# Electrotape Use in Establishing Basic and Supplemental Control for Aerial Surveys

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•SINCE THE Federal Highway Projects Office of Region 9, U. S. Bureau of Public Roads, first began to make aerial surveys in 1956, a continual effort has been made to up date survey methods and equipment in order to reduce costs and to increase accuracies. The methods and equipment employed in obtaining distance measurements have varied. Conventional taping methods were initially employed in this phase. Due to ruggedness of the mountainous terrain and lack of expert chainmen, however, this method soon proved to be expensive and to be the source of many of the ground control errors. It is not difficult to assume that errors in tape-measured distances had existed prior to aerial surveys; however, their detection was much more difficult than with current photogrammetric methods of checking measurements.

To overcome taping mistakes and to speed up the field control surveying work, the 10-ft portable subtense bar was placed in operation in 1956. Later, in 1959, this bar was redesigned and lengthened to 12 feet. Although sometimes clumsy to operate in rugged terrain, the distances measured by use of the bar were usually much more accurate than distances measured by taping. The hours required to measure a distance were in many cases reduced by four to six times. Because the theory of the subtense bar is based on a set bar length and a horizontal angle measured between the ends of the bar, the most obvious source of error comes from measuring the angle. Herein lies the fault of the subtense bar. Adverse weather conditions, poor operation of the angle-measuring instrument, and improper handling of the bar all contribute to incorrectly measured angles and, thus to obtainment of distances which are in error.

To provide a check on the accuracy of the supplementary control, whether surveyed by tape or subtense bar measuring, markers of basic control check points were set at an interval of 2 to 3 miles. Their position was then measured by triangulation methods, using the T-2 theodolite for measuring the angles. For some highway survey projects, their remoteness or lack of geodetic monuments near them necessitated the establishment of entire triangulation networks. This operation proved to be time consuming, expensive, and, in some cases, required considerable adjustment to obtain a reasonable closure. The costs of surveying basic control in several cases exceeded the costs of surveying the supplemental control.

These occurrences led to investigating other means of establishing basic control.

## TELLUROMETER

In the fall of 1961, a Tellurometer (Model MRA-1) electronic distance-measuring unit was used on a trial basis. To evaluate the equipment, accuracy, and the savings in costs, a contract was negotiated with a commercial firm for surveying the position of basic control points along 71.5 miles of aerial surveys in Yellowstone National Park and Hoback Canyon, Wyoming.

The probable cost of triangulating the basic control, using U. S. Bureau of Public Roads' personnel, was estimated and compared to the actual costs encountered through use of the Tellurometer. The savings accrued by use of the Tellurometer are given in Table 1.

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TABLE 1

COSTS OF TRIANGULATION VERSUS COSTS OF USING THE TELLUROMETER FOR SURVEYING BASIC CONTROL

| Project | Length (mi) | Estimated Triangulation Costs ($) | Actual Tellurometer Costs ($) | Savings ($) |
|---|---|---|---|---|
| East entrance | 17.0 | 4,770.00 | 784.00 | 3,986.00 |
| Norris-Beryl Springs | 10.0 | 1,590.00 | 882.00 | 708.00 |
| Northeast entrance | 8.0 | 2,650.00 | 196.00 | 2,454.00 |
| South entrance | 11.0 | 1,325.00 | 686.00 | 639.00 |
| Red Lodge-Cooke City | 12.0 | 2,650.00 | 392.00 | 2,258.00 |
| Hoback Canyon | 13.5 | 4,033.50 | 320.00 | 3,713.50 |
| Total | 71.5 | 17,018.50 | 3,260.00 | 13,758.50 |

Later in 1961, a set of Tellurometer units, Model MRA-1, was leased on a monthly basis. U. S. Bureau of Public Roads' personnel were trained as operators by the leasing agency. These units were primarily used in surveying basic control for aerial surveys in New Mexico and Utah. On one survey in New Mexico, however, an attempt was made to survey both the basic and supplementary control by use of the Tellurometers. The basic control survey points were spaced 3 miles apart, whereas the supplementary points varied from 400 to 1,200 feet apart. Considerable trouble was encountered in obtaining reliable measurement of distances shorter than 1,000 feet. No better than third-order accuracies were obtained for the supplementary control, whereas the closures of all basic control surveying were second-order or better. On the basis of this project, the Tellurometer, Model MRA-1, was considered inadequate for measuring distances in accomplishing supplementary control surveys.

## ELECTROTAPE

In 1961 the Cubic Corporation of San Diego, California introduced to the surveying profession a fully transistorized electronic distance-measuring instrument—Electrotape. The Electrotape system consists of two identical interchangeable units, each capable of transmitting or retransmitting microwave signals.

The transmitting unit is normally referred to as the interrogator and the receiving unit as the responder. These units are designed to operate on 12- or 24-v wet cell batteries. Total weight of each unit is 27 lb including a built-in radio-telephone system for communication between units. The Electrotape unit is designed to measure distances from 150 feet to 30 miles in length.

On basis of the performance record of the Electrotape with other Government agencies and the realization that short distances ranging from 300 to 1,000 feet could be accurately measured, two units, Model DM-20, were purchased in June 1962. Peripheral equipment also purchased included tripods, automatic psychometers, nickel-cadmium batteries, and a heavy-duty battery charger.

Since purchased, the Electrotape units have been used at altitudes varying from 5,000 to 12,000 feet and under various climatic conditions. Temperatures have ranged from a minus 10 F upward to plus 95 F. Terrain has varied from low, rolling topography to mountain canyons. Vegetational coverage has varied from sagebrush and scrub piñon to aspen and pine forests.

Observed adverse effects resulting from such operating conditions are as follows:

1. When temperatures are so low as to be classed extremely cold, a set of batteries provided power for only one hour of operation. To operate under this condition, additional battery sets have been purchased.

2. Moving objects, such as tree leaves and branches, in the line of sight affect the measurements, resulting in a difference of as much as 10 centimeters between forward and return measurements of the distance.

Inasmuch as the Electrotape units were in part replacing the subtense bar, a comparison was made of the two methods from the standpoint of the number of distances measured per day. During an average 8-hr day, a four-man survey party using a T-2 theodolite and two subtense bars could measure 20 traverse distances. The same number of men using the Electrotape units would measure only 15 distances. Average time required for making both forward and return measurements by use of the Electrotape has been 18 minutes per set-up. It should be pointed out that the horizontal angles are measured and recorded concurrently when the subtense bar is used, whereas measuring angles is an additional operation when using electronic distance-measuring equipment. Attempts to combine both operations have not proved fruitful.

TABLE 2

| Electrotape Measured Slope Distance (M) | Total Field Correction (M) | Correction per Meter (M/M) | Total Correction Using Average Factor (M) | Difference Between Cols. 2 and 4 (M) |
|---|---|---|---|---|
| 240.830 | 0.0091 | 0.0000379 | 0.0136 | 0.0045 |
| 199.705 | 0.0084 | 0.0000421 | 0.0113 | 0.0029 |
| 293.475 | 0.0136 | 0.0000464 | 0.0166 | 0.0030 |
| 297.325 | 0.0150 | 0.0000504 | 0.0169 | 0.0019 |
| 212.595 | 0.0107 | 0.0000504 | 0.0120 | 0.0013 |
| 342.645 | 0.0197 | 0.0000576 | 0.0194 | 0.0003 |
| 178.590 | 0.0104 | 0.0000585 | 0.0101 | 0.0007 |
| 226.060 | 0.0143 | 0.0000631 | 0.0128 | 0.0015 |
| 215.070 | 0.0135 | 0.0000630 | 0.0123 | 0.0012 |
| 216.280 | 0.0139 | 0.0000641 | 0.0123 | 0.0016 |
| 191.120 | 0.0143 | 0.0000748 | 0.0108 | 0.0035 |
| 245.190 | 0.0129 | 0.0000526 | 0.0139 | 0.0010 |
| 207.305 | 0.0122 | 0.0000589 | 0.0118 | 0.0004 |
| 241.230 | 0.0139 | 0.0000576 | 0.0137 | 0.0002 |
| 221.340 | 0.0141 | 0.0000636 | 0.0125 | 0.0016 |
| 257.920 | 0.0172 | 0.0000665 | 0.0146 | 0.0026 |
| Average | | 0.0000567 | | |
| Corrected index | 1.000263 | | | |

An analysis of field procedures revealed considerable time was lost by the operators of one Electrotape unit while the other unit was being moved from one control point marker to the next.

To overcome these lost man-hours and to accomplish the same amount of work as previously obtained when the subense bar was used, a third Electrotape unit, Model DM-20, was purchased in June 1963. With three units a leap-frog type of procedure was used.

Consider the three units as A, B, and C. While the distance between Units A and B was being measured, Unit C was being set up over the marker of the next control point beyond Unit B. When the measurements between Units A and B were completed, Unit A was moved to the marker of a control point beyond Unit C. In the meantime, Units B and C were being used. By this procedure 24 to 26 measurements can be completed in an average 8-hr day. This field surveying method with the Electrotape has proved to be very effective. Normally, two men are assigned to each unit—one as operator and measurement reader and the other as recorder and computer. Personnel permanently assigned to the units are responsible for their use and care. Due to the simplicity of the units, a man can be adequately trained to operate the Electrotape instrument in one day. Should one of the units fail electronically, no attempt is made to repair the interior components. Such units are shipped by air freight directly to the factory in San Diego, California for repair. During the period from the day they were purchased and first used to September 1963, a total of three breakdowns has been experienced. In each case, only three to four days of use time were lost. The availability of the third unit greatly reduces operational time loses; as, in the event of one unit failing, the other two units can still be used in measuring distances.

An index of refraction of 1.000320 has been applied to the internal circuitry of each Electrotape unit. Thus, each measurement is automatically modified by this factor to give absolute measurement under ideal atmospheric conditions. Unfortunately, these conditions never exist; therefore, the index must be adjusted for the various atmospheric changes. Wet bulb temperature, dry bulb temperature, and atmospheric pressure are used to determine the correction factor. These temperature and pressure measurements are recorded before and after each series of distance readings. This has proved to be quite time consuming and, as subsequently shown, unnecessary when surveying supplementary control. A review of several highway survey projects in which the supplementary control had been measured by use of the Electrotape revealed the amount of correction applied to each distance was consistently the same for each project. Table 2 contains corrections compiled from the Electrotape measurement notes on a survey project in Dinosaur National Monument.

Data in Table 2 reveal, for all practical purposes, that one factor can be used to correct all of the supplementary control survey measured distances on a particular survey. The Dinosaur survey project would have had a corrected index factor of 1.000263. When measuring distances of less than 1,500 feet, it can be concluded meteorological data need be recorded only four times during the average 8-hr day. From these four, an average index of refraction can be computed and applied to all of the measured distances.

Analysis of corrections applied to distances longer than 1,500 feet reveals it is not necessary to compute a new index for each distance measured. The same index can be applied to two consecutive measurements, provided atmospheric conditions do not change appreciably. The maximum error introduced by this procedure was 1 part in 50,000.

As of September 1963, the longest distance measured with the units was approximately 8 miles and the shortest distance was 162 feet. The poorest closure obtained in surveying supplementary control was 1 part in 7,000 for distances varying from 300 to 1,000 feet. The most consistent Electrotape measurements between interrogator and responder units have been obtained on the longer distance measurements.

As of September 1963, 130 miles of basic and 26 miles of supplementary control had been surveyed using the Electrotape units. Cost records are not complete enough to establish an average cost per highway route mile for such control surveying.

## CONCLUSIONS

Model DM-20 Electrotape distance-measuring units are an effective means for measuring distances ranging in length from 150 feet to many miles, and only a minimum number of third-order accuracies will occur. The instruments are versatile, are constructed for rough usage and are operable when weather conditions are extreme, are simple to operate, and are relatively free from maintenance. In establishing supplementary control for highway surveys, three measuring units are much more effective and greater savings per highway mile may be realized than when using only two units. In measuring distances shorter than 1,500 feet, the amount of meteorological data obtained and used can be reduced without affecting the results.

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