Design Standards Letter

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Subject: **Field Procedure and Solution by Electronic Computer for Second Order Traverses**

Body

TO ALL DIVISION, DISTRICT AND URBAN ENGINEERS:

With the increasing complexity of urban projects and the advent of the use of photogrammetry, it is anticipated that our need of high order horizontal surveys will increase. With this in mind, study and experiments on actual field surveys have been conducted and the computer section has written a program for the adjustment of traverses that eliminates practically all need for manual calculation. We are furnishing this procedure, which has proved to be very satisfactory, for the use of the Districts in future survey work of this nature.

Horizontal surveys are divided into four orders of accuracy: First, second, third and fourth orders. The following tabulation indicates the degree of accuracy commonly accorded to each order of survey.

First Second Third Fourth
Order Order Order Order

Distance Check 1/25,000 1/10,000 1/5,000 Any work not Angle Closure 10" /N 20" /N 40" /N falling in lst, 2nd or 3rd

(N = No. of P.I.'s in line)

It should be noted here that merely obtaining results which fall into a certain order of accuracy does not indicate this order of survey has been accomplished. This would allow the possibility of a poorly executed survey with compensating errors to indicate false accuracy. Definite procedures peculiar to the order of survey must be used.

Most of our center-line surveys fall in the third or fourth order. Special equipment not commonly available to our personnel is required for first order work, and we do not anticipate any need for this type of accuracy. With proper procedure, second order

work can be done with our equipment and this paper will deal primarily with second order requirements and procedures.

I. <u>Equipment</u>

A. Transit - The 20" repeating type transit commonly available in the Districts is suitable for second order work. If a better instrument is available, it, of course, should be used.

B. Chain - A 100' steel chain, free of kinks and splices and checked against a calibrated chain will be satisfactory. The Main Office can furnish a calibrated chain if none is available to the District.

C. Thermometer - An accurate thermometer which can be read to the nearest degree and which is quickly influenced by changes in temperature is necessary.

D. Tension Gauge - A gauge to determine the proper tension or pull on the chain is necessary. This may be purchased locally, or through any supplier of surveying equipment. It should be of a size easily handled in the field and should register up to 25 pounds. It should be calibrated before being put into use and periodically throughout the life of its use.

E. Miscellaneous - In addition to the above, normal survey equipment, including two range poles, two extra tripods, and two extra plumb bobs with clean heavy strings will be needed. A chain clamp will prove helpful for the rear chainman.

II. <u>Procedures</u>

There are three steps necessary for horizontal surveys: Establishing transit stations (P.I.'s), turning angles, and measuring distances. These will be discussed in the above order.

A. Establishing Transit Stations - This is normally the first step taken after the general location of the survey has been made. Points selected should be easily accessible and visible to the point ahead and behind. The points should be selected so that the line between them will lend itself to easy chaining. Traffic, parked cars, and the location of objects which might cause refraction should be considered. If at all practical, set P.I.'s so the bottom of the range pole or plumb bob string may be seen from the P.I. ahead and behind.

After the locations of the P.I.'s have been determined, permanent monuments should be erected and referenced. The monument should be of a material not subject to easy deterioration or movement. (Examples: X in pavement, steel bars driven below frost line and center punched, concrete post either precast or poured in place with X or nail in top.)

B. Turning Angles - Different authorities vary considerably on the method and number of times an angle should be turned to give second order results. Using a 20" transit, the following methods will give the required results.

1. Time of Observations - Endeavor to turn angles at a time of day when conditions are best suited for this type of work. Early morning offers the advantage of lack of heat waves and little reflection. Traffic of course, must be considered. It is often advantageous to shade the transit when angles are being turned under a hot sun.

2. Sights - Use range poles on long sights, plumb bob on short sights. Use a tripod to hold the range pole or plumb bob over P.I. If a range pole is used, check it for plumb with a plumb bob, transit, or range pole level. If a plumb bob is used, it will normally be necessary for some member of the party to check swing during the observations.

3. Turning Angles - Carefully level the transit and center it over the P.I. Set the plates near 0° 01'. (In this method, the final angle read will be approximately the initial setting on the plates. A reading of zero degrees is not used for the initial setting to avoid obtaining final readings such as 359° 59' 50".) With telescope direct, take your backsight. Record both veniers. Loosen upper plate, turn a direct angle to the right to the foresight, read and record both veniers. Loosen lower plate, shoot backsight, repeat until this angle has been turned six times. At sixth turning of angle, read and record both veniers. (If angle is over 60°, some multiple of 360 must be added to the reading.) The mean of the sixth angle should be checked against the first angle to see if there is a degree or minute error. Reverse the telescope and, with the original foresight as a backsight and the original backsight as a foresight, turn the explement (360° angle) of the angle six times. Read and record both veniers on the last angle. This reading will be close to the original setting. Obtain the mean of the first six angles and the mean of the last six angles. These should check within 10". If they do the mean of the mean should be used. If not, the procedure is repeated until satisfactory results are obtained.

4. Distances by Stadia - While the transit is set up, stadia should be read and the stadia distance recorded.

C. <u>Chaining</u> - Horizontal chaining will normally not give the desired results. The following paragraphs describe slope chaining with a fully supported chain. A fully supported chain will be considered as one which has no unsupported length of more than 25 feet. Using this method will avoid the need of a sag correction to the lengths measured. There will be isolated instances on the survey where it will be impractical to use a fully supported chain. In these cases either slope or horizontal chaining may be used, with a note in the field book stating the unsupported length of the chain.

1. Chain Length - Prior to chaining the chain to be used should be checked against a calibrated chain. The difference in length, the temperature and the tension used should be recorded in the field book.

2. Line - A range pole should be stacked on the P.I. at ends of the line being changed. Both the Head and Rear Chainmen are responsible for keeping on line.

3. Chaining Points - Chaining points are established by the Head Chairman. They will be numbered starting with zero at each P.I., and progressing to the next P.I. in line. They should not be considered as stations; they need not be 100' or any constant distance apart. They should be marked with as fine a line as possible.

4. Chaining - The chain is stretched between the chaining points with care being taken that it is free from any bends or humps. The Rear Chainman will hold some foot mark on the established chaining point, the Head Chainman will apply proper tension (normally 20 pounds) and establish the next chaining point. Both chainmen will sight range poles on the P.I.'s to assure correct line. The Head Chainman will mark the exact point to which he chained. Both chainmen will call out what they are holding and then repeat what the other chainman held. Both chainmen will record the measured distance between the two chaining points, and the Chief of Party will also record it in the final field book. This process is repeated until the ahead P.I. is reached. At this time, the Chief of Party and both chainmen will compare notes to assure that there is no discrepancy, and the measured distance will then be compared to the stadia distance. Any discrepancies should be investigated and corrected at this time.

5. Temperature - Temperature of the chain should be recorded at the start of each line and at each place the temperature is likely to change. (Temperature will easily change when the surface cover changes; that is, when leaving pavement and entering a grass area or when leaving a sunny area and entering a shady area.)

6. Elevations - Actually, the difference in elevation between adjacent chaining points to the nearest one-half foot would normally be adequate. However, it is almost always necessary to run a line of levels either to establish or check bench marks. We suggest running this line in conjunction with the chaining and obtaining the elevation of each chaining point. These notes can be kept in a separate book and only the elevations recorded in the final field books.

III. Polaris Observations - To properly close some traverses it may prove necessary to obtain the correct bearing or azimuth of some of the lines involved by Polaris observations. Computations for second order observations of Polaris at any hour can be found in any ephemera's. A suggested method for field procedures and recording is described below.

Set transit over P.I. and level carefully. With telescope direct, take a backsight on P.I. at other end of line being checked. Read and record both veniers. Loosen upper plate and sight star. (Bring vertical hair to star by compressing spring.) Call out "tick" at the instant the star passes behind cross-hair. Record time to nearest second. Read and record both veniers. Repeat six direct sights on star, recording the time of each sight. At sixth sight, read and record both veniers. After the sixth sight, reverse the telescope and take six more readings of the same angle with the telescope reversed, recording the

time of each star sight. Read and record both verniers on the twelfth shot. Obtain the mean of the twelve readings and the mean time to use in computations.

There are three very important considerations in the above procedure. (1). The transit must be level. (2) The time must be correct. (3) A smooth orderly progress must be used from the time of the first star shot until the time of the last star shot. The first and third consideration depend on the transit being in adjustment and on good workmanship by the instrumentman. Correct time can be obtained by radio from the Bureau of Standards, 2.5, 5.0, 10.0, 15.0 and 25.0 megacycles, the Naval Observatory, 113 kilocycles (5 minute period every hour), or the Canadian Observatory, 7.5 megacycles. If a portable short-wave radio is available, it may be taken to the field. If not, the watch used should be checked both before and after the observations.

IV. Traverse Closure and Adjustments - To be sure of the accuracy of any traverse, it must be closed. This can be done by completing a loop; that is, closing the traverse on itself. It can also be done by typing the traverse to points in another traverse or triangulation network of as high or higher order; that is, a second order traverse can be tied to a first or second order traverse or triangulation network, but not to a third order network.

Some cities will have monuments established by first or second order surveys, the positions of which are recorded. Most high order monuments were established by one of two governmental agencies; the USC&GS or the USGS. Description, state grid coordinates, geodetic locations, and grid and geodetic azimuth can be obtained for these monuments by contacting the proper governmental agency. The Main Office has many of these on file and will be glad to help in obtaining others.

The process of changing geodetic positions and azimuth to state grid positions and azimuth to modified grid positions and azimuth will not be discussed here. The Computer Section will handle any necessary computations on traverses they close and adjust. The following publications are on the subject:

"The State Coordinate System" Special Publication No. 235, and "Plane Coordinate Projection Tables - Missouri" Special Publication No. 319.

Both publications are by the U. S. Department of Commerce, Coast and Geodetic Survey, and can be obtained from the "Superintendent of Documents, U. S. Government Printing Office, Washington, D. C."

The main office will be glad to give any assistance requested.

V. Electronic Computer Traverse Program - The computation of traverse data on the electronic computer is designed to make corrections to chain lengths and adjustments in bearings with a minimum of effort.

When traversing between monuments established by the USC&GS or USGS, a scale

factor is computed that adjusts the given state plane coordinates to the average elevation of the traverse for listing results, and later is used to return coordinates at the average traverse elevation to the state coordinate plane. The beginning geodetic azimuth is translated to a state grid bearing for listing results and at the ending control station it is translated back to a geodetic azimuth with correction being made for convergency of longitudinal lines in order to check angular closure. When the traverse is closed upon itself the above adjustments are not necessary.

The results consist of bearings, recorded lengths, temperature, slope, and chain corrections, adjusted lengths, balance correction, accumulated adjusted lengths, and X-Y coordinates. In addition, at the end of the first, or unbalanced run, the following are listed: The angular error of closure, the hypotenuse of the X-Y coordinate error, and the proportion of error. If the errors of closure are within allowable limits, a second run is made balancing the traverse by distributing the errors equally throughout the traverse. If the errors of closure are not within allowable limits the listing of the unbalanced run will be returned to the District for further field checking.

The input data required for the traverse program is indicated on the attached samples of the beginning and ending sheets from actual traverses, one closed by running from one USC&GS monument to another, and the other closed by forming a loop. The information required is detailed in the following lines:

VI Load Data - The information entered in the blocked portion of the first and last sheet contains general information on the chain used, the location of the beginning and ending geodetic stations, and data on the transverse Mercator projection within which the traverse lies. This information is referred to as the load data.

The load data is obtained in detail as follows;

<u>Line (1)</u> Chain Corr_____ 0101 x.xxx

Chain Correction - This information is obtained by comparing the chain used in the survey against a chain calibrated by the Bureau of Standards. It may be a positive, or negative correction. If the tape is longer than standard, the observed distance is less than the true distance and the correction is positive. If the correction is negative, insert an "X" in the provided box. The correction is given to the thousandth of a foot as indicated by the small x.xxx mark.

<u>Line (2)</u> Rec. Temp. Deg. F. _____0102 xxx.x

The Recording Temperature in degrees of Fahrenheit. This is the temperature at which the chains are calibrated by the Bureau of Standards. It is normally 68°. If it is not possible to check the calibrated tape against the tape used in (1) above at this temperature, a temperature correction should be made to both chains to obtain a corrected reading. The temperatures are recorded to the degree.

<u>Line (3)</u> R Minus _____ 01/03 .oxxx

The reduction radius in feet per thousand at the central meridian of the appropriate transverse Mercator zone. The reduction radius is given to four decimals. It varies in Missouri according to these zones:

Eastern zone, R Minus = .0667
Central zone, R Minus =.0667
Western zone, R Minus =.0588

No entry is required for traverses closed by forming a loop.

<u>Line (4)</u> Beg. or, End AZI. _____ 0105 xxx^{O} xx'xx.xxo"

The beginning, or ending azimuth is obtained from the description of the beginning, or ending geodetic station. The azimuths are given to the thousandth of a second.

On traverses closed by forming a loop, the district should indicate the bearing they desire to be used between any two indicated P.I.'s.

<u>Line (5)</u> Beg. or, End Lat. _____ 0105 xxx^{O} xx'xx.xxo"

The beginning, or ending latitudes are obtained as in Line (4) above.

No entry is required for traverses closed by forming a loop.

<u>Line (6)</u> Beg. or End. Long. _____ 0106 xxx^{O} xx'xx.xxo"

The beginning, or ending longitudes are obtained as in Line (4) above.

No entry is required for traverses closed by forming a loop.

<u>Line (7)</u> Central Meri. Long. _____ 0107 xxx^{O} xx'xx.xxo"

The central meridian longitude of the appropriate transverse Mercator zone. The value for Missouri are:

Eastern zone = 90°30'
Central zone = 92° 30'
Western zone = 94° 30'

No entry is required for traverses closed by forming a loop.

The following table gives the counties within each traverse Mercator zone:

ZONES

Western Central Eastern

Andrew Adair Mercer Bollinger
Atchison Audrain Miller Butler
Barry Benton Moniteau Cape Girardeau
Barton Boone Monroe Carter
Bates Callaway Morgan Clark
Buchanan Camden Osage Crawford
Caldwell Carroll Ozark Dent
Cass Chariton Pettis Dunklin
Cedar Christian Phelps Franklin
Clay Cole Polk Gasconade
Clinton Cooper Pulaski Iron
Dade Dallas Putnam Jefferson
Daviss Douglas Randoph Lewis
DeKalb Greene Saline Lincoln
Gentry Grundy Schuyler Madison
Harrison Hickory Scotland Marion
Henry Howard Shelby Mississippi
Holt Howell Stone Montgomery
Jackson Knox Sullivan New Madrid
Jasper Laclede Taney Oregon
Johnson Linn Texas Pemiscot
Lafayette Livingston Webster Perry
Lawrence Macon Wright Pike
McDonald Maries Ralls
Newton Reynolds
Nodaway Ripley
Platte St. Charles
Ray St. Genevieve
St. Clair St. Francois
Vernon St. Louis
Worth St. Louis City
Scott
Shannon
Stoddard
Warren
Washington
Wayne

VII. Detail Information

The detail information following the general information is divided into columns as shown below:

A. P.I. Pt. Col. 1-3 xxx

This is a three digit field for numbering the points of deflection. P.I. Pts. are not repeated for each Ch. Pt.

B. Ch. Pt. Col. 405 xx

This is a two digit field for numbering the chaining points between points of deflection.

C. Elevation Col. 6-10 xxx.x

This column is used to give the elevation at each chaining point for use in determining slope corrections.

D. Deflection Col. 11-20 xxx^{O} xx'xx.xxo"

The deflection angles turned at each P.I. are placed on the line following he P.I. number. The deflection angles are positive for right turns, and negative for left turns. Left turns are indicated by placing an "X" in the provided box. In the example given, the transit was plunged 180° from the beginning azimuth before making the first deflection angle.

E. Recorded length Col. 21-26 xxx.xxx

This six digit column is used to record the chain lengths to a thousandth of a foot.

F. Temp. Col. 27-30 xxx.x

This four digit column is used for recording temperatures at the same time of chaining. Space is left for recording to the nearest tenth of a degree. However, the nearest degree is sufficient.

G. results Col. 31-60

The input data sheets and the tabulated sresults are similar, with the columns 31-60 used for additional information obtained from the completed results. The resultant tabulations are explained later in the paper.

H. X Coord. 61-70 xxxxxxx.xxx

I. Y Coord. 71-80 xxxxxxx.xxx

These two columns are filled out only at the beginning and ending P.I.'s which correspond to the beginning and ending geodetic stations. The X and Y state plane coordinates are obtained from USC&GS descriptions of the geodetic stations. On traverses which close by forming a loop arbitrary coordinates should be assigned to the

beginning P.I.

VIII. Traverse Output Data - The first traverse output data sheet is for the unbalanced traverse. The angular error, hypotenuse of error of the X - Y coordinates, and the percentage of error is recorded. If these fall within acceptable limits, the input data is rerun and the actual adjustment of the error is accomplished.

The adjusted traverse output is tabulated on a form similar to the input sheets and a sample is shown for the same sections of Camden 54 as the example input sheets. The output listing is tabulated under these headings:

P.I. PT. Points of deflections
CH. PT Chaining points.
ELEV. Elevation at the associated chaining point.
ADJ. BEARING The bearing of the traverse line.
REC. LENGTH The length recorded by the field party to a thousandth of a foot.

CORRECTIONS:

TEMP. The corrections to chains for expansion due to temperature change
SLOPE The corrections to chains for slope chaining
CHAIN The constant correction to bring the chaining to standard.

ADJ. LENGTH The recorded length with all corrections including balancing
BAL. CORR. Any distributed error in length.
ACCUMULATED ADJUSTED
LENGTHS The accumulation of the adjusted lengths P.I. to P.I.
X-Y COORDINATES The grid coordinates at the average elevation of the project.

IX. Formulae Used in Traverse Program

1. Chain correction

^{L}Rec - Recorded length in feet.

^{C}Rec = Recorded length in feet.
^{C}ch = Chain correction. If the tape is longer than standard, the observed distance is less than the true distance and the correction is positive. Correction is given in feet.

^{L}i = Intermediate resultant length.

2. Temperature Correction

$^{C}t = 0.00000645\ L\ (t_1 - t_0)$

L_1 Intermediate resultant length in feet.

t_1 = Temperature of tape at time of chaining in Fahrenheit.

t_0 = Temperature of tape at time of standardization in Fahrenheit.

C_t = Temperature correction to feet.

$L = L_i + C_t$

3. Slope Correction

$h = E_F - E_B$

$L_{adj} = \sqrt{L^2 - h^2}$

E_F = Elevation at forward chaining point.
E_B = Elevation at back chaining point.
L_{adj} = Adjusted and corrected length.

4. Combined Scale Factor

To adjust given state plane coordinates to the average level of the survey a combined scale factor is computed.

A. To convert from state coordinate plane to sea level.

$$S_{S.P.\ to\ S.L.} = R_{MIN} + 0.0000001144 \left(\frac{X^1}{10{,}000}\right)^2$$

R_{Min} = The negative value of the reduction radius given in the load data.

X^1 = The distance in feet along the X-axis from the central meridian. In Missouri all three central meridians have values equal to 500,000.

$S_{S.P.\ to\ S.L.}$ = Scale factor from state plane to sea level. The average. $S_{S.P.\ to\ S.L.}$ of the beginning and ending stations is used.

B. To convert from sea level to average level of survey.

$$S_{S.L.\ to\ A.L.} = \frac{E1_{AV}}{20{,}906{,}000}$$

^{E1} AV = Weighted average elevation of traverse.

^{S}S.L. to A.L. = Scale factor from sea level to average level of traverse.

C. Combined scale for converting from state coordinate plane to average level of traverse.

^{S}C = ^{S}S.P. to S.L. + ^{S}S.L. to A.L. + 1.0
^{S}C = Combined scale

5. Convert geodetic Azimuth to Grid Azimuth

The correction to the geodetic azimuth in seconds is equal to the difference in seconds of the longitude of the geodetic station and the longitude of the central meridian multiplied by the sine of the latitude of the geodetic station

AZ = Long. sine Lat.

The correction must be added if the station lies west of the central meridian, or subtracted if the station lies to the east. U. S. Department of Commerce Special Bulletin No. 319 contains the tabular method of conversion. The geodetic azimuth at the beginning of the traverse is converted to grid azimuth and the grid azimuth at the end of the traverse is adjusted for convergency and converted back to a geodetic azimuth.

6. To Convert X-Y Coordinates to Latitudes and Longitudes

The following approximate formulae will give answers to the nearest second up to five miles from a known point of latitude and longitude.

$$\text{Lat} = \text{Arc sine } \frac{Y}{R}$$

$$\text{Lat} = \text{Arc sine } \frac{Y}{R \cdot \text{Cos. Lat.}}$$

R = 20,906,000 - Radius of earth

Exact conversion can be accomplished with the aid of U. S. Department of Commerce Special Publication No. 319.

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