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THE GEODETIC AND TOPOGRAPHIC SURVEY OF PITTSBURGH AND ALLEGHENY COUNTY*

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INTRODUCTION

The realization of the need of a comprehensive and accurate city survey of Pittsburgh dates from the earliest organized interest in city planning matters of the district. In a report, "Pittsburgh Main Thoroughfares and the Down Town District," 1911, prepared for the Committee on City Planning of the Pittsburgh Civic Commission§ by Mr. Frederick Law Olmsted, the value of such a survey is stressed. While the general purpose of this paper is the detailed description of the survey and the progress attained thus far in each of the various elements which compose it, it may be well to give here a few facts regarding its general character and purpose.

The city survey, here officially termed the Triangulation and Topographic Survey from its two principal divisions, is an inventory of the physical facts relating to the surface of the ground and to the public improvements thereon. It seems trite and too obvious to say that, since land is the only thing a city has to build itself upon, the city should early possess itself of these facts; and yet it is true that Pittsburgh, in common with most American cities, has only recently begun the comprehensive and systematic assembling of this information. Hitherto such knowledge of this character as was possessed was obtained piecemeal by small surveys for specific and unrelated problems, was speedily lost sight of, and so was valueless beyond its immediate purpose. Perhaps the most salient point of the present survey is its fundamental and lasting character. It is designed to obtain every bit of the necessary information throughout its area, and, because of its high accuracy, to do this without appreciable error. It is further so designed as to permit of indefinite expansion upon the same basis, as the future needs of the district may require.

Briefly described, the topographic survey is a bird's-eye view of

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the city or of a part of its area. Reduced in scale to desk size, it portrays, by means of contour lines and other symbols, the hills and hollows, streets and watercourses of the section under consideration. From it the exact elevation and shape of the ground's surface at any point may be readily ascertained, and by its use the best and most economical locations and routes for streets, viaducts, bridges, sewer and water lines, parks and all public improvements may be determined. A further and very definite use is in the determining of proportional assessments for improvements, especially sewerage and drainage projects, on the benefit-assessment system. Specific instances of its use may be multiplied without number, for they are almost as broad and varied as the city's activities. Broadly speaking, the survey supplies a sure foundation of facts upon which scientific planning and replanning may be conducted.

The triangulation, precise traverse and precise levels later described are all necessary, integral parts of the survey and an invaluable basis for all of the city's engineering activities. The accurate co-ordinates, bearings and distances determined for the monuments and reference points of these divisions of the survey will be transferred to and incorporated with existing property and street monuments, thus making possible the exact replacement of such property and street markers when lost through regrading or other causes.

Appreciating the fact that the need of basic planning data is not limited to the incorporated area of Pittsburgh, Allegheny County, through its Department of Public Works and the County Planning Commission, has been co-operating with this department since July 1, 1925, in extending the present survey. Triangulation, precise traversing and leveling have been started in the county. The city and county surveys are fully co-ordinated.

It is planned that the Pittsburgh survey shall be fundamental and comprehensive in character. To make this possible, consideration has been given to the ideal schedule of the community's necessary basic engineering information, and to the preparation of definite specifications covering each division. The detailed specifications and their characteristics will be indicated hereinafter. The general schedule adopted is as follows:

1. Precise triangulation over the metropolitan area. The stations of this triangulation should average about one per square mile in incorporated or built-up territories, and about one for every two square miles throughout the rest of the county; the accuracy of the triangulation to be such that the probable error of any distance will not exceed one part in 100,000.

2. Precise traverse amplifying and making usable the results of the triangulation. The stations of the traverse should be well monumented and referenced, and should coincide as far as practicable with existing property monuments. The traverse should have an accuracy represented by a limiting closing error of 1 : 20,000.

3. Precise levels with elevations established upon bench-marks on permanent structures along the routes and upon traverse and triangulation monuments.

4. Topographic map published upon a scale of one inch equals 200 feet.

5. Property map upon a scale of one inch equals 50 feet. This is the base map for all departmental information where figures and dimensions are required. Editions of this map may also be used for underground structures, etc.

6. Wall or desk map on a scale of one inch equals 800 to 1000 feet, showing streets and, in general, the same data as given upon the larger-scale topographic maps from which it is to be compiled.

TRIANGULATION

Description. Triangulation is the framework or foundation of the horizontal survey. It is basically a series of overlapping triangles. Angles of these triangles are measured, and at proper intervals a triangle side is also measured. From this side length, measured upon the ground, lengths for the air-lines which constitute all other triangle sides are computed by trigonometric rules. On account of the overlapping of the triangles certain geometrical figures are formed, which, with the triangles themselves, are subject to rigid geometrical laws, making this form of survey capable of great accuracy in adjustment and computation and in the consequent quality of final results. Triangulation may be considered as being, generally speaking, of either a linear (or chain) type—usually executed for cross-country control—or of the area type, such as is essential for cities and counties. The present survey is, of course, of the latter sort (See Fig. 1).

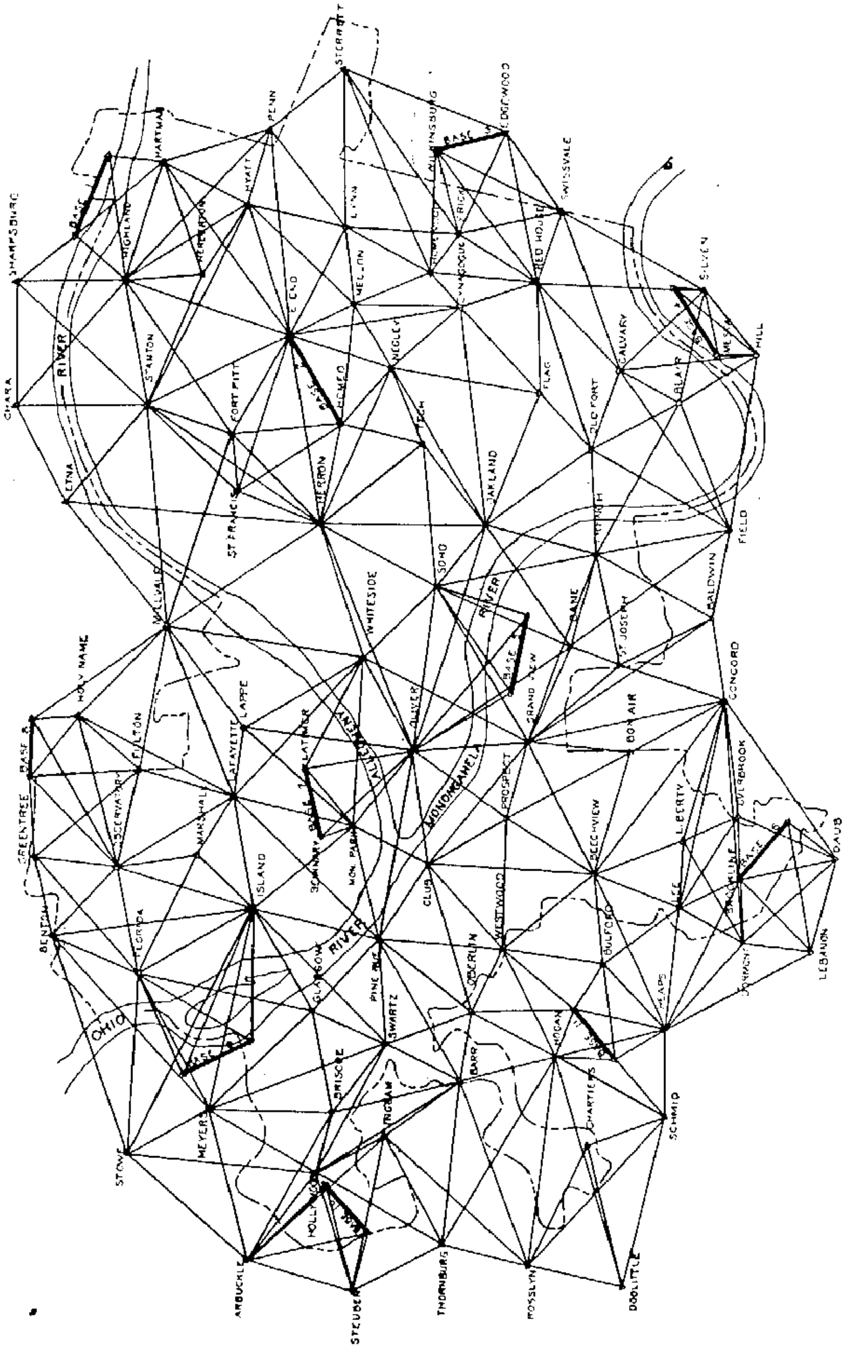

Fig. 1. Triangulation.

Co-ordinates and Azimuth. The Pittsburgh triangulation is being computed upon two co-ordinate systems. The geographic system establishes latitude and longitude values for all triangulation station positions, and also astronomic azimuths.

Geographic position is determined by accepting a mean of the position values of three United States Geological Survey stations which have been incorporated in the city triangulation. The rectangular co-ordinate system has its origin and reference meridian at North latitude 40 degrees and 26 minutes and West longitude 81 degrees. The exact intersection falls in the Monongahela River west of the Smithfield Street bridge. This is, of course, unimportant, as every point in the triangulation may be used as a reference or origin from which to redetermine every other point. The theoretical origin is assigned a value of 100,000 feet North and 100,000 feet East, so that all plane co-ordinates in Allegheny County will have plus values.

Azimuths for the plane system are carried throughout from the reference meridian of 81 degrees longitude. Disagreement between plane and astronomic azimuths increases east and west of this meridian at the rate of approximately 40 seconds per mile. Observations upon Polaris for azimuth were made at two different points in the triangulation scheme, and a mean value taken.

Accuracy. It was believed desirable at the beginning of the survey to make the triangulation of such an order of accuracy as might be considered sufficient for years to come. Accuracy of triangulation is largely judged by the size of the triangle closures, the base-to-base discrepancies, and the probable error of an observed direction. Investigations were made as to the precision attained in comparable city surveys such as New York, Cincinnati, Richmond, Va., etc. Based upon the experience of these and other cities, and appreciating the fact that city survey methods are constantly tending towards increased precision, it was decided that the Pittsburgh scheme should be executed with the highest practicable degree of accuracy. Specifications were accordingly adopted which require that discrepancies in length between measured bases shall not exceed one part in 100,000. This is to say that between any two base-lines, the computed length of one base as carried through the triangulation from the other must check the actual length of the second base by 1: 100,000. For a base one mile long the allowable error is about five-eighths of an inch. Triangle closures were limited to an average of 1.5 seconds, with a maximum closure not exceeding 4.0 seconds. The base-lines themselves are measured with a probable error not exceeding 1 : 500,000.

Planning for Accuracy. Proper planning for a specified degree of accuracy requires consideration of the principal expected sources of error. Triangulation errors originate in the measurement of bases and in the measurement of angles. Of angle measurement, which is the greater source of error, those factors which are external to the instrument are the most troublesome. With a given instrument, a certain program of observation will be found productive of the greatest accuracy practicable, and this program may be depended upon to give the same standard of results in the hands of any qualified observer. Errors arising from refraction and disturbed signals are not so predictable.

In the Pittsburgh triangulation there are many sights of less than a mile in length, these occurring usually within the city itself. To secure the required triangle closure it is desirable that each angle of a triangle be measured with an accuracy approaching ½ second. When it is considered that an angle of ½ second is subtended by approximately ⅛ inch at a distance of one mile, the difficulties of erecting and sighting signals within this limit become apparent. One of the chief sources of error is phase, or uneven illumination of the signal at the time of sighting. The observer unavoidably centers the apparent image, which is that part of the signal having strongest illumination. To overcome this, signal rods of triangular cross-section are employed, these being oriented anew so as to face each successive instrument station. Flagpoles, cupolas, etc., which have been customarily used in similar triangulation were avoided, resulting in the elimination of eccentric instrument stations necessary when such existing signals are used. Precautions were also taken to reduce the chances of horizontal refraction, which occurs when lines of sight pass close to heated buildings, smoke-stacks, or even hillsides. These latter difficulties, in the Pittsburgh district, are obvious.

The accuracy introduced into a triangulation scheme by the measurement of a base-line is rapidly dissipated as this measured length is carried through a number of triangles. This loss of accuracy bears a definite relation to the number of triangles through which the length is carried, and to the shape of the triangles themselves. Given a certain standard of accuracy in angular measurement, the base-to-base checks will be better or worse in proportion to the number and shape of the triangles intervening between base-lines. Experience has shown approximately what this loss of accuracy is and indicates the approximate position for base-lines to obtain a certain desired accuracy. The probable strength of a particular chain of triangles, for the purpose of computation of lengths, is denoted by the expression R_1. The amount or summation of the factors entering into the formula representing this expression should not exceed 25, for an accuracy of 1 : 100,000. The average value of R_1 between the Pittsburgh bases equals 19. Eleven base-lines were employed to control the 103 stations and the 100 square miles of the triangulation of the city proper, no station in the scheme being more than three figures removed from a measured base.

Location of stations and base-lines was made by thorough field reconnaissance. This reconnaissance was made graphically, by the plane-table method, all possible sights between stations being drawn upon the sheet as the stations were visited. After rejecting those sights which were not essential to the scheme, or were undesirable because of probable smoke interference or horizontal refraction, the strength of figures was computed. A special effort was made to locate all stations either directly upon the ground or upon the roofs of permanent buildings, eliminating for the purpose of reduced cost and increased accuracy the building of temporary towers for elevation of the instrument (See Fig. 2). The selection of base-line sites was sometimes difficult. It was desirable that each base be at least 0.75 miles long, preferably straight, of reasonably low grade; and, furthermore, so situated that its incorporation into the triangulation scheme could be accomplished without undue expense or loss of accuracy.

Field Procedure. Upon completion of the reconnaissance, all stations were marked with suitable monuments. These consisted of bronze castings, three inches in diameter, screwed to iron pipes set in concrete piers three to four feet in length, and protected by cast-iron boxes with lids. All monuments are referenced to nearby objects so that they may be quickly located.

Observation of angles has been accomplished by the use of both the direction type and the repeating type of theodolite. The selection of the particular instrument has, as far as possible, been dictated by the character of the station to be occupied. In general, experience has indicated that the use of the direction instrument is preferable, satisfactory results being secured with less expense than with the other. During the latter part of the city observing and upon the county work, now in progress, the repeating instrument has been employed only where the instrument support was not stable enough to insure good results with the direction type. The direction instrument used is a Bausch & Lomb theodolite having an eight-inch horizontal circle

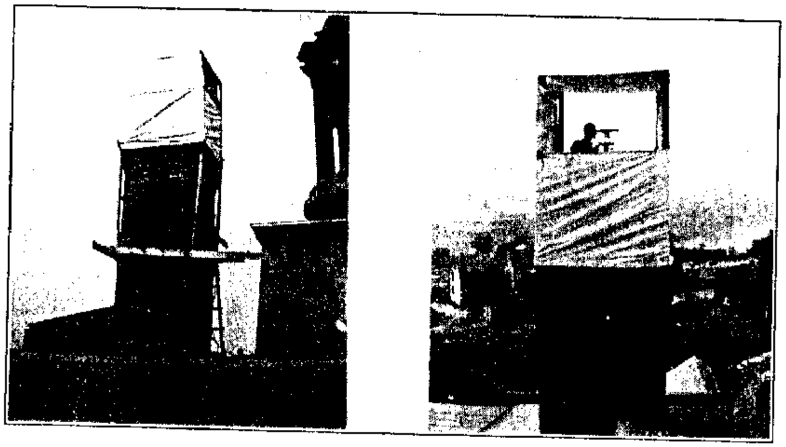

Fig. 2. Two Views on Chimney of Swisshelm School.

and reading by micrometer microscopes to two seconds (See Fig. 3). Two repeaters were available, one being manufactured by the Buff & Buff Manufacturing Company, and one by the Bausch & Lomb Optical Company, both reading to 10 seconds on eight- and seven-inch circles, respectively. In using either type, the instrument is kept shaded from the direct rays of the sun and sheltered from the wind by large umbrellas or tents (See Fig. 4).

The signal rods are of a special design, as has been indicated. They are triangular in section, from 8 to 12 feet in height, and about five inches across the face. For the longer sights of the county tri-

angulation, rods with seven-inch faces are used, with flags attached to aid in locating them (See Fig. 5). The bottom of the rod is fitted with a tapered iron shoe with a sharp point which exactly fits into a hole in the center of the bronze cap of the station monument. The face is painted alternately red and white in one-foot bands, and the rear sides are black. Since the center of the face is the observing center of the signal, centering the visible image by the observer (the black sides are not visible) results in uniformly accurate pointings. The

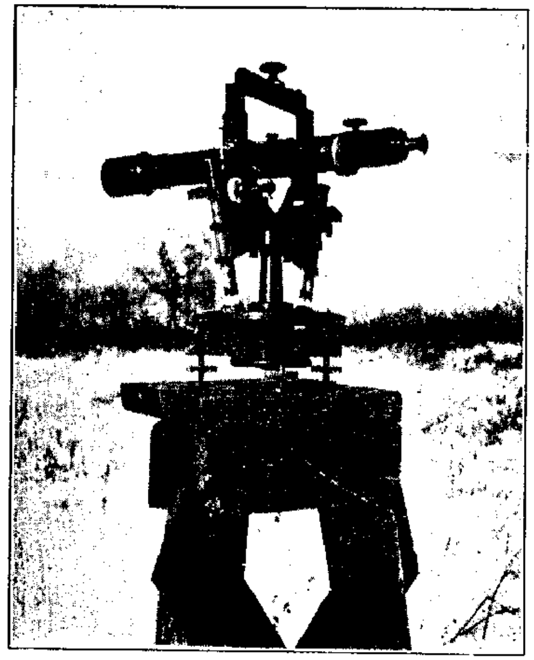

Fig. 3. Direction Instrument Used by Observing Party.

maximum viewing angle of the rods is about 60 degrees. Beyond this limit, it is necessary to re-orient the signal. For this purpose the upper end of the rod is rounded to fit into a metal collar by which it is guyed into the proper vertical position with wires and turnbuckles. Orientation is easily accomplished by rotating within this collar.

It has become increasingly the practice, on this survey, to employ lights for signals. Special six- to eight-volt automobile spot-lights are fitted in boxes provided with means for directing the beam along the line of sight, and connected to 150-ampere-hour storage batteries (See Fig. 6). Signals of this sort are employed for night work and are, also, especially useful in daylight observing for penetrating smoke and haze and for sights where, due to dark or neutral backgrounds, the rods are not readily visible. It is certain that the use of such signal lights results in greater progress, as time is utilized which otherwise would

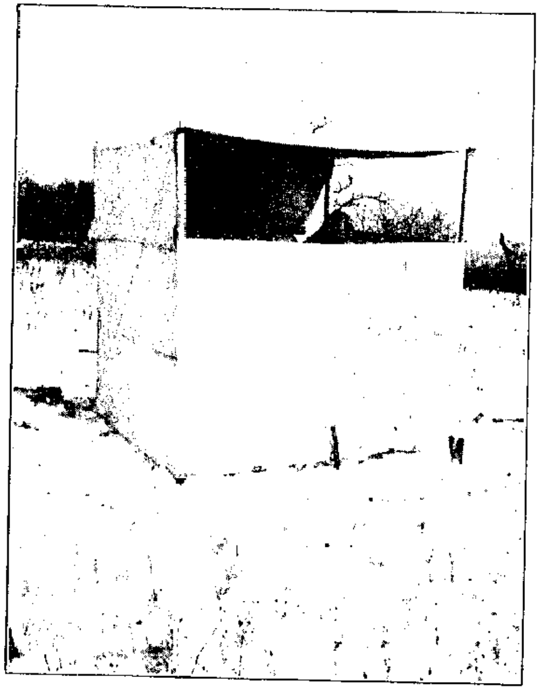

Fig. 4. Observing Party Protected from Wind and Sun.

be wasted in waiting for favorable atmospheric and visibility conditions; it is also believed that the use of the lights effects a lowering of unit costs, in spite of the increased attention necessary to operate the lamps.

The instrumental program for the direction theodolite consists of 16 sets of readings, each set being made up of one pointing with the telescope direct and one with the telescope reversed. The initial read-

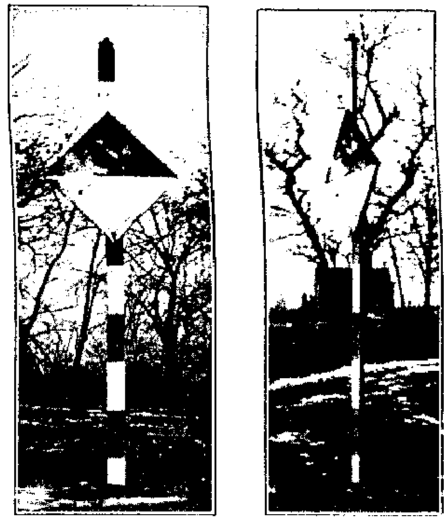

Fig. 5. Two Views of Triangular-Shaped Rods Used as Signals.

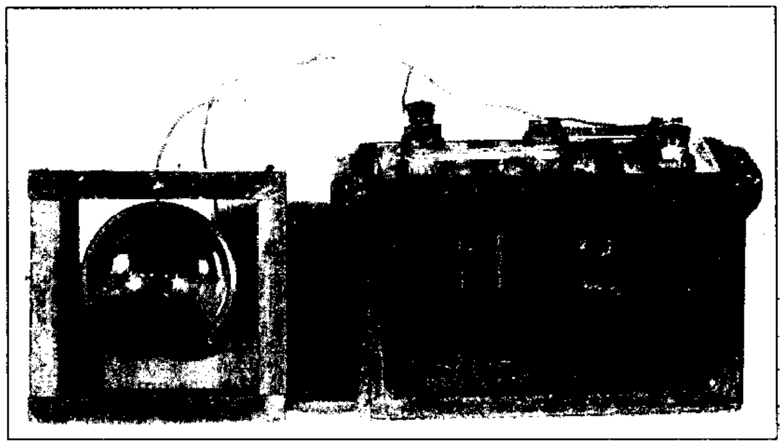

Fig. 6. Signal Light with Storage Battery.

ings for the sets are in all cases evenly distributed over the circle. The program for the repeating instrument employs from six to eight sets for each individual angle; a set in this instance being 12 repetitions—six with the telescope direct, and six with the telescope reversed.

Base measurement has been carried on simultaneously with angle observing, in order that preliminary lengths might be computed and ample time allowed for frequent standardization of tapes. The principal item of base measuring equipment is, of course, the tape. This has proved, in the present survey, to be the most troublesome, as will be discussed later. Original tape equipment consisted of two 50-meter invar tapes and one 50-meter steel tape. Six additional steel tapes of similar length were secured later. Further items were spring balances graduated in kilograms, tape stretchers, portable tripod supports for tape-end contacts, accurately calibrated thermometers, etc.

Upon all bases measured with the steel tapes, the hours between midnight and six a. m. were selected in order to secure more uniform temperature and consequently more accurate tape-temperature determinations. Since many of the bases are upon streets or railroads, night measurement has also been advisable because of less traffic interference. Most of the measures, being over paved streets, were made with the portable tape supports, or bucks. Wooden stakes, two by four inches in section, were used as supports in fields or other open ground where stakes could be driven. The base party consists of from 8 to 10 men. Two men make forward contact, one man stretching the tape and the other making and checking the forward mark; one man attends to the middle tape support; two more give tension and contact to the rear end of the tape. A levelman and one rodman determine elevations on all tape supports. Additional helpers are required for night work and to guard the tape against traffic interference.

Meter tapes are used for all base measurements because of the fact that the United States Bureau of Standards at Washington is equipped to standardize meter units about three times as accurately as feet. The 50-meter length is best adapted for base use, being about 164 feet long. All tapes were standardized for various conditions of support, and for a standard tension of 15 kilograms (about 33 pounds). Thermal coefficients for all tapes were determined by the Bureau over a range of 15 to 20 degrees C.

It is a matter of common knowledge that invar has a coefficient

of expansion only 1/25 as great as that of steel, and for that reason its use would seem to be preferable for base measurement. The difficulty is that invar is a less stable metal than steel. Without giving a detailed record of the action of the various tapes as shown by different standardizations during the survey, it may be mentioned that the invar tapes purchased by the city in 1914 have shown minus coefficients in recent tests—that is, they have shortened with increases of temperature and have shown wide variations in absolute length. Under the most favorable conditions, invar will tend to kink and develop slight bends and warps which will operate to shorten the tape. When this tendency becomes abnormally great and when minus and variable coefficients occur, it is evident that the physical structure of the metal is too unstable for practical use. Inquiry has not developed a source of supply for invar tapes that are satisfactorily guaranteed against such gross defects. Therefore, the demands for progress on the survey program have necessitated the use of steel tapes. Such tapes are capable of results well within the desired limits, and have been employed in spite of the difficulties of accurate determination of tape temperatures, necessity of night measurement, etc.

Each base has been measured a minimum of six times, a different tape being employed for each measurement.

In connection with the discussion of bases and base tapes, it may be of value to give the experience of this Survey in regard to testing and standardizing steel tapes. Six 50-meter, steel tapes were sent at one time to the United States Bureau of Standards for determination of absolute lengths and thermal coefficients. The tests for lengths and coefficients were made on a steel bench, the length of which is correct within about one part in 300,000. The coefficient of the bench has been determined and checked several times during the past few years. The lengths of the six tapes were compared directly with the length of the bench, at a temperature of 27 degrees C.; then, with the tapes still in position on the bench, the room temperature was lowered to 13 degrees C., and the difference between bench and tapes noted. The differences were also noted at a high temperature of 31 degrees C. From these observations, and knowing the correct coefficient of the bench, the coefficient of each tape was computed. The tape coefficients figured from this test averaged 0.0000132 per degree C., or 14 per cent. greater than for normal steel, which is 0.0000116 per degree C.

Computation of the field bases on which these tapes were used, with an average of more than five measures per base, showed unduly large discrepancies between the measures. An inspection of the results seemed to show that, as a rule, the higher the temperature the greater the length, leading to the conclusion that the coefficients of expansion, as given by the tests, were too large. Therefore, in an attempt to secure a temporary coefficient for preliminary use, a separate coefficient for each base was figured, assuming that all the separate tape coefficients would be of the same numerical value. The computations were made by two computers, working independently. The mean value, determined by assigning weights to the different values for the various bases, was 0.0000116, which is the average for tape steel. Using this new coefficient, and the corrections for absolute lengths which were refigured using the new coefficients, the base lengths were refigured and the new results showed satisfactory agreement among the various tapes.

Upon completion of the field work on the bases, the tapes were sent back to the Bureau of Standards for new length tests and redetermination of thermal coefficients. On this test the Bureau was requested to.

1. Determine all lengths on the geodetic comparator instead of the steel bench.

2. Determine length corrections at a room temperature of 20 degrees C. (68 degrees F.), or under, since this temperature would be nearer the actual temperatures encountered in the field.

3. Determine the coefficients on the geodetic comparator by fundamental tests—that is, to observe the actual difference in lengths at maximum and minimum temperatures.

The new coefficients, obtained in this latter test, averaged 0.0000120, or, assuming these coefficients as correct, the original values furnished by the bench test were in error by 10 per cent.

Astronomic azimuths have been observed at two stations on opposite sides of the city triangulation scheme, the results being checked by azimuths carried through the connecting triangles. The regular instrumental equipment employed on angular measurement was used for this, with the addition of a very sensitive striding level for determining the inclination of the axis of the telescope. A sidereal watch,

compared daily with the sidereal clock at the Allegheny Observatory, was used.

Computations. The first step in computation is the testing of triangles for angular closures and sine-to-side proportions, this test being based on the trigonometric theorem that in any triangle the sines are proportional to the opposite sides. Actual lengths are, of course, not known; but in a figure of four overlapping triangles, such as a quadrilateral, it is possible to make this test without knowing them. This proportion test is applied to all figures regardless of closures, but it is especially useful in locating errors where the angular closures are high. The proportion test is, however, not always an accurate index of errors, its usefulness being limited by the type of figure and size of angles involved.

Bases are computed immediately after measurement in order to test the accuracy attained. The various corrections applied to the field measures are, inclination, temperature, absolute length (pull and sag), and reduction to the sea-level and to the 1000-foot-level planes. Each individual tape length is corrected separately for inclination and absolute length. The temperature correction is applied to the entire base for an average temperature, and the plane corrections applied to the final mean of all the measures for any one base. In order to simplify computations, a special table has been compiled for inclination corrections to 25-meter tape lengths.

After the several measures for each base have been computed, the results are averaged and the probable error determined. It was desired to establish the base lengths with a probable error not exceeding 1:500,000. This, however, does not mean that the actual error is within that limit. For instance, if there were a constant mistake of one kilogram in the tension applied to the tape, the results might agree very closely, but the actual length still be considerably in error. The probable error is simply a mathematical value derived from the theory of least squares, and is a useful means of comparison. It may be said that, if everything connected with the base measurement is fundamentally correct, the actual error is not likely to be greatly at variance with the probable error.

After all triangles have been satisfactorily closed and base lengths computed, the next step is the least-squares adjustment. This adjustment is made to remove all angular discrepancies; to make the sines proportional to the opposite sides; to insure that each triangle side will check for length, from whatever base it is computed; and to make the sum of the squares of the corrections a minimum. This latter requirement is based upon the theory of least squares—that is, that the most probable value from any set of observations is that value which will make the sum of the squares of the residuals a minimum.

In the Pittsburgh city scheme the entire net is divided into seven major adjustment divisions. This was found advisable, because any attempt to handle the entire scheme as a unit would result in computations of such unwieldy proportions as to be difficult of solution. Because of the fact that the triangulation itself is of a high order of accuracy, and because considerable thought was given to determining the best lines at which to break the adjustment, it is believed that no appreciable amount of accuracy has been lost because of the system of section adjustment. In order to make the entire net geometrically consistent, all lines and angles occurring in previous adjustments are held fixed.

The condition equations for removing discrepancies are of three types:

1. Angle equations, which remove the closures from the triangles and make all triangles total exactly 180 degrees.

2. Sine or side equations, which make all sines proportional to the opposite sides.

3. Length equations, which remove the length discrepancies between bases and insure that any side will check for length no matter from which base it is computed.

The unknown quantities in these equations are the corrections to the angles of the triangles which will satisfy the above-mentioned conditions. The absolute terms in the equations are the triangle closures, the sine discrepancies in the figures, and the base-to-base length discrepancies.

These condition equations are transformed into normal equations, at the same time inserting the additional condition that the sum of the squares of the corrections shall be a minimum. The normal equations are then solved by the Doolittle method. The corrections obtained are inserted back in the triangles, and, if the solution has been properly

executed, all triangles will close exactly 180 degrees, all figures will be of correct proportions, and the lengths will check through from base to base. The quality of the field work is then tested by obtaining the probable error of an observed direction, the average and the maximum correction to a direction.

To illustrate the amount of labor involved in one of these adjustments, it may be said that the largest Pittsburgh section has 82 condition equations with 132 unknown quantities. All seven adjustments have 393 equations with 700 unknowns.

After the entire net has been made rigid by a complete adjustment, the triangles are all computed and lengths obtained for each side. The observed azimuths are computed, brought to a central point, corrected for convergence of meridians, and averaged, so that bearings and co-ordinates may be determined. Having a starting azimuth, and geometrically perfect figures with all angles and lengths known, the rectangular co-ordinates are figured.

Before computing geographic co-ordinates a new set of distances is obtained, using the base lengths reduced to sea-level. With these new lengths and a true azimuth, the latitudes, longitudes, and geographic azimuths are computed based upon the Clarke spheroid, this spheroid having been adopted by the governments of the United States, Canada, and Mexico for similar computations.

Progress. At this date all of the field work on the city triangulation has been completed, including angular observing, base measurement, and astronomic observations. It is known, however, that from time to time, as the office work progresses, it will be necessary for an observing party to reoccupy some of the stations in order to lower occasional large triangle closures. All bases have been transferred, where this was necessary, to the regular stations. The office work is approximately 60 per cent. completed, including four of the seven major least-squares adjustments.

The triangulation of Allegheny County, which is similar in character to that of the city and which is being executed by this department, has been started. The reconnaissance for 242 square miles is complete. Approximately 79 station monuments have been set and observing completed on six stations.

Significant Data. The Pittsburgh triangulation includes 103 stations, 68 of which are ground stations, 35 being on roofs of buildings, etc. The area within the net itself is approximately 78 square miles and the area controlled by the triangulation is about one hundred square miles. Of the 11 bases, five are direct triangle sides, while six were required to be transferred to the regular stations. The significant figures on the adjustments so far completed are as follows:

TABLE I. ADJUSTMENTS AND DISCREPANCIES

Summary of adjustments, numbers 1, 2, 3, 4, 5, 6, and 15

Total number of triangles	116
Total number of directions, or unknowns	246
Total number of condition equations	121
	Inches
Average triangle closure	1.45
Maximum triangle closure	4.40
Average correction to a direction	0.53
Maximum correction to a direction	2.40
Probable error of an observed direction	±0.64

Base-to-base discrepancies

From	*To*	*Discrepancy*
Base No. 1	Base No. 2	1 part in 200,800
Base No. 2	Base No. 5	1 part in 103,000
Base No. 5	Base No. 7	1 part in 142,000
Base No. 5	Base No. 4	1 part in 300,000

It is estimated that more than 50,000 instrumental pointings have been made during the measurement of field angles, with about the same number of circle readings.

PRECISE TRAVERSE

Description. Precise traverse is logically a part of the triangulation system, as its purpose is simply to furnish additional monumented points along the streets, where they will be more available for every-day use than the widely scattered and sometimes inaccessible triangulation stations. Such traverse is essentially a series of second-

or third-class connected base-lines, with the angles between these lines measured by triangulation methods. The co-ordinates of these traverse monuments are the actual bases for map work and for departmental and private surveys.

Accuracy Desired. The precise-traverse system is usually of a slightly lower order of accuracy than the triangulation itself, but, on the other hand, it should be accurate enough to control all ordinary surveys. Since the triangulation was designed to have a precision of 1 : 100,000, and as ordinary city surveys seldom exceed 1:15,000 to 1: 20,000, it was decided that an indicated maximum in the latitude and departure closures of 1 : 20,000 would be sufficient, with an average of 1 : 35,000 or better. In computing this closure it is assumed that the triangulation, after adjustment, is perfect; and all triangulation co-ordinates are held fixed, the angular and linear discrepancies of the traverse being distributed between triangulation stations. This limit of accuracy compares favorably with other cities, where the allowed maximum closure is often much greater than 1 : 20,000, and the average seldom higher than 1 : 35,000.

Location of Traverse Lines. In executing precise traverse there are several conditions to be considered:

1. The lines should be evenly distributed.
2. They should be located on improved streets and in such places that the traverse stations are not apt to be destroyed.
3. The stations must be selected with the future use of the traverse in mind.
4. To obtain the necessary accuracy the lines should follow streets with low grades and with courses averaging 500 feet or more in length.

Furthermore, it is essential that the lines follow those streets upon which the city street-corner monuments are already in place. Effecting the best compromise between the above-mentioned conditions is often a difficult problem. Where only one condition can be satisfied, that of permanency of monumenting is given preference.

The approximate location of lines is first laid out in the office on a city street map so as to give even distribution of control. A field reconnaissance party then goes over the area with authority to shift the line to suit the field conditions. The line is then monumented and properly referenced.

Field Procedure. Upon completion of the reconnaissance, the next step is the observation of angles. This is done by a four-man party using a 10- or 20-second repeating theodolite. The sight rods used are about seven feet long and are made of white pine, warping being prevented by strap-iron stays. The face of this rod is about one inch wide, painted white, with a ⅛-inch red stripe down the center. The iron point on the shoe of the rod is lined up with the center of this red stripe. The sides of the rod are painted black so as to prevent phase. Bull's-eye bubbles are attached for plumbing. Small tripods are carried by the rodmen for bracing the rod in position. The instrumental program is exactly the same as for triangulation, except that only one set of 12 repetitions is taken.

Traverse taping is similar to base-line measurement except that each course is measured only once and some of the refinements of base work omitted. One-hundred-foot tapes are used, with spring balances for tension reading in pounds, ordinary Fahrenheit thermometers for temperature, portable bucks for tape supports, and level and level rods (See Fig. 7). The party consists of five men, two at the front end of the tape, one at the rear end, one levelman and one level rodman. The bucks are lined in between stations by eye, except in the case of long courses, where a transit is used. Levels are obtained upon the bucks at the time of taping so that the inclined distances may be reduced to horizontal. Thermometers are read at every other tape length. At the last tape length of any course, which is usually an odd distance, the tape is independently read and recorded by the party chief and the instrument man.

Computations. The angles on all lines are first totaled to determine the angular error per station. If this is acceptable, the angular discrepancies are adjusted by establishing a mean azimuth at the intersections of traverse lines. Azimuths are brought to each intersection from all possible triangulation stations, by all possible routes, and each azimuth so determined is given a weight which is in proportion to the reciprocal of the square root of the number of intervening instrument

stations. A weighted mean azimuth is thus obtained for each intersection or junction point, and angular discrepancies distributed between adjacent junction points, or between junction points and triangulation stations. After the angles are so adjusted, azimuths are figured for each course and the bearings computed.

Distance-reduction computations for traverse taping are similar to triangulation-base reductions. It may be stated here that the absolute length corrections for the 100-foot tapes are obtained by compar-

Fig. 7. Taping on Precise Traverse.

ison with the 100-foot standard which has been established by this department in the basement of the City-County building. This standard was originally measured with two 100-foot invar tapes which had been standardized by the Bureau of Standards, and was later checked by two 100-foot steel tapes tested by the Bureau of Standards.

After bearings and distances have been computed, rectangular latitudes and departures are figured for all courses, and the lines tested for closing discrepancies between triangulation points. If all closures are within satisfactory limits, the latitude and departure discrepancies are removed by a junction-point adjustment similar to the azimuth adjustment. In this case co-ordinates are determined for each junction point by all possible routes and weighted mean values established, the weights being proportional to the reciprocal of the square roots of the distances. Intermediate latitudes and departures are then adjusted in straight proportion to the distance between adjacent junction points or triangulation stations, and co-ordinates for all stations computed.

Significant Data. The progress to date on the city precise-traverse scheme is approximately one hundred linear miles, most of this being in the eastern part of the city. Several sections of the traverse in this portion of the city were run before the triangulation had been established and, consequently, additional lines will be necessary in this area in order to tie the old traverses to triangulation stations. Since final triangulation co-ordinates are not yet available, it is impossible to state the exact closing discrepancies of the traverse. However, judging from loop closures and from closures based upon preliminary triangulation co-ordinates, it is believed that a large majority of the lines will be within the prescribed limits of accuracy.

Due to the rugged topography of Pittsburgh, its crooked streets and uneven grades, it is expected that double chaining on many of the lines will be necessary in order to obtain the desired accuracy. Because of the many short sights it will also be necessary to "throw in" azimuth control lines at frequent intervals. This is accomplished by observing nearby triangulation stations visible from traverse set-ups, then revisiting the triangulation stations and reading angles to the traverse points.

In the county geodetic survey the precise-traverse and level lines are usually identical, and the traverse monuments are used as bench-marks. The reconnaissance has been completed and monuments set on about fifty miles of the county traverse scheme.

Possibility of Errors. For the benefit of those who anticipate using the precise-traverse results, it may be stated that traverse is not capable of a rigid mathematical proof of accuracy, as is triangulation; and, in spite of all the precautions that can be taken, there is the pos-

sibility that compensative minor mistakes in distances or angles may slip by undetected. Engineers who discover such errors should report them to this department so that corrections may be made and the computations revised.

PRECISE LEVELS

Description. Precise levels are the foundation of the vertical-survey system as the trianguation is of the horizontal. Precise-level bench-marks furnish elevations of known accuracy from which other level surveys may be started. The precise elevations are especially useful in the design and construction of major improvements such as viaducts and bridges, sewerage systems, water-distribution systems, railroads, tunnels, etc.

Leveling in 1912. Pittsburgh is unusually well supplied with precise-level bench-marks, having probably as complete a system as any city in this country. This network of levels run in 1912 by the Bureau of Surveys included 435 miles of double-run levels over permanent bench-marks. All bench-marks were marked with bronze castings set in masonry, and all the sections were within the standard limits for this class of levels. The criterion for acceptable accuracy is that the two runnings over any one section, one backward and one forward, shall agree with each other within $0.017\sqrt{M}$, in which M is the length of the section in miles.

Field Procedure. The level equipment used consisted of a Bausch & Lomb coast survey model precise level. The essential features of this type are:

1. The metal used is invar, having a low coefficient of expansion, thereby reducing distortion in the instrument due to changes in temperature.

2. The sinking of the level bubble into the telescope tube, so that the bubble itself is very close to the line of collimation, and any distortion which does occur thereby has less effect upon the parallelism of bubble and line of sight.

3. A micrometer screw at the eye end of the instrument for bringing the bubble exactly to the center during readings.

4. The addition of a secondary telescope with mirror and prisms for viewing the level bubble.

5. A very sensitive level bubble usually ground to an arc of from two to five seconds per division.

The rods used are of the wooden type, T-shape in section, with the face about three inches wide. The graduations are in yards, the smallest graduation being 0.01 yard, and this being divided by estimation into 10 equal parts, or thousandths of a yard. The yard divisions are marked by silver plugs inlaid in the wood. Each separate yard is marked by a different color, thereby reducing the chances of blunders in the yard readings. The rod is supplied with a thermometer and has a circular bubble for bringing it into a vertical position. Special portable iron turning-points are carried by the rodman and used as supports for the rods (See Fig. 8). Additional equipment used by this party consisted of an umbrella for sun protection, folding windshield, specially printed note forms and standardized tape for measuring the rods.

Future leveling executed by this survey will be done with the newer type of rods which have independent invar strips for the fine graduations, thus reducing the errors due to the changing lengths of the wooden rods. The field program is briefly as follows: The instrument is set up and leveled approximately by the small circular bubble. It is then pointed to rod "A" (the same rod is always sighted first whether it be in the backsight or foresight position, to reduce errors due to settling of the instrument), and the bubble brought to the center by means of the micrometer screw. While the bubble is exactly in the center—this being viewed through the secondary telescope with the left eye—the three horizontal wires are read and recorded. Immediately thereafter the instrument is pointed to rod "B," the bubble brought to the center and the three horizontal wires read. The recorder checks the mean of the three wires and notes the agreement between this and the middle wire. In cases where the discrepancy, or lack of agreement, exceeds a certain amount the reading is repeated. With an experienced observer this discrepancy rarely exceeds the allowable limit. Before leaving a station, the recorder also computes the two half intervals, notes their agreement, and completes the backsight and foresight distance totals.

Some of the features which differentiate precise leveling from ordinary leveling are:

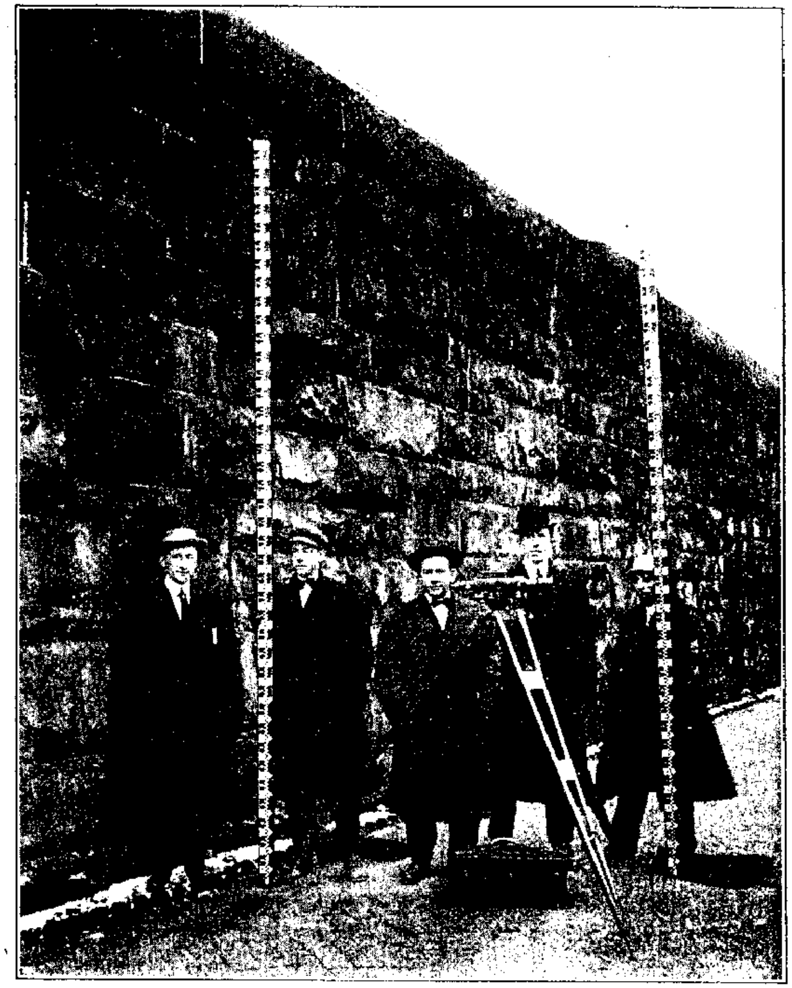

Fig. 8. Precise-Level Party and Equipment.

1. Measurement of rods at regular intervals to determine absolute length.

2. Correcting rod lengths for temperature and humidity.

3. Adjustment of level at least once every day and determination of constant for correcting bubble error.

4. Making backsight and foresight distances on each "set-up" agree within a specified limit; and also making totals of backsight and foresight distances approximately equal for the section.

5. Protection of the instrument from sun and wind.

Computations. The Pittsburgh precise-level system has already been completely adjusted by the method of least squares, and elevations have been computed for all of the bench-marks. The datum used is mean sea-level as established by the United States Geological Survey. In some of the outlying sections of the city it has been found necessary to extend and amplify the 1912 survey for the purpose of supplying bench-marks at closer intervals for the plane-table surveys. In these cases the new lines are adjusted to the old elevations, this being held absolutely fixed. The method of adjustment is, in the case of a single line, simply to distribute the closing discrepancies in proportion to the distances. Where two or more lines intersect, forming junction points, the regular junction-point method of adjustment, similar to that for precise traverse, is used.

Bench-Marks. The type of bench-mark used on the 1912 levels is a flat bronze disk having a shank about four inches long. This disk is set into substantial masonry structures wherever possible. Where solid masonry is not available, the disk is set in a concrete monument 12 to 15 inches in diameter and three to four feet deep.

County Levels. The Allegheny County precise-level system has been started and approximately twenty miles of levels completed. It is expected that precise levels will be run over most of the improved roads with bench-marks at every road intersection, and at intermediate points. The county system will have two types of benches:

1. A bronze cap screwed onto an iron pipe and set in a concrete pier, this monument to be not only a level bench-mark, but also a precise-traverse station.

2. A bronze disk, similar to that used on the city levels, set in solid masonry structures such as bridge piers, culverts, etc.

TOPOGRAPHIC SURVEY

Description. The topographic map, which is being made of the incorporated area, is a definite and valuable result of the Pittsburgh survey. This map, as has already been mentioned, is a bird's-eye view of the ground. On it are shown to exact scale and position all streets, roads, alleys, curbs, retaining walls, steam and electric railroads, bridges, public, semi-public and industrially important buildings, streams, lakes, etc. The conformation and elevation of the surface of the ground are shown by means of contour lines. From the topographic map grades may be accurately computed, drainage areas may be scaled within a fraction of an acre, and excavation quantities computed. The Pittsburgh map sheets are published on a scale of one inch equals 200 feet, with a 2.5- and a 5-foot contour interval. The datum plane for contour elevations is mean sea-level, thus placing the maps upon the ultimate datum plane and agreeing with federal, state and other maps.

The publication scale of one inch equals 200 feet was adopted as best fitting the conditions imposed, which are:

1. The map scale must be large enough to indicate clearly and accurately all of the information desired to be shown.

2. The scale should bear a definite relation to the accuracy of field measurements, and, since the majority of the positions are located by stadia, and stadia distances are dependable only within one foot, the scale should be such that distances may be plotted and scaled to the nearest foot.

3. The scale of the map must be small enough so that the area covered by any one map sheet would be of such size that ordinary district improvement projects may be covered and studied upon one sheet, without the necessity of assembling and matching various adjoining sheets.

4. From an economic standpoint it is desirable to keep the scale as small as possible, in order to decrease the cost of the field work and of reproduction.

While the scale of publication is 200 feet, the field scale, upon which the maps are sketched in the field, is 165 feet. The purpose of this is the possible increase in accuracy of scale by the reduction, which is a part of the photographic process of publication, and the sharpening of lettering and other cartographic details and consequent improvement in appearance of the final published copies. It is of further advantage to make the field scale as large as is consistent with stadia methods for the purpose of making enlargements. It is, for instance, possible to make a better photographic enlargement to a scale of 100 feet by using an original copy on a scale of 165 feet than would be the case if the original were on a 200-foot scale.

Uses. One of the most constructive phases of city planning is the laying out of streets and thoroughfares in outlying districts in advance of development. In most cities this has not been possible because of the lack of information regarding the topography of these areas. It is, however, becoming increasingly the practice, as is evinced by the fact that in one state there is a statutory provision enabling cities to lay out streets and thoroughfares within five miles of their limits, but this permission is given only to those cities having accurate topographic information upon which to base their plans. Upon completon of the Pittsburgh map sheets it will be possible to do this sort of planning. Having worked out definite ideas as to the proper street system, reasonable plans can be shown to owners and subdividers who wish to place new plats on record. The city's planning, being logically based upon thorough information and study, will protect the public interest and will usually appeal to the subdivider also, even without the exercise of any legal authority to compel him to conform. At the present time, as new subdivisions come before the City Planning Commission for approval, the lay-out of the streets and lots is studied carefully, using the topographic map as a basis whenever it is available.

The map is also of great value in the selection of locations for bridges, tunnels, parks and boulevards, and an invaluable aid in the design of such improvements as sewers, harbor and river projects, etc. It is also helpful in establishing rates of assessments on the benefit-assessment plan, especially on such items as storm sewers and drainage projects.

Map Projection. In deciding upon the system of projection to be used on the map sheets, there were three conditions to be considered:

1. The projection must be such that the maps will always be in correct orientation—that is, the boundaries of each sheet should always be true north and south, east and west, in order that the true azimuth or bearings of any line may be quickly scaled from the map.

2. The projection should permit of practically indefinite expansion.

3. In order to be joined correctly and easily to other maps, such as those published by the federal government, state, Interstate Commerce Commission, etc., the boundaries of each map sheet should be some even value of latitude and longitude, these values being co-ordinates based upon the North American Datum.

4. For ease and simplicity of ordinary distance, bearing, and position computations, the maps should have superimposed upon them a rectangular system of co-ordinates. A specimen sheet is shown in Fig. 9 (folding plate).

The projection which has been adopted meets all the conditions satisfactorily and is very simple to compute and plot. Each map sheet covers one minute of longitude and 35 seconds of latitude. Starting at the origin of rectangular co-ordinates—latitude 40° 26′ 00″, longitude 81° 00′ 00″—and making this point the common corner for four sheets, the lay-out was extended to cover the entire city. Knowing the geographic size of each sheet and having the origin to start from, the geographic co-ordinates of all the other corners were computed. Then, for convenience in plotting the sheets, the geographic co-ordinates of each sheet corner were converted to rectangular co-ordinates, and from these the dimensions of each sheet figured. It is to be noted that each sheet is 0.7 foot narrower across the top than across the bottom, making an extreme difference in sheet width from the northernmost sheet to the southernmost of 8.7 feet. The north and south distances do not vary by more than 0.1 foot. The formulas and arc lengths used in converting geographic to plane co-ordinates are given in Special Publication 71, of the United States Coast and Geodetic Survey, entitled "Relation Between Plane Rectangular Co-ordinates and Geographic Positions."

Preparation of Field Sheets. The map sheet used in the field on the plane-table board is of heavy white drawing-paper mounted upon aluminum. These metal-mounted sheets are used in order to prevent the expansion or distortion which occurs when ordinary muslin-mounted sheets are exposed to the weather. The sheet is plotted in the office with geographic boundaries, even 1000-foot rectangular co-ordinate lines, triangulation points and bench-marks shown. The actual plotting of the co-ordinate lines is as follows:

A construction rectangle, 22.5 by 27 inches in size, is drawn on the sheet by means of a metal templet cut to exactly this size. The templet is used in order that the overall size of all sheets will be correct. Knowing the exact size of the sheet to be plotted, the offset distances to the sheet corners are scaled on right-angle lines from the corners of the construction angle. The sheet corners are then joined with straight lines, the resultant figure being theoretically a trapezoid, but for all practical plotting purposes a simple rectangle. The intersections of the 1000-foot co-ordinate lines with the map edges are then scaled from the corners along the edge lines, and these intersections joined. The triangulation and traverse stations are then plotted in their correct positions by means of rectangular co-ordinates. Before any sheet is allowed to go into the field the edges of adjacent sheets which have been previously worked are transferred to it.

Field Mapping. The plane-table party consists of three men. The topographer is chief of the party, operates the instrument, plots the stadia readings, and sketches the terrain. The recorder records all instrument readings, descriptions of turning-points and bench-marks, and computes elevations and distances. The rodman goes about over the area giving rod readings on critical points. The equipment used is a Johnson-movement tripod, a plane-table board, size 24 by 31 inches, a 12-inch telescopic alidade, a 14-foot stadia rod, stadia-slide rule, etc.

It is generally conceded that, in the hands of experienced operators, the plane-table method of taking topography is, from the standpoints of accuracy and cost, superior to any other method. Its chief advantage lies in the fact that the topographic details are sketched while observing the ground, any material blunders and mistakes being thus eliminated. Furthermore, a more accurate delineation of the surface of the ground is secured because of the fact that the contours are sketched while the party is on the ground. Comparative figures over a number of years have proved that the use of the plane-table results in lower unit costs.

Specifications under which the field parties work are briefly as follows:

1. Plane-table traverse closures must not exceed three feet for the first 1000 feet traversed, and two feet per thousand thereafter. In no case must the total closure exceed seven feet. Closures must, on the average, fall midway between control traverses and shall be distributed in proportion to the distance.

2. Levels carried by the plane-table shall close within one-fourth of the contour interval—that is, on reasonably flat country where the 2.5-foot interval is being used, the closure shall not exceed 0.6 foot, and on steep country such as rugged hillsides and bluffs, the closure shall not exceed 1.25 feet.

3. Instrument readings for distance, bearing, and elevation shall be taken with such frequency and the topographic details so sketched that:

a. Elevations taken from the contour map shall be correct within one-half the contour interval.

b. Horizontal distances between well defined points shall scale correctly within three feet.

Each map sheet covers an area of 0.59 square mile or about 377 acres. The average dimensions are 3542 by 4640 feet. The total city area scheduled to be mapped is in excess of 55 square miles, and includes 121 map sheets. The average number of "shots" per acre has been about 15, with about one instrument set-up per acre. The total progress accomplished to date in field mapping is 6.51 square miles, this comprising 10 complete sheets and seven fractional parts of sheets. The sheets completed are in widely separated areas, having been mapped for studies for specific improvements in those areas. Fig 10 (folding plate) shows the arrangement of topographic sheets.

The field maps are tested occasionally by means of random profile lines run with transit and level, each profile being plotted on the same sheet with similar profile scaled from the map. Such checks have indicated that the vertical and horizontal accuracy of the sheets is well within the limit specified (See Fig. 11). Another test on the general accuracy is the checking of the sheet edges, each topographer checking by random "shots" that part of the edge which has been transferred to his sheet from adjoining sheets previously mapped.

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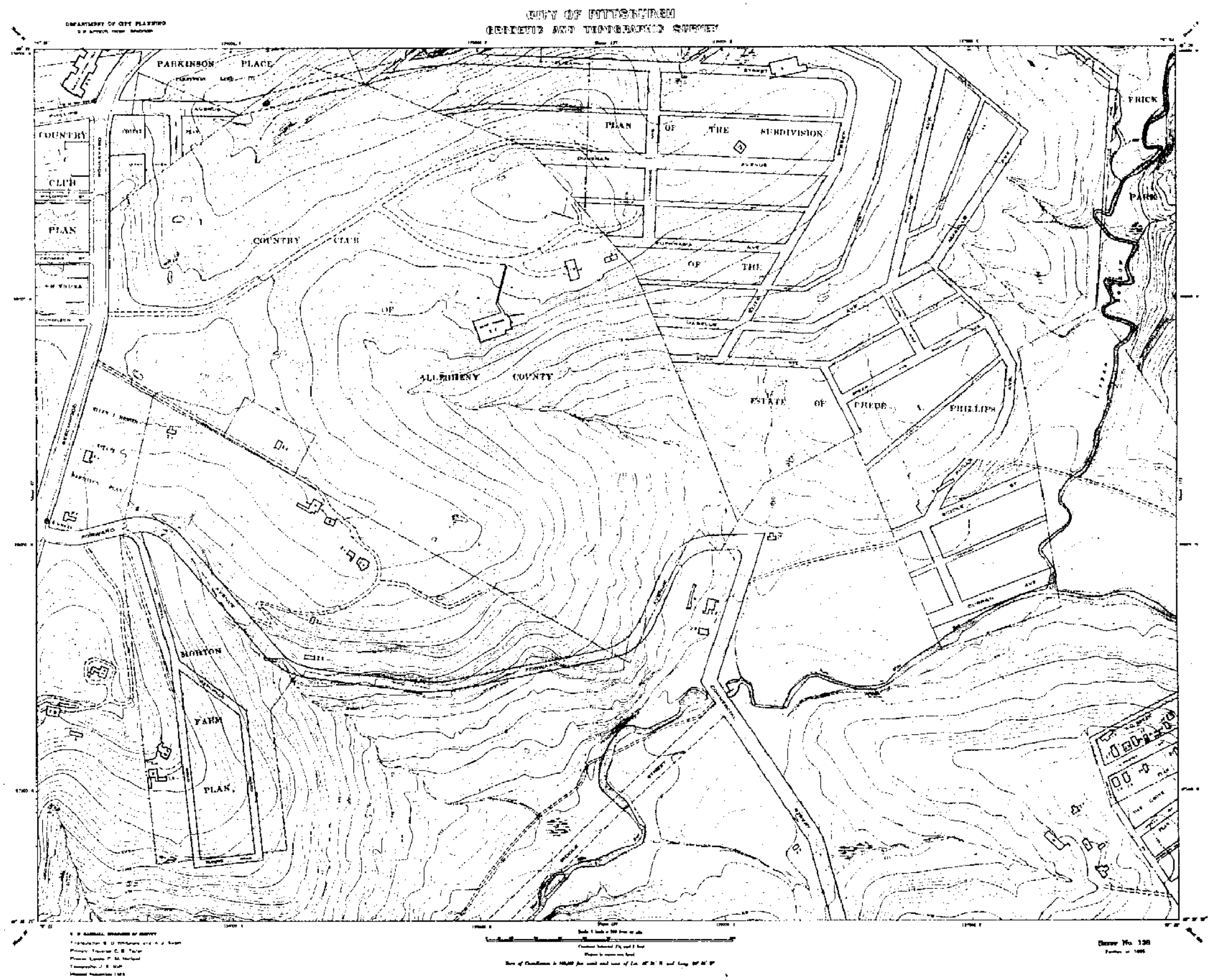

Fig. 9. Specimen Topographic Sheet.

Checking Property. Upon completion of the field sheets, the next step is the office searching for property information. All available record plats of subdivisions, property atlases, etc., are first assembled. Then the distances between points, such as monuments, fences,

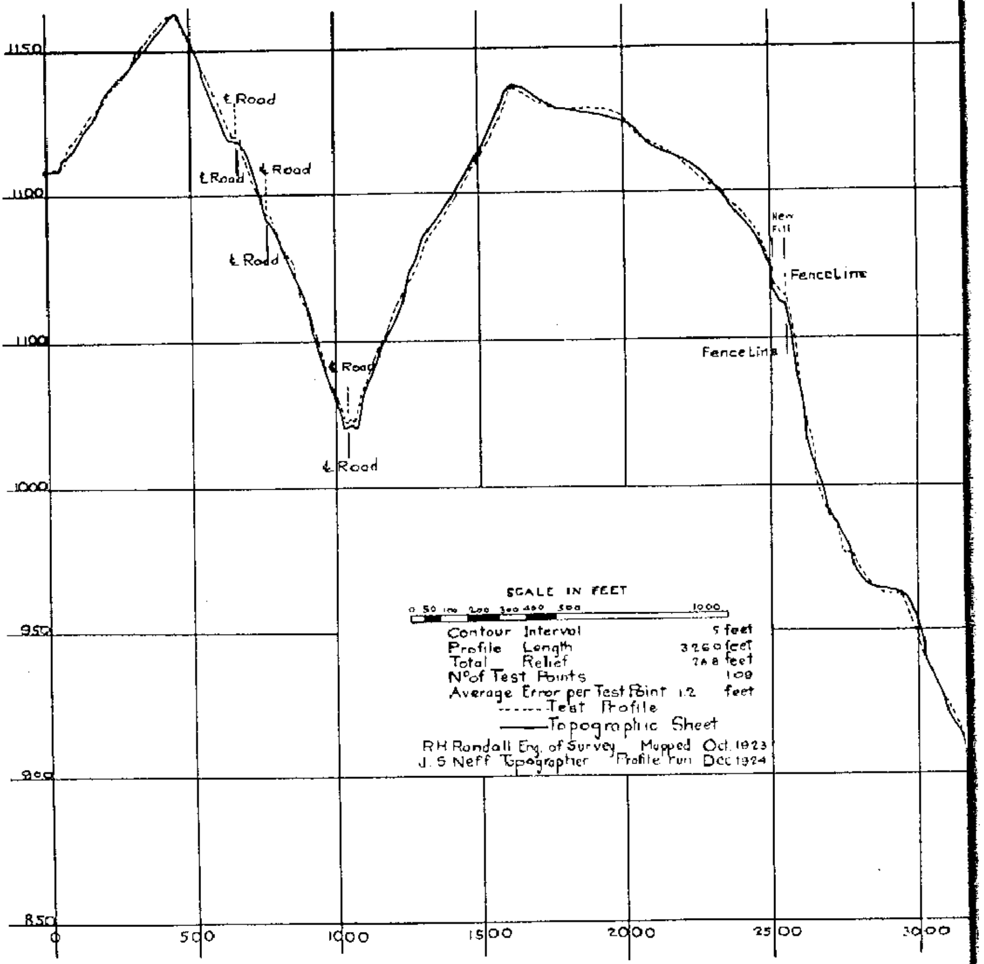

Fig. 11. Test Profile on Topographic Sheet No. 128.

street lines, block corners, etc., which can be identified upon the record plat, are scaled from the field sheets and compared with distances shown on the plat. In those cases where there are considerable

discrepancies between the scaled and recorded distances, the field sheet is returned to the field to be checked. When all identified lengths have been checked against the plats, these checked lines are used as a basis from which the recorded information on the remaining lines and corners are plotted. The property lines shown upon the sheets are the street and alley lines, boundaries of recorded subdivisions, boundaries of public property, including parks, playgrounds, schools, cemeteries, etc. In some cases the boundaries of large, privately owned, undeveloped tracts are shown.

For convenience in reproducing, a cover sheet or information tracing is drawn. This is merely a tracing of the cultural information on the field sheet and shows all streets, roads, alleys, boundaries of other properties, buildings, bridges, tracks, and all lettering to be shown on the reproduced map.

Reproduction. After completion, the field sheet is reproduced in four colors. Cultural information is shown in black, contours in brown, drainage in blue, and public property in green. The reproductions are to exact scale within the limits of paper expansion, and registration is correct at all points, the allowable registration error being 0.01 inch. Two hundred copies on light-weight paper of these four-color reproductions are printed on the initial order. In addition, ten copies are printed on "lenora" cloth for use in binding in atlas form. It is also expected that several copies will be secured showing the cultural information only.

The printing plates become the property of the city and are stored for use in printing future editions, and the making of revisions. Copies of the reproduced maps will be available for distribution to other city and county departments and to the general public.

The beginning of the survey, in the fall of 1923, was made under a handicap due to the necessity of obtaining immediate topographic information and the necessity of starting the control surveys. It was desired to do all plane-table mapping on the regular sheet lay-out with correct co-ordinates, so that each area mapped would be a unit of the final survey. Correct co-ordinated positions were obtained in the first area, in advance of the triangulation, by running precise traverses from the nearest government points having geographic positions on the North American Datum. These traverses were kept in correct orientation by means of frequent azimuth observations, and the co-ordinated positions checked with some former city secondary triangulation which had been tied to another government station in the northwest part of the city. The entire survey from the beginning has been planned so that possible future expansion into the metropolitan area would be easy and convenient. This scheme has now been adopted for the expansion of the city survey to cover the entire area of Allegheny County.

It is probable that the Pittsburgh survey will help to standardize the specifications and standards of accuracy for similar surveys in this country. It is believed that the triangulation and traverse surveys are of a higher degree of precision than has heretofore been obtained over any similar area. Certain instruments, formulas, and mathematical tables and charts have been devised or improved upon during the progress of the survey, and upon completion of the work this information will be published and made available.

The Department of City Planning acknowledges appreciation of the helpful co-operation which the various city and county departments, railroad officials, private engineers, etc., have given. In return for this assistance this survey has already been helpful in furnishing contour maps and other survey data to departments and individuals. A feature which has met with favor among engineers in Pittsburgh is the tape standard established in the basement of the City-County building.

It is strongly recommended that engineers practising within the survey limits make use of the precise triangulation and traverse stations for testing the accuracy of their surveys and co-ordinating such surveys with the city system. The advantages of this to both the city and the engineers are apparent.

PUBLICATION OF REPORTS

It is planned to publish reports giving detailed information concerning the various phases of the survey, designed for the convenience of engineers, as soon as the different divisions of the work shall have been completed. These reports of the city survey will take the following form:

Triangulation. A report giving a sketch of the triangulation net, station names, descriptions, co-ordinates, azimuths and distances.

Precise Traverse. A report giving the results of the traverse system, including description of stations, co-ordinates, distances and azimuths.

Precise Levels. A report giving the elevations and descriptions of all precise bench-marks within the city.

Similar reports for the work in the county, outside the city limits, will be published as the progress of the survey justifies such action.

SUMMARY

Briefly summarizing, at the end of the second full year, the Pittsburgh Triangulation and Topographic Survey has accomplished the following:

1. Completion of all field work necessary for the city triangulation scheme, which includes 103 stations with 11 base-lines. The least-squares adjustment on over sixty per cent. of this system is also completed. In the county scheme, 79 stations have been located and monumented covering an area of 242 square miles. Six of these have been occupied and observed.

2. In the field, 118 miles of precise traverse, controlling approximately twenty-five per cent. of the total area of the city, have been completed. In the county 50 linear miles have been completed for reconnaissance, controlling 30 square miles and referenced by 47 monuments.

3. Fourteen miles of precise levels, augmenting the old city system, have been run and adjusted, and 24 miles of the county system have been run.

4. Eighty-three miles of secondary levels, furnishing bench-marks for the plane-table parties, have been completed.

5. Six and one-half square miles of topography have been mapped in the field.

6. Reproduction on three sheets has been completed and a satisfactory and economical process evolved. Arrangements are now being made for the awarding of a contract for this work.

The survey of the City of Pittsburgh and Allegheny County are both being made by the Department of City Planning, City of Pittsburgh, under the supervision of the City Planning Commission, of which Morris Knowles is Chairman, and Frederick Bigger, James M. Clark, George S. Davison, Charles A. Finley, James D. Hailman,

A. J. Kelly, Jr., James F. Malone, and W. C. Rice are members, with Norman F. Brown, Director Department of Public Works, Allegheny County; Charles M. Reppert, Assistant Director Department of Public Works, Allegheny County; and Edward Schmidt, Division Engineer, Allegheny County Planning Commission, consulting as to the survey outside the limits of the City of Pittsburgh. The immediate planning and execution of the survey are under the direction of the writers, assisted by G. D. Whitmore, Geodetic Engineer, and M. Y. Poling, Topographic Engineer.

DISCUSSION

J. M. RICE:* I would like to ask whether it is proposed to tie in this system to existing city monuments and give us co-ordinates on those monuments?

U. N. ARTHUR: Yes, it is proposed to tie in all existing monuments with this system and give their plane co-ordinates.

J. M. RICE: It would be interesting to know how this compares in cost with similar work in other cities, such as Cincinnati and New York. Is it costing more or less, and how is it justified?

U. N. ARTHUR: It is rather difficult to compare the costs of our survey with those in the other cities named. The bases on which the surveys are made are entirely different. We are working on a scale of accuracy of 1:100,000, while in New York it was 1:25,000, which makes a considerable difference. The Cincinnati survey was conducted on a different system. Mr. Randall can perhaps answer this question more fully.

R. H. RANDALL: What Mr. Arthur has said about comparison of costs is very much to the point. Besides the question of the accuracy which it is desired to obtain, consideration must be given to the local conditions which will affect this survey in comparison with

*Consulting Engineer, Pittsburgh.

others. There is probably no section in this country which presents more difficulties in triangulation than does Pittsburgh. It happens that location of stations has been rather easy, the hills and prominent points occurring at such intervals as to fit in very well with our scheme; but the scheme itself has had to be governed by visibility limitations.

I have here some figures on comparable triangulation costs. In the New York survey, just mentioned, the cost was $415.30 per station. There were 146 stations occupied, and 183 stations of which the co-ordinates are published. The total cost was about $76,000. The accuracy obtained in New York is about 1:25,000. Triangulation in Cincinnati had a cost of $106 per station, and the accuracy is from one-half to one-third of what Pittsburgh is obtaining. In the survey of Richmond, Va., the triangulation cost per station was $105, and the accuracy 1:42,000. These are about all the statistics available for a comparison.

J. M. RICE: What is Pittsburgh's cost?

R. H. RANDALL: The direct labor cost is $255 per station, to which are to be added certain overhead charges, which can not be estimated very well before the work is entirely completed. It is believed that $280 will probably cover the cost per station.

J. M. RICE: What is the total cost to give us the map for the city of Pittsburgh?

R. H. RANDALL: I do not know that I can answer that question exactly at this time. The triangulation is substantially completed over the city's present area, and about 6.5 miles of plane-table mapping have been completed; but, although we have complete records of the unit costs of this work, it is not possible to be sure that they will apply to everything that remains to be done. The exact extent of the area to be mapped is also undetermined. Present plans call for about 115 map sheets, but this will obviously be extended as the city's growth shall require. Costs will also be largely influenced by the order in which different areas are mapped. Certain sheets will from time to time be demanded for the study of specific improvements, even though these are in widely scattered localities and consequently entail increased mapping costs. Thus, while cost is an important factor, the necessity for the vital information furnished by the survey is the governing consideration. These three factors, then—the relatively small amount of unit costs yet available, the undetermined extent of the mapping, and the necessity of securing needed information even at the expense of the best economic procedure—make it practically impossible to give total costs at this time. The justification of our costs must rest upon comparisons with the unit costs of other similar surveys, when these are available, and upon the value of the completed work to the community.

J. HAMMOND SMITH:* I would like to ask to what extent you found it necessary to take into account the curvature of the earth in these surveys?

R. H. RANDALL: The curvature of the earth is allowed for and is represented in the geodetic co-ordinate values. All of the triangulation statistics are to be published with two sets of co-ordinates, the geodetic and the plane. Not only has the curvature been considered in our basic computations, but distances for the traverse lines are corrected for their average elevation above sea-level.

W. E. FOHL:† Will both values be given at these points?

R. H. RANDALL: Both co-ordinate values will be given for all triangulation points, but only one set, the plane, will be published for the traverse stations.

J. M. RICE: It seems to me we are missing an important opportunity of putting on record here just what advantages this topographic survey will be to the municipal authorities and also to the individuals who have to make surveys or use them now; and, secondly, we ought to put on record quite clearly what it will not do. I think that is probably as important as the first. It will not do away with the necessity for a lot of engineering work of a surveying nature. I

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†Consulting Mining Engineer, Pittsburgh.

think Mr. Randall or Mr. Arthur ought to go into that a little more in detail, because we are all interested in that phase of it.

U. N. ARTHUR: We all recognize the limitations of a survey of this kind. Shortly after entering the city service I was impressed with the necessity of some means of co-ordinating the various surveys, made by the Bureau of Surveys, in order that they might be of more permanent value. We hope by this system to have all surveys tied in with the triangulation scheme and co-ordinated, which will not only give a check on such minor surveys, but will make the data secured a permanent part of the city records.

The basic survey maps will furnish a sufficiently accurate basis to determine the feasibility of suggested new projects, especially for proposed new streets, bridges, viaducts, etc. It will also be possible to determine from the topographic maps the approximate cost of all contemplated new work. The main drainage systems can be studied and sufficiently close approximations of the areas of the watersheds determined to establish the sizes of all sewers. Of course, as Mr. Rice intimates, it will not do away with a large amount of engineering work of a survey nature, such as the determination of property lines, etc., but it will do away with a great deal of what we term preliminary surveys, so that engineers, after a study of the maps, can devote their attention to the details of the location of any proposed enterprise without being obliged to spend a lot of time and money in developing the feasibility of the project.

From my own experience in municipal work I feel that one of the chief values of the triangulation survey will be the possibility of establishing absolute co-ordinates for the intersection and angle points on our streets, so that the absolute location of the streets when once fixed can be accurately re-established at any time. Even though the points on our streets are accurately monumented, it is very difficult to preserve such monuments, and when disturbed it is extremely difficult to relocate with any degree of accuracy, unless there is such a definite control system to tie in the location. This survey should save a great amount of money and trouble and many lawsuits by having all surveys co-ordinated so that they can be redetermined and re-established on the ground with a minimum margin of error.

W. E. FOHL: I do not recall whether you fixed the probable time of completion of the work.

U. N. ARTHUR: That depends entirely on the amount of appropriations received. Up until the present time the work has been pushed about as rapidly as was proper. We have now reached the mapping stage and the work can be carried on as rapidly as the funds will permit, provided the necessary number of skilled men in this particular branch of the work can be secured. There are about eighty sheets within the present city limits remaining to be mapped. If ten to twelve parties could be placed in the field it would be possible to complete this work in about one year.

W. E. FOHL: In what way will these results be available to engineers and the public at large?

U. N. ARTHUR: The map sheets are to be published and will be available for distribution. We also plan to publish all information relative to the triangulation, traverse, and level nets. The sheets will show the location and number of the bench-marks and location of the triangulation monuments.

WINTERS HAYDOCK:* In addition to those you have mentioned there are a large number of private land owners who would use the surveys in developing their holdings, are there not?

U. N. ARTHUR: Such property owners should find the topographic maps very helpful in the development of their properties, and especially in the subdivision of the larger tracts.

J. M. RICE: In order to make this available earlier, does the program contemplate picking out undeveloped areas for the first mapping, like the Frick Woods, or the section between Stanton Avenue and the river, or the undeveloped section north of Beechview, which are only partially laid out at the present time?

U. N. ARTHUR: It is our intention to map such areas first. We started mapping at the eastern city line and have the field work com-

*Chief Engineer, Transit Commission, Pittsburgh.

pleted for the entire area within Frick Park. In one of the larger areas you speak of, in the Beechview and West Liberty districts, the traverse is now practically completed. We expect to follow as rapidly as possible with the mapping of former St. Clair Borough and certain outlying districts on the North Side.

J. M. RICE: Those places that are likely to need it first would save a lot of money by the survey to that extent.

U. N. ARTHUR: Yes. For instance, we have mapped the sheet covering the location of the proposed bridge across East Street from Perrysville Avenue to Reserve Township and the Spring Hill district. We are trying to anticipate future improvements and developments such as that, and get the districts mapped in advance as far as possible.

J. M. RICE: In order to tie that into the old monuments will you have to rerun them with the same accuracy of your traverse system?

U. N. ARTHUR: Yes, we will have to run precise traverse to include all monuments.

J. M. RICE: That is quite a job.

U. N. ARTHUR: We realize it is a very troublesome job.

WEBSTER HINNAU:* Mr. Arthur deserves to be congratulated and commended for offering such a comprehensive paper upon a subject of which so little is known. It certainly should be gratifying news to the average engineer in the Pittsburgh district to know that a survey of this kind is being undertaken and at last the city and county have an accurate geodetic and topographic survey well under way.

The necessity for such a survey to be followed by complete maps has always been very apparent to the local engineers, and its need is very clearly shown when we know it is next to impossible with our present information to try to determine the true direction or bearing for the most of our streets in this city. This lack of information often

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makes it impossible to place upon a plan of survey the necessary data often required to draw a correct description of a piece of property which may be in transfer. This predicament is often very embarrassing to an engineer, as the average client knows very little of such matters, and the less he knows the more difficult it is to explain such inaccuracy. After this survey is completed our worries over the variation of the compass and the declination of the needle should be at an end, and there should no longer be any excuse for deeds of adjoining properties giving different courses or bearings for the same common line.

If the members of council could realize as we do the importance of this work, they would gladly appropriate enough money to push this survey to completion as quickly as possible. On the basis of the figures quoted, giving the cost of this work as averaging $1.50 an acre, there certainly could not be any complaint as to cost, for I know the average engineer, including myself, can not take topography for much less than $15 an acre.

When Pittsburgh and Allegheny County have this survey and map completed and the co-ordinates of all monuments of various street corners, it should then be followed by a state act and a city ordinance requiring all descriptions and surveys to be made and drawn in accordance with this geodetic survey, and half the trials and tribulations of the various engineers and surveyors would be at an end.

Morris Knowles:* Since his earliest connection with the city and civic affairs, the writer has been vitally interested in the subject of an accurate survey for the city of Pittsburgh. His attention was first directed to the seriousness of the situation in connection with the studies and preliminary surveys for a proposed new water-supply for Pittsburgh. This was in 1897 and 1898. The paucity of data with regard to the outlying limits of the city, where new works were to be located, was early made clear.

The next notable evidence occurred during the period from 1908 to 1910, in connection with the work of the Pittsburgh Flood Commission and service upon the Engineering Committee thereof. The studies for protection of the city made it apparent that accurate maps of the city and the river fronts did not exist. At this time some local

*Chairman, City Planning Commission, Pittsburgh.

surveying was done for the particular areas to be studied and the triangulation system of the river survey was tied in with some of the city data and railroad surveys.

About the same time, in 1910 to be exact, the Civic Commission called attention to the need of such data in its work. This body was headed by H. D. W. English, who had not only conceived this activity but the Flood Commission work as well while President of the Chamber of Commerce, and was actively interested in both. He requested a few friends to serve on what was called the "Pittsburgh Civic Commission" to study the physical needs of the city. The writer is pleased to have been among the number.

The Sub-Committee on City Planning employed Frederick Law Olmsted to make a study of the main thoroughfares and to report as to desirable improvements. Here again the lack of accurate map data was at once apparent. Some of the comments in this report are particularly pertinent, as for instance:

"No other city has such imperative need of accurate and comprehensive surveys as a basis for the layout of streets, sewers and all public works, for the purpose of avoiding the extravagant mistakes, misfits and reconstructions that are bound to result from groping, piecemeal work done amidst such obstacles.

It is not necessary to give a long list of examples of incompleteness and inaccuracy of much of the old data . . . Every surveyor and engineer in Pittsburgh . . . is familiar with the conditions . . . That there is no adequate system for protecting the monuments that do exist, so that the city has no sure recourse against abutting owners who have encroached upon a street; and finally that no general official surveys whatever exist of the complicated topography of the undeveloped areas."

Following this, it was recommended in this report that:

"Pittsburgh should take example . . . because its peculiar topography is bound to make evil results of unprogressive medieval methods more serious than in other cities. It should take pains to *surpass* rather than to lag far behind in this respect."

The objects then stated to be attained were:

"A.—an accurate framework of reference points;

B.—the existing local surveys and records to be tied into the framework thus established;

C.—complete topographical maps based upon the framework first described."

The writer's next experience was in 1919, when the newly formed Citizens Committee on City Plan faced the ever-recurring problem of making studies for the development of the city and its environs. Again, the scarcity of map data of an accurate nature was early evident. It was also apparent that dissipation of much money in surveying alone would be discouraging to an active business mind that likes to see results. For this reason a program was developed to make a map of the city on a 400-foot scale and another map of the county, including the city, on a 2000-foot scale, which should be reasonably accurate for general planning purposes.

It appeared feasible to co-ordinate some of the important work done in the past and thus prepare the framework of such a map, upon which were to be placed the details, the latter to be acquired from various public and private sources. This work was carried on during the 12 months ending in the summer of 1920, with a force of 50 men, and it is gratifying to know that a really creditable piece of work was accomplished, at a small expense.

The method followed was to secure the original data of the various earlier triangulation and traverse surveys, making new observations and measurements where necessary, to tie in with one another. The whole network was then recalculated to a common basis, checking up traverse closures and reducing various level bases to a common system, so that the data acquired from various engineers and municipalities could be plotted on a uniform basis. From these, and the utilization of all the municipal, railroad, public-utility and private maps of the district, assembled and studied, we were able to prepare these maps for the county and city areas. These served as an excellent framework for all of the planning work of the Citizens Committee which has become so familiar to the citizens of Pittsburgh.

With this historical background and with the realization of the need of accurate survey data, the writer was quite ready, upon his appointment to the City Planning Commission in 1922, to discuss anew the important question of the basic survey for the city of Pittsburgh. It was realized that much preliminary planning could be done with the existing maps; also, that detail planning would require special survey information for the area to be studied. Nevertheless, for the purpose of having an accurate framework, not only for the city but for the entire county; for the purpose of establishing all relations,

horizontally and vertically, upon a common basis; for the purpose of fixing points on which all engineers and surveyors in the district could base their work; for the purpose of giving an opportunity to the city authorities to indicate the reasonable lot and block development of certain parts of the unbuilt acreage; and for other reasons, too obvious to be mentioned among engineers, it was early decided that one of the important functions of the City Planning Commission would be to try to provide for such an accurate survey.

It is gratifying to note that upon such recommendation, and with the approval and warm support of the Mayor, city council was good enough to appropriate $25,000 for the year 1923 to begin such a survey. The next year $50,000 was asked for. The sum of $25,000 was first appropriated and an additional amount of $15,000 was made available before the end of the year. In the year 1925, with a similar request, only one-half the money was appropriated. But during this year arrangements were made with the Commissioners of Allegheny County for the use of $25,000 to expend upon extending the triangulation and precise traverse survey into the territory of the county outside the city limits. At such rates of appropriation it will take a total of 10 years to finish the work for the city area.

When one realizes the importance of this work and when a few samples of finished maps are shown, it is hoped that engineers, realtors, and all having vital interest in such map records will see to it that more liberal appropriations of money are made available for carrying on the work. Such work is really a capital expenditure, because it relates to records to be used for all time. It furnishes data to be used in various expenditures for public works which are outlays of capital. For this reason such moneys may very properly be raised by issuance of bonds rather than by dependence upon annual tax levy and appropriation from the budget.

The survey itself has been so carefully and completely described by the authors that little remains to be said about the methods employed. It should, however, be of great interest to the engineers to have these data recorded in so complete a manner. It is gratifying to know of the general approval accorded to the work, now that its character and purpose are fully realized. Perhaps this is not only the most complete record published in engineering proceedings of such surveying and mapping, but Pittsburghers may take pride in the fact

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that, in harmony with the recommendations in the report of the Pittsburgh Civic Commission by Frederick Law Olmsted, the city has taken pains to *surpass* rather than lag behind in the character and quality of this work. The accuracy, while not meticulous, is the best that has yet been planned for such a survey. It continues to be carried out with the care that was contemplated and promises Pittsburgh a valuable contribution to the ultimate betterment of the city.