UTILIZATION OF ELECTRONIC INSTRUMENTS IN GEODETIC SURVEYS FOR HIGHWAYS

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The first of the Geodimeter family of distance-measuring instruments, the Model 1, was being accepted into the spectrum of useful geodetic tools as early as 1953. The Model 2 became available about two years later and the Models 3 and 4 have more recently appeared. The Tellurometer appeared in America within the last 2 or 3 years. The engineering journals abound with descriptions of these instruments and the intrinsic physical theory upon which they are based. We will be concerned here with an evaluation of their use, particularly with respect to the Federal Highway Program.

THE TELLUROMETER

The Coast and Geodetic Survey obtained its first Tellurometers in June 1957 which were assigned immediately to the Coast Survey Ship *Explorer,* operating in Alaskan waters, for use in making a traverse survey along the rugged south coast of Atka Island in the central Aleutians. Traverse stations were about 2 miles apart with several 10-mile legs. The field computations showed that a proportional-part accuracy of about 1/19 000 was attained over the 48-mile traverse.

The Tellurometer equipment was then transferred to the State of Virginia to be used in traverse surveys to establish the basic control needed in connection with the Federal Highway Program. Traverses averaged about 12 miles with intermediate stations at 3-mile intervals, end points of the traverses being Coast and Geodetic Survey first- or second-order triangulation stations. Field computations for this project show that the position closure of the Tellurometer traverses averaged about 1/40 000 (1).

Repeatability

Since the Tellurometer was designed to give best results over 10-30-mile lines, it seemed desirable to check repeatability of the instrument

IHB Note. — The numbers in brackets indicate references at the end of the article.

in measuring relatively short lines for which it was actually being used. A taped base of 1.7 miles which had also been measured with the Geodimeter was measured 32 times over several days of October 1957; March, April, and May of 1958. Several master units were used and measurements made under a variety of meteorological conditions. Proportional-part accuracies varied from 1/11 000 to 1/500 000 with a mean of about 1/25 000. Only 5 measurements were short. The ground swing is a spread in the observations brought on by the change in the frequency. Ground swing varied from 4.8 to 25.5 inches with a mean of 12.8 inches. There was no apparent correlation of ground swing with proportional-part accuracy. The ground swing of the worst check obtained, 1/11 000, was only 9 inches. The lowest ground swing, 4.8 inches, gave a check of 1/24 000. The highest, 25.5 inches, gave a check of 1/20 000. On some of the measurements, the master unit was placed on line but 3, 6, or 9 metres toward the remote or 3 or 6 metres away from it. There was no improvement except at 6 metres toward the remote where a check of 1/78 000 was obtained.

To check the instrument over some lines in the design range of the instrument, 4 geodetic lines of 15.7, 12.7, 12.6, and 21.3 miles, which had also been measured with the Geodimeter Model 2, were measured with the Tellurometer. The 15.7- and 12.7-mile lines were each measured twice with each of two master units. The 12.6-mile line was measured twice and the 21.3-mile once. The lowest single measurement check was 1/82 000, the highest 1/4 991 000. The mean proportional-part checks for 15.7, 12.7, 12.6, and 21.3 miles were 1/490 000, 1/103 000, 1/781 000, and 1/510 000, respectively.

The sides (3.1, 5.0, 7.5, and 2.7 miles) and diagonals (5.2 and 7.0 miles) of a quadrilateral, which is part of an adjusted triangulation net, were measured with Tellurometer with checks of 1/375 000, 1/47 000, 1/37 000, 1/64 000, 1/215 000, 1/300 000, respectively.

From these results and additional highway traverse work in several states, it would appear that the Tellurometer when used on relatively short lines is capable of first-order geodetic accuracy occasionally, but that it cannot be depended upon to give a first-order measurement every time even over longer lines.

Effect of meteorological and topographical conditions

The effect of temperature and pressure errors is about the same as for the Geodimeter. Humidity determination is about 100 times more critical for the Tellurometer, small errors in its determination causing very large errors in the wavelength determination. An error of 1°F (in the humidity determination) will cause an error in length of the line being measured of about $7/10^7$; an error of 0.1 inch of mercury in atmospheric pressure will cause an error of $1/10^6$; an error of 0.006 inch in vapor pressure will cause an error of $1/10^6$. The main cause of error is that the mean of the meteorological readings taken at each end of the line may not correspond closely with the average conditions along the line; that is, an irregular gradient is more likely as the line length is increased, hence a practical limit to length is about 30 miles.

Refracted waves and unwanted reflection being returned because of local topography affect the accuracy of reading and repeatability of the partial wavelength in the Tellurometer. Hence a line to be measured with this instrument should have little ground clearance and should be covered with vegetation which absorbs the ground waves. Lines with terminals on sharply elevated points above a flat, smooth, highly reflective surface, such as water, should be avoided, altough such lines may be measured satisfactorily if the master and remote units can be shifted so as to cause the line to graze at each end.

Obstructions, such as trees, telephone poles, etc., have no effect unless they are near the instrument. Measurements made in the bottom of narrow canyons give poor results because of the reflections. Measurements are often possible when the line of sight is blocked by a bump or shoulder. But a clear line of sight through a woods clearing or through a gap in a wall, etc., may not be measurable. However, the U.S. Army Map Service, in tests conducted near Boston in September 1957, found that the instrument may be operated successfully in areas of concentrated microwave operations.

The Coast Survey found that in Alaska, open-line operation was not always best. A tundra knoll near one station weakened the signal. Over water, the rippling would cause the signal on the cathode-ray tube to oscillate circularly. It was found best to work with sky-line stations — background bare hills gave reflections.

The Tellurometer can be used day and night but best results are obtained on a clear dry day with a wind blowing along the line being measured and with the line free of objectionable topographical features. Ground swing should never exceed 4 feet and should preferably be less than 2 feet.

Field operations

Experience of the Coast and Geodetic Survey indicates that 2 coarse sets of readings and 12 fine readings are sufficient for exploiting the inherent accuracy of the instrument in a single line measurement. The time for a measurement is about 40 minutes which includes setting up the equipment, making the observations, and repacking the equipment. Included in this time are careful measurements of humidity, pressure, and temperature made at both ends of the line, at the beginning and end of a set of observations.

Three men are presently employed to operate one master unit and one remote unit; two at the master, one of these recording the observations. A modification, if practical, by eliminating eye-accommodation fatigue, should make it possible for the observer to record his own measurements in about the same time. A man can be taught to operate a remote instrument in one day and to operate the master unit in three days.

While the instrument is portable, the total weight of a unit (Tellurometer, carrying case, power pack, tripod, and battery) is 85 pounds. Modifications can reduce its weight.

The instrument is rugged, but rough handling will cause circuitry wires to loosen. Tubes have to be replaced occasionally. On one occasion, a Coast Survey unit was accidentally dropped from a height of about 10 feet. A few broken electrical connections resoldered and adjustment of the klystron restored it to operable condition. On another occasion, a transformer in the power supply had to be replaced in a Coast Survey unit. Such maintenance is considered normal for this type of equipment.

With respect to the Tellurometer traverse work done by the Coast Survey in Alaska, the following observations were made. The tripod as furnished with the equipment was considered to be too weak. The carrying case, although compact, was not waterproof. The straps and buckles fell off and were replaced by web straps. The back packs as supplied by the manufacturer of the Tellurometer were found to be inadequate and were replaced by Army packs (Nelson packs).

Suggested modifications

The following modifications, although not imperative, would improve the operations associated with Tellurometer measurements.

(1) A stronger tripod with better plumb-bob suspension.
(2) A head-supported phone system to free the observer's hands.
(3) Plug-in connectors for power packs.
(4) Lighter, more easily portable batteries.
(5) Improved illumination of the reticle on the cathode-ray tube. (The Coast Survey is experimenting with an illuminated plastic reticle for the face of the tube in an attempt to eliminate the required shade and the reflection from the observer's face, which would then permit him to do his own reading without eye fatigue from constant accommodation. The Coast Survey found that magnifying spectacles with a focal length of the sunshade helped in reading the reticle).
(6) Printed and transistorized circuitry to reduce the size and weight of the instrument.
(7) Crystal oven to keep the temperature of the crystal its normal operating range of 23° - 32°C. (The Geodetic Survey of Canada has already accomplished this modification. The Coast Survey is in process of making this change).
(8) Separations of the parabolic antenna from the instrument, which will allow the antenna to be placed on a telescoping mast for elevation above trees and obstructions and eliminate the necessity for tower construction. (The National Research Council, Division of Applied Physics, Ottawa, Canada, has already accomplished this modification).
(9) Installation of a voltage control in the plate supply circuit for the horizontal-control stage. This provides an additional centimetre margin in the circle centering adjustments for use in regions where magnetic deflection horizontally of the cathode-ray-tube electron beam is large. The Coast Survey is making this modification to all of its instruments.

Expected accuracy and recommendations

Since the Tellurometer accuracy depends on favorable topography and meteorological conditions to minimize reflections and refractive waves, the highest accuracy cannot be depended on for any particular line. It is capable of giving results of the order of $1/10^5$ or better and is considered accurate enough for traverse work and second-order baselines. It can be used for trilateration, but with all lines of the order of 15 to 25 miles, it can only be safely said that the resulting accuracy will be equivalent to or better than second-order triangulation.

A new manual

Based upon the experience of the Coast Survey, recommendations of the manufacturer, and results of an evaluation study made for the Engineering Research and Development Laboratories, a manual for the Tellurometer has been prepared and submitted by the Coast Survey to the Government Printing Office. It should be available from that office in February 1959 (3).

Included in the manual are a description of the system and theory, recommended equipment for a Tellurometer survey party, setup procedure, recording observations, taking a set of readings, interpretation of ground swing, computations (new recording and computing forms are introduced), field troubleshooting, instructions for Tellurometer traverse, and reconnaissance for Tellurometer sites.

THE GEODIMETERS

The experience of the Coast and Geodetic Survey has been with the Models 1 and 2, which are the heavy precision instruments, and since 1953 over 70 lines have been measured with them. Their accuracy is high enough to make possible their use by the Coast Survey for first-order baselines in triangulation schemes (4). That is, a baseline may be inserted practically at will in a triangulation net. They are also used to check adjusted triangulation lines to determine if any distortion has been introduced by the adjustments. They may be used to calibrate other electronic instruments as the Tellurometer and for traverse or trilateration, but transporting the equipment becomes a real problem, particularly in rough terrain.

The Model 3 Geodimeter is a scaled-down version of the Model 2, weighing only 58 pounds, and is quite portable (5). The California Highway Department has been using this instrument since September 1957 in traverse surveys needed in connection with the Federal Highway Program (6). Typical traverses were about 20 miles with intermediate stations at 4-mile intervals, the end points being Coast Survey triangulation stations.

Since many of their traverses were located along major highways, it was thought that background lights would be a problem. Seldom was this a bother, since a change in height of the reflector tripod eliminated the extraneous light source because of the small acceptance angle of the Geodimeter Model 3. They traversed under neon signs, between street lamps, and over cities with no difficulty. They were bothered by the halo around headlamps caused by smog when the line of sight fell along the shoulder of a busy highway.

They have measured over 200 lines with the Geodimeter Model 3, ranging from 1 200 feet to about 17 miles under varying observing conditions as light ground haze, full moon, light rain, heavy downpour, strong winds, etc. On several occasions, they completed measurements through brush and trees, not knowing at that time that the stations were actually not intervisible, but enough light had filtered through. Their traverse closures have varied between 1/25 000 and 1/60 000 when based on secondary Coast Survey triangulation, and about 1/100 000 when measuring across a main scheme net. They claim their Geodimeter Model 3 has a mean error of about 0.2 foot and may vary from 0 to a maximum of 0.5 foot.

They found the instrument apparently unaffected by rough handling, maintenance amounting to little more than replacing an occasional projector lamp, and it has been particularly useful for traversing in the vicinity of lakes and in narrow canyons where triangulation would be awkward.

Effect of meteorological conditions on the geodimeters

An uncertainty of one degree centigrade in temperature, or one-tenth inch of mercury in atmospheric pressure, will cause a one-part-per-million error in the length measured. The relative humidity has a small effect, never more than a fraction of one part per million.

Optimum conditions for making observations are a dark night with good visibility under heavy overcast sky or with a strong breeze blowing across the line, since temperature and pressure will then tend to be uniform.

CONCLUSION

Since the microwave propagation characteristics in a system like the Tellurometer are more sensitive to topographical and meteorological conditions than the Geodimeter Model 2, the repeatability of such a system will approach but cannot equal that of the Geodimeter Model 2. Such instruments are very useful additions to the spectrum of surveying instruments but realistic evaluations must be made of their capabilities and of the results obtained with them. It would be trite to enumerate the many ways in which the new distance-measuring instruments are saving both man-hours and costs in the surveying field. But anyone who has carried a tape and rod through the thorny flora, over the rocks and canyons of terrain as found in the Gila river country of Arizona needs no selling.

The Geodimeters and the Tellurometer have been welcome additions to the geodetic instruments of the Coast and Geodetic Survey.

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