Idaho Highway Surveys Using the Tellurometer

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•THE State of Idaho has the mixed blessing of a wide variety of climatic and topographic conditions, ranging from semi-arid plains and mountains in the south to timbered mountains, fertile praries, and deep canyons of the central and northern portions. The highways range in elevation from 740 feet at Lewiston to 8, 701 feet at Galena Summit. Many of the highways follow rivers, whereas others cross plains or climb canyons and traverse mountain ridges or prairies.

Through the years, the survey work for highway projects has been slow and laborious in the rugged canyons and mountains. In past years, many traverses were loose-ended, some were closed in bearing by solar observations, and some were closed by costly circuit surveys. Arbitrary plane coordinate systems were used which started and ended on themselves, with no assurance constant errors did not exist in loose-ended surveys. As land values increased and surveying errors became more objectionable, it was evident new methods, tools, and procedures were required.

In 1958 two far-reaching decisions were made in the Idaho Department of Highways, both of which were made in an attempt to modernize preliminary engineering methods and procedures. First, it was decided all future survey projects, wherever practical, would be tied to markers of basic control surveys in the Idaho State Plane Coordinate System. Second, the location and/or design of future highway projects, wherever economically feasible, would be made by use of appropriate photogrammetrically compiled topographic maps.

The first major step in implementing this program was an immediate agreement with the U. S. Coast and Geodetic Survey to establish second-order horizontal and vertical control along all proposed Interstate highway routes with survey stations monumented at an interval of one to three miles. The establishment of this control on the Interstate System reduced, but did not eliminate, problems encountered in placing other highway survey projects on the State plane coordinate system.

After nearly a year of using laborious triangulation methods involving short bases and measuring traverse distances by taping and angles by angle-measuring instruments, it became apparent use of more modern surveying equipment and methods must be resorted to for fulfilling satisfactorily the desire for placing highway survey projects on the State plane coordinate system. It was decided some type of electronic distance-measuring instrument would be a natural teammate for use with the 1-sec reading theodolites already in use by the department. After considerable research, the following features seemed desirable for the instrument which should be selected:

1. Portability—the inaccessibility of many survey station markers would result in the instrument having to be backpacked.
2. Long range—many distances would have to be measured for tying and closing highway surveys to markers of isolated control points.
3. Ability to operate in nearly all weather conditions—the northern portion of the State is especially prone to extended periods of fog, rain, and snow.
4. Production—the general plan of future surveying operations was accomplishment of basic control surveying by traversing which would require measurement of numerous traverse segments per day.

The Tellurometer seemed best fitted for this program, except for its inability to measure short distances. This handicap could be overcome by taping, by short base

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triangulation, and by employing the subtense bar, as appropriate and convenient.

In the fall of 1959, the department purchased one complete Tellurometer set, Model MRA 1/CW, with headsets and transistorized power packs. The headsets have since proved to be a wise investment, being instrumental in boosting the average daily number of measurements to 14 traverse segments.

The Tellurometer units were checked out locally and, after familiarization, were taken to an accessible U. S. C. and G. S. first-order base for making measurement accuracy checks and for possible calibration. The base was accurately extended by 50-ft increments and the total distance measured along this base and extensions. After reduction there appeared to be a constant error in the distance measurements of approximately 0.20 foot, always positive. Further checks were made between a series of U. S. C. and G. S. triangulation stations. These tests confirmed the former findings. Results of the latter tests confirmed reports which had been previously received from other highway departments. Tellurometers seemed to have a constant error of approximately the same magnitude and same sign. It was decided a calibration factor of -0.20 foot should be applied to all measurements. Consequently, it appeared possible to measure short distances and still retain an order of accuracy sufficient for most highway purposes, one part in ten thousand.

On the first survey project, subsequent to establishing the probability of the error constant, survey closures were computed using and not using the constant. Results attained upheld the validity of using the constant of -0.20 foot, which should be subtracted from the slope distance of each measured distance. A recent Tellurometer Field Reduction Computer Program received from the Arizona Highway Department incorporates the same constant in its calculations. From the first, it was apparent proper use of the Tellurometer would result in large savings in time and money.

Idaho, perhaps due to its rugged topography and sparse population, still has vast areas containing little, if any, horizontal and vertical control. An example of this is Owyhee County in the southwest corner of the State. In early 1960, a highway survey project was initiated for realignment and/or relocation of Idaho 51, which is the only major highway through this area. It was also desirable to place this entire survey project on the Idaho State Plane Coordinate System. Without the Tellurometer or some other electronic measuring device, this would have required a 40-mi triangulation arc to make adequate survey ties between the existing Snake River triangulation network to the Idaho-Nevada State line triangulation network. Due to the nature of the intervening terrain, a minimum of six to eight quadrilaterals would have been required to complete this control surveying project. A conservative estimate of the time required to accomplish this type of survey would be two to three months. Instead, a 40-mi Tellurometer and Wild T-2 traverse was measured from U.S. C and G.S. Triangulation Station SLICK in the State Line Net to Triangulation Station WICKAHONEY in the Snake River Net. This traverse consisted of making measurements between 19 main station markers and 13 auxiliary station markers which were tied to points in the proposed "L" line of the highway location. The Tellurometer work, 32 traverse segment measurements, was completed in 3 days. The azimuths were determined at night by measuring azimuth angles at 12 positions with a Wild T-2 theodolite and using a 5-sec rejection limit. All field surveying work on this project, including reconnaissance, was completed in slightly over two weeks. The azimuth closure, before adjustment was 02 seconds per station and the apparent position closure was 1:80,455 on U. S. C and G. S. triangulation stations. In addition to the tremendous saving in time and money, the Tellurometer-measured traverse had one other decided advantage over a triangulation network survey. It was possible to place station markers of the traverse on or very nearly on the proposed "L" line location for future control in photogrammetric work, whereas the positions of the triangulation stations would have been dictated by terrain, as it affected intervisibility and shape of the quadrilaterals.

On several other projects requiring extension of control from station markers in the basic network established by the U. S. C and G. S., various expedient forms of triangulation were combined with Tellurometer measurement of traverses. These triangulation forms, such as trilateration and two-point intersection, also employed the Tellurometer and Wild T-2. Trilateration by use of the Tellurometer has proved to be very successful where weather conditions make angular measurements difficult or nearly impossible. As a check on the Tellurometer work, however, it is advisable to measure one angle. Two-point intersections, where azimuths and distance from two known stations are determined, have proved to be the most desirable method for position surveying of isolated control points situated at strategic locations for future expansion of control for highway surveying, including topographic mapping by photogrammetric methods for location, design, and preparation of detailed construction plans.

Although extension of basic control and establishment of basic control for highway survey projects has been a fundamental use of the Tellurometer, by far its greatest advantage has been in surveying supplemental control for mapping of highway survey and design projects by photogrammetric methods.

One of the early examples of this type of project was the survey made of the Lookout Pass highway route during the summer of 1960 for determining the best possible location for I-90 between Mullan, Idaho and Saltese, Montana. This project, lying in the heart of the beautiful Coeur d'Alene Mountains in the famous Coeur d'Alene mining district, was to be a joint project with the Montana State Highway Commission. The survey study was to include compilation and use of a 200 feet to 1 inch reconnaissance type topographic map containing a basic contour interval of 10 feet. Montana was to fly the route and take the photography and to compile the maps because, at the time, Idaho did not own any precision photogrammetric instruments. Both States, however, were to survey all necessary ground control in their respective areas of jurisdiction.

Idaho's segment of control for the route was approximately 8 miles long and 3 miles wide at its widest point. A deep canyon traversed its entire length from east to west. While being a tremendous tourist attraction, the area did not readily lend itself to any of the conventional methods of control surveying on the ground. It was therefore decided all control survey planning, both horizontal and vertical, should require fullest possible utilization of the Tellurometer and the Wild T-2 theodolite.

A careful and thorough study of the aerial photographs resulted in a plan for supplemental control containing nearly 60 image points for horizontal and 100 image points of vertical control. The points where images were selected for vertical control ranged in elevation from 3,000 feet above sea level in the bottom to 6,000 feet above sea level on either side of the canyon, with all possible passes being at an elevation of approximately 5,000 feet.

The extremely steep and rugged north side of the canyon, having been a portion of the area burned by the Great Kellogg fire of 1910, contained considerable low brush but very little timber. It was also nearly devoid of any roads or trails negotiable by anything other than a four-wheel drive narrow-track jeep. On the other hand, the south side of the canyon was heavily timbered and contained a fairly complete network of roads and trails, including present US 10, the Northern Pacific Railroad, and numerous Forest Service and logging roads. The south side of the canyon also contained all of the available vertical control and the bulk of horizontal control established by the U. S. C. and G. S. under the 1958 agreement.

The first step in surveying supplemental control for this project was to extend the horizontal control to the north side of the canyon. This was done almost entirely by two-point intersections using the Tellurometer to measure the distance and the T-2 theodolite to measure the azimuth angles. After a basic network of control comprised of strategically located points on the north side of the canyon had been surveyed, the supplemental horizontal control was measured to the objects of which the photographic image points were selected by making two-point intersections or by measuring short traverses with the Tellurometer. On this project all attempted measurements with the Tellurometer were accomplished successfully.

Simultaneously with this extension of horizontal control, two level parties were busy measuring the elevation of bench marks along the bottom and along roads and trails on the south side of the canyon. An elevation of additional bench marks along the top of the ridge on the south side of the canyon was also measured. These latter bench marks were later used to extend the measurement of elevations across the canyon by means of Tellurometer-measured distances and vertical angles measured by use of the Wild T-2 theodolite.

By this method of vertical control extension, the Tellurometer was used to measure distances from at least two points of known elevation on the south side of the canyon to the object or point for which a photographic image had been selected to serve as a vertical control point on the north side. Reciprocal vertical angles were then measured with a T-2 theodolite. If possible, these reciprocal measurements were made simultaneously. On some occasions, however, several hours duration occurred between making the separate vertical angle measurements. The ground points for which images were selected to serve as control points ranged from 500 to 2,000 feet higher in elevation than the nearest bench mark in the canyon bottom and were from one to three miles away (horizontally) from the points of known elevation on the south side. In all instances, the two or three independent elevations thus established for each selected image point agreed within one foot, thereby making them entirely acceptable as pass point elevations for leveling and orienting to scale the stereoscopic models used to photogrammetrically compile the maps. If conventional methods of differential leveling had been used to measure the elevation of these supplemental control points, some of them would have required 100 to 200 setups of the level for just one direction on the circuit. A conservative estimate would be an average of from four to five hours of survey party time were saved by use of the Tellurometer in measuring the elevation of each of such vertical control points.

It is also doubtful if any more accurate results could have been consistently attained by differential leveling. In all, the elevation of 37 vertical control points was measured in this manner, resulting in a possible net time savings of approximately 160 crew hours, or 20 crew days.

In surveying the supplemental horizontal and vertical control for this highway mapping project, approximately 80 traverse segments were measured by use of the Tellurometer without rejecting a single measurement. Ten men with two sets of level surveying equipment, two Wild T-2 theodolites, and one Tellurometer set completed surveying control for this highway mapping project in six weeks. This time included reconnaissance, selection and circle identification of selected image points, all field surveying work, and completion of all field computations.

Upon request from the Surveys and Plans Engineer, a close estimate was made of the apparent savings in time and money made possible with the aid of the electronic distance-measuring equipment. A conservative estimate indicated an approximate savings of 25 survey crew days at a minimum cost of $200 per day, comprising a total savings of nearly $5,000. This savings on one project would make reimbursement for one-half the initial cost of the Tellurometer equipment.

As previously mentioned, the reciprocal vertical angle measurements were not always performed simultaneously on this project, yet no apparent loss of accuracy was indicated. This can probably be attributed to the exceptionally stable atmospheric conditions encountered while the measurements were made and to the dense tree coverage over most of the area. Consequently, the vertical refraction was reduced to a minimum. Such conditions did not occur on some subsequent highway survey projects, as, for example, the Mountain Home to Bliss project surveyed in the fall of 1960.

The latter highway survey project was to consist of reconnaissance type mapping at a scale of 400 feet to 1 inch with a basic contour interval of 10 feet. Its locale lay almost entirely within the arid to semi-arid region bordering the north bank of the Snake River in south central Idaho. The topography of this portion of the State consists chiefly of large sage brush covered prairies which are cut by deeply eroded canyons. The canyons are generally topped by nearly insurmountable rim rock cliffs. While the humidity over large portions of this area remains exceptionally stable, between 15 and 25 percent, the temperature range is extreme. The temperature may vary from a high of 120 F at 2 PM, to a low of 60 F at 2 AM. Even the temperature from sunny areas to shady areas, caused by intermittent cloud coverage, may change as much as 20 to 30 degrees. Perhaps this extreme range in temperature causes sufficiently large variations in the vertical refraction as to make it necessary to accomplish all reciprocal vertical angle measurements simultaneously. This limitation, however, did not reduce the effectiveness of the Tellurometer and Wild T-2 theodolite combinations in surveying accurate supplemental vertical control over a very wide area at minimum cost. This method was used to measure the elevation of 81 vertical control points with sufficient accuracy. All vertical angles were measured by simultaneous reciprocal observations.

Also, on this project another variation of triangulation was developed for use of electronic distance-measuring equipment. Three of the prime, most strategically situated U.S. C. and G.S. Triangulation Stations, were either impossible or extremely difficult to occupy. One station was an airway beacon, another was located on top of a mesa completely surrounded by a rim rock cliff 60 feet high, and the other entailed a long rough jeep ride followed by a difficult hike on foot.

To fully utilize these strategically positioned stations without having to occupy them, with either the T-2 theodolite or the Tellurometer, two men, traveling very light, were sent to each station for the purpose of building a signal on it. This work was completed in one day with a minimum of effort. For the next several weeks, these stations in the basic network of control were utilized for surveying position and computing the State plane coordinates of approximately 40 image points without having to return to any of the three stations. In computing plane coordinates for each image selected to serve as a supplemental horizontal control point, one of the nearly inaccessible stations was used in conjunction with an easily accessible basic control point. The distance between the ground point imaged on the photographs and the accessible control point was measured with the Tellurometer and the angles at these two points were also measured to the signal on the inaccessible point. This procedure resulted in two known angles and two known distances (one computed and one measured) for each triangle. These data were sufficient for solving the triangle as well as for checking the results of the survey.

Since then this method has been used on other highway survey projects in proximity to which water towers, smoke stacks, radio towers, and similar objects were markers of basic control points established by the U.S. C. and G.S.

During the three and one-half years in which the Tellurometer has been in use by the Idaho Department of Highways, it has also proved to be extremely valuable for making survey ties between highway survey projects and land subdivisions, land survey section corners, and quarter corners, etc., for right-of-way purposes. In making ties to basic control for highway route mapping for design and for other highway survey purposes, these ties to land survey corners more often than not occur in some of the most rugged terrain where making such ties by conventional surveying methods would be extremely laborious and time consuming.

Within the past two years surveys made by the department with the Tellurometer have become more and more closely allied to the department's electronic computer program and have reached the point where all Tellurometer-made measurements are reduced to slope distances, all traverses are computed and adjusted, and all single triangles are solved by use of applicable computer programs. These three programs alone have reduced the office computing time by at least two-thirds of what former computation procedures required.

Perhaps Tellurometer users in the Idaho Department of Highways have been extremely fortunate when their experiences are compared with experiences reported by some other users of electronic distance-measuring devices, including Tellurometers. In measuring over 1, 300 traverse distances during the past three and one-half years, not more than a dozen distances have had to be discarded because accurate results could not be attained. In some of these cases, it was felt local microwave units operating in the area could have caused the difficulties. In addition, 90 percent of all maintenance has been performed at the Department's own radio and radar repair facilities, thus reducing maintenance cost to a nearly negligible amount.

Principal users of the Tellurometer within the Idaho Department of Highways feel the versatility of any electronic distance-measuring equipment is limited only by the imagination and flexibility of its users.