Evaluation of the Tellurometer for Highway Survey Control in Maryland

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A brief description of the field procedure and use of the Tellurometer in Maryland is presented. Results obtained, as affected by topography, land use, traffic, wind, and temperature, are reported, together with the efficiency of the Tellurometer as compared to surveys by chaining in certain regions of Maryland.

●THE BUREAU of Control Surveys of the Maryland State Roads Commission was established in 1939 to provide a central depository for information concerning horizontal and vertical control established locally by Federal Government, state agencies, and private engineering concerns. The Bureau's field survey party is continually engaged throughout Maryland extending USC&GS control to areas of eventual highway construction designated by the Highway Location Division.

In March 1958, this Bureau, in cooperation with the U.S. Bureau of Public Roads, began a period of testing and evaluation of the Tellurometer for making control surveys relevant to highway surveys and design. The contents of this paper are based on 18 months of field operations completed in October 1959.

Most engineers are familiar with angle and distance measuring in making traverse surveys. Consequently, a detailed account of field survey procedure and traverse surveying will not be given, but a few pertinent facts will be mentioned. Traverse surveys with the Tellurometer are less restricted by topography, land use, and ground cover than are traverse surveys by conventional methods. In control surveying with the Tellurometer, it is advantageous for a two man reconnaissance party to explore the most suitable routes for traverses with respect to sight distances and positioning of permanent control stations. Since most of the distance measurements are made by ground-to-ground observations without the aid of towers to elevate the instruments, the thoroughness of this preliminary field work can have an important bearing on the results attained on a particular project. Permanent station markers to serve as survey monuments are positioned by the reconnaissance party at desired intervals of from 1 to 3 mi, and at major highway junctions.

Angle measurements are made with a Wild T-2 Theodolite. For traverses with average sight distances of 1 mi or less, 8 readings of each angle measurement are made, four direct and four reverse. Where longer courses are measured, 12 to 16 readings of the angle measurements are made depending on the average length of sight between the measurement stations. Vertical angles are observed from each end of the measured course. The mean of a direct and reverse angle reading is used for determining the correction to be applied to the slope distance measured with the Tellurometer.

For distance measurements, 12 Tellurometer readings are obtained on successive frequencies for each course. Occasionally, one or two readings of a set will appear erratic, and then additional readings are obtained. For reduction of Tellurometer readings to State plane coordinate distances, a form used by the USC&GS has been adopted. A slight revision of this form permits all machine computations for each course, including reduction to datum of the State plane coordinate system and application of the scale correction factor, to be completed on one sheet.

As mentioned before, most of the field work has been completed with ground-to-ground observations. As a result, the topography and ground conditions have had a great influence upon the degree of accuracy and the efficiency to be obtained for each project. Maryland affords three distinct types of topography over which the Tellurometer has been utilized with varying degrees of success. The most consistent results have been obtained in central and northeast Maryland, where high, rolling hills permit sight distances averaging from 3, 000 to 7, 000 ft with little or no clearing of lines. Of the 31 traverses completed in this area, an average closure of 1 part in 56, 000 has been obtained.

The mountainous region of western Maryland has permitted very good results particularly during the spring and fall of the year. The numerous fire towers of this area have been used with great success to extend control into portions of this region where no USC&GS control previously existed. Three nets, totaling 112 mi of traverse, were recently established in this area with average closures of 1 part in 115, 000. To position permanent stations at desired intervals and at major highway junctions, approximately 45 mi of secondary traverses were established from these nets. These traverses have average closures of 1 part in 43, 000. The differences in the accuracy of these closures are due to average length of lines used for each type of traverse; the accuracy of shorter lines being limited by the ± 2-in. error that may occur with each measurement.

Results have shown that the relatively flat ground in southern Maryland and in the Eastern Shore areas is not as suitable for Tellurometer surveying as the topography in other regions of Maryland. The closures obtained thus far in flat ground areas, however, have been satisfactory for highway work. The frequent large wooded areas and the predominance of agriculture in this region have confined most of the traversing to highway and railroad rights-or-way, thus necessitating shorter lines and in several cases the inclusion of chained distances. Whenever possible, sight distances have been lengthened by occupying fire towers, church belfries and roof tops. Of the four traverses completed in this area, closures have averaged 1 part in 23, 000.

During the field demonstration and instruction period, prior to the operations with the Tellurometer, ideal ground conditions for measurements, such as depression of ground between stations and light vegetation to minimize reflected waves, were described. Realizing that these conditions would be impossible to obtain in certain regions of Maryland, the first two traverses were established in areas with conditions similar to those which would prevail throughout the projects. The closures obtained were 1:27, 000 and 1:48, 000, respectively. From the adjusted courses of these traverses, triangles were projected over and through various types of ground cover to simulate conditions likely to occur in future work. Intervisible courses were measured from within a wooded area to a point on open ground, over fields of wheat and low brush, and with trees or obstructions adjacent to the line of sight.

The closures of these triangles indicated little or no adverse effects resulting from these conditions. Terrain conditions were also altered between several of these base courses by chaining eccentric points. Readings were taken with the intermediate terrain rising adjacent to the line, and again satisfactory results were obtained. While all of these simulated conditions permitted satisfactory results, it should not be concluded that all intervisible lines will permit accurate measurements. On several occasions, courses were measured where no apparent cause for reflective interference existed, and yet the readings were scattered, with high and low readings differing as much as 6 to 8 ft. On still other intervisible courses, weak and unstable signals were encountered from which readings could not be obtained. Fortunately, these instances occurred so infrequently they did not constitute a hindrance or weakness in the overall performance of the Tellurometer.

Prior to establishing ground control for the Potomac River Crossing of the Washington Circumferential Highway near Alexandria, Va., several overwater tests were conducted. Computed distances, between first-order USC&GS triangulation stations established along the shores of the Magothy River in Anne Arundel County, Maryland, were used for base courses. The height of the instrument above the water surface varied from 10 to 25 ft, and the distances measured ranged from 4, 000 to 11, 000 ft. Closures from 1:14, 000 to 1:58, 000 were obtained indicating that satisfactory results could be expected under these conditions.

To determine what adverse effects might result from the motion of vehicles and the reflective surfaces of roadways, a series of tests were conducted along US 40, west of Baltimore. At the time and place these tests were made, the average daily traffic for this section of divided highway was 11, 000 vehicles.

Using a base course previously established by first-order traverse, quadrilaterals were projected to select test courses on and near the roadway. Measurements were made parallel, diagonal, and perpendicular to the flow of traffic. In each of these tests, comparison of the measured and triangulated distances gave closures of 1:18, 000 and better, indicating practically no adverse effects from these conditions. It was concluded that in most cases, where the flow of traffic did not pass through the direct measuring signal, very little delay occurred while obtaining the readings. When vehicles passed near the direct line being measured, the reading trace of the oscilloscope had a tendency to expand and contract, but the value of the phase shift was not affected by this interference. Thus a trained instrument operator could continue reading without delay.

When measuring where the flow of traffic passed directly through the measured signal, delays could not be avoided. The amount of delay, in each case, depended on the volume of traffic, and the acuteness of the angle between the measured line and the direction of the traffic movement. The least delay occurred when measurements were being made perpendicular to the direction in which traffic was moving.

When measuring on, or across paved roadways, care should be taken to watch for erratic readings, as certain frequencies may be affected by reflected signals. In extreme cases, certain frequencies may be affected so much as to preclude readings being made. This seldom occurs for more than one or two frequencies for any group of readings. If necessary, additional readings may be taken at other specified frequencies to obtain the desired number of readings, with little, if any, effect on the final result.

Ideal meteorological conditions for making Tellurometer measurements, such as dry and clear weather with light breezes, are not considered when scheduling the measurements. The average length of courses used in the majority of the work permits little variation of temperature and vapor pressure throughout the intervening terrain. Psychrometer and barometric readings are recorded at both the master and remote units and the arithmetic mean of these values is used when applying the meteorological corrections.

Experience shows that light to heavy winds can cause considerable delays when measuring near trees and foliage. Light breezes will permit readings if foliage is not adjacent to the measured line, but winds greater than 10-15 mph will cause interference from moving foliage a considerable distance from the line. Delays that would be caused by continually prevailing winds have been avoided by scheduling angle measurements at other times.

The Tellurometer, Model MRA-1, has not been adapted with the cold weather conversion assemblies perfected by Tellurometer, Inc. By jacketing the instrument to retain the internal heat, it was possible to operate it satisfactorily at temperatures above freezing. The greatest disadvantage of operating in cold weather is the 20- to 30-min warm-up period necessary before making any measurements. Test measurements over pre-established courses at temperatures below freezing have resulted in inaccurate distances and difficulty in synchronizing the crystals. Winters in Maryland, with the exception of western Maryland, are relatively mild and sub-freezing temperatures seldom prevail for more than one or two weeks. Operational delays have been avoided by scheduling angle measurements at these times. No attempts have been made to determine the effects of rainfall or snowfall on measurements, nor has there been occasion to measure during extremely high temperatures.

From experience in establishing horizontal control by chaining methods, it was estimated that the daily rate of traversing for six men was 1 mi; with probable closures of 1:10, 000 to 1:35, 000. This figure includes clearing of lines, positioning of permanent station markers, and making the angular measurements.

From records kept by the field party, covering 84 mi of traverse over various types of terrain, the daily rate of Tellurometer traversing was estimated to be 2. 1 mi. Closures of from 1:10, 000 to 1:180, 000 were obtained. The rate of traversing, if estimated to include the entire 18 months of operations, would average or exceed 2. 5 mi per day.

As mentioned before, when traversing with the Tellurometer by ground-to-ground measurements, character of topography and type and intensity of ground cover govern the rate of traversing to be expected on a project. When short lines (less than 1, 500 ft) can be avoided, with a minimum of brush cutting and packing of equipment to remote points, traversing should exceed 3 mi per day. When adverse conditions cannot be avoided, the rate of traversing may be less than 1, 5 mi daily. Greater efficiency may be obtained if the work in these difficult areas is scheduled with respect to the seasons of the year, thus minimizing hindrances attributable to farm crops and heavy foliage.

During the 18-month period covered by this report, 608 linear miles of traverses have been completed to position permanent station markers forming a network of horizontal control along 354 centerline miles of primary and secondary highways. Second-order closures and better have been obtained throughout. Of the 36 control survey projects completed thus far, 119 mi have been of second-order closure. The remaining 489 mi have closed 1 part in 25, 000 and better. The best adjusted closure obtained thus far has been 1:264, 000.

A cost analysis was not computed for any of the aforementioned projects as the daily rate of traversing is too variable on individual projects to provide useful cost-per-mile basis.

Based on a six man field party, utilizing two carryall trucks, the present daily cost of operations is $140 to $160 depending on the travel distance to and from the work area. Assuming that 60 percent of the traverse mileage is actually for centerline control, our average daily rate of centerline control is 1. 5 mi. This would put the approximate cost per centerline mile at $100. The unit cost, however, would vary from $70 to $150 per highway mile depending on the frequency and location of existing basic control, and the character of the topography throughout the survey area.

The Tellurometer system of microwave distance measurement has not only proven its effectiveness in making horizontal control surveys for highways, but also, as compared to previous chaining results, it has reduced cost and time for traversing by at least 50 percent, improved the quality of work, permitted traversing of basic control into sparsely controlled regions which would have been impractical by chaining methods, and eliminated practically all field operations to which most errors of distance measurements are attributed.