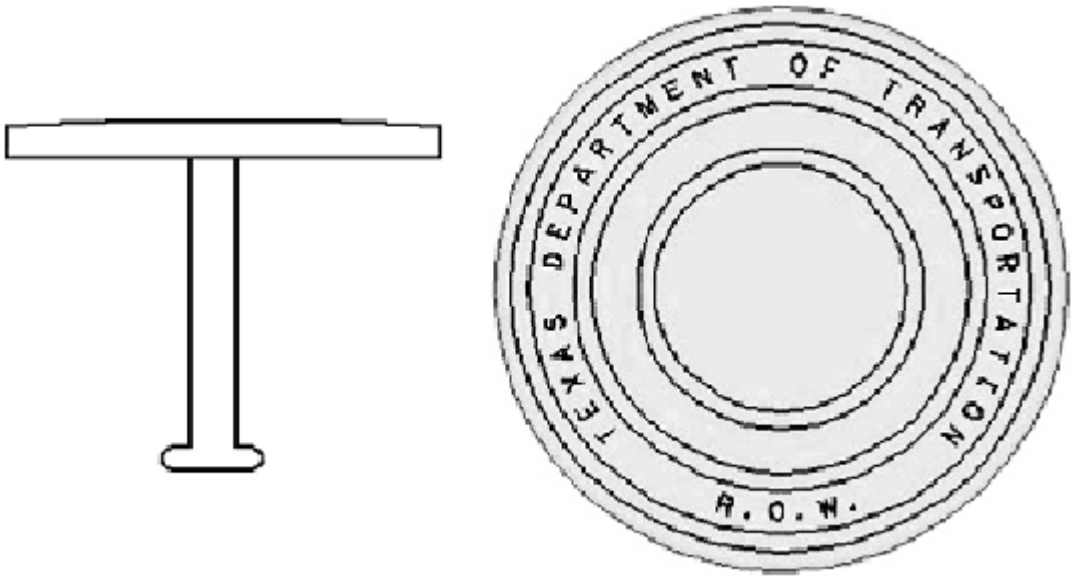

Figure C-1. ROW Marker. DHT #3247. Marker, Survey, Bronze 4", ROW.

Control Point Marker

Example:

This aluminum dome-top disk is pre-punched for setting as project control points. The triangle symbol has traditionally been used for horizontal control but this type of monument may also have an elevation value as well. There is a configuration for setting in rock and concrete and a configuration for use as a rebar cap. With the plastic spacer removed, the rebar cap can be driven onto a ¾ inch aluminum datum point rod section if preferred. Both configurations come with an imbedded magnet for aid in location with a magnetic detector.

Configuration A: DHT #164946. Marker, Survey, Control point, 3 ½" alum for rock and concrete

Configuration B: DHT #164949. Marker, Survey, Control point, 3 ¼" alum rebar cap

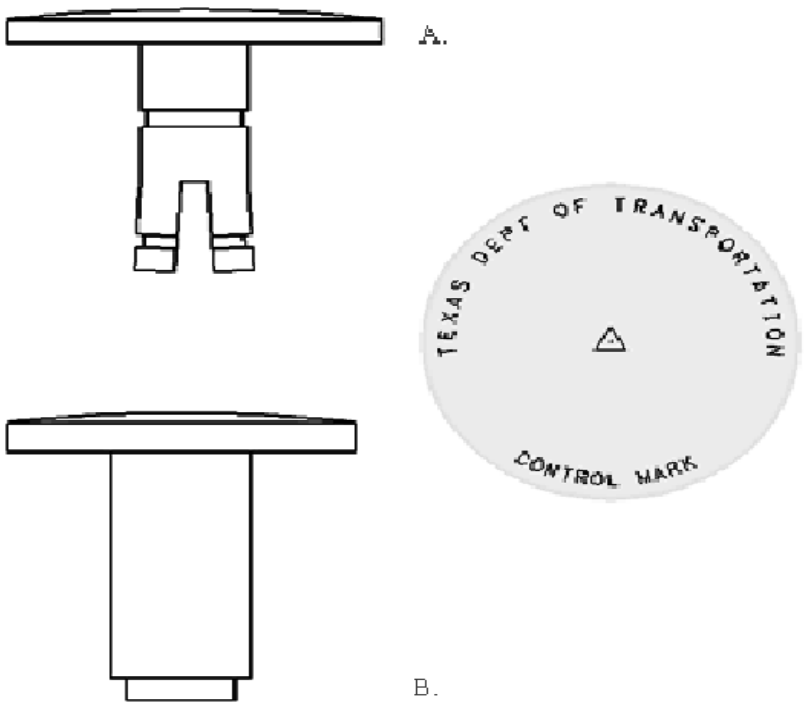

Figure C-2. Control Point Markers.

Bench Mark

This aluminum dome-top disk is intended for permanent elevation stations. The engraved mark is a standard notation for bench marks. The rock and existing concrete configuration can be mounted on a vertical surface if necessary.

EXAMPLE:

Configuration A: DHT # 164948. Marker, Survey, Bench Mark, 3 ½" alum for rock or concrete

Configuration B: DHT # 164947. Marker, Survey, Bench Mark, 3 ¼" alum cap for 5/8" rebar

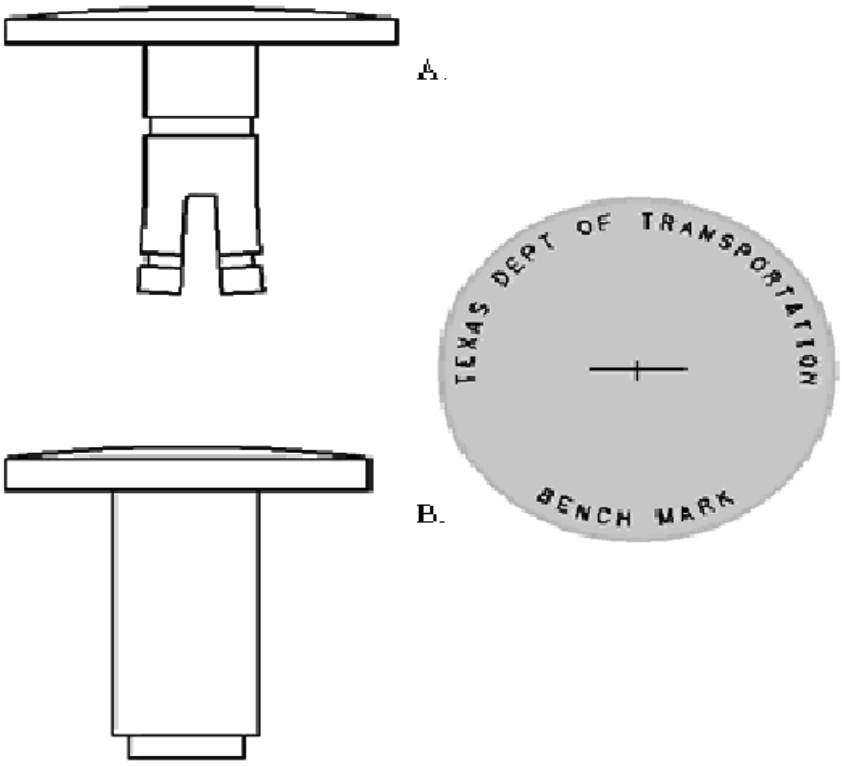

Figure C-3. Bench Mark Markers.

Property Corner Marker

This smaller 2" diameter disk is used to mark the intersection of existing property lines with new ROW. If it must be set in rock or concrete, several grooves should be filed into the sides to give it more gripping power.

EXAMPLE:

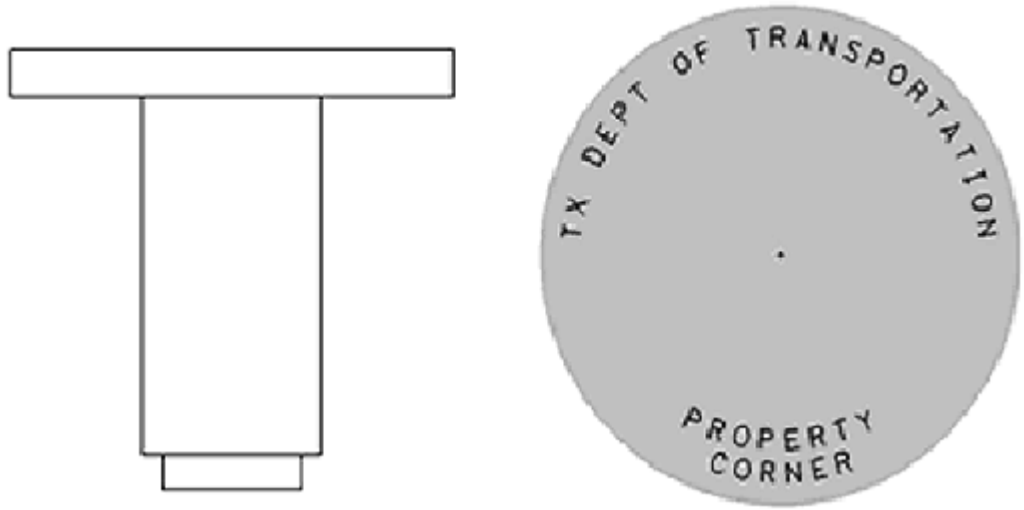

Figure C-4. Property Corner Marker. DHT # 164950. Marker, survey, property corner, 2" alum cap for 5/8" rebar.

Denial of Access Marker

This 2" diameter disk is used to mark points on the ROW line indicating control of access when a bronze ROW marker does not fall at the point. The face is flat and open for stamping pertinent information such as “beginning,” “ending” or an arrow indicating direction of denied access. It is to be driven onto a piece of rebar of appropriate length – usually 18".

EXAMPLE:

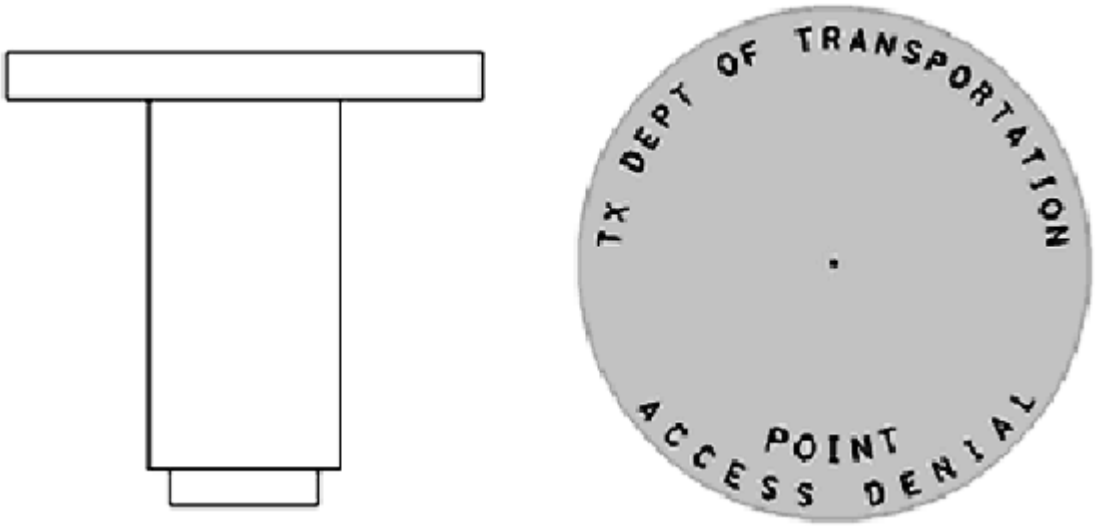

Figure C-5. Denial of Access Marker. DHT # 165012. Marker, survey, denial of access, 2" alum for 5/8" rebar.

Rock Setting

A disk can be bonded into a drill hole in bedrock for a very stable setting. A similar setting in a large concrete structure can be used but is more subject to movement over long periods of time. Culvert headwalls are convenient for bench marks but make poor locations for static GPS occupations.

A two-part epoxy or other high strength cement is recommended. The stem hole can be drilled with a power hammer drill or a star drill can be used. A recess should be chiseled for the head. As depicted below by the dashed lines on the stem, any of the disks with ferrules or flare legs can be used.

Stability: Rock settings are very stable when in bedrock (NGS stability code A if in bedrock, otherwise B, or C)

Uses: Bench marks, project and secondary control points, property corners, ROW markers

EXAMPLE:

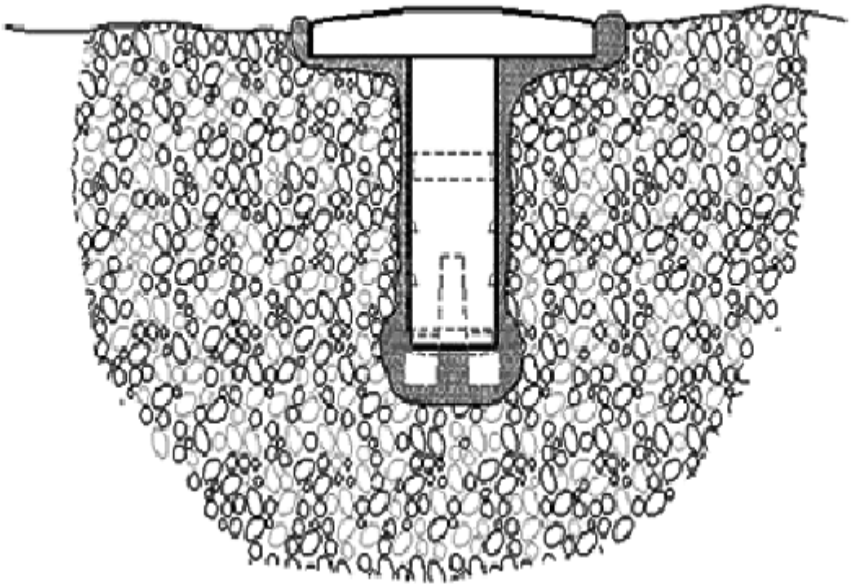

Figure C-6. Rock Setting.

Datum Point Rod

This is a very stable and secure configuration and should be used whenever possible for major project control points and TxDOT levels 1 and 2 GPS positions. A power driver should be used to drive the rod sections to refusal. However, with proper protection of the rod end, the rod can be hammered into the ground manually. This is similar to an NGS Class A rod mark but lacks the grease sleeve.

Stability: Very good (NGS stability code B)

Uses: Bench marks and control points

EXAMPLE:

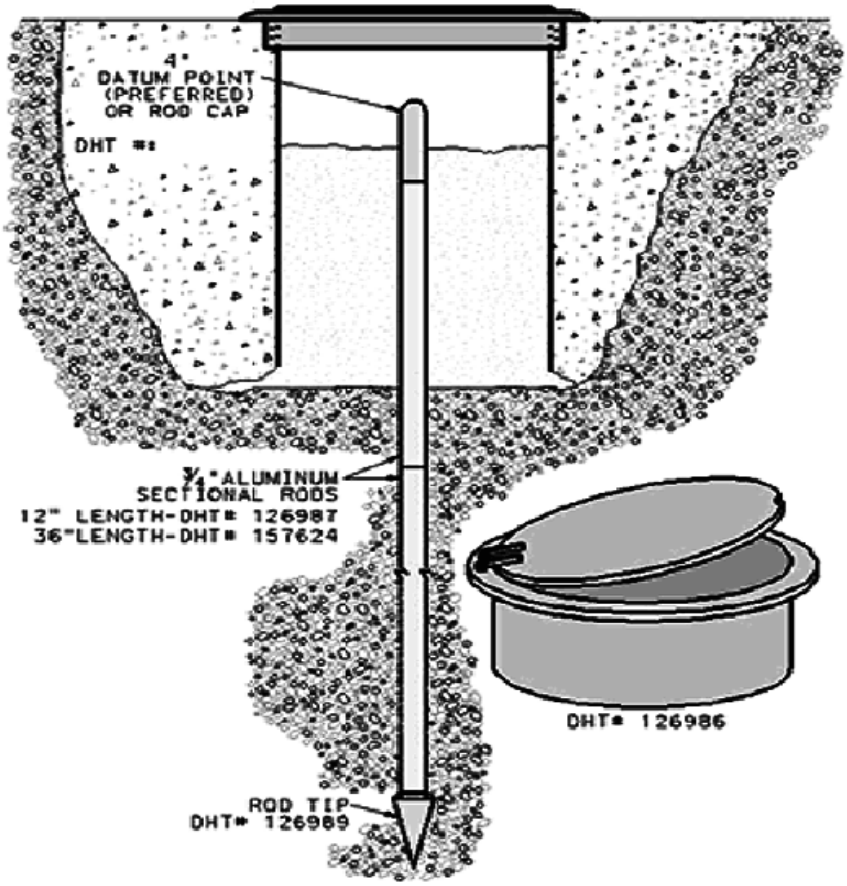

Figure C-7. Datum Point Rod Setting.

Poured Concrete Setting

A disk placed in a freshly poured concrete post as shown in the following sketches will provide a stable setting. It should be reinforced with either 1/2" or 5/8" rebar as shown. This is the setting of the old Type II monuments. It should be used where it is important to hold the position well. It is shown here with the ROW marker but can also be used for control points and bench marks.

Stability: Good (NGS stability code C)

Uses: ROW markers, bench marks and control points

EXAMPLE:

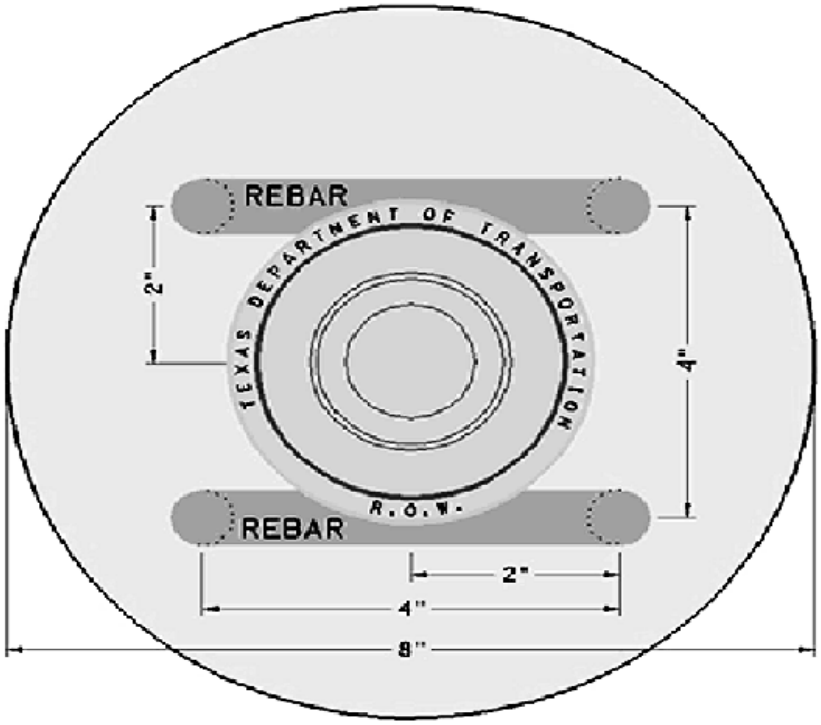

Figure C-8. Poured Concrete Setting, Top View (M-92).

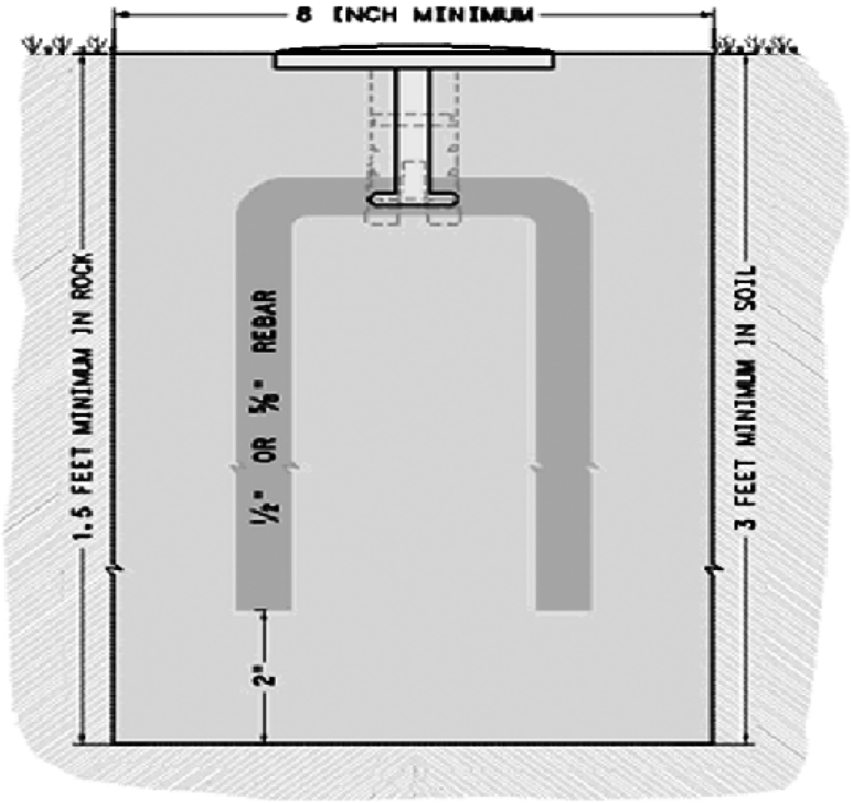

Figure C-9. Poured Concrete Setting, Cross Section (M-92).

Light Duty Setting

A cap type disk can be driven onto a length of 5/8" rebar and set in the ground. This is a more economical setting where setting a more stable monument is not justified. A hole at least 12" in rocky soil or 18" in loose soil should be dug before driving the rod. The rod should be driven to refusal when practical. A 3/4" aluminum sectional rod may be used if it is not known how much resistance will be met. The hole shall be filled flush to the surface with concrete. Consult the district survey coordinator to determine what circumstances are appropriate for setting this type of monument.

Stability: Poor (NGS stability code D)

Uses: For secondary survey control

EXAMPLE:

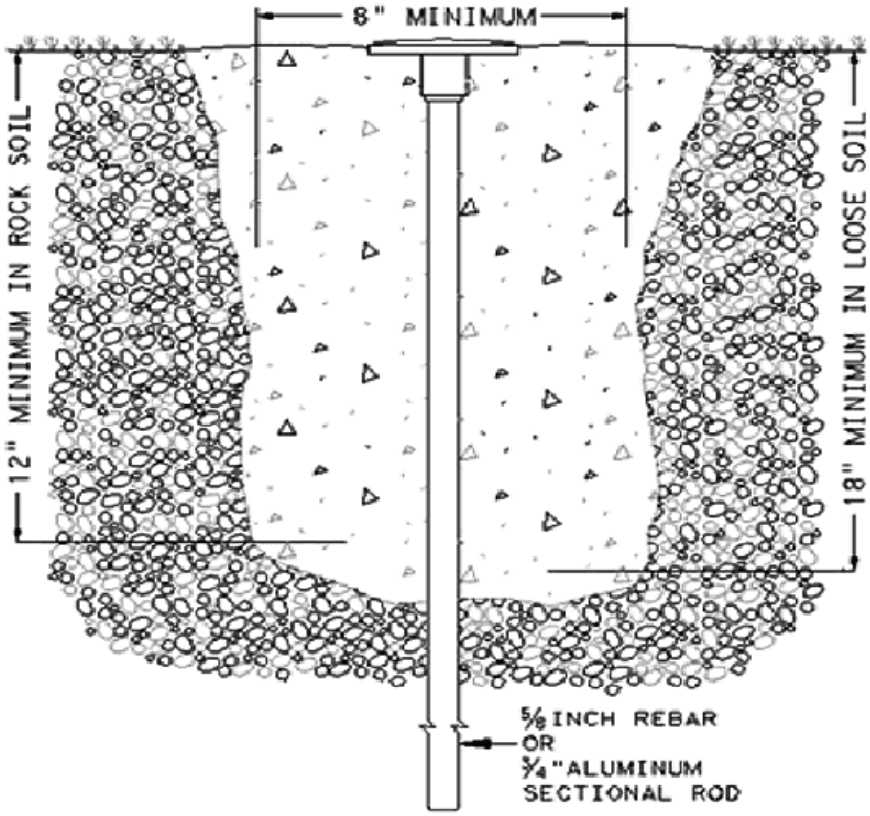

Figure C-10. Light Duty Setting.

Appendix D — Glossary

Introduction

Some terms and definitions within this appendix have been obtained from the Texas Board of Professional Land Surveying (TBPLS) and/or the Texas Society of Professional Surveyors.

This appendix contains the definitions of most, but not all GPS and survey related terms. The terms and their descriptions below are explained as used/intended in the context of this manual. Other or more elaborate descriptions may exist for the terms listed.

Other Definitions – Terminology used in this manual shall be defined herein, or when not defined herein, shall refer to the **Definitions of Surveying and Associated Terms**: (1978), as compiled by the joint committee of the American Society of Civil Engineers and the American Congress on Surveying and Mapping.

1

1-sigma – 1-sigma is one standard error from the mean.

A

accidental error – An error for which it is equally probable that the sign of the error is a plus or minus value; an error for which there is no proportional change or relationship between measurements, conditions and the sign or magnitude of the error; an error, evident in a series of measurements, which is compensated in total effect.

accuracy – Accuracy is how close measurements are to the accepted value of truth.

accuracy of the bearing (or course) – In relation to source, accuracy of the bearing (or course) is the relationship of each bearing as expressed on a map, plat and/or in a description of the new survey shall not exceed the angular relationship of the stated source by more than the following tolerance:

- Sin ∠ = (approximately) and rounded to nearest 5 seconds
- Where ∠ = + bearing accuracy in seconds (rounded)
- p = the denominator of the allowable error of closure (precision) for the particular Condition (i.e. 5,000; 7,500; 10,000 or 15,000)

adjusted values – Adjusted values are the values derived from observed data (measurement) by applying a process of eliminating errors in that data in a network adjustment.

adjustment – Adjustment is the process of determining and applying corrections to observations for the purpose of reducing errors in a network adjustment.

adjustment convergence – Adjustment convergence occurs when the network adjustment has met the defined residual tolerance or last ditch residual tolerance within a defined number of iterations.

algebraic sign – An algebraic sign is a sign (+ or -) associated with a value which designates it as a positive or negative number.

algorithm – An algorithm is a set of rules for solving a problem in a finite number of steps.

almanac – An almanac is data transmitted by a GPS satellite which includes orbit information on all the satellites, clock corrections, and the atmospheric delay parameters. This data is used to facilitate rapid SV acquisition within GPS receivers.

ambiguity – Ambiguity is the unknown integer number of cycles of the reconstructed carrier phase contained in an unbroken set of measurements. The receiver counts the radio waves (from the satellite as they pass the antenna) to a high degree of accuracy. However, it has no information on the number of waves to the satellite at the time it started counting. This unknown number of wavelengths between the satellite and the antenna is the ambiguity. Ambiguity is also known as integer ambiguity or integer bias.

angular closure – Angular closure for each **condition** is expressed as the number of seconds allowable for any angle multiplied by the square root of the number of angles in the traverse. This value should not be exceeded in any loop closure. The basis for this angular value is well documented in standard textbooks on surveying practice and procedures.

antenna height – Antenna height is the height of a GPS antenna phase center above the point being observed. The uncorrected antenna height is measured from the observed point to a designated point on the antenna, and then corrected to the true vertical manually or automatically in the software.

antenna phase center – Antenna phase center is the electronic center of the antenna. It often does not correspond to the physical center of the antenna. The radio signal is measured at the Antenna Phase Center.

antenna phase correction – Antenna phase correction is the antenna phase correction is the phase center for a GPS antenna is neither a physical nor a stable point. The phase center for a GPS antenna changes with respect to the changing direction of the signal from a satellite. Most of the phase center variation depends on satellite elevation. Modeling this variation in antenna phase center location allows a variety of antenna types to be used in a single survey. Antenna phase, center corrections are not as critical when two of the same antennas are used since common errors cancel out.

anti-spoofing (AS) – Anti-spoofing is a feature that allows the U.S. Department of Defense to transmit an encrypted Y-code in place of P-code. Y-code is intended to be useful only to authorized (primarily military) users. AS is used with selective availability to deny the full precision of GPS to civilian users.

autonomous positioning – Autonomous positioning is a mode of operation in which a GPS receiver computes position fixes in real time from satellite data alone, without reference to data supplied by a base station. Autonomous positioning is the least precise positioning procedure a GPS receiver can perform, yielding position fixes that are precise to ±100 meters horizontal RMS when selective availability is in effect, and to ±10-20 meters when it is not. This is also known as absolute positioning and point positioning.

azimuth – The azimuth is a surveying observation used to measure the angle formed by a horizontal baseline and geodetic north. When applied to GPS observations, it refers to a normal section azimuth.

B

base station – A base station is an antenna and receiver set up on a known location. It is used for real-time kinematic (RTK) or differential surveys. Data can be recorded at the base station for later Postprocessing. In GPS surveying practice, the user may observe and compute baselines (that is, the position of one receiver relative to another). The base station acts as the position from which all other unknown positions are derived.

baseline – A baseline is the position of a point relative to another point. In GPS surveying, this is the position of one receiver relative to another. When the data from these two receivers is combined, the result is a baseline comprising a three-dimensional vector between the two stations.

bearing source – The source of the bearing (or course) must be stated in the report, on the Plat or in any description as one of the following:

- geodetic bearing
- grid bearing of the Texas Coordinate System of 1983 (or 1927), with the proper zone specified, Sec. 21.071, et seq., Tex. Nat. Res. Code Ann. (Vernon 1978), or
- record bearing or the relation thereto, along a line monumented on the ground as called for in said record.

bench marks – A bench mark is a relatively permanent object, natural or man-made, bearing a marked point, whose elevation above or below an adopted datum is known. Usually designated as "BM," such a mark is sometimes further qualified as a PBM (permanent bench mark) or as a TBM (temporary bench mark). Often, a TxDOT disk is set in a concrete monument or drilled into a concrete surface or object is used.

C

C/A code – The standard (Course/Acquisition) GPS code. A sequence of 1023 pseudorandom, binary, biphase modulations on the GPS carrier at a chip rate of 1.023 MHz. It is also known as the "civilian code." C/A code helps the receiver compute the distance from the satellite.

CAF – Combined Adjustment Factor. CAF is the product of the scale factor and the elevation factor. The CAF times the surface distance yields the corresponding distance on the state plane grid.

calculation of area - accurate and carried to – The perimeter courses and distances as shown on a map, plat or drawing representing the survey shall compute to the area stated on the Plat. The decimal shall be carried only so far as it is compatible with the precision of the survey and not beyond the last significant number. A one-acre survey with a precision of 1:5,000 will result in an area calculation of + value of 0.0002 acre. The acreage should then be carried only to the nearest 0.001 acre. Likewise a survey of a one-acre tract with a precision of 1:15,000 will result in an area calculation of + 3 square ft. or about + .00007 acre. The acreage can then be carried to the nearest .0001 acre. Similar values can be mathematically applied to any size tract by the formula:

- Ae = A - (e/(e+1) x A)
- Where: Ae = + probable error in square feet
- A = area of tract in square feet, determined from survey
- e = denominator of error of closure for the particular Conditions (5,000; 7,500; 10,000; 15,000).

carrier – A carrier is a signal that can be varied from a known reference by modulation.

carrier frequency – Carrier frequency is the frequency of the unmodulated fundamental output of a radio transmitter.

Cartesian coordinates – See fixed earth-centered-earth Cartesian coordinates.

category – Category is a unit dividing major professional services of a RPLS into defined segments of similar nature, procedure and practice. A Category is comprised of one or several services or products that are closely allied. A Route Survey is a Category. A Land Title Survey is a different Category. Each Category has specific requirements.

CBN – Cooperative Base Network. CBN consists of B order stations set in cooperation with various governmental agencies for the purpose of densifying the National Spatial Reference System.

channel – A channel of a GPS receiver consists of the circuitry necessary to tune into the signal from a single GPS satellite.

chi-square test – Chi-square is an overall statistical test of the network adjustment. It is a test of the sum of the weight squares of the residuals, the number of degrees of freedom and a critical proba-

bility of 95 percent or greater. The purpose of this test is to reject or to accept the hypothesis that the predicted errors have been accurately estimated.

clock bias – Clock bias is the difference between the clock's indicated time and true universal time.

clock offset – Clock offset is the constant difference in the time reading between two clocks. In GPS, usually refers to offset between SV clocks and the clock in the user's receiver.

closure – Closure is a mathematical application whereby a determination is made as to the exactness that a geometrical form is generated or attained within its confined elements of connecting lines and points. It is a computation method used by a land surveyor to test the quality of field survey measurements and to apply corrections in balancing or adjusting the survey to meet precision specifications.

coarse acquisition – A course acquisition is a pseudorandom noise (PRN) code modulated onto an L1 signal.

code – Code is the GPS code and is a pseudorandom noise (PRN) code that is modulated onto the GPS carrier signals. The C/A code is unclassified and is available for use by civilian applications. The P code is also known and unclassified, but may be encrypted for national defense purposes. Code measurements are the basis of GPS navigation and positioning. Code also is used in conjunction with carrier phase measurements to obtain more accurate survey quality baseline solutions.

collection rate – The rate at which a receiver collects SV data.

component – A component is one of the three surveying observations used to define a three-dimensional baseline between two control points. The same baseline can be defined by azimuth, delta height, and distance (in ellipsoid coordinates); by delta X, delta Y, and delta Z in (Earth Centered Cartesian coordinates); and by delta north, delta east, and delta up (in local plane coordinates).

constant systematic error – A Constant systematic error is represented by conditions that do not change during a series of measurements.

constellation – A constellation is a specific set of satellites used in calculating positions: three satellites for 2-D fixes, four satellites for 3D fixes. It is all of the satellites visible to a GPS receiver at one time. The optimum constellation is the constellation with the lowest PDOP.

constrained – Constrained is a way to hold (fix) a quantity (observation and coordinate) as true in a network adjustment.

constraint – Constraint is external limitations imposed upon the adjustable quantities (observations and coordinates) in a network adjustment.

contour interval – A contour interval is a predetermined difference in elevation (vertical distance) at which contour lines are drawn. The contour interval is usually the same for maps of the same scale.

contour line – A contour line is an imaginary line on the ground, all points of which are above or below a specified datum.

contour map – A contour may is a map that portrays relief by means of contour lines.

control – A control is a system of points whose relative positions have been determined from survey data.

controlling monument – A monumented land corner to which a land survey is referenced.

control point – A point that has a very accurate coordinate. This may be a published NGS point or one that was surveyed by other means. This is the type of point that a reference receiver should be placed on.

control stations – Control stations are stations whose position (horizontal or vertical) has been determined from survey data and is used as a base for a dependent survey.

control survey – A control survey is a survey that provides positions (horizontal or vertical) of points to which supplementary surveys are adjusted.

conventional observation – A conventional observation is an observation in the field obtained using a total station or theodolite.

coordinates – Coordinates are linear or angular quantities, or both, which designate the position on a point in relation to a given reference frame.

correlated – When observations are correlated, there are two or more observations (or derived quantities), which have at least one common source of error.

CORS - Continuously Operating Reference System – CORS is a network of the highest quality horizontal stations, forming the National Spatial Reference System and providing the public with 24-hour raw GPS data.

covariance – Covariance is a measure of the correlation of errors between two observations or derived quantities. Covariance also refers to an off-diagonal term (that is, not a variance) in a variance-covariance matrix.

covariance matrix – A matrix that defines the variance and covariance of an observation. The elements of the diagonal are the variance and all elements on either side of the diagonal are the covariance.

covariant values – This is the publication of the propagated (computed) a posteriori errors in azimuth, distance, and height between pairs of control points resulting from a network adjustment. The term covariant indicates that this computation involves the use of covariant terms in the variance-covariance matrix of adjusted control points.

cycle slips – A discontinuity in the measured carrier beat phase resulting from a temporary loss of lock in the carrier loop of a GPS receiver.

D

data collector – A data collector is a handheld electronic field notebook. It connects to a total station, level, or GPS receiver to receive and temporarily store raw data.

data logging – Data logging is the process of recording satellite data in a file stored in the receiver, a data collector, or on a PC card.

data message – A message included in the GPS signal which reports the satellite's location, clock corrections, and health.

datum – Datum is a mathematical model of the earth designed to fit part or all of the geoid. It is defined by the relationship between an ellipsoid and a point on the topographic surface established as the origin of the datum. It is usually referred to as a geodetic datum. The size and shape of an ellipsoid, and the location of the center of the ellipsoid with respect to the center of the earth, usually define world geodetic datums.

datum grid/multiple regression – Datum grid/multiple regression are datum transformations, usually convert data collected, in the WGS-84 datum (by GPS methods) onto datums used for surveying and mapping purposes in individual regions and countries.

datum transformation – Datum transformation defines the transformation that is used to transform the coordinates of a point defined in one datum to coordinates in a different datum. There are a number of different datum transformation methods including seven-parameter and three-parameter (or Molodensky).

de-correlate – To de-correlate is to remove the covariances between observations. This may be done through elaborate orthogonal transformations, or by computing separate horizontal and vertical adjustments.

deflection of the vertical – A deflection of the vertical is the angular difference between the upward direction of the plumb vertical line (vertical) and the perpendicular (normal) to the ellipsoid.

degrees of freedom – Degrees of freedom is a measure of the redundancy in a network.

delta elevation – Data elevation is the difference in elevation between two points.

delta N, delta E – Delta N and delta E are coordinate differences, expressed in a Local Geodetic Horizon delta U coordinate system.

delta X, delta Y, delta Z – Delta X, Y, and Z are coordinate differences, expressed in a Cartesian coordinate system.

differential positioning – Precise measurement of the relative positions of two receivers tracking the same GPS signals.

discrepancy – The difference between two measurements of the same quantity.

DOP – Dilution of Precision is a measure of the accuracy of a GPS position based on the relative positions of the satellites. DOP is an indicator of the quality of a GPS position. It takes account of each satellite's location relative to the other satellites in the constellation, and their geometry in relation to the GPS receiver. A low DOP value indicates a higher probability of accuracy.

Standard DOPs for GPS applications are:

- PDOP Position (three coordinates)
- HDOP Horizontal (two horizontal coordinates)
- VDOP Vertical (height only)
- TDOP Time (clock offset only).

doppler shift – A doppler shift is the apparent change in frequency of a signal caused by the relative motion of satellites and the receiver.

double differencing – Double differencing is an arithmetic method of differencing carrier phases simultaneously measured by two receivers tracking the same satellites. This method removes the satellite and receiver clock errors.

DTM – Digital Terrain Model. DTM is a representation in graphic form, on the computer, of the terrain through the area being surveyed.

dual-frequency – A dual frequency is a type of receiver that uses both L1 and L2 signals from GPS satellites. A dual-frequency receiver can compute more precise position fixes over longer distances and under more adverse conditions because it compensates for ionospheric delays.

E

earth-centered-earth – An earth-centered-earth is a Cartesian coordinate system used by the WGS-84 reference frame.

easting – Easting is an eastward reading of grid values. Easting is read left to right on a grid (X-axis).

elevation – is the vertical distance of a point above or below a datum plane.

elevation mask – This is the angle above the horizon, below which satellite signals are not used.

ellipsoid – The Earth is neither perfectly smooth or round. Earth scientists (geodesists) have mathematically smoothed the surface of the Earth by averaging the highs and lows. This new calculation is called an ellipsoid. GPS uses WGS 84 as its ellipsoid base.

The ellipsoid is a mathematical model of the earth formed by rotating an ellipse around its minor axis. For ellipsoids that model is the earth, the minor axis is the polar axis, and the major axis is the equatorial axis.

- An ellipsoid is defined by specifying the lengths of both axes, or by specifying the length of the major axis and the flattening.
- Two quantities define an ellipsoid; these are usually given as the length of the semi-major axis, a, and the flattening, where b is the length of the semi-minor axis.

ellipsoid distance – An ellipsoid distance is the length of the normal section between two points. Ellipsoid distance is not the same as the geodesic distance.

ellipsoid height – An ellipsoid height is the distance, measured along the normal, from the surface of the ellipsoid to a point.

ephemeris – An ephemeris is a set of data that describes the position of a celestial object as a function of time. Each GPS satellite periodically transmits a broadcast ephemeris describing its predicted positions through the near future, uploaded by the control segment. Postprocessing programs can also use an ultra rapid, rapid or precise ephemeris, which describes the exact positions of a satellite in the past.

epoch – An epoch is the time interval when the receiver logs data to its memory. An epoch is the measurement interval of a GPS receiver. The epoch varies according to the survey type.

epoch date – The epoch date is the date, usually expressed in decimal years for which published coordinates and data are valid.

epoch interval – Epoch interval is the measurement interval used by a GPS receiver; also called a cycle.

error – An error is the difference between the measured value of a quantity and its true value. Surveying errors are generally divided into three categories: blunders, systematic errors, and random errors. Least squares analysis is used to detect and eliminate blunders and systematic errors, and least squares adjustment is used to measure and properly distribute random error.

error ellipse – An error ellipse is a coordinate error ellipse is a graphical representation of the magnitude and direction of the error of network adjusted points.

error of closure – Reflects the precision of the survey and is the result of mathematically determining the latitude and departures and subsequently the misclosure of the traverse. Once this value has been determined and found to be of no lesser quality than required, any suitable adjustment may be made.

events – Events are represented as a record of the occurrence of an event, such as the closing of a photogrammetric camera's shutter. A GPS receiver can log an event mark containing the time of the event and an alphanumeric comment entered through the keypad to describe the event. An event can be triggered through the keypad or by an electrical signal input on one of the receivers' ports.

F

fast ambiguity resolution – Fast ambiguity resolution is rapid static or fast static GPS surveying techniques, utilizing multiple observables (dual-frequency carrier phase, C/A and P codes) to resolve integer ambiguities, with shortened observation periods. The method may also be used for observations with the receiver in motion known as on-the-fly ambiguity resolution.

faststatic – FastStatic is a method of GPS surveying using occupations of up to 20 minutes to collect GPS raw data, then postprocessing to achieve sub-centimeter precisions. Typically the occupation times vary based on the number of satellites (SVs) in view. FastStatic is also referred to as RapidStatic.

FBN – Federal Base Network – An FBN consists of A and B order stations set by the NGS for the purpose of densifying the National Spatial Reference System.

FCA – An FCA is a fully constrained adjustment.

feature codes – Feature codes are abbreviations used to define an object collected during a radial survey.

FGCS - Federal Geodetic Control Subcommittee

FGDC – Federal Geodetic Data Committee.

fixed – See constrained.

fixed (ECEF) – Earth-centered-earth fixed (ECEF) is a Cartesian coordinate system used by the WGS-84 reference frame. In this coordinate system, "fixed" refers to the center of the system that is at the earth's center of mass. The z-axis is coincident with the mean rotational axis of the earth and the x-axis passes through 0× N and 0× E. The y-axis is perpendicular to the plane of the x and z-axes.

fixed coordinates – Fixed coordinates are point coordinates that do not move when performing a network adjustment.

fixed elevation – A fixed elevation is an elevation obtained, either as a result of tide observations or previous adjustment of leveling, which is held at its accepted value in any subsequent adjustment.

fixed position – A fixed position is an adjusted value of the position of a point on the earth. The positions obtained by the adjustment are called adjusted positions, and when used a control for other survey work they are called fixed positions.

fixed solution – A fixed solution is a solution obtained when the baseline processor is able to resolve the integer ambiguity search with enough confidence to select one set of integers over another. It is called a fixed solution because the ambiguities are all fixed from their estimated float values to their proper integer values.

flattening – A flattening is a mathematical expression of the relative lengths of the major and minor axes of an ellipsoid.

flattening inverse – A flattening inverse is an expression of the flattening that is easier to read and edit.

float solution – A float solution is a solution obtained when the baseline processor is unable to resolve the integer ambiguity search with enough confidence to select one set of integers over another. It is called a float solution because the ambiguity includes a fractional part and is non-integer.

free adjustment – Performs a network adjustment in which no point (coordinate) is constrained. The network adjustment uses inner constraints.

frequency – Frequency is the size and spread of residuals in a data set; graphically shown in distribution histograms.

fully constrained – Fully constrained is a network adjustment in which all points in the network that are part of a larger control network are held fixed to their published coordinate values. Fully constrained is used to merge smaller with larger control networks and old to newer networks.

G

GDOP - Geometric Dilution of Precision – GDOP is the relationship between errors in user position and time and errors in satellite range. See also DOP.

geodetic azimuth – A geodetic azimuth is the angle between the geodetic meridian and the tangent to the geodesic line of the observer, measured in the plane perpendicular to the ellipsoid normal of the observer; clockwise from north.

geodetic datum – A geodetic datum is a mathematical model designed to fit part or all of the geoid. It is defined by the relationship between an ellipsoid and a point on the topographic surface established as the origin of a datum.

- The size and shape of an ellipsoid and the location of the center of the ellipsoid with respect to the center of the earth define world geodetic datums. Various datums have been established to suit particular regions.
- For example, European maps are often based on the European datum of 1950 (ED-50). Maps of the United States are often based on the North American Datum of 1927 or 1983 (NAD-27, NAD-83). All GPS coordinates are based on the WGS-84 datum surface.

geographic (geodetic) coordinates – Latitude, longitude, and ellipsoid height.

geoid – A geoid is an Earth model that takes into account the Earth's gravity field. Geodesists have recalculated the Earth's surface so that an object does weigh the same no matter where it is placed.

A geoid is the surface of gravitational equipotential that closely approximates mean sea level. It is not a uniform mathematical shape, but is an irregular figure.

- Generally, the elevations of points are measured with reference to the geoid. However, points fixed by GPS methods have heights established in the WGS84 datum (a mathematical figure).
- The relationship between the WGS-84 datum and the geoid must be determined by observation, as there is no single mathematical definition that can describe the relationship. The user must utilize conventional survey methods to observe the elevation above the geoid, and then compare the results with the height above the WGS84 ellipsoid at the same point.
- By gathering a large number of observations of the separation between the geoid and the WGS84 datum (geoidal separation), grid files of the separation values can be established.
- This allows the interpolation of the geoidal separation at intermediate positions. Files containing these grids of geoidal separations are referred to as geoid models. Given a WGS84 position that falls within the extents of a geoid model, the model can return the interpolated geoidal separation at this position.

geoid model – A geoid model is a mathematical representation of the geoid for a specific area, or for the whole earth. The software uses the geoid model to generate geoid separations for the user's points in the network.

geoid separation – Geoid separation is the distance between the ellipsoid and geoid at a given point.

geomatics – Geomatics is the design, collection, storage, analysis, display, and retrieval of spatial information. The collection of spatial information can be from a variety of sources, including GPS and terrestrial methods. Geomatics integrates traditional surveying with new technology-driven approaches, making geomatics useful for a vast number of applications.

GPS - Global Positioning System – A GPS is based on a constellation of twenty-four (24) satellites orbiting the earth at a very high altitude.

GPS baseline – A GPS baseline is a three-dimensional measurement between a pair of stations for which simultaneous GPS data has been collected and processed with differencing techniques. This baseline is represented as delta X, delta Y, and delta Z; or azimuth, distance, and delta height.

GPS observation – A GPS observation is an uninterrupted collection of GPS data at a particular point in the field. A number of observations are done simultaneously in a session to create baselines by processing the data.

GPS raw data – GPS raw data is the data collected by a GPS receiver for the purpose of processing at a later time.

GPS time – GPS time is a measure of time used by the NAVSTAR GPS system. GPS time is based on Universal Time Coordinated (UTC) but does not add periodic leap seconds to correct for changes in the earth's period of rotation.

GPS week – A GPS week is an incremental number of weeks, starting at 0 hour UTC on the date January 6, 1980. April 6, 1007 is the first day of GPS week 900.

gravity void – A gravity void is a block or area of blocks within the gravity measurement database without observations. A geoid model relying upon this database would be weak and possibly in error at these blocks.

grid – A grid is a two-dimensional horizontal rectangular coordinate system, such as a map projection.

grid azimuth – A grid azimuth is measured from grid north.

grid conversion – A grid conversion is the conversion between geographic and map projection coordinates.

grid coordinates – Grid coordinates are the numbers of a coordinate system that designates a point on a grid.

grid declination - The angular difference in direction between grid north and true north at any given place.

grid position – Grid position are the grid coordinates of a point.

ground control – Ground control, in photomapping, is the control obtained from surveys as distinguished from control obtained by photogrammetric methods.

grid distance – The grid distance is the distance between two points that is expressed in mapping projection coordinates.

ground distance – Ground distance is the distance (horizontal distance with curvature applied) between two ground points.

ground plane – A ground plane is a large flat metal surface, or electrically charged field, surrounding a GPS antenna used to deflect errant signals (multipath) reflected from the ground and other near-by objects.

GRS 80 guard stake – A GRS 80 guard stake is a stake driven near a point usually sloped with the top of the guard stake over the point. The guard stake protects, and its markings identify the point.

H

HDOP – Horizontal Dilution of Precision.

height measurement – A height measurement is a measuring tool supplied with an external GPS antenna and used rod for measuring the height of the antenna above a point.

H. I. – Measurement from point on the ground to the antenna of either the base or rover receiver.

histogram – A histogram is a graphical display of the size and distribution of residuals in a network adjustment.

horizontal – A horizontal is a point with horizontal coordinate accuracy only. The control point elevation or ellipsoid height is of a lower order of accuracy or is unknown.

horizontal control survey – is performed for the purpose of placing geographic coordinates of latitude and longitude on permanent monuments for referencing lower levels of surveys. A projection is used to place the coordinates on a plane of northing and easting values for simplified measurements. Scale and elevation factors are applied to make the distance measurements applicable to the exact project location on the working surface and the type of projection chosen is an “equal angle” type. The required datum for all TxDOT surveys is NAD 83 (HARN adjustment) unless otherwise directed by TxDOT.

horizontal datum – A datum is a set of precisely surveyed points on the ground that have been referenced to a given ellipsoid.

horizontal distance – A horizontal distance is the distance between two points, computed horizontally from the elevation of either point.

horizontal position – A horizontal position is a point with horizontal coordinates only.

HTDP – Horizontal Time Dependent Positioning model. HTDP is a computer database and interpolation program developed by NGS to predict horizontal displacements between coordinate points over time. The program can work backwards in time where it includes earthquake parameter or forward in time where only the secular motion is analyzed.

hub – A hub is a wooden stake set in the ground, with a tack or other marker to indicate the exact position. A guard stake protects and identifies the hub.

I

independent – An independent is the subnetworks, observations, and control points not connected by geometry or errors. This term is the opposite of correlated.

independent baseline – An independent baseline is a non-trivial baseline. Those vectors determined from differencing common phase measurements only once. For any given session there are n – 1 independent vectors where n is the number of receivers operating.

inner constraint – An inner constraint is a network adjustment computed without fixing any point coordinates.

instrumental errors – From imperfections or faulty adjustment of the instruments or devices with which measurements are taken.

integer ambiguity – Inner ambiguity is the whole number of cycles in a carrier phase pseudorange between the GPS satellite and the GPS receiver.

integer search – Integer search is the GPS baseline processing, whether real-time or postprocessed, requires fixed integer solutions for the best possible results. The software which processes the GPS measurements used to derive a baseline does an integer search to obtain a fixed integer solution. The search involves trying various combinations of integer values and selecting the best results.

iono free – Ionospheric free solution (IonoFree). IonoFree is a solution that uses a combination of GPS measurements to model and remove the effects of the ionosphere on the GPS signals. This solution is often used for high-order control surveying, particularly when observing long baselines.

ionosphere – The band of charged particles 80 to 120 miles above the Earth's surface.

ionosperic delay – An ionospheric delay is a signal delay or acceleration as a wave propagates through the ionosphere. Phase delay depends upon the electron content and affects the carrier signal. Group delay depends upon the dispersion in the ionosphere as well, and affects the code signal.

ionospheric modeling – Ionospheric modeling is the time delay caused by the ionosphere varies with respect to the frequency of the GPS signals and affects both the L1 and L2 signals differently. When dual frequency receivers are used the carrier phase observations for both frequencies can be used to model and eliminate most of the ionospheric effects. When dual frequency measurements are not available an ionospheric model broadcast by the GPS satellites can be used to reduce ionospheric affects. The use of the broadcast model, however, is not as effective as the use of dual frequency measurements.

iteration – An iteration is a complete set of adjustment computations that includes the formation of the observation equations, normal equations, coordinate adjustments, and computation of residuals.

K

K reduced column – K reduced column is an abbreviated version of the normal equations in which the profile equations are reordered to minimize the computer memory required to store all nonzero elements.

kinematic surveying – Kinematic surveying is a method of GPS surveying using short Stop and Go occupations, while maintaining lock on at least 4 satellites. It can be done in real-time or post-processed to centimeter precisions.

known point initialization – A known point initialization is used in conjunction with kinematic initialization. If two known points are available, the baseline processor can calculate an inverse between the two points and derive an initialization vector. This initialization vector, with known baseline components, is used to help solve for the integer ambiguity. If the processor is able to successfully resolve this ambiguity a fixed integer solution is possible, yielding the best solutions for kinematic surveys.

L

L1 – L1 is the primary L-band carrier used by GPS satellites to transmit satellite data. Its frequency is 1575.42 MHz. It is modulated by C/A code, P code, and a Navigation Message.

L2 – L2 is the secondary L-band carrier used by GPS satellites to transmit satellite data. Its frequency is 1227.6 MHz. It is modulated by P code and a Navigation Message.

land survey, boundary survey or property survey – A survey performed by a RPLS for the primary purpose of locating, describing, monumenting and mapping a parcel of land.

land title survey – A survey of real property performed by a RPLS to be used by a title insuring agency for purposes of insuring title to said real property.

latitude – 1.) latitude the angular distance north or south of the equator. 2.) latitude, in plane surveying, is the amount that one end of a line is north or south of the other end. As the plane coordinates of a point are known as the easting and northing of the point, the latitude is the difference between the northings of the two ends of the line, which may be either plus or minus.

least squares – A mathematical method for the adjustment of observations, based on the theory of probability. In this adjustment method, the sum of the squares of all the weighted residuals is minimized.

level of confidence – A level of confidence is a measure of the confidence in our results, expressed in a percentage or sigma.

level datum – A level datum is a level surface to which elevations are referred. The generally adopted level datum for leveling in the United States is mean sea level. For local surveys, an arbitrary level datum is often adopted and defined in terms of an assumed elevation for some physical mark (bench mark).

leveling – is the operation of measuring vertical distances, directly or indirectly, to determine elevations.

level net – Level net are lines of spirit leveling connected together to form a system of loops or circuits extending over an area. Level net is also called a vertical control net.

level of significance – A level of significance is an expression of probability. A one-sigma (standard) error is said to have a level of significance of 68 percent. For one-dimensional errors, a 95 percent level of significance is expressed by a 1.96 sigma, and a percent level of significance is expressed by a 2.576 sigma.

local ellipsoid – A local ellipsoid is the ellipsoid specified by a coordinate system. The WGS-84 coordinates are first transformed onto this ellipsoid; then converted to grid coordinates.

local geodetic – A local geodetic is the latitude, longitude, and height of a point. The coordinates are those expressed in terms of the local ellipsoid. A local geodetic is at any point, a plane at the ellipsoid height of a given point, which is horizontally parallel to the tangent plane to the ellipsoid at that point. Coordinate values for the local geodetic horizon are expressed as North, East, and Up. The LGH is used for rotating EC Cartesian Coordinate differences, before modeling a baseline on the ellipsoid. Azimuth values computed from LGH components must be corrected for skew normals as part of modeling on the ellipsoid.

loop closure – Loop closures provide an indication as to the amount of error in a set of observations within a network.

- A loop closure is calculated by selecting a point from which one or more observations were taken, adding one of those observations to the point's coordinates, and calculating coordinates of the second point based on that observation.

- This process is repeated one or more times around a loop, finally ending at the original starting point. If there were no errors in the observations, the final calculated coordinate would be exactly the same as the original starting coordinate.
- By subtracting the calculated coordinate from the original coordinate a misclosure is determined. Dividing this error by the length of the line allows the error to be expressed in parts per million.
- This technique can also be used between two different points when both points are known with a high degree of accuracy. This is also known as a traverse closure.

M

mapping angle – Mapping angle is the angle between grid north on a mapping projection and the meridian of longitude at a given point. Also know as convergence.

major axis – See ellipsoid.

major collector – A major collector is an area public way for purposes of vehicular travel, usually interstate or federal highways; includes the entire area within the right of way.

map projections – These are representations of the Earth's features that are transferred to a flat two-dimensional plane, such as, paper maps and computer generated maps.

mapping projection – Mapping projection is a rigorous mathematical expression of the curved surface of the ellipsoid on a rectangular coordinate grid.

mask angle – Cut-off angle. A mask angle/cut-off angle is the point above the observer's horizon below which satellite signals are no longer tracked and/or processed. Ten to twenty degrees is typical.

MCA – minimally constrained adjustment.

mean sea level – A mean sea level is the mean height of the surface of the ocean for all stages of the tide. Used as a reference for elevations.

meridian – A meridian is a north-south line from which longitudes (or departures) and azimuths are reckoned.

minimally constrained – A minimally constrained network is a network adjustment in which only enough constraints to define the coordinate system are employed. It is used to measure internal consistency in observations.

minor axis – See ellipsoid.

mistake or blunder – An unintentional fault of conduct arising from poor judgment or from confusion in the mind of the observer.

modeling – Modeling is the expressing of an observation and its related errors mathematically and geometrically on some defined coordinate system, such as an ellipsoid.

monument – A monument is any object or collection of objects (physical, natural, artificial) that indicates the position on the ground of a survey station.

multipath – A multipath is an interference (similar to ghosts on a television screen) that occurs when GPS signals arrive at an antenna after traveling different paths. The signal traveling the longer path yields a larger pseudorange estimate and increases the error. Multiple paths may arise from reflections from structures near the antenna.

multipath errors – Errors caused by the interference of a signal that has reached the receiver antenna by two or more different paths. This occurs when the antenna is placed too close to a large object, such as water towers, overhead storage tanks, etc.

multi-channeled receiver – A GPS receiver that can simultaneously track more than one satellite signal.

N

NAD27 – North American Datum of 1927 referenced to the Clark 1866 ellipsoid.

NAD83 – North American Datum of 1983 referenced to the GRS80 ellipsoid.

NAD83/HARN93 – This datum is more accurate than NAD83 because it is based on a more accurate network of control points. To avoid confusion it should be considered a separate datum from NAD83.

narrow-lane – A narrow-lane is a linear combination of L1 and L2 carrier phase observations (L1 + L2) that is useful for canceling out ionospheric effects in collected baseline data. The effective wavelength of the narrow-lane is 10.7 centimeter.

natural or external errors – From variations in the phenomena of nature such as temperature, humidity, wind, gravity, refraction, and magnetic declination.

NAVD88 – North American Vertical Datum of 1988.This vertical datum is the most recent and most accurate.

NAVDATA – NAVDATA is the 1500-bit navigation message broadcast by each satellite. This message contains system time, clock correction parameters, ionospheric delay model parameters, and

details of the satellite's ephemeris and health. The information is used to process GPS signals to obtain user position and velocity.

negligent error – The difference between the measurement and the true value in a given quantity.

network – A network is a set of baselines. See also subnetwork.

network adjustment – A network adjustment is a solution of simultaneous equations designed to achieve closure in a survey network by minimizing the sum of the weighted squares of the residuals of the observations.

network status – Network status is an indication that a particular observation will be included in the adjustment. Network means that it is included in the adjustment and non-network means that it is excluded from the adjustment.

NGS - National Geodetic Survey

NGVD29 – This vertical datum is mostly outdated, but is still used in the USGS 7.5 minute quadsheets.

NMEA – National Marine Electronics Association. The NMEA 0183 Standard defines the interface for marine electronic navigational devices. This standard defines a number of strings referred to as NMEA strings that contain navigational details such as positions.

NSRS – National Spatial Reference System.

normal – A normal in geodesy is the straight line perpendicular to the surface of the ellipsoid.

normal distribution curve – A normal distribution curve is a graphical illustration of the theoretical distribution of random variables around an expected value according to probability theory. It is used with histograms.

northing – A northing is a northward reading of a grid value.

O

observation – An observation is an uninterrupted collection of GPS data at a particular point in the field. A number of observations are done simultaneously in a session to create baselines by processing the data.

observation residual – An observation residual is the correction applied to an observation, as determined by the adjustment.

occupation time – An occupation time is the amount of time required on a station, or point, to achieve successful processing of a GPS baseline. The amount of time will vary depending on the

surveying technique, the type of GPS receiver used, and the precision required for the final results. Occupation times can vary from a couple of seconds (kinematic surveys) to several hours (control or deformation surveys that require the highest levels of precision and repeatability).

occupied station – An occupied station is a traverse or triangulation station over which a theodolite or an engineer transit is set up for the measurement of angles at this station. It is also a station at which angles have been measured.

offset line – An offset line is a supplementary line close to, and usually parallel to a main survey line to which it is referenced by measured offsets. When the line for which data is desired is in such position that it is difficult to measure over it, the required data is obtained by running an offset line in a convenient location and measuring offset from it to salient points on the other line.

OPUS – On-line Positioning User Service (OPUS) provides GPS users easier access to the National Spatial Reference System (NSRS) and is operated by the National Geodetic Survey (NGS). OPUS allow users to submit their GPS data files to NGS, where the data will be processed to determine a position using NGS computers and software. Each data file that is submitted will be process with respect to 3 CORS sites and the results are e-mailed to the user.

OPUS-RS – OPUS-RS is a version of OPUS designed to obtain geodetic quality positioning results from user data sets as short as 15 minutes. The reference station selection algorithm for OPUS-RS differs from that for regular OPUS. OPUS-RS searches the reference stations in order of increasing distance from the user's station (the rover), selecting reference stations that have suitable data.

order of accuracy – An order of accuracy is a mathematical ratio defining the general accuracy of the measurements made in a survey. The orders of accuracy for surveys are divided into four classes named: first-order, second-order, third-order, and fourth-order.

origin – an origin is the intersection of axes in a coordinate system. It is the point of beginning.

orthometric height – An orthometric height is the distance between a point and the surface of the geoid. It is usually called the elevation.

OTF search method – On-the-fly (OTF) search method is a GPS baseline processing, whether real-time or postprocessed, requires fixed integer solutions for the best possible results.(See integer search.)

- Historically, this search was done using measurements collected while two or more receivers were stationary on their respective points. Modern receivers and software can use the measurements collected while the roving receiver is moving. Because the receiver is moving, the data is described as collected On-the-fly (OTF) and the integer search using this data is an OTF search.

outlier – An outlier is an observation which is identified by statistical analysis as having a residual too large for its estimated error. The term derives from the graphical position of an observation in a histogram.

over-determined – An over-determined network is a network for which more measurements have been made than are necessary to compute the coordinates of the network. It is related to redundancy.

P

parallax – A parallax is a change in positions of the image of an object with respect to the telescope cross hairs when the observer's eye is moved. This can be practically eliminated by careful focusing.

parameter – A parameter is an independent variable in terms of which the coordinates of points on a line or surface are given.

parity – Parity is a form of error checking used in binary digital data storage and transfer. Options for parity checking include even, odd, or none.

P-code – The Precise or Protected code. A very long sequence of pseudo-random binary biphase modulations on the GPS carrier at a chip of 10.23 MHz which repeats about every 267 days. Each one-week segment of the code is unique to one GPS satellite and is reset each week.

PDOP – Position Dilution of Precision is an indication of the current satellite geometry. A PDOP is a unitless figure of merit expressing the relationship between the error in user position, and the error in satellite position. It is the result of a calculation, which takes into account each satellite's location relative to the other satellites in the constellation. A low PDOP indicates a higher probability of accuracy. Usually a PDOP of 6 or below gives excellent positions.

Geometrically, PDOP is proportional to 1 divided by the volume of the pyramid formed by lines running from the receiver to four satellites that are observed. Values considered "good" for positioning are small, for example 3. Values greater than 7 are considered poor. Thus, small PDOP is associated with widely separated satellites.

PDOP is related to horizontal and vertical DOP by:

$$PDOP^2 = HDOP^2 + VDOP^2$$

PDOP cutoff – A receiver parameter specifying a maximum PDOP value for positioning. When the geometric orientation of the satellites yields a PDOP greater than the mask value, the receiver stops computing position fixes.

PDOP mask – A PDOP mask is the highest PDOP value at which a receiver will compute positions.

Personal Errors – This error occurs from the limitation of the human senses of sight and touch.

phase center models – Phase center models are models used to apply a correction to a GPS signal based on a specific antenna type. The correction is based on the elevation of the satellite above the horizon and models electrical variations in the antenna phase center location. These models are useful for eliminating errors introduced when identical antennas are not used at both the base and rover points. See also antenna phase correction.

phase difference processing – Relative positioning. Phase difference processing is a computation of the relative difference in position between two points by the process of differencing simultaneous reconstructed carrier phase measurements at both sites. The technique allows cancellation of all errors which are common to both observers, such as clock errors, orbit errors, and propagation delays. This cancellation effect provides for determination of the relative position with much greater precision than that to which a single position (pseudorange solution) can be determined.

PI – A PI is the Point of Intersection of back tangent and forward tangent.

picture point – A picture point in surveying is a terrain feature that is easily defined on an aerial photograph. Its horizontal or vertical positions have been determined by survey measurements. Picture points are marked on the aerial photographs by the surveyor and are used by the photomapper.

plane coordinates – See grid coordinates.

plane survey – A plane survey is a survey in which the effect of the curvature of the earth is almost entirely neglected, and computations of the relative positions of the stations are made using the principles of plane geometry and plane trigonometry.

plumbing – Plumbing is the act of aligning the antenna or instrument along a vertical line (plumb line) perpendicular to the equipotential surface of earth's gravity field.

point positions – See autonomous positioning.

positions – Positions are the place occupied by a point on the surface of the earth. Positions are data that defines the location of a point with respect to a reference system.

positional tolerance – A measure of the accuracy of the position of a monumented boundary corner with respect to its described location without error.

positional tolerance of any monument – The distance that any monument may be mislocated due to normal imperfect measurements opposed to its actual location by nearly perfect measurement.

- This value can be determined by dividing the length of any course of a closed traverse by the denominator of the required error of closure. The results of this calculation will establish the tolerance or radius around a point.
- No traverse adjustment shall be made to any distance larger than this positional error. If the measurements are checked with a one-second theodolite and a recently calibrated distance-measuring device of known high accuracy, the values must fall within the tolerance or radius calculated.
- All distances between monuments from 0 through 200 feet shall have a positional error not to exceed 0.03 feet. This short distance may be checked with a recently standardized tape, taking temperature, tension and sag into consideration.
- It is important to allow for the elapsed time between the date of any measurement and the date of any check made on that measurement in order to consider climatic conditions, man-made or other disturbances that may have affected the monuments.

post-processing – A procedure used to obtain accurate coordinates by correcting errors in the rover receiver data. This is accomplished by processing the rover receiver data with the base receiver data. The rover receiver and the base receiver must run concurrently and include the same satellites.

PPM - Parts per million – PPM is a standardized representation of a scale error in distance measurements. A 1 PPM error would result in 1 millimeter of measurement error for every 1000 meters of distance traveled.

precise ephemeris – See ephemeris.

precision – How close multiple measurements of a single point are to each other.

prime meridian – A prime meridian is the initial or zero median from which longitudes are reckoned. At an international conference in 1884, the Greenwich Meridian was adopted by most countries as the prime meridian for the earth.

prime vertical – A prime vertical is a vertical circle perpendicular to the plane of the celestial meridian. The plane of the prime vertical cuts the horizon in the east and west points.

PRN – Pseudorandom number – 1.) A sequence of digital 1's and 0's that appear to be randomly distributed like noise, but that can be exactly reproduced. PRN codes have a low autocorrelation value for all delays or lags except when they are exactly coincident. 2.) Each NAVSTAR satellite can be identified by its unique C/A and P pseudorandom noise codes, so the term PRN is sometimes used as another name for GPS satellite or SV.

probability – Probability is a statistical percentage expressing what portion of a hypothetical number of observations will fall within the defined limits. It is sometimes called level of significance.

probable value – A probable value is the adjusted value for observations and other quantities, assuming that the adjustment has been done correctly. It is the closest approximation to true value that is possible.

professional surveying – from Section 2 of the TBPLS Practices Act means the practice for compensation of land, boundary, or property surveying or other similar professional practices.

- The term includes any service or work the adequate performance of which involves the application of special knowledge of the principles of mathematics, related applied and physical sciences, and relevant laws to the measurement and location of lines, angles, elevations, natural features, and existing man-made works, and, on the beds of bodies of water, the determination of areas and volumes, for:
  - the location of real property boundaries
  - the platting and layout of lands and subdivisions of land
  - the preparation and perpetuation of maps, record plats, field note records, and real property descriptions that represent those surveys.

projection – A projection is used to create flat maps that represent the surface of the earth or parts of the Earth's surface.

propagated error – A propagated errors are computed errors derived from estimated observational errors and expressed in terms of coordinate positions. Propagated coordinate errors may, in turn, be propagated into relative errors in azimuth, distance, and delta height between points.

pseudorange – A pseudorange is a measure of the apparent propagation time from the satellite to the receiver antenna, expressed as a distance. The apparent propagation time is determined from the time shift required to align a replica of the GPS code generated in the receiver with the received PGS code.

- The time shift is the difference between the time of signal reception (measured in the receiver time frame) and the time of emission (measured in the satellite time frame). Pseudorange is obtained by multiplying the apparent signal-propagation time by the speed of light.
- Pseudorange differs from the actual range by the amount that the satellite and receiver clocks are offset, by propagation delays, and other errors including those introduced by selective availability.

pseudostatic GPS – Pseudostatic GPS, also known a pseudo-kinematic and repeat occupation, is a relative positioning technique which relies upon two or more simultaneous observations at a point pair, separated by some time interval (typically 60 minutes or more), in order to solve the integer bias terms from the change in satellite geometry occurring between the repeat observations.

Q

quality acceptance test – A quality acceptance test is one or more software evaluation tests, performed on raw GPS measurement data, to determine if the data passes or fails a set of tolerance values that the user defines. These tests either remove data from further processing or mark data requiring quality improvements.

QC records – Quality Control records. QC records are used with precise positioning applications. This receiver option allows a user to process RTCM-104 corrections and satellite data in real time to provide position precision statistics.

R

ratio – A ratio is used during initialization. The receiver determines the integer number of wavelengths for each satellite. For a particular set of integers, it works out the probability that it is the correct set.

- Ratio is the ratio of the probability of correctness of the currently best set of integers to the probability of correctness of the next-best set.
- Thus, a high ratio indicates that the best set of integers is much better than any other set. This gives us confidence that it is correct. The ratio must be above 5 for new point and OTF initializations.

RDOP – Relative Dilution of Precision.

real-time corrections – Real-time DGPS uses a data link (beacon or commercial) to transmit correctional data from the reference to the rover receiver. These corrections are used by the rover receiver to correct its errors as the satellite signal is received. No post-processing is required to obtain positions corrected to meter level accuracy.

real-time kinematic – Real-time kinematic is a method of GPS surveying in real-time using short (stop and go) occupation, while maintaining lock on at least 4 satellites. The real-time kinematic method requires a wireless data link between the base and rover receivers.

record – Any documentary material filed in the public records of a city, county or state office that pertains to the location of real property.

rectangular – A rectangular are coordinates in any system in which the axes of reference intersect coordinates at right angles.

redundancy – Redundancy is the amount by which a control network is over-determined, or has more observations than are needed to strictly compute its parts.

redundancy number – Redundancy number is a measure of the degrees of freedom in a portion, rather than the entirety, of a control network.

redundant baselines – Redundant baseline is a baseline observed to a point that has already been connected to the network by other observations. A redundant baseline can be either an independent re-observation of a previous measurement, or an observation to a point from another base. It is redundant because it provides more information than is necessary to uniquely determine a point. Redundant observations are very useful. They provide a check on the quality of previous measurements.

redundant – Redundant is a repeated observation or an observation which contributes to over-observation determining a network.

reference factor – See standard error of unit weight.

reference frame – A reference frame is the coordinate system of a datum.

reference station – A reference station is a base station.

reference variance – A reference variance is the square of the reference factor.

Registered Professional Land Surveyor – means an individual registered as a registered professional land surveyor by the TBPLS.

relative errors – A relative errors are errors and precisions expressed for and between pairs of network-adjusted control points.

relative precision – A relative precision is defined as a measure of the tendency of a set of numbers to cluster about a number determined by the set (e.g. the mean). The usual measure is the standard deviation with respect to the mean.

- Relative precision denotes the tendency for the various components (X, Y, Z) between one station and other stations in the network to be clustered about the adjusted values.
- Current custom is to express relative precision at the two-standard deviation (95% confidence) level. This may be stated in terms of a relative error ellipse or as a proportion of the separation distance (e.g. 10 ppm or 1:100,000).

residual – A residual is the correction or adjustment of an observation to achieve overall closure in a control network. It is also, any difference between an observed quantity and a computed value for that quantity.

RINEX – Receiver INdependent EXchange format – A RINEX is a standard GPS raw data file format used to exchange files from multiple receiver manufacturers. An interchange format that permits data collected by one specific receiver to be read by another vendor's receiver.

RMS – Root Mean Square – A RMS expresses the accuracy of point measurement. It is the radius of the error circle within which approximately 68% of position fixes are found. It can be expressed in distance units or in wavelength cycles.

RMSE – Root Mean Square Error.

rotated meridian – A rotated meridian is a zone constant for the oblique Mercator mapping projection.

rotation – In transformations, a rotation is an angle through which a coordinate axis is moved around the coordinate system origin.

rover – A mobile GPS receiver that when used in conjunction with a stationery receiver can obtain differentially corrected ground coordinates. Any receiver used in a dynamic mode is called a rover.

ROW – Right of Way

regional reference point (RRP) – TxDOT presently operates 47 Regional Reference Points that are positioned across the state.

RTCM – Radio Technical Commission for Maritime Services. RTCM is a commission established to define a differential data link for the real-time differential correction of roving GPS receivers.

RTK – A real-time kinematic is a type of GPS survey.

S

SAF – Surface Adjustment Factor. SAF is a published TxDOT-developed value for each county which, when multiplied times a distance on the state plane grid, yields the corresponding distance on the surface.

satellite constellation – The arrangement in space of a set of satellites.

satellite geometry – A satellite geometry is a position and movement of GPS satellites during a GPS survey.

satellite vehicle (SV) – A Department of Defense satellite orbiting the Earth.

scalar – In least squares, a scalar is a value applied to the variances (errors) based on the required level of confidence.

scale – A scale is a multiplier used on coordinate and other linear variables, such as for map projections and transformations.

SCOS - Standing Committee on Surveying

SDMS – Survey Data Management System. SDMS ® is a data collection and processing software based on a set of format definitions. AASHTO maintains this system.

secular motion – A secular motion is that portion of crustal motion which is continuous and at a constant velocity. Secular motion is uniformly predictable over time and is independent of any seismic events.

selective availability (S/A) – SA is an artificial degradation of the GPS satellite signal by the U.S. Department of Defense. The error in position caused by S/A can be up to 100 meters.

semimajor axis – Semimajor is one-half of the major axis.

semiminor axis – Semiminor is one-half of the minor axis.

session – A session is a period during which a number of GPS receivers log satellite data simultaneously for the purpose of creating baselines.

set-up error – Set-up errors are errors in tribrach centering or height of instrument at a control point.

sideshot – A sideshot is an observed baseline with no redundancy.

sigma – Sigma is a mathematical symbol or term for standard error.

signal to noise ratio (SNR) – An indicator of the strength of a satellite signal.

single-frequency – Single-frequency is a type of receiver that only uses the L1 GPS signal. There is no compensation for ionospheric effects.

site calibration – Site calibration is a process of computing parameters which establishing the relationship between WGS-84 positions (latitude, longitude and ellipsoid height) determined by GPS observations and local known coordinates defined by a map projection and elevations above mean sea level. The parameters are used to generate local grid coordinates from WGS-84 (and vice-versa) real-time in the field when using RTK surveying methods.

skyplot – A skyplot is a polar plot that shows the paths of visible satellites for the time interval selected for the graph. The elevation of the satellite is represented in the radial dimension and the azimuth is shown in the angular dimension. The result depicts the satellite's path as it appears to an observer looking down from a place directly above the survey point.

slope distance – A slope distance is the distance in the plane parallel to the vertical difference (slope) between the points.

SNR – Signal-to-Noise Ratio.

solution types – Solution types refer to a description of both the data and techniques used to obtain baseline solutions from GPS measurements.

- Typical solution types include descriptions such as code, float, and fixed. These describe techniques used by the baseline processor to obtain a baseline solution.
- Solution types also may include descriptions such as L1, L2, wide-lane, narrow-lane, or ionospheric free. These describe the way the GPS measurements are combined to achieve particular results.

standard deviation – A standard deviation is a standard error. Surveying applications use the conventional formula for sample standard deviation. Standard deviation is a measure of the strength of a satellite signal. SNR ranges from 0 (no signal) to around 35.

standard error – A standard error is a statistical estimate of error, according to which 68 percent of an infinite number of observations will theoretically have absolute errors less than or equal to this value.

standard error of unit weight – A standard error of unit weight is a measure of the magnitude of observational residuals in an unit weight adjusted network as compared to estimated pre-adjustment observational errors.

State Plane Coordinate System (Texas) – Consists of five zones North (4201), North Central (4202), Central (4203), South Central (4204), and South (4205). Each zone is referenced to its own axis.

static (surveying) – Static is a method of GPS surveying using long occupations (hours in some cases) to collect GPS raw data, then postprocessing to achieve sub-centimeter precisions.

static network – A static network is a network that describes the geometry and order in which GPS baselines collected using static and fast static techniques are organized and processed.

- The baseline processor first examines the project for points with the highest quality coordinates, and then builds the processing network from those points. The result is a set of static baselines that are derived using accurate initial coordinates.

status – Status is every observation and set of keyed-in coordinates for a point has a status field (available in the Summary page of the Properties window). The status can be enabled, enabled as check, or disabled:

- Enabled observations and coordinates are always used by recomputation in determining the calculated position for the point.
- Enabled as check observations and coordinates are only used if there are no Enabled ones Disabled observations and coordinates are never used.

stochastic model – A stochastic model is a general reference to the techniques used to estimate errors in a network adjustment.

substantial compliance – The compliance or conformity with essential requirements. Also the equivalent of substantial performance, where inconsequential, trivial variations or omissions are minimized, but may occur.

surveyor, land surveyor or registered professional land surveyor – A person holding a valid license to practice land surveying as a Registered Professional Land Surveyor (RPLS) in the state of Texas, as issued by the Texas Board of Professional Land Surveying (TBPLS).

survey observation – A survey observation are the measurements made at or between control points using surveying equipment (conventional or GPS).

SV – satellite space vehicle.

systematic error – An error which, for known changes in measurement conditions, results in proportional changes of values which remain unchanged, both in magnitude and sign. This error, evident in a series of measurements, may be instrumental, personal, or natural and always follows some definite mathematical or physical law and is cumulative in total effect.

T

target – A target is any object to which the instrument is pointed. A target may be a plumb bob or cord, a nail in the top of a stake, a taping arrow, a range pole, a pencil, or any other object that will provide a sharply defined, stationary point or line. A target usually placed vertically over an unoccupied transit station.

tau (value) – A tau is a value computed from an internal frequency distribution based upon the number of observations, degrees of freedom, and a given probability percentage (95%).

- This value is used to determine if an observation is not fitting with the others in the adjustment. If an observation's residual exceeds the tau, it is flagged as an outlier. Tau values are known as tau lines in the histogram of standardized residuals; vertical lines left and right of the center vertical line.

tau criterion – A tau criterion is Allen Pope's statistical technique for detecting observation outliers.

TBPLS - Texas Board of Professional Land Surveying

TDOP – Time Dilution of Precision.

terrestrial observation – A terrestrial observation is an observation in the field using a laser rangefinder or conventional instrument.

Texas Statewide Mapping System (TSMS) – This is a standardized statewide (uninterrupted by zones) projection. TSMS possesses more map distortion than the zoned projection.

tie – A tie is a survey connection from a point of known position to a point whose position is desired.

tolerance – The allowable imperfection of any value stated or established in a survey. Each category has four conditions, and each condition has certain tolerances or specifications for values that must be met. The following explanations of tolerance items are to be used with the tolerance chart for each category.

total station – A total station is an electronic theodolite that provides both angle and distance measurements and displays them automatically.

total systematic error – In any given number of measurements is the algebraic sum of the individual errors of the individual measurements.

TOW – Time of Week. TOW is measured in seconds from midnight Saturday night/Sunday morning GPS time.

tracking – The process of receiving and recognizing signals from a satellite.

transformation – A transformation is the rotation, shift, and scaling of a network to move it from one coordinate system to another.

transformation group – A transformation group is a selected group of observations used to compute transformation parameters unique to that group of observations. Typically, the observations within the group are the same type with similar errors and measured using a common method.

transformation parameters – Transformation parameters is a set of parameters derived for a network adjustment or user-parameters defined, that transform one datum to another. Typically, with GPS the parameters are generated to transform WGS-84 to the local datum.

transit station – A mark over which the instrument is, has been, or will be accurately positioned for use.

tribrach – A tribrach is a centering device used for mounting GPS antennas and other survey instruments on survey tripods.

tribrach centering errors – Tribrach centering errors are errors associated with centering (plumbing) the tribrach over errors the observed point. These errors are estimated. The estimate is based on surveying the quality of surveying methods and should be conservative.

tropo correction – tropospheric correction. Tropo correction/tropospheric correction is the correction applied to a satellite measurement to correct for tropospheric delay.

tropo model – tropospheric model – A tropo model occurs when GPS signals are delayed by the troposphere.

- The amount of the delay will vary with the temperature, humidity, pressure, height of the station above sea level, and the elevation of the GPS satellites above the horizon.
- Corrections to the code and phase measurements can be made using a tropo model to account for these delays.

TSPS - Texas Society of Professional Surveyors

turning points – Turning points are temporary points of known elevation.

TxDOT - Texas Department of Transportation.

U

UDN – User Densification Network. A UDN is a station set by the public that have been "blue-booked" by the NGS for the purpose of providing additional control stations adjusted to the National Spatial Reference System.

univariate – Univariate is a mathematical function describing the behavior of one-dimensional random errors in angle, distance; difference in height, elevation, or ellipsoid height.

- angle
- distance
- difference in height
- elevation
- ellipsoid height

universal time – Universal time is local solar mean time at Greenwich Meridian.

- UT0 – Universal Time as deduced directly from observations of stars and the fixed numerical relationship between Universal and Sidereal Time; 3 minutes56.555 seconds.
- UT1 – UT0 corrected for polar motion.
- UT2 – UT1 corrected for seasonal variation in the earth's rotation rate.
- UTC – Universal Time Coordinated; uniform atomic time system kept very closely to UT2 by offsets. Maintained by the U.S. Naval Observatory. GPS time is directly relatable to UTC. UTC-GPS = 9 seconds (in 1994).

Universal Transverse Mercador (UTM) – A projection created by the U.S. Army to obtain a series of maps that would encircle the Earth. Texas is covered by zones 13, 14, and 15.

unknowns – The computed adjustments to coordinates and transformation parameters; also used to compute observation residuals.

URA – User Range Accuracy. URA is the contribution to the range-measurement error from an individual error source (apparent clock and ephemeris prediction accuracies), which is converted to range units; assuming that the error source is uncorrelated with all other error sources.

US National Geodetic Survey – This is the United States government agency that maintains the national geodetic datum and all geodetic survey control networks within the US and its territories.

U.S. Survey Foot – 1200/3937 meter. The official unit of linear measure for NAD-27.

UTC – Universal Time Coordinated. UTC is a time standard based on local solar mean time at the Greenwich meridian.

V

variance – The square of the standard error.

variance factor – Reference variance, variance of unit weight. A statistical measure of how close the observation residuals match the predicted errors.

- It is the square root of the sum of the weighted squares of the residuals divided by the degrees of freedom. If the errors in a network have been weighted correctly, the variance factor will approach 1.0.

variance component – A least-squares technique for estimating the relative error estimation of different portions of a network.

variance group – A variance group is one of the groups of observations for which variance component estimation is being used in a network adjustment.

variance-covariance – A variance-covariance is the set of numbers expressing the variances and covariances matrix in a group of observations.

variable systematic error – Conditions change, resulting in corresponding changes in the magnitude of the error.

VDOP – Vertical dilution of precision.

vector – A vector is a three-dimensional line between two points.

vertical – A vertical is similar to the normal, except that it is computed from the tangent plane to the geoid instead of the ellipsoid.

vertical adjustment – A vertical adjustment is a network adjustment of vertical observations and coordinates only.

vertical control – A Vertical control is an established benchmarks.

vertical control point – A vertical control point is a point with vertical coordinate accuracy only. The horizontal position is of a lower order of accuracy or is unknown.

vertical control survey – is performed in order to accurately determine the orthometric height (elevation) of permanent monuments to be used as bench marks for lower quality leveling.

- spirit leveling is the usual method of carrying elevations across the country from "sea level" tidal gauges. However, GPS can be used indirectly but with less accuracy
- eight measurements from the ellipsoid (as opposed to the "sea level" geoid) can be determined very accurately with GPS and only with GPS
- trigonometric leveling with a total station is not acceptable for vertical control work

vertical datum – A vertical datum is a set of precise levels that have been referenced to a geoid to establish mean sea level.

vertical datum plane – is the level surface to which elevations are referred. In the past, mean (average) sea level was the most common datum used for the United States. Today, the more common reference datum is NAVD 88. This datum is required for all TxDOT surveys unless specifically directed otherwise by TxDOT.

W

WAAS – Wide Area Augmentation System. WASS is a satellite-based system that broadcasts GPS correction information. WAAS capable GPS receivers can track WAAS satellites. WAAS is synonymous with the European Geostationary Navigation Overlay (EGNOS) and Japan's Multifunctional Transport Satellite Space-based Augmentation System (MSAS).

water course – A stream of water such as a river, brook, creek, bayou, etc. A watercourse is a visible channel for water such as a ditch, channel, or streambed.

weight – The weight is the inverse of the variance of an observation.

weights – The set of weights, or the inverse of the variance-covariance matrix of correlated observations.

WGS84 – World Geodetic System. Datum referenced to the WGS 1984 ellipsoid. WGS is the mathematical ellipsoid used by GPS since January 1987. WGS84 is used to identify both a datum and an ellipsoid.

wide-lane – A wide-lane is a linear combination of L1 and L2 carrier phase observations (L1 - L2). This is useful for its low effective wavelength (86.2 cm) and for finding integer ambiguities on long baselines.

working sketch – A drawing prepared from record data depicting the relationship of the various record tracts, usually in, but not limited to, the immediate vicinity of the parcel being considered or surveyed.

X

X, Y and Z – In the Earth-Centered Cartesian system, X refers to the direction of the coordinate axis running from the system origin to the Greenwich Meridian; Y to the axis running from the origin through the 90× east longitude meridian, and Z to the polar ice cap. In rectangular coordinate systems, X refers to the east-west axis, Y to the north-south axis, and Z to the height axis.

Y

Y-code – Y-code is an encrypted form of the information contained in the P-code. Satellites transmit Y-code in place of P-code when anti-spoofing is in effect.

Z

zenith – The zenith is the point at which a line opposite in direction from that of the plumb line (at a given point on the Earth's surface), meets the celestial sphere.

zenith angle – A zenith angle is the angle measured positively from the observer's zenith to the object observed.

zenith delay – A zenith is the delay, caused by the troposphere, of a GPS signal observed from a satellite directly overhead. As a satellite approaches the horizon, the signal path through the troposphere becomes longer and the delay increases.

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