

TELLUROMETER OPERATIONS IN TOPOGRAPHIC MAPPING

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ABSTRACT

The U. S. Geological Survey uses the Tellurometer principally to increase the speed and reduce the costs of control surveys for topographic mapping. Increased accuracy is a welcome byproduct. In this application, it largely replaces triangulation and transit-and-tape traverse. Most of our Tellurometer work consists of traverse, with angles measured by a one-second optical theodolite. Second-order accuracies are obtained at lower costs than for previous third-order work. All traverses are tied to the basic geodetic net. Where geodetic azimuth ties are not readily available, azimuths are obtained from Polaris observations. Our basic traverse operations are supplemented, where appropriate, by a small amount of trilateration, numerous side shots or radial measurements from strategically located control stations, and triangulation intersections of conspicuous points. The Tellurometer is also used effectively for testing the accuracy of finished maps.

This report presents some statistical data on quantities, accuracies, and costs, developed during about one year of operations of four field parties.

Data-reduction problems included development of a visual aid for interpreting Tellurometer coarse readings and a plastic computer for obtaining the semivelocity of the radio wave in the atmosphere as a function of wet- and dry-bulb temperatures and barometric altitudes. Vertical-angle measurements are used to reduce Tellurometer distances to horizontal and to sea level, and to compute elevations. The resulting geographic positions and elevations are adjusted by simple proration or by least squares, as appropriate.

INTRODUCTION

Improvements in measuring equipment or techniques are generally intended to accomplish one or both of two major objectives — *a*) to increase the accuracy of a particular type of measurement, or *b*) to reduce the time and/or cost of making the measurement. It sometimes happens that a single development can accomplish both objectives, either simultaneously or alternatively. The Tellurometer was developed to increase the speed with which high-accuracy geodetic measurements could be made. For this purpose it was intended to be competitive with triangulation methods. An apparent byproduct of the original intent is its application to lower-order surveys, where increased accuracy is a welcome addition to the savings in time and cost.

U. S. GEOLOGICAL SURVEY APPLICATIONS

The U. S. Geological Survey has found the Tellurometer well suited to several types of operation. Our requirements for basic horizontal control stipulate third-order accuracy. In open mountainous terrain, such as the Western States, we have traditionally used networks of triangulation to locate control points at the required spacing density. In the Central Plains areas and in the Eastern States, where triangulation would not be practicable without building towers to overcome the earth's curvature or where heavy timber cutting would be necessary to clear the lines of sight, transit-and-tape traverse has been used extensively. Most of the traverse lines have been run along roads for ease of accessibility.

With the Tellurometer, both methods of control have been modified. Most of our Tellurometer work consists of traverse; distances between stations are measured with the Tellurometer, and angles between courses are measured with a one-second, optical-reading theodolite. Although our basic requirements call for only third-order accuracy, we find the Tellurometer capable of producing second-order accuracy at no additional expenditure of time and effort. For this reason, we have improved our angle measurements beyond the needs of third-order work and are obtaining essentially second-order surveys at lower cost than for our previous third-order control. Since the theodolite is present at each station for horizontal-angle measurement, we are also measuring reciprocal vertical angles (or zenith distances) over each course. These vertical angles are used to reduce the measured distances to horizontal and also to compute elevations for supplemental control in the more rugged areas.

At least one end, and preferably both ends, of each traverse must be tied to the national geodetic network of first- and second-order triangulation established by the U. S. Coast and Geodetic Survey. When convenient, a starting azimuth is obtained by backsight on another triangulation station, and a closing check azimuth is obtained similarly. When geodetic azimuth ties are not readily available, azimuth is obtained by observation on Polaris. If the traverse is long or has many courses, additional intermediate Polaris observations are required.

On those relatively rare occasions when good Tellurometer measurements can be made but stations are not optically intervisible because of atmospheric conditions, intervening foliage, or similar obstructions, trilateration techniques may be used. This method is used, however, only when ordinary traverse methods are not practicable.

In the course of traverse operations, stations are sometimes located on high points overlooking large areas of the surrounding countryside. At such stations, side shots are made by measuring angles and Tellurometer distances to other locations not on the main traverse line. A single, well-situated traverse station may thus be the central point from which a large number of control stations are located radially. Usually the side stations are established by single rays from the central station, sometimes by a spur traverse consisting of two or more courses.

When conspicuous natural or manmade objects are visible at a distance from several stations along a traverse route, it is not unusual to turn angles to such objects from several traverse stations to locate them by triangulation intersection.

Another important application for the Tellurometer has been found in field-testing our finished maps to check compliance with established standards for both horizontal and vertical accuracy. The Tellurometer is used most effectively in this application when one or more basic control stations are so situated as to provide a good general view of the mapped area. A theodolite and Tellurometers are set up at the controlling station and several roving Tellurometers visit a large number of readily identifiable points shown on the map. Distances are measured to each of these points from the central station, together with horizontal and vertical angles, from which the positions and elevations of the map features are readily computed to check the information shown on the map. These accuracy tests are made on only a specified percentage of our maps, on a sampling basis, and the Tellurometer technique is used in only those open areas in the West where terrain and foliage conditions make it economical.

STATISTICAL DATA

The Topographic Division of the Geological Survey is organized geographically into four operating areas. Although the end product — the topographic map — is the same for all, terrain and other local conditions vary widely between, and often within, the areas. The field survey techniques must necessarily be tailored to local conditions and cannot be too thoroughly standardized. Similarly, a report on operating experience must reflect rather wide variations among the items included.

Our first Tellurometers were delivered in 1957. After extensive familiarization, testing, and evaluation by our headquarters staff engineers, selected engineers were brought in from each of the areas for a short period of intensive training and indoctrination. The equipment was delivered to our field personnel in the spring of 1958, one master unit and two remote units to each of the areas. This report therefore reflects about one year's operating experience of four parties. Additional Tellurometers were purchased later that year and were delivered late in 1958. Their influence on these statistics is believed to be only minor.

Approximately 6 542 miles of Tellurometer lines were measured in 40 projects during the year. These lines varied in length between 400 feet and 126 miles, with an average length of 13.0 miles per line. By far the bulk of this work consisted of traverse, as described above, to control about 22 283 square miles of mapping, but 305 miles were involved in trilateration and 835 miles in accuracy test surveys. Traverses varied from two to 33 courses, with an average of 8.8 courses between ties. About 1 414 stations were occupied, and 1 377 new stations were established.

Accuracies attained are indicated by circuit closures of closed traverse loops or by checks on first- or second-order geodetic stations. These closures include the errors in the angle measurements as well as those remaining in the basic geodetic net after its own adjustment. (Some of the geodetic stations connected by Tellurometer traverse were widely separated along their respective triangulation arcs). The average proportional closure was 1 part in 54 000, the apparent best was 1 in 338 800, and the poorest was 1 in 9 300. In terms of linear error, the best closure was 0.28 foot, in a 9.5 mile traverse; the poorest, 7.5 feet, in a 13.2 mile traverse.

The cost of this work varied greatly, according to local conditions and needs and the experience level of the operating personnel. Throughout the Division, the cost of Tellurometer work, including transportation, reconnaissance, angle measurement, other related field activities, and overhead averaged about \$ 124.75 per station, \$ 32.07 per linear mile, or \$ 8.97 per square mile of mapping controlled. These costs compare with average triangulation costs of \$ 217.55 per station and \$ 7.95 per square mile, and with average transit-and-tape traverse costs of \$ 67.36 per linear mile and \$ 15.31 per square mile.

DATA REDUCTION

One of the first problems we encountered in training new personnel was in the interpretation of the coarse distance readings. Some beginners have difficulty in visualizing the decade relationship that exists between the respective differences of the A pattern and the B, C, and D pattern readings, whereby the tens digit of one difference helps determine the proper units value of the adjoining difference. For this problem, we found a visual aid very helpful. We prepared a chart with four dials, each with a movable pointer. We then compared this series of dials with those on the familiar gas meter or electrical watt-hour meter and explained how a full revolution of the pointer on one dial produces a simultaneous 1/10 revolution on the adjoining dial, and showed the student how minor adjustment can be made in each of the differences to make them consistent without changing the overall picture.

Perhaps our most significant contribution to the simplification of the data-reduction problem was our Tellurometer Computer, for computing the semivelocity of the radio wave through the atmosphere. The original recommendation of the Tellurometer manufacturer called for determining first the vapor pressure of the atmospheric moisture, then its barometric equivalent, then the index of refraction, and finally the velocity. We investigated various tables that were available from the Smithsonian Institution, the Bureau of Standards, and the Weather Bureau. All the available

tables require interpolation, usually in two directions. Although not difficult, the procedure was time consuming. We considered various charts and nomograms that were available or could be produced easily. Then we discovered a semimechanical chart that had been prepared by the Naval Electronics Laboratory for determining the index of refraction of the air under various conditions. From the NEL report we extracted the combination of parts that best suited our needs and modified it to fit our own requirements. The final computer is prepared photographically on a plastic base by contact printing from a negative original. It consists of two parts, a base and a rotating sector. The base contains a series of spiral curves representing wet-bulb temperatures. Surrounding these curves are two semicircular scales, one representing the 4th, 5th, and 6th decimal places of the index of atmospheric refraction, and the other showing one-half the corresponding velocity of propagation in feet per millimicrosecond. The sector has on radial scale for dry-bulb temperature, which rides over the wet-bulb curves, and a circular scale representing barometric pressure but graduated in feet of altitude because our field engineers use barometric altimeters instead of ordinary barometers. The two parts of the computer are riveted together at the common centers of the circular scales so that the sector is free to rotate.

In use, the dry-bulb scale of the sector is rotated over the spiral wet-bulb curves of the base to bring the two temperature readings into coincidence. Either the semivelocity or the refractive index may then be read on the base at the appropriate altitude mark of the sector. Thus, by a single setting of the computer, the semivelocity of the radio wave may be read as a function of wet- and dry-bulb temperatures and barometric altitude. A number of minor approximations were made in the design and construction of this computer. The resulting readings may not be adequately precise for the highest-order surveys, except at low barometric altitudes, but are well within acceptable tolerance for most practical applications. We believe that the computer is essentially as accurate as is justified by the quality of the meteorological measurements made and their wide separation in a nonhomogeneous atmosphere.

Tellurometer slope distance is obtained by multiplying the Tellurometer transit time, corrected for crystal temperature, by the semivelocity obtained from the computer. We have determined that the difference in length between the actual curved ray path and the corresponding chord is insignificant for the lengths and accuracies with which we are concerned. For reduction to horizontal, we multiply the slope distance by the cosine of the vertical angle, properly corrected for vertical refraction. Where reciprocal vertical angles have been measured, the mean of the two angles is the corrected vertical angle. We have found that altimeter readings are usually not good enough for reduction to horizontal if the difference of elevation is appreciable. The horizontal distances apply to the mean elevation of the line; they are reduced to sea level by the usual formulas. Again we find the difference between chord and arc to be insignificant.

Differences of elevation are computed as the product of slope distance and the sine of the corrected vertical angle.

To convert our Tellurometer survey data to geographic positions, we first adjust the angle measurements. The convergence of meridians is

computed and applied between azimuth ties to determine the amount of instrumental error. This error is then prorated among the respective angle measurements, and geographic positions are computed by the usual triangulation formulas. If the traverse consists of a single chain of lines, the position closure is prorated along the chain. If it consists of a network of loops or closed circuits, it is adjusted by the usual least-squares methods. For this purpose we find our Electrical Survey-Net Adjuster (ESNA) very effective. The elevations determined from the vertical-angle measurements are adjusted similarly.