Tellurometer Use in Control Surveys for Mapping by Photogrammetric Methods

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Results of use of the Tellurometer in control surveys for mapping by photogrammetric methods for highway survey purposes over a wide range of temperature and humidity, over a variety of topography with various types and intensities of ground cover, and away from and near traffic, are reported. Special tests and remeasurements made to determine the effectiveness of the equipment, while the control surveys work was accomplished, are also reported. Slight modifications in operating techniques were adopted to admit of more efficient use of the equipment under specific conditions. Included are a report on maintenance required during evaluation, the training given personnel, minor modifications made in the equipment, and a program for electronic computation of slope distances from Tellurometer data.

●THIS PAPER is based on field use of the Tellurometer, an electronic distance measuring device, in Arizona for a period of 14 months. The equipment was procured and field work conducted in cooperation with the U.S. Bureau of Public Roads.

The scope of the Tellurometer research program, as approved for Arizona, covered evaluation over wide variations of temperature; near heavily traveled highways and in remote areas; over terrain varying from plains through rolling hills to mountains; under a variety of ground cover; and in surveys to determine adaptability to location and coordination of section corners and picture points for use with photogrammetric techniques. In addition, other items encountered were investigated and included as matters of general interest and usefulness. Examples of such items are the programming of Tellurometer field data for electronic computation and the development of field and office techniques. In several instances, although no apparent cause was determined observed data were recorded for possible later evaluation by this or other agencies. The Tellurometer was used to establish control for photogrammetric mapping projects and on evaluation tests, all conducted throughout the state under a variety of field conditions. Each of these projects on which the equipment was used was a live photogrammetric mapping project and as such, the results were used to compile photogrammetric maps. Problems or unique conditions encountered were usually remeasured and in a number of instances these lines were made the subject of special evaluation tests in an effort to determine a relationship between the conditions encountered and the readings obtained. Field work on these projects required the transportation of the equipment for thousands of miles on highways and over extremely rugged terrain. Short and long distances were measured, however, most were less than one mile in length.

An attempt has been made to cover most phases of Tellurometer usage in the field, including field procedures and results. Little is said about the electronic principles of the equipment since that aspect has been well covered in numerous other publications. It is hoped that results and procedures covered in this paper may be of value to other agencies in the use of electronic distance measuring devices for surveys requiring rapid accurate measurement of longer distances.

As can be seen on the Arizona Tellurometer Projects Map (Fig. 1), the Tellurometer was used throughout the state over a wide range of elevations along and away from major highways. These projects also offered a variety of ground cover, terrain, and meteorological conditions. Ground cover varied from none to heavy timber; terrain from flat desert, to rolling hills, to rugged, rocky mountains; and meteorological conditions from cold wet weather to dry desert heat. Numerous remeasurements were made on some projects and later special studies were made to determine the consistency of readings under varying meteorological conditions.

In establishing control for the photogrammetric mapping projects on a statewide basis, field work was successfully accomplished under virtually all conditions existing in Arizona. Measurements were made with the instruments at elevations ranging

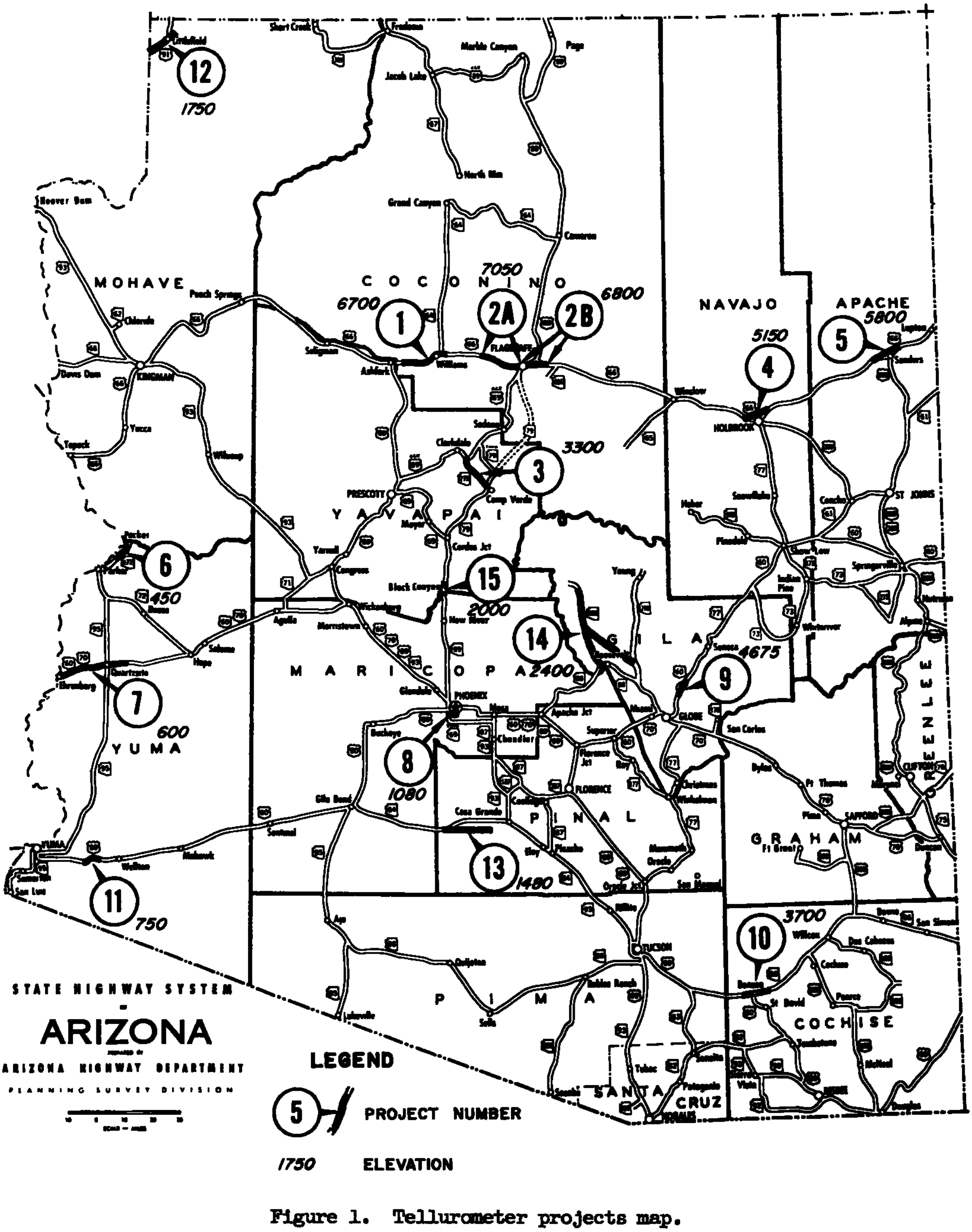

Figure 1. Tellurometer projects map.

from 200 ft to 9,200 ft above sea level, humidity varied from 11 to 95 percent and temperatures ranged from 16 F to 115 F.

The only problems encountered under these conditions were due to temperature. In cold weather, equipment warm-up required more time than the measurements. In hot weather, crystal synchronization was difficult over 90 F. Each of these problems was solved through use of a cold weather kit modification which kept crystals at a constant 50 C, plus or minus 1 C, and resulted in automatic crystal synchronization. Late in the research program, warm-up time in cold weather was again considered excessive, over 20 min, and on many occasions manual synchronization was necessary. These problems are not considered major, and minor additional modifications will undoubtedly improve the equipment in this respect.

Terrain varying from flat desert to rolling hills, canyons and mountains on which ground cover ranged from none to a dense growth of timber were encountered and successfully surveyed. In a few instances erratic measurements were obtained and the survey point had to be moved. No difficulty was experienced in finding a substitute point nearby, from which normal instrument readings could be obtained. Selection of points was made first for location in respect to position for control purposes, second for intervisibility, and third for minimum interference from brush and trees, or man-made obstacles very near the line of sight and measurement. An ideal Tellurometer line has ground sloping down between the instruments with no intermediate grazing conditions (line lying close to ground or skimming tops of trees) or flat reflective surfaces to adversely affect measurements, yet lines over ground with these characteristics were often difficult to measure.

The optimum conditions need not be present to obtain accurate results but the probability of encountering troublesome readings or results is reduced by selecting such lines. Successful measurements were made in Arizona from points in the immediate vicinity of microwave stations, radio antennas, across and under high voltage transmission lines, and in one instance an accurate measurement was made between non-intervisible points. A line on which very good results will be obtained cannot be definitely determined prior to actual field measurement. Also, lines which do not appear to be satisfactory for measurement may yield excellent results. In the case mentioned regarding non-intervisible points, the stations were visually separated by a low hill. Later work revealed an angle check within one second of arc between trilateration computation and the angle turned in the field.

The Tellurometer party, equipped with a master and two remote units plus a theodolite and level, normally consisted of 5 persons. This assumes packing to about one-half the survey points. Two men were at the master station, two at one remote and one at the other. Although two men are usually needed to carry the equipment, one man can easily operate a remote unit, therefore stations accessible to driving or to short walking and packing were handled by one man.

Several persons experienced in surveying have been trained in use of the Tellurometer. In a relatively short period of time they have become proficient in operating the instrument as well as in performing the necessary field checks and computations. It has been found that a person with surveying experience can be trained in one day to operate the master and remote units, record notes, and perform the necessary computations. With two or three weeks of practice he can then become proficient in these operations.

A minimum of maintenance has been required by the Tellurometer units operated in Arizona. Routine checks have been made every 2 to 3 months by the Highway Patrol Radio Shop to check crystal frequencies, detect weak tubes, and make necessary replacements. During the report period, three tubes were replaced, an A-crystal which drifted off frequency had to be replaced and two fuses burned out. No other replacement items were needed. A routine periodic check of the equipment is considered necessary in order to be assured of best results and a minimum of "down time."

Included in these periodic checks is a general check of all small screws and fittings to insure against loss. Excessive maintenance was required of the tripods furnished with the equipment and their use in the field was discontinued. Wild IIIb tripods have been substituted.

The psychrometer is now the item requiring most maintenance, in that the thermometers are easily broken during its use. Over 24 thermometers were broken accidentally during the report period, some of which broke when exposed to sun temperatures during hot weather tests. Breakage was reduced somewhat during the latter part of the report period to a rate of approximately one thermometer every three weeks.

Batteries were recharged on the average of 2 times per week. With this amount of recharging the water level and acid strength of the battery were checked regularly.

The most undesirable characteristic of the wet cell batteries, has, of course, been the acid. Batteries, battery cases and cable clips should be kept clean to minimize acid damage. Care must be taken at all times in handling these batteries to avoid spilling acid on personnel, clothing, and equipment. A supply of soda and water carried in each vehicle can be used to reduce damage after accidental spillage.

As in any type work standardization of procedures results in the saving of much time and effort. The adoption of several standard procedures for Tellurometer operation has reduced the time required to measure a distance to less than 15 min.

A reconnaissance of the project is made first to select and set station markers at the control points on sites which meet mapping control requirements and are suitable for making Tellurometer measurement. The sites selected are relatively free of brush and trees, at least in the direction of measurement. Grazing lines are avoided and brush immediately on line 100 to 150 ft in front of either instrument is removed. By careful site selection, a minimum of brushing was done during the report period, even though surveys were made through heavily wooded areas.

Brush or high grass in front of either instrument made observations difficult during windy weather. The movements caused a blurred or oscillating pattern on the master cathode ray tube which could not be accurately read.

In selecting places for station markers and instrument points, a distance of less than 2, 000 ft between measurement points was avoided. Distances were kept long to reduce an accumulation of small measurement errors in the survey which could occur if a large number of short distances were a part of the primary traverse. In many instances, the topography of Arizona has permitted horizontal control to be easily established along a straight line. A few high points along the line were used as the master stations and remote units occupied all other points on line. Checks were made by adding or subtracting the lengths of various segments of the measured traverse. This procedure not only reduced field time but computations were also greatly simplified, base sheet layout was faster and azimuth control in steroscopic compiling instruments was easily maintained.

Only crystal warmup time, which varied from 3 to 30 min, was the most frequent reason to increase measurement time. The warmup time was greatest for the first measurement in cold weather. On subsequent measurements it was usually less, since some heat was retained in the insulated crystal chamber from the previous measurement.

One of the most important items in reducing time losses was the use of one cavity tune number for initial tuning to establish contact. The Arizona Highway Department uses the 3 setting on the remote cavity tune dial. This setting (usually referred to as channel 3) is always used. The remote operator sets the cavity tune dial to channel 3, brings the milliamp reading to maximum and waits for the master to tune to his remote. The master always tunes to the remote. If at any time contact is broken the units return to channel 3 setting to re-establish contact.

The observer soon could tune and read the master unit faster than the recorder could record clear legible figures. The speed at which readings were taken was then governed by the recorder's ability to record neat legible information. The repetitious nature of Tellurometer readings was used by the recorder to detect an erratic reading almost as it was read. If several erratic readings were obtained during a measurement a careful check of all readings was made before moving the equipment.

Motorcycle batteries weighing 16 lb were used successfully on pack stations in rough country. They were used to measure up to three distances without recharging. Regular 6v automotive batteries were used on all drive or short pack stations. These batteries will last one to two days before a recharge is needed, depending on observation time. During the research project a maximum of 25 distances were measured in one day without a battery charge. Equipment was turned off after each measurement.

A slow battery charger which can be plugged into a regular 115v outlet to recharge three batteries connected in parallel proved to be very satisfactory. A rotation system whereby batteries were used every other day seemed the best solution to keep charged batteries on hand at all times.

Mirror signals between stations served to conserve batteries to a great extent. As was usually prearranged, the operator at each station signaled by flashing a mirror when ready. Equipment was not turned on until these signals were received, unless a long warmup time was anticipated. Battery life was thus lengthened. Long measurements requiring an indefinite travel or pack time were frequently made earlier than expected when an operator arrived at his station sooner than anticipated, and signaled the other station. Signals from a small shaving mirror have easily been seen at a distance of over 20 mi. Mirrors used in Arizona have saved much time and effort. The preponderance of sunny days in this state has undoubtedly aided this procedure.

Evaluation of the Tellurometer under hot, dry desert conditions was made on several mapping projects and by special hot weather tests. The mapping projects were successfully completed with no difficulty experienced in obtaining accurate results. Special hot weather tests, which will be described in some detail, were designed to study the effect of high temperatures on the procedure of distance measurement with the Tellurometer.

The technique followed in conducting these tests was to measure several distances (one per day) a number of times through the heat of the day keeping most variables constant. The equipment was set up in umbrella shade to begin measurements at 9:00 a.m. and then measure again each hour on the hour from that time through 6:00 p.m. On a few occasions the readings were taken each half hour. Temperatures were usually above 95 F at 9:00 a.m., rose to a high between 105 and 115 F near 4:00 p.m. and dropped to near 100 F by 6:00 p.m. The equipment was not moved during the day except to move the umbrellas slightly to maintain a shaded condition. Shade temperatures near 110 F frequently indicate temperature in the sun has reached 150 F and it was assumed these sun temperatures would have a much greater effect on personnel than equipment, therefore no sun tests were made. It was occasionally necessary to wait for the crystals to cool to the 122 F temperature maintained thermostatically by the internal heaters.

No difficulty was encountered in reading, tuning or operating the equipment during the hot weather tests. All electronic components functioned properly as far as could be ascertained by experienced operating personnel. Although no effect on readings was apparent, later checks of the readings determined that a majority of the variation in measurement was due to small variations in the fine readings. The cause of these small variations was not determined; however, the computed effect of the change in atmospheric conditions as it in turn affects signal transit time, did not account for a variation of the magnitude encountered.

As an example of graphs prepared to analyze test results, Figure 2 was prepared to represent an average case. Wet bulb depressions were slightly less than average but the curve of readings is normal. Relative accuracy encountered is indicated on the right. Since measurements varied by 0.36 ft under these test conditions, with intervening ground characteristics and instrument setup remaining constant, a measure of accuracy to be expected under these conditions has been obtained. Similar results were found on the other lines measured during the hot weather tests. It is believed that the equipment will produce satisfactory results on surveys under these conditions, keeping in mind of course that minimum length of measurements would be governed by the magnitude of variation and accuracy desired.

Remeasurements of some of the same lines made during cooler weather checked each other from 0.03 to 0.15 ft and thus, if more accurate work were required, better results should most probably be obtained during cooler weather.

An interesting phenomenon was encountered in obtaining wet bulb temperature readings under hot dry conditions. With the relative humidity under 15 percent, the normal method of wetting the wet bulb wick and twirling the thermometers to obtain a low reading did not produce a true low temperature. Water evaporated from the wick very rapidly and did not allow sufficient time for the wet bulb temperature to drop the necessary 40 F or more. A depression of this magnitude was routine during the tests.

To overcome such conditions, the psychrometer was not twirled immediately. The wet bulb wick was kept wet and normal evaporation in a slight breeze soon cooled the thermometer to the approximate low point. With the wick wet near the low temperature reading the usual method for obtaining a low reading was employed to obtain accurate results.

In the course of measuring many lines it was necessary to tilt the master and/or remote unit to overcome the difference in elevation between the master and slave instruments and to avoid reflective surfaces, or to minimize the effect of slightly grazing lines by tilting each instrument up in the direction of measurement. Since the plumb bob is not suspended from the measurement center of the Tellurometer any tilting introduces an eccentricity to the setup which can be easily measured as shown in Figure 3.

This eccentricity was expected to be the same at each unit in most instances, however, the difference can amount to more than 0. 03 ft per unit. It is usually much greater than the crystal temperature correction and, therefore, all work should take into account the eccentricity in each instrument setup. (Theoretically the eccentricity should be measured parallel to the line of measurement. In this instance, such a minute difference is involved that measurement along the top edge of the side panel of the instrument, as shown in Figure 3, is considered satisfactory.)

Figure 4 is a graphical comparison between the results obtained with a line, with obstacles near one end, is measured twice, once with the master unit at each end. In this instance, a point was to be established on the median strip of a deck-type bridge. The bridge had metal handrails on each side. The line of sight was almost perpendicular to the bridge centerline and just cleared the handrail. Measurement started with the master unit on the bridge and the remote unit approximately 2, 000 ft away. After measurement, the units were switched in position and the line was measured a second time. Similar results were obtained on other lines and as a result, in order to reduce the effect of such obstacles, the master unit has since occupied the more open site. Open

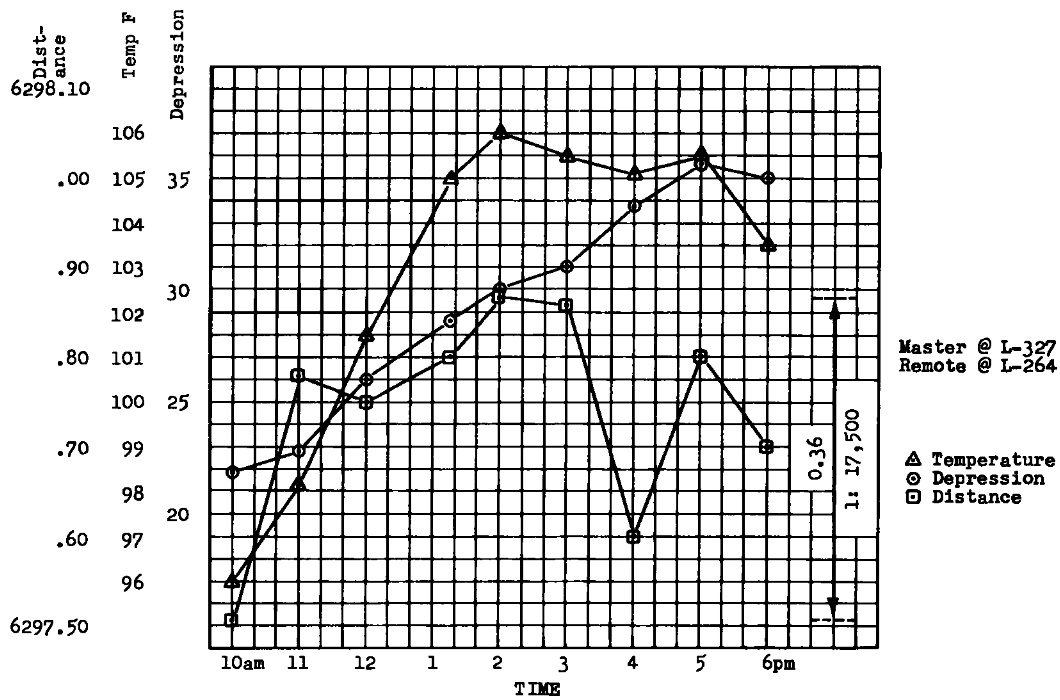

Figure 2. Hot weather measurement.

sites with nearby highly reflective surfaces such as water, pavement, walls or buildings are not used when the incoming signal may reflect from these surfaces to the receiving antenna. Another site with more acceptable characteristics is selected in such cases.

Through use of the Tellurometer, control was successfully established for photogrammetric mapping in all areas of the state. Accurate measurements were obtained with a minimum of operational difficulty and under normal field conditions, 15 to 18 measurements were made each day. The number of lines which can be measured per day is primarily dependent upon travel time to occupy stations. Average accuracy for traverse closures was near 1:25, 000 and ranged from 1:17, 000 to 1:88, 000. The equipment proved to be well designed for field use and is sufficiently rugged to be transported in survey vehicles with the same care given other survey instruments.

The special evaluation tests revealed a variation in measurements slightly in excess

C = Instrument Center

P = Point of plumb bob suspension.

T = Center of top edge of side panel.

M = Plumb line point to be marked on side panel.

e = Eccentric introduced by tilting instrument.

CP = TM

Procedure

Mark top edge of side panel in 0.01' graduations from "T" (ahead +, back -)

Mark point "M" on centerline of side panel so that TM = CP.

Hold plumb line alongside side panel so string passes through "M" and read eccentricity on top edge of panel.

Report + or - eccentricity in remote units to master for record. Example: A negative eccentricity indicates a short line measurement.

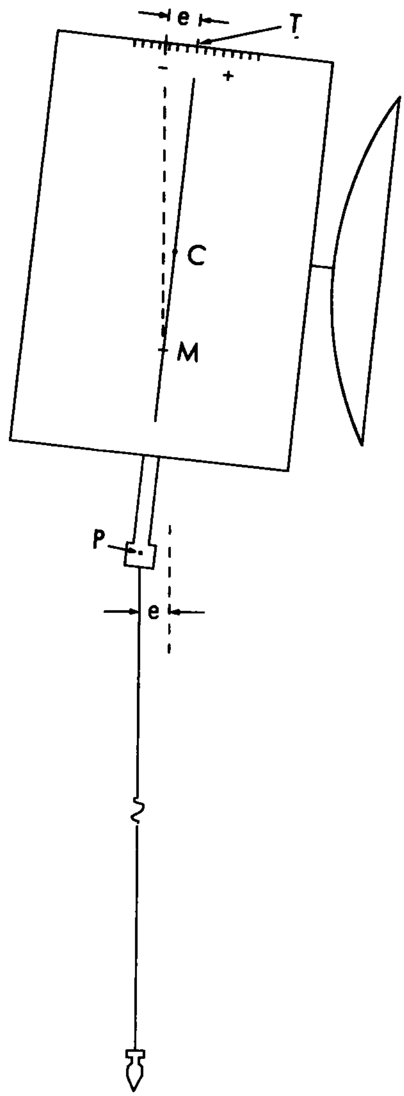

Figure 3.

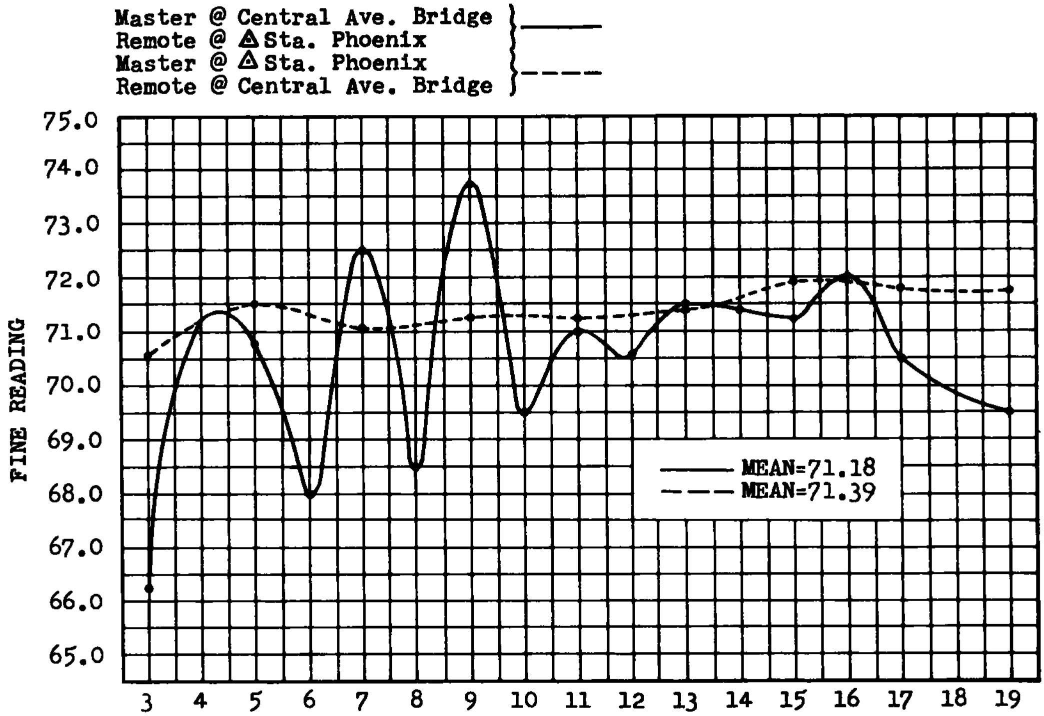

Figure 4. Channels.

of the expected results. With the variation known, however, it has served to increase the minimum distance to be measured in a few cases in order to meet accuracy requirements for the project. Electronic measurement devices are considered essential to photogrammetric mapping projects in the establishment of primary nets of basic horizontal control upon which maps and other survey data can be based. The Tellurometer has proved to be very satisfactory in this respect.