CHAPTER 5 - GENERAL SURVEY INFORMATION AND CONSULTANT COORDINATION

5.1 SURVEY DATUMS AND THE TENNESSEE GRID SYSTEM

5.1.1 ORIGIN OF DATUMS

The North American Datum of 1927, established by the United States Coast and Geodetic Survey (USC & GS), has recently been adjusted and republished by the National Geodetic Survey (NGS). This new North American Datum of 1983 (NAD 83) has been adopted for reference of control for all TDOT projects. The reference for vertical control, the Sea Level Datum of 1929 established by the USC & GS, has also been adjusted by NGS. This new North American Vertical Datum of 1988 (NAVD 88) has been adopted for reference of vertical control for all TDOT projects.

5.1.2 VERTICAL DATUM

Vertical datum is mean sea level. A network of monuments has been established throughout the United States and a listing has been published by NGS. An assumed vertical reference will **not** be used unless authorized by the Regional Survey Supervisor.

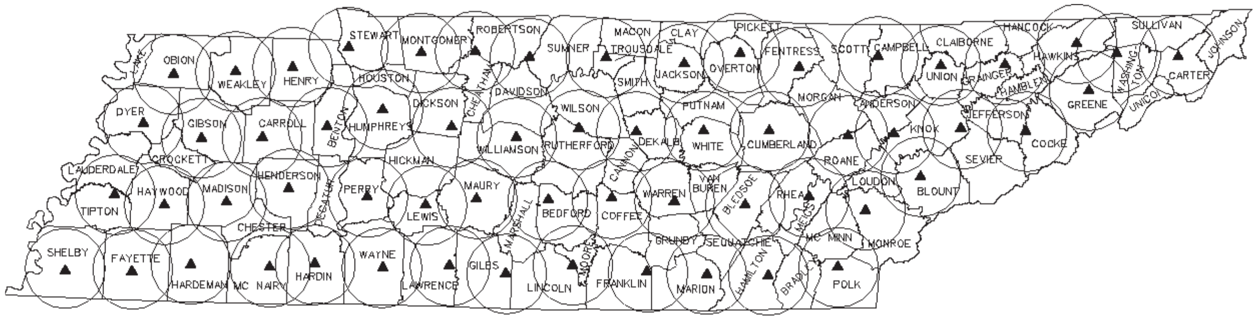
5.1.3 HORIZONTAL DATUM

All route survey projects shall be tied to the Tennessee Geodetic Reference Network (TGRN). This will allow all surveys to be correlated to a single reference framework. Point locations will be fixed and cannot be considered legally lost. Overlapping projects will be consistent and plane surveying will be possible over large areas without the introduction of significant error. Also, a uniform computational base will be established and fewer errors will go undetected.

5.1.4 TENNESSEE GEODETIC REFERENCE NETWORK (TGRN)

To more easily and accurately provide for ties to NAD 83, the TGRN has been developed. It is a highly accurate network of three dimensional monuments designed for use with GNSS equipment. The TGRN was tied to and is consistent with NAD 83. The sixty network monuments (Refer to Figure 5-1) are evenly spaced throughout the state so that no project shall be more than 15 miles from a network station. The internal accuracy of $1:10^7$ makes the network ideally suited for ties with highly accurate GNSS equipment. Network monument locations were also chosen with attention to visibility and accessibility desirable for GNSS equipment. Additional information concerning the TGRN is available through the State Survey Coordinators Office, any Regional Survey Office, or by referring to the TGRN manual developed by TDOT. The TGRN manual is accessible through the following website:

http://www.tdot.state.tn.us/Chief_Engineer/assistant_engineer_design/design/field_surveys.htm



15 mile radius coverage

▲ TDOT Reference Network Point

Figure 5-1
TGRN Network

5.1.5 TENNESSEE GRID SYSTEM

The Tennessee Grid System is derived from the Lambert Conformal Conic Projection. The Lambert projection is used in approximately 31 states in the United States and is best suited for states with East-West elongation, such as Tennessee.

Conformal means that the configuration of the area projected is maintained. Conic implies that the projection is extended to the surface of a large cone, as shown in Figure 5-2. Assume that the cone intersects the spheroid (slightly flattened sphere) or the mean earth's surface along two lines known as standard parallels of latitude [B-C and D-E in Fig. 5-2 (a)]. Parallels of latitude [F-G and H-I] are the limits of the projection. The apex of the cone of projection is point "A". Line J-K is the central meridian line. The central meridian for Tennessee is longitude 86°-00'. Fig. 5-2 (b) shows a portion of the plane surface developed from the cone of projection. If the limits of the projection do not exceed 158 miles, the North-South distortions are one part in 10,000 or less. The scale, defined as the ratio of a length on the projection grid distance to a corresponding geodetic distance on the sphere's sea-level surface, varies in the North-South direction. The scale is exact along the parallels in an East-West direction.

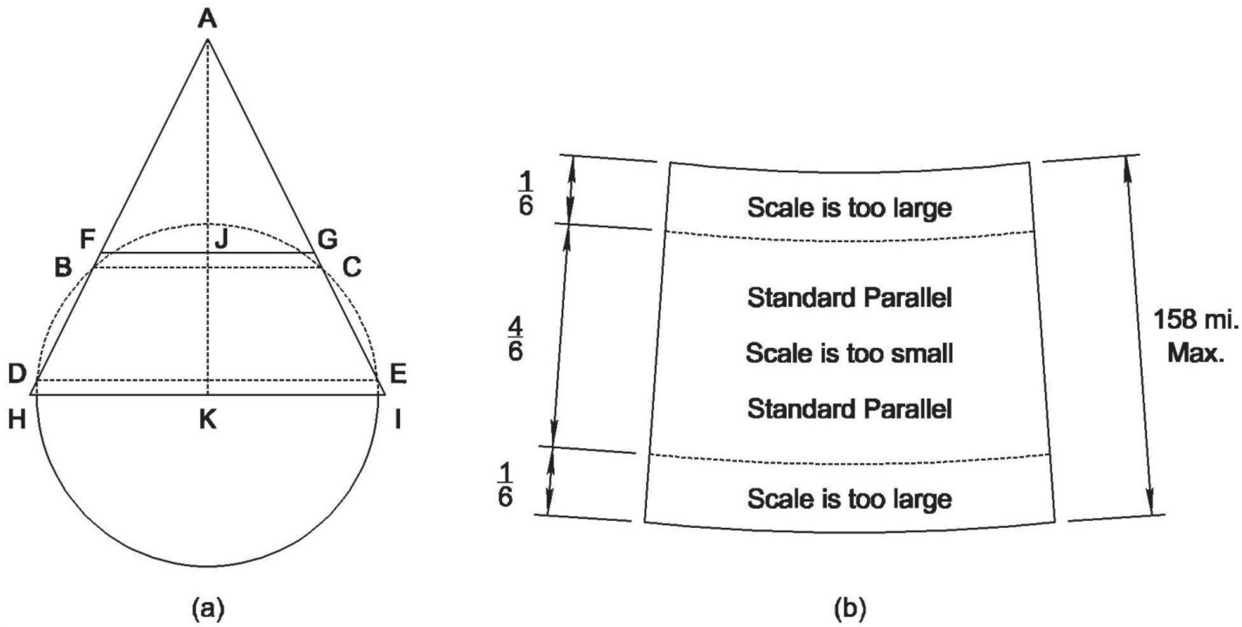


Figure 5-2
Lambert Conformal Map Projection

The Appendix of this manual (beginning on page A-37) contains excerpts from NOAA Manual NOS NGS 5, "State Plane Coordinate System of 1983" by James E. Stem. The manual, distributed by the U.S. Department of Commerce, gives a more detailed look at SPCS and computations involved. Most surveying software on the market today provides for easy conversion of coordinates from one datum to another. Therefore, details of the computations are not included in the body of this manual.

All TDOT surveys that relate to the grid system shall be datum adjusted to raise or lower the plane of projection of the surveyed points to the earth's surface. This facilitates staking of centerline, R.O.W., and construction points. Procedures used by GNSS crews, when establishing project control (Refer to Section 3.2), provide for this required datum adjustment. Each datum adjustment factor is project specific and is computed by TDOT personnel with the assistance of computer software developed specifically for this purpose.

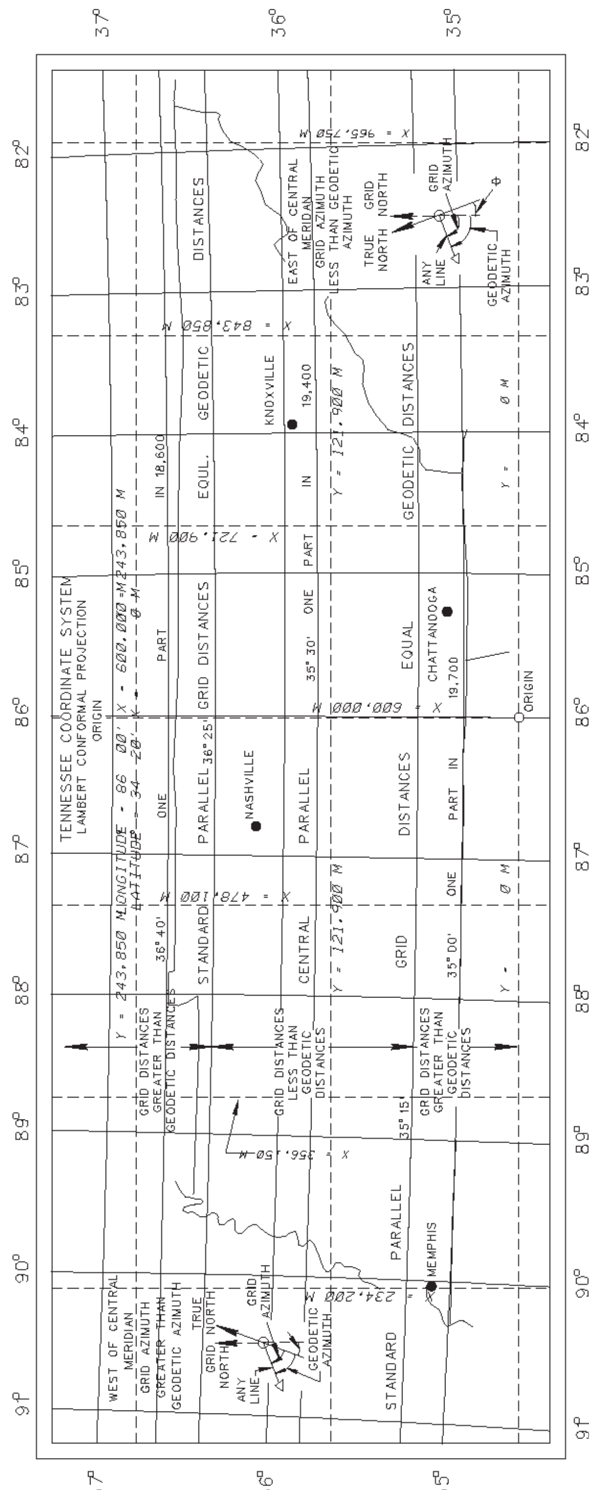


Figure 5-3
Tennessee Lambert Map Projection

5.2 ACCURACY AND ERRORS

5.2.1 ACCURACY AND PRECISION

The accuracy of a field survey depends directly upon its precision. Accuracy is the degree of conformity with a standard or a measure of closeness to a true value. Precision is the degree of refinement in the performance of an operation or in the statement of a result. Accuracy relates to the quality of the result obtained when compared to a standard. Precision relates to the quality of the operation used to attain the result.

Surveys with high order accuracies could be attained (through luck) without high order precision, therefore making such accuracies meaningless. All measurements and results shall be quoted in terms that are commensurate with the precision used to attain the results. Similarly, all surveys must be performed with a precision which assures that the desired accuracy is attained.

Precision is indicated by the number of decimal places to which a computation is carried and a result stated. Actual precision is governed by the accuracy of the source data and the number of significant figures, rather than by the number of decimal places.

5.2.2 SIGNIFICANT FIGURES

5.2.2.1 DEFINITION

Significant figures are those digits that are known plus one doubtful digit.

5.2.2.2 EXAMPLES

16.423	5 significant figures (such as reading a steel chain to the nearest thousandth of a foot)
21.63	4 significant figures (such as reading a steel chain to the nearest hundredth of a foot)
12.1	3 significant figures (such as reading a cloth tape to the nearest tenth of a foot)
0.4	2 significant figures (such as reading a level rod or cloth tape to the nearest tenth of a foot)
38	2 significant figures (such as reading a cloth tape to the nearest foot)
5	1 significant figure (such as reading a cloth tape to the nearest foot)

5.2.2.3 FIELD NOTES

Recorded field measured values shall never indicate a precision greater than that used in the actual survey.

Method Used	Recorded Value Not To Exceed
Stadia	Nearest 1 foot
Cloth tape	Nearest 0.1 foot
Steel tape or chain	Nearest 0.01 foot
Transit or theodolite	Least count
Level	Nearest 0.01 foot
Hand level	Nearest 0.1 foot
Total Station	As recommended by manufacturer
GNSS	As recommended by manufacturer

5.2.3 CALCULATIONS

The result must not reflect a greater accuracy than the methods used to gather field data.

Addition and Subtraction - The answer can contain no more significant figures to the right of the decimal than that of the least accurate number in the calculation.

Example: 24.1 + 16.32 = 40.4, not 40.42

Multiplying and Dividing - The answer must not contain more significant figures than the term with the least number of significant figures.

Example: 12.182 x 11.1 = 135 (three significant figures)

Exception: When one term has a beginning numeral that is close to a double digit number, such as 8 or 9, another significant number may be used.

Example: 9.2 x 2.11 = 19.4, not 19.

When calculations involve several steps, it is advisable to use one extra significant figure throughout the intermediate steps. However, the final result must always be rounded off to the appropriate number of significant figures.

5.2.4 ORDER OF ACCURACY

Table A-4 and Table A-5 in the Appendix give the standards of accuracy for horizontal and vertical control. GNSS control parties shall maintain First Order as a minimum. All other survey parties shall maintain Second Order - Class II.

5.2.5 DEFINITION OF ERROR

Error is the difference, after blunders have been eliminated, between a measured or calculated value of a quantity and the true or established value of the quantity.

A blunder (also called a mistake) is an unpredictable, human mistake and is not, by definition, an error. Examples of blunders are: transposition of two numbers, neglecting to level an instrument, misplacing a decimal point or misunderstanding a spoken number. Blunders are caused by carelessness, misunderstanding, confusion or poor judgment. All blunders must be eliminated prior to correcting and adjusting a survey for errors.

5.2.6 TYPES OF ERRORS

5.2.6.1 SYSTEMATIC

A systematic error is one which will always have the same magnitude and same algebraic sign under the same conditions.

Examples - Thermal contraction and expansion of a steel tape, refraction, or a particular chainman’s tendency to always overpull a tape.

Effect - A systematic error, of a single kind, is cumulative. However, several kinds of systematic errors occurring in any one measurement could compensate each other.

Detecting and Minimizing - Since systematic errors can be difficult to detect, one must recognize the conditions (instrument imperfections, atmospheric pressure and temperature, personal habits, etc.) that cause such errors. Once the conditions are known, the effect of these errors can be minimized as follows:

- Use procedures that will automatically eliminate systematic errors, such as: balancing level foresights and backsights, turning angles direct and reverse, and using standardized tapes.
- When systematic errors cannot be eliminated by procedures, corrections are applied to the measurements. An example would be temperature correction applied to a taped measurement. All systematic errors must be eliminated prior to any adjustment of a survey for accidental errors.

5.2.6.2 ACCIDENTAL

An accidental error (also called a random error) is one which does not follow any fixed relation to the conditions or circumstances of the observation.

Example - An instrument man's inability to point a total station exactly. However, if his personal habits make him consistently point off to the same side of the sight line, this error becomes a systematic error.

Effect - Theoretically, an accidental error has an equal chance of being negative or positive. Thus, these errors tend to be compensating. However, since the magnitude is also a matter of chance, accidental error to a small degree remains in every measurement.

Compensating - Corrections cannot be computed for accidental errors, therefore, they must be compensated by adjustments.

Least Squares Adjustment - This method provides the most probable values. All systematic errors must first be eliminated because any adjustment method is applicable only to truly random error.

Adjustment Results - Any adjustment only provides what one believes to be the best solution for the total survey. Even after proper adjustment, each individual value (such as a point position) is in error by an amount depending on the precision of the survey. Possibly, an adjustment could increase the error for a specific point. Collectively, however, the errors have been reduced and the total survey is improved.

5.2.7 SOURCE OF ERRORS

5.2.7.1 PERSONAL

These errors are caused by the physical limitations of the observer and by his personal observing habits. They can be either systematic or accidental.

Personal Systematic Errors - These errors are caused by the observer’s tendency to react the same way under the same conditions, e.g., a chainman measuring slightly long each time because of a peculiarity of his stance. Everyone makes a personal systematic error to some degree on each individual observation. Fortunately, such errors are minimized by proper procedures.

Personal Accidental Errors - These errors are caused by the physical limitations of the observer. Absolutely correct observations are impossible because of these human limitations.

5.2.7.2 INSTRUMENTAL

These errors are caused by imperfections in the design, construction, and adjustment of instruments and other equipment.

Examples:

- Eccentricity of theodolite circles

- A chain which is too short or too long
- Misadjustment of level vials

Type - In an individual observation, instrumental errors are systematic because they will be of the same magnitude and sign under the same observing conditions. However, if several observations are made of the same value (such as observing an angle at different positions of the circle), the error of each observation could have the effect of an accidental error on the resulting value.

Eliminating or Minimizing - Most instrumental errors are eliminated by using proper procedures such as observing angles direct and reverse, balancing level foresights and backsights, and repeating measurements. Instrumental errors that are not eliminated by procedures must be minimized by maintaining a regular program of periodically checking, adjusting, or calibrating instruments and other equipment.

5.2.7.3 NATURAL

These errors result from natural physical conditions such as atmospheric pressure, temperature, humidity, gravity, wind, and atmospheric refraction.

Type - These external errors are systematic. But if undetected and thus not eliminated, or if incorrectly determined, they can have the same effect as accidental errors.

Correction - Natural errors are removed by determining corresponding corrections from known relationships between an error and the natural phenomena. Example: The atmospheric pressure and temperature correction applied to EDM measurements and temperature corrections applied to chain measurements.

Eliminating or Minimizing - Sometimes the effect of natural errors can be eliminated by using proper procedures. For example, the effect of curvature and refraction can be eliminated by balancing level foresights and backsights. Natural errors can be minimized by making observations only when natural conditions are most favorable. For example, chaining at night or in cloudy weather and turning vertical angles other than in early morning or late afternoon when refraction is changing most.

5.3 DESIGN CRITERIA AND STANDARD DRAWINGS PERTAINING TO SURVEYS

5.3.1 GENERAL

Design criteria for each type of road are found in the TDOT Standard Roadway and Structure Drawings under the heading “Roadway Design Standards”. When a design speed is given, it is considered a minimum. A lower design speed shall not be used without the consent of the Regional Survey Supervisor. The highest feasible design speed is desirable. However, the mixing of design speeds shall be avoided (produces unsafe conditions).

5.3.2 ALIGNMENT CRITERIA GIVEN

Knowing the minimum design speed, the tables in the TDOT Standard Roadway and Structure Drawings will yield the required radius, spiral length of runoff, grades, sight distance, etc.

5.3.3 DESIGN CRITERIA

The TPR will be given to the Field Office Supervisor before starting the survey and will provide the following information:

- Proposed typical section
- Design speed
- Current ADT and projected ADT
- General route location

Environmental Impact Statements (EIS) may contain items which shall be addressed during the survey.

The “TDOT Roadway Design Guidelines” have been developed as a reference for Road Design Engineers. Some of the sections directly affect the survey function and may be referenced in this survey manual.

5.4 REPORTS AND CORRESPONDENCE

5.4.1 WEEKLY REPORT

The report is prepared by the Field Office Supervisor and shall be received in the Regional Survey Supervisor’s Office the first workday of each week. The percent complete and estimated completion date is shown for each active project.

5.4.2 MAN-DAY REPORT

The report is prepared by the Field Office Supervisor and submitted to the Regional Survey Supervisor with each completed survey. It is optional at the discretion of the Regional Survey Supervisor.

5.4.3 SURVEY TRANSMITTAL LETTER

The letter is prepared by the Field Office Supervisor transmitting the survey to the Regional Survey Supervisor. The Regional Survey Supervisor uses it in transmitting the survey to the appropriate agency or office.

5.4.4 SURVEY CHECK SHEET

The check sheet is prepared by the Field Office Supervisor or Consulting Engineer, submitted to the Regional Survey Supervisor with each completed survey, and kept as part of the regional survey project file. Each survey shall be checked for completion by using the survey check sheet item by item. It is not required for additional information and update surveys.

5.5 FIELD BOOKS

5.5.1 GENERAL

The primary method of recording data for field surveys is the electronic data collector. However, field books are frequently used to supplement recorded data or for narrative information, e.g., record of discussions with property owners or utility company representatives. The front cover of each book shall be labeled with project number, county, survey route, project location (from and to), and book number. The pages of each book shall be numbered. Notes must be legible and written with clarity.

5.5.2 BENCH MARK LEVELS

Bench Mark level notes are recorded in the field book and must be reduced and checked. Refer to Figure A-14 and Figure A-15 in the Appendix.

5.5.3 PROFILE NOTES

Usually profiles are developed from the Digital Terrain Model. However, conventional profile runs are sometimes required by the Regional Survey Supervisor. An example of profile notes may be found in Figure A-17 in the Appendix.

5.6 HORIZONTAL AND VERTICAL MEASUREMENTS

5.6.1 LINEAR MEASUREMENT

Electronic distance measuring equipment shall be used whenever possible to obtain linear measurements. Total stations shall be used to measure the distances between P.O.T.'s or between P.I.'s on the centerline of a survey.

Horizontal distances are to be used in the preparation of maps and plans, in deed descriptions, and in centerline stationing.

5.6.2 ANGULAR MEASUREMENT

A horizontal angle, such as a delta angle turned at a P.I., shall be turned in accordance with Table A-4 of the Appendix. A "position" is the act of making one direct and one reverse observation on each backsight and foresight point, and averaging the angles.

Vertical angles shall be read in both direct and reverse positions of the scope, and the angles averaged.

For extending straight lines, "double-centering" of the transit or theodolite shall be used.

5.6.3 VERTICAL MEASUREMENT

When an engineer's level and level rod are used, the turning points shall be "balanced", and the level run tied to a known bench mark.

When an EDM is used, vertical angles shall be read in both direct and reverse positions of the scope, and angles averaged.

5.7 COORDINATION OF CONSULTANT SURVEY PROJECTS

5.7.1 GENERAL

Consultant firms providing surveying services for the Department will be considered an extension of state forces and will be subject to controls and procedures specified within this manual. Exceptions to this policy will include some reporting procedures and specific exclusions stipulated in the contract or directed by the Regional Survey Supervisor or other appropriate Department representative. The Department has developed an estimate form using the computer software Microsoft® Excel. This current form will be used on all survey projects and on survey and design projects where applicable at the discretion of the Survey Coordinator.

5.7.2 CONTACTS

5.7.2.1 CONTRACTUAL MATTERS

The Consultant shall contact the appropriate Civil Engineering Manager 2, Survey and Design on all matters pertaining to contract interpretation, billing procedures, payments, extensions to contracts, future projects, etc.

5.7.2.2 WORK RELATED MATTERS

The Regional Survey Office shall be consulted on matters pertaining to scope of work, procedures, and requests for supplies and assistance.

5.7.3 ESTIMATES

5.7.3.1 CONTACTS

The Consultant shall contact the Regional Survey Office to discuss scope of work, procedures, difficulty factors, etc. before an estimate for cost of services is prepared. The Regional Survey Office will provide TPRs, location sketches, etc. as required. It is recommended that a meeting at the job-site or in the Regional Survey Office serve as this contact. In the case of extremely small or simple projects, phone contact may suffice. This contact will allow for negotiations on all activity difficulty factors as well as items entered on the project summary sheet.

5.7.3.2 PREPARATION

The proposal for services shall use the current Microsoft® Excel form for Survey and Design estimates. The most current version of this form may be found at the following internet address:

http://www.tdot.state.tn.us/Chief_Engineer/assistant_engineer_design/design/survey.htm

Proposals not submitted in this manner cannot be properly evaluated and may be deemed unacceptable. The form is designed to be used for most types of surveys; therefore, all items will probably not apply to a particular survey.

5.7.3.3 DEPARTMENT

A separate estimate of man-days required will be made by the Regional Survey Supervisor or the Survey Coordinator using the most recent version of the TDOT survey and design estimate form created in Microsoft® Excel. This estimate will be identical to the consultant's, since the project data and difficulty have been negotiated.

5.7.3.4 SUBMITTAL

Consultant - The "Manday Proposal" and any other supporting documents included in the proposal will be submitted to the Survey Coordinator.

Department - An "Estimate for Field Surveys" and a "Project Summary Form" are completed by the Regional Survey Supervisor and submitted to the Survey Coordinator.

5.7.3.5 PROCEDURES

The Consultant shall notify the Regional Survey Office when work has begun and report progress at the end of each second week thereafter. This notification may be in the form of a letter, e-mail, or by phone at the discretion of the Regional Survey Supervisor.

The completed survey will not be reviewed if the project is to be designed by the same firm performing the survey. The following procedures apply for projects for which Department personnel will develop R.O.W. and Construction Plans:

- Completed surveys will be submitted to the Regional Survey Office.
- The Regional Survey Office will be responsible for review of completed projects to assure that all required information is present and in acceptable format. In the event

that additional information is required or other problems exist, necessary arrangements with the Consultant will be made by the Regional Survey Office.

- Upon successful completion of the survey, (all necessary information submitted and approved), the appropriate Civil Engineering Manager 2, Survey and Design shall be notified. This notification (in writing) shall indicate that the project is complete and additional comments made as to the quality of the product, cooperation and competency of the Consultant, and any other information pertinent to the project. The Survey Coordinator shall receive a copy of the letter.
- Submitting of the survey, after checking, will be according to usual procedures (Refer to Section 1.7).

5.8 COORDINATION OF CONSULTANT SURVEY AND DESIGN PROJECTS

5.8.1 GENERAL

The development of surveys by agencies outside the Department for their use in the design of bridge or roadway projects will be consistent with the directions of this manual. No special information, reduction in necessary information, or change of format shall be required. The Consultant shall coordinate all phases of the survey with the Regional Survey Office including matters of scope, control, etc. Refer to Section 1.7 for transmittal requirements.

5.8.2 BRIDGE SURVEY / SETTING GRADES

Firms responsible for survey and design of bridge replacement projects shall submit a copy of survey data including: present layout sheet, plotted stream profiles, suggested structure grade, etc., and request for hydraulic analysis directly to:

Engineering Director
Structures Division
1200 James K. Polk Building
Nashville, Tennessee 37243-0339

A copy of the request shall be forwarded to the Regional Survey Office. Personnel of the Structures Division will provide a direct response in regards to setting the grades and sizing the structure.