The Tennessee Geodetic Reference Network (TGRN): An Update*

James H. Zeigler
Tennessee Department of Transportation

INTRODUCTION

As the Tennessee Department of Transportation (T.D.O.T.) considered the introduction of Global Positioning System (GPS) technology into its survey program, the need for an appropriate reference system became apparent. Evaluation of a series of test projects indicated that the National Geodetic Reference System (NGRS) in Tennessee was not adequate for GPS surveys. The T.D.O.T. entered into a cooperative agreement with the National Geodetic Survey (NGS) to develop a statewide reference network specifically for GPS use. The TGRN is a moderately spaced, highly accurate system of three dimensional points tied to the NGRS using stations of the Eastern United States Strain Network. It is also being used to evaluate the NAD/83 adjustment in Tennessee and could serve as a framework for the natural development of a statewide cadastre.

As GPS technology develops, new applications and techniques are appearing rapidly. Most of these in the surveying area employ relative positioning principles. So an important consideration in most projects is the reference system from which to begin. In many areas the existing NGRS is inadequate for GPS work. As part of the plan to implement GPS surveying, T.D.O.T. decided to develop its own reference system. This paper will describe the TGRN, the reasoning behind various decisions during its development, the cooperative efforts of the various agencies and private organizations involved and the current status of the project.

GPS IN THE TDOT

In 1983 and 1984, the T.D.O.T. staff began investigation of GPS capabilities and its potential application to transportation surveying. A major part of the process was a series of test projects involving GPS surveys. The surveys, performed by private contractors, consisted of establishing pairs of points at the beginning, end and along the length of several highway projects statewide. T.D.O.T. staff closely monitored each step of the projects, including reconnaissance, field operations and office processing.

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Results of the investigation, including test projects, indicated that GPS technology would be well suited for control of T.D.O.T. highway surveys. Plans were begun for incorporation of GPS equipment and procedures into the survey process.

There was, however, one disturbing finding resulting from the test projects that would precipitate a new avenue of thought concerning the GPS surveying process. On almost every project there seemed to be some problem with reference points. They included:

1. **Lack of available reference points.**
   Often no existing NGRS monumentation was available in the project area.
2. **Accuracy of reference points.**
   First order triangulation stations were first choice for project control. Many times it was necessary to use second order reference points.
3. **Poor accessibility of monuments.**
   When appropriate reference points were located, they often were not accessible by vehicle.
4. **Visibility problems.**
   Recovered points were often located in areas with poor overhead visibility (under fire towers, adjacent to a stand of trees, etc.). The NGRS was developed horizontally with little concern for vertical visibility.
5. **Reliability questioned.**
   Because the GPS method of surveying was generally more accurate than reference points, the points were usually the first thing questioned when problems arose.
6. **Time consuming reconnaissance.**
   Even when the problems mentioned above were overcome, and appropriate, usable, accessible NGRS reference points were recovered, it was noted that a major part of the project survey involved reconnaissance.

Preliminary discussions with T.D.O.T. staff, NGS staff and private GPS surveying firms, led to the conclusion that a reference network specifically designed for GPS surveying could be developed in Tennessee at a reasonable cost.

NETWORK PLANNING

The initial discussion concerned the type of reference system to be implemented. The two basic schemes considered were a network of widely spaced, continuously operating, automatic stations (similar to the approach by the Texas D.O.T.) (Merrell 1986), or a more dense, conventional network. The latter was chosen based on the following summary of the analysis:

Continuous Stations

Continuous Stations are a system of widely spaced, very accurately located points occupied by receivers that track available satellites twenty-four hours a day. The receivers are controlled by a computer system that also logs data and provides on-line data transfer capabilities.

Negative:

1. Stations require a high degree of technical skill for development (computer control, data transfer, etc).

2. Stations require continuous maintenance.
3. Stations do not provide consistency (even highly accurate methods produce significant actual error over great distances).
4. There is potential for problems in the distribution of data (mail, modems, formatting, etc.).

Positive:
1. Fewer stations are required.
2. One fewer receiver is needed in field.
3. There is no fear of points being destroyed (automatic trackers would normally be at well-established locations).

Conventional

This is a system of moderately spaced points located to an accuracy greater than the project surveys that use it as a reference.

Negative:
1. Larger number of stations are required to facilitate logistics of project surveys and reduce error.
2. Location of stations must be carefully chosen to avoid future loss.
3. Network stations must be located and occupied at beginning and ending of each job.

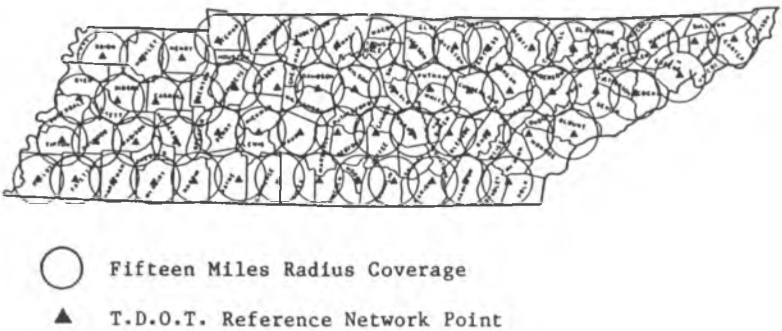
Positive:
1. Most users would have at least two receivers on any job (therefore no real advantage to getting data from automatic station as opposed to conventional).
2. Distance from control is shorter, so actual error would be smaller.
3. Conventional system encourages traverse as opposed to radial GPS surveys.
4. The system is moderately easy to implement and maintain.
5. The system encourages ties at the local level (natural development of cadastre).
6. Others using the network would not be dependent on T.D.O.T. for data supply.

The next decision reached concerned the accuracy of the TGRN. Global Positioning System equipment can routinely provide results in the 4 ppm range, with proper planning and roughly an hour of data collection. It seemed that the TGRN should be considerably more accurate than project level surveys, so initial plans were for an accuracy of 2 ppm. Conversations with prospective contractors suggested that the accuracy could be upgraded to approach 1 ppm with an increase in cost of about 40 percent.

Further conversation with NGS indicated that a reduction and adjustment of the network relative to their Very Long Baseline Interferometry (VLBI) stations would insure the 1 ppm accuracy with the possibility of achieving 0.1 ppm. As discussions progressed, the potential value of the network as a framework for a state-wide Geographic Information System (GIS) was reinforced. This potential value, coupled with the desire to get as good a product as possible, influenced the decision to proceed with a 1 ppm GPS survey.

The configuration of the network was developed within an economical constraint of roughly $100,000 for the survey and the desire that no point in the state be farther than twenty to twenty-five kilometers from a TGRN monument. The state's shape conveniently allowed the placement of four east-west lines, thirty miles apart and fifteen miles from the north and south borders. Network stations were then spaced alternately thirty miles apart on each line assuring that few locations in the state would be farther than fifteen miles or roughly twenty-five kilometers from a TGRN station. Figure 1 illustrates the proposed network configuration of the sixty station primary control points, with circles showing the area of coverage within fifteen miles. These maximum distances seemed well within the limits of the single frequency receivers planned for purchase.

(Fig. 1. Proposed Network Configuration)



Since the TGRN would consist of a series of highly accurate three dimensional points, the monumentation used was conventional caps in exposed bedrock outcrops, or NGS 3-D monuments.

Consultation with NGS concerning ties to the NGRS resulted in a plan to provide horizontal ties within each one degree (latitude and longitude) quadrangle and vertical ties to at least seventy five percent of the TGRN stations. Horizontal ties would ideally be to NGRS first order triangulation or Doppler stations and located near the center of each quadrangle. These ties would be used to provide a connection to the NGRS at the local level. The connection would provide a means of evaluating the NGRS and provide for possible local refinement. Vertical ties would, if possible, be run from an existing first order benchmark to a TGRN station and then tied to another first order benchmark. Leveling would be conventional spirit leveling meeting second order closure requirements. An effort would be made to establish elevations at all network stations. These conventionally established elevations would be used with GPS survey results to improve the geoid model in Tennessee.

NETWORK DEVELOPMENT

The development of a sixty point GPS reference system with sixteen horizontal ties and accurate elevations over a 42,000 square mile area presented a formidable task for the T.D.O.T. staff. To address this problem, a cooperative agreement between T.D.O.T. and NGS was developed. The major points of the agreement were:

T.D.O.T. Responsibilities

1. Provide reconnaissance for all TGRN and tie points.
2. Provide elevations for at least forty-five of the TGRN points.
3. Hire a consultant to do a GPS survey of the TGRN and provide preliminary horizontal coordinates.
4. Accept responsibility for maintenance of the TGRN.
5. Survey forty-three FAA airports, tied to the TGRN using GPS, including two monumented points and a point at the center of each runway end.

NGS Responsibilities

1. Provide technical expertise, including advice during development and review of technical specifications.
2. Place the sixty TGRN monuments.
3. Coordinate with the consultant to insure acceptability of data relative to National Geodetic Survey VLBI stations.
4. Final reduce and adjust final data and publish coordinate values.

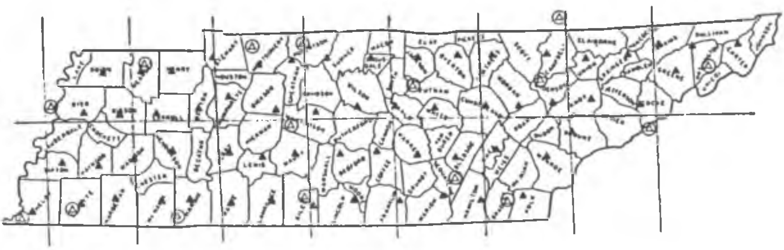
The reconnaissance effort provided some unexpected challenges. However, careful attention to details and planning during this phase made the following operations much easier. Locations for the TGRN points were expected to meet the following criteria:

1. Points must be reasonably close to the predetermined location on the statewide grid.
2. Points must be accessible by vehicle (within fifteen meters).
3. There must be a relatively clear view of the horizon (above 15° for 360°).
4. Points must be located on property unlikely to be disturbed or developed for the next fifteen years (school, fire hall, utility, roadway, church, airport).
5. There must be no nearby objects that could cause multipathing of the GPS satellite signals.

Efforts to locate points suitable for tying the TGRN to the NGRS substantiated the original position that the national system (at least in Tennessee) is not suitable for GPS work. Though only sixteen ties were sought, in several instances first order triangulation stations were not available in the area required and, if found, were not suitable for GPS work. It was necessary to use several second order triangulation stations, and their location within the quadrangle was less than desirable. Figure 2 illustrates the final selection of network points, reference grid areas and horizontal tie points used.

The contract and the specifications for the GPS survey of the TGRN were developed using the publication, *Proposed Geometric Geodetic Survey Standards and Specifications for Geodetic Surveys Using GPS Relative Positioning Techniques*, (Hothem 1986). An observing scheme was provided for a four, five or six receiver operation, and an observing session of four to five hours specified was specified. The contractor was to make observations in accordance with specifications for Order B geometric accuracy standards using any one of the schemes provided. Day to day processing and checks would insure internal consistency of the survey, and a minimally constrained three dimensional least squares adjustment of the TGRN was required. The specifications also required coordination with NGS to assure that observations were being made concurrent with the National Geodetic Survey VLBI stations. This would allow NGS to perform additional reduction and adjustment of the data later.

(Fig. 2. Network Points, Reference Grid Areas and Tie Points)



▲ T.D.O.T. Network Points

Ⓐ Horizontal Ties to National Network

Elevations were determined for fifty of the sixty network points through the services of state forces and two private contractors. Once again a lack of existing control was a problem, often requiring the running of conventional levels over great distances.

STATUS

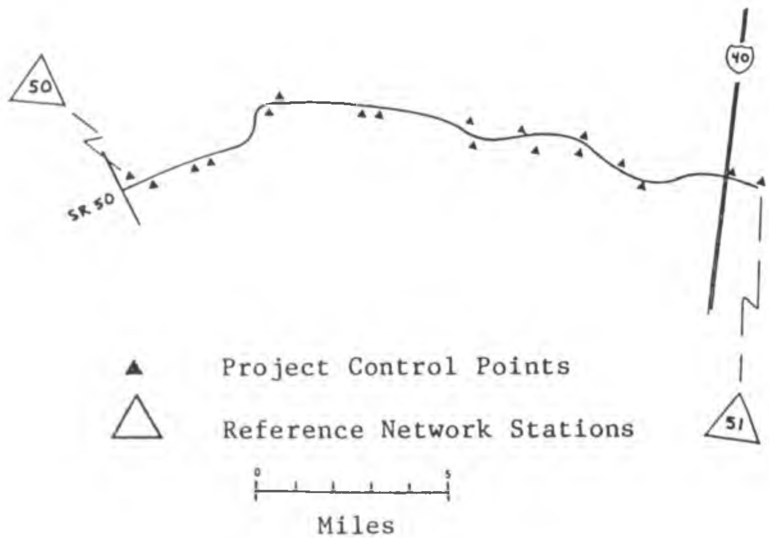
At the writing of this paper, all field work has been completed by the contractor, preliminary TGRN coordinates provided to NGS and T.D.O.T., and GPS work using this control is underway in Tennessee. Preliminary coordinate values are being used, however, and there are two significant steps yet to be taken. Final reduction of the data and publication of the final coordinates by NGS, and completion of surveys for the forty three FAA airports by T.D.O.T. will complete the project. It is hoped that these tasks will be accomplished soon.

NGS adjustment procedures were hampered initially because of equipment failure and other problems at VLBI stations during the survey. Observations were not made at two and sometimes three of the VLBI stations during several sessions of the TGRN survey. Because of the missing data, NGS elected to tie the TGRN to the NGRS using three stations of the Eastern United States Strain Network, which are also stations of the TGRN. NGS adjustments using precise ephemeris data have resulted in internal accuracies of 1 to 0.1 ppm. Horizontal closures have averaged 3.3 cm E/W, 2.1 cm N/S and 7.3 cm ht. over average loops of 355 kilometers. Independent of NGS, Dr. Yehuda Bock, using simultaneous orbit and network adjustment techniques, has achieved similar results with a small portion of the network (Bock and Ladd 1988). Plans are underway for an expanded effort by Dr. Bock which would include the entire TGRN.

As mentioned previously, part of the reason for tying to the NGRS was to provide a means of evaluating NAD 83 values at the local level. Adjustments using the TGRN Global Positioning System survey data and precise ephemeris have indicated changes in position of +/- 30 cm for the sixteen NGRS tie points. At this time NGS feels that these findings indicate the need for adjustment and possible re-publication of some NAD 83 coordinate values in Tennessee.

T.D.O.T. specifications for highway surveys have been changed to require that all work be tied to the TGRN using GPS equipment. Work is currently underway using the preliminary coordinates. Figure 3 illustrates a typical job using GPS to bring control to the project area. The job is a seventeen mile highway project in southeast Tennessee. Pairs of survey points (used for control and azimuth) are located at various distances along the project (one to three miles, depending on the topography). The GPS project survey is tied to the TGRN at the beginning and end of the survey.

(Fig. 3. Typical GPS Survey Project)



CONCLUSIONS

The TGRN project demonstrates that a small staff with a modest budget and little previous GPS knowledge can develop a good GPS specific reference system. A key factor is the full utilization of the knowledge and skills of industry and government people who are willing to help. T.D.O.T. staff found many such people available, especially the staff of the NGS.

Use of the network for almost a year has confirmed our contention of its usefulness. T.D.O.T. crews begin and end all GPS surveys without the need of time consuming reference mark reconnaissance. Plus, the choice of sites provides for quick and easy access and equipment set up. The reliability of station coordinates also relieves T.D.O.T. staff of one variable when problems arise. Reference station positions are never in question.

As previously discussed, another benefit of the TGRN is its potential as a natural base for a statewide cadastre. This potential is being realized even before the completion of the project. Using preliminary coordinates, the Tennessee Valley Authority (TVA), the Department of Energy and the Tennessee cities of Chattanooga, Knoxville and Columbia have all tied, or are considering tying, major surveys to the network. Necessary adjustments will be made upon publication of the final coordinates.

As GPS surveys become common place and accuracies in the 4 to 5 ppm range are expected as a result of sound procedures, the existing NGRS will become less and less satisfactory as a reference. Networks such as the TGRN can provide an appropriate alternative.

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REFERENCES

Hothem, L. D. 1986. *Proposed Geometric Geodetic Survey Standards and Specifications for Geodetic Surveying Using GPS Relative Positioning Techniques*. Version 4, Federal Geodetic Control Committee, Washington, D. C.

Merrell, R. L. 1986. "Geodetic Reference Systems in GPS Environment", *Journal of Surveying Engineering*, ASCE, Vol. 112(2), pp. 83-89.

Bock, Y., and J. W. Ladd. "Simultaneous Orbit and Network Adjustment in Tennessee", *Journal of Surveying Engineering*, ASCE, Vol. 115(1), pp. 34-45.