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PREPRINT

USE OF CONTROL FOR LAND SURVEYS

By

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Preface: During man's entire stay on earth, land and the ownership of land have been the major substance for sustaining his existence and his most prized possession. The division of these lands and the delineations of their boundaries have led to most international wars, internal strife and revolution, long legal entanglements at the local as well as the national level and in numerous individual instances, the destruction of life long friendships.

The central figure eventually, if not initially, in these aforementioned catastrophes, calamities and irritants has been the surveyor. This is not to imply that the surveyor is responsible for the great wars or the national disagreements over major internal subdivisions or the extensions thereof; but it is certain he must assume much of the responsibility for the problems at a local level.

Although the causes of many local problems can be attributed to incompetence, ignorance and unethical practices, numerous present day difficulties resulted simply from procedures which were accepted or at least tolerated in the past. Land was cheap, the population was small and most clients were more interested in the cost of a survey (as many still are) than its accuracy and permanency of its monumentation. Incompetent, ignorant and unethical operators, one cannot call them surveyors, are practicing today, but fortunately each year their numbers grow fewer as stricter licensing laws are enacted and enforced and the State professional land surveyor societies grow in stature and numerical strength. Land, however, is no longer cheap or abundant in many areas as our burgeoning population clusters in numerous, every expanding megalopoli and once widely separated communities become as one.

In these localities the survey inconsistencies which have been tolerated for so long must be quickly rectified, by legal or other means, so that logical and progressive development will not be impeded. Control surveys can aid in resolving some of these problems inherent from the past and form the sound foundation that will assure similar problems will be kept to a minimum in the future.

Control Surveys: By definition, a control survey is one which provides positions (horizontal and/or vertical) of points from which supplemental surveys are extended and to which the supplemental surveys are adjusted. In general, such surveys are accomplished to a greater precision and accuracy than the surveys dependent upon them. However, in a broad sense, every survey can be considered to be in this category for each does control something -- whether it be the limits of a tract of land or the placement of sewer pipes.

Many papers have been prepared and delivered expounding the value of control surveys in densely populated areas and most, if not all, have rightly emphasized that the orderly step by step regression of survey accuracies is most desirable. Where funds and personnel are readily and regularly available, this is without doubt the proper sequence of operations. But in smaller communities, which are not yet part of an urbanized conglomerate, many land and engineering surveys can contribute to a local control system which can be satisfactorily integrated when necessary into and coordinated with an eventual control survey of the broad area. This same concept can be applied to sections within high density population regions where a total system does not exist or to those localities which may never become part of one of the great population corridors.

To develop such a control network requires the cooperation of surveyors at both the private and public level. It is the intent here to offer suggestions for implementing these systems with particular emphasis placed on the advantages that would accrue to the land surveyors. Cooperation and planning are essential to the success of these endeavors and achieving these particular objectives are undoubtedly the largest task that must be faced. The American professional land surveyor is often a strongly independent person and the idea that he should contribute to an effort that might benefit others in the profession, perhaps to a greater degree, than he would receive, could lessen his enthusiasm. Nevertheless, to develop a control system along the lines as envisioned here will require, to some extent, an additional effort by all participants.

This idea, of course, can be adapted to those communities which are served by a single surveyor. As a matter of fact, very satisfactory control systems have been developed by numerous individual surveyors. One such man, a long time friend of the author of this paper, took the better part of a lifetime to establish his network. Today his once small town is a fair sized city, served by several surveying firms, all of which use the control established by this man. He willingly shared his accumulated data with others, being one who did not believe in confidential offset points and while the legacy he left his community may not be as impressive as a statue, it is much more beneficial.

As may be drawn from the previous remarks, the proposed control network would be pieced together from segments of different projects performed by various surveyors and organizations. Obviously to establish such a network, there must be an overall plan and each section of the basic framework must be accomplished to identical or compatible specifications. A certain amount of direction would be needed and a central depository for copies of the data designated. Much of this effort could be undertaken by committees composed of local surveyors from both the private and public domain or the local section of the national or state societies. Eventually, overall adjustments of the control networks (horizontal and vertical) would need to be made and some system devised to maintain and issue the adjusted data. Ideally as further breakdowns were made within the fundamental net, these data should also be made available to all, but this is probably too much to expect and perhaps in the final analysis the entire idea may meet with little acceptance. Nevertheless, the thoughts involved will be carried to a conclusion.

There is little doubt that any control system, even one that barely meets a minimum acceptable standard, (for argument sake, minimal third-order) is better than none. The inherent problems of the metes and bounds system which has been described as a system where "every parcel of land is a floating island surrounded by other floating islands" and the indefiniteness and inaccuracy of the township-range description of property can be overcome to a large extent through the use of coordinated control.

At this point in time it is not proposed or suggested that these methods and any others that may be presently used to describe land parcels in the United States be superseded by coordinates, but it is highly recommended that these descriptive methods be supplemented by a coordinated control system. Sooner or later however and hopefully sooner the archaic land surveying and description practices will be discarded and replaced by modern technology which will include computerized property identifiers. One day the phrase "the art and science of measuring land" will fully apply to the profession of land surveying.

Even the best of control systems cannot resolve all the existing problems. It cannot, for example, be used to restore lost corners not referenced to the system with any more certainty than present practices, but it can assure that those corners that are in place or replaced by acceptable means will never be permanently lost in the future. As land values rise, the truly accurate demensions of land parcels and their relationship to adjoining properties are essential to purchasers as well as the taxing authorities.

Where the control network includes vertical positioning referenced to a single datum the solutions to numerous problems involving grading, flood plain mapping, gravity dependent systems, subsurface facilities and correlated mapping of areas, large and small are simplified. National Geodetic Survey records show that there are substantially more requests for vertical data than for horizontal control. Since there are many more bench marks than horizontal control stations in the national network, this would seem to indicate that the local land surveyor will employ a control system when the monumentation is readily available. There may be other reasons -- reasonably accurate differences of elevations can be obtained with a small effort using equipment long available and the computations are quite simple.

The non-sophisticated instrumentation for horizontal positioning such as engineer's transits and tapes (chains) have also been in long use and can, when properly employed, give results of much better quality than often realized. But the effort required is greater and the computations somewhat more difficult than leveling. However, it is not thought these are the entire reasons that many surveyors do not attempt to attain better results. Most will say, it is not needed in the type of work they perform, and perhaps this is true in many cases, but in others it is believed excessive caution in trying something new is the real reason. This conclusion is drawn from conversations with numerous surveyors regarding the State coordinate systems and especially with those surveyors who practice in areas of adequately spaced control. However, we are in a time of necessary change and the advantages of a properly designed control system far offset any of the imagined detriments. In one recent article, for instance, the possibility of plat recording errors when using state plane coordinates was emphasized. Yet the argument made little sense, since all the survey elements which were stressed as the major attributes of the present system would still be recorded in addition to the coordinate values for the corners.

Cooperative Networks: The first step in this type of endeavor is to bring together all whose interests would be served. This would include not only the surveyors in the public and private sectors but also those associated with the utilities serving the area and local industry. Attorneys who specialize in real-estate law, planners and representatives of construction firms should be invited and encouraged to actively participate. Local governing bodies should be kept fully informed because it may be necessary to request some monetary support for the complete implementation of the network and enactment of local laws to insure that the system will be utilized and maintained.

Once a harmonious relationship has been obtained, one or more committees should be formed to select the primary and secondary survey routes, set standards and specifications, decide station spacing, types of monumentation, coordinate system to be employed and to delegate the responsibilities for computing, maintaining and issuing the data and the overall direction of the entire project. Although haste in anything is to be avoided, many cooperative ventures often become committee bound and long delays in getting started will soon disenchant the most enthusiastic supporters.

It would be highly recommended that a concerted effort be made to promptly select, at the least, the primary routes. Inasmuch as these surveys will probably involve traverses, the plans must consider the junctioning with other primary routes and the orderly expansion of the secondary systems. Due consideration should be given where good quality surveys have been completed, monumented and the data are available or where major projects such as road or sewer construction, etc. are contemplated in the near future. Along the primary routes, points at one-half-mile spacing are usually satisfactory with further breakdowns at lesser accuracies. Eventually the ideal control network would have monumented points, whose horizontal and vertical positions are known to at least third-order accuracy at each street or road intersection. It may be found that numerous surveys previously accomplished are of sufficient quality to be incorporated in these further breakdowns of the primary net. Expensive monumentation is not required for every control point, cross cuts in masonary structures or boulders, driven rods and similar forms of marking, if properly described may be entirely satisfactory.

As previously noted, identical or at least compatible standards and specifications must be employed. In most instances a 1:20,000 to 1:30,000 standard for the primary net will suffice with secondary and tertiary breakdowns at 1:10,000 and 1:5,000 respectively. These standards are somewhat less than those usually recommended by the NGS in highly developed areas where that organization has established the primary network but for many smaller communities these accuracies are acceptable and achievable. It must be stressed however these are minimum standards, the average closures should be better by a factor of about two.

Where modern theodolites and electronic distancing equipment are available, very little additional effort would be necessary to attain significantly higher standards. However, a few words of caution must be offered -- a higher standard is always desired but should this require a much greater contribution by one or two organizations, it might be better to accept something slightly less if more surveyors and organizations would be directly involved. One final comment in this regard, the National Geodetic Survey is always available for advice concerning standards and specifications and other facets of control surveys.

Recently a paper was presented (7) which included standards and specifications for horizontal surveys where control points were spaced at intervals of 1/2 mile or less. This segment of a rather lengthy paper which dealt with computations as well has been extracted and included in the appendix accompanying this document.

Plane Coordinate Systems: Two primary courses of action, with several alternatives, are open for consideration. One involves local systems and the other, State plane coordinate grids. Both have certain merits in specific situations, but generally where sufficient national network control is available, the State grid system would be preferred. A review of the coordinate systems, alternatives that may be taken and modifications which might be beneficial in some circumstances follow:

1. Local Systems

(a) In a purely local system, one point is selected as the origin and usually assigned X and Y coordinates of sufficient numerical size to assure that negative values will not result. Occasionally the quadrant format is used, that is, the coordinates of the points are defined as N and E, S and W, etc. from the origin. Except in rare instances, the assumed coordinates assigned to the origin in this case are X = 0.00 feet and Y = 0.00 feet. The grid is generally, but not necessarily, referenced to a meridian through the origin, determined from Polaris or solar observations.

One of the advantages in employing this system is that scale reduction factors are not required, however, the distances should be reduced to the datum plane of the origin. Recorded plat distances should be shown as ground level values.

For small areas and some engineering projects where a high degree of accuracy is required this purely local form of plane system is quite adequate. Its major disadvantages are as follows: limited range, it should not be extended more than 20 to 30 miles in any direction from the origin; the points are only related to each other and should two such systems overlap, problems in closures, scale, and rotating and translating from one origin to the other are troublesome and in some cases impractical of resolution. Similar and perhaps more complex problems would be incurred if it were eventually decided to connect to the State coordinate grid.

(b) As an alternative to the local grid just described, (1.a), the origin or some point in the control system should be connected to a station of the national network and the datum plane corrected to sea level. The decision would then need to be made whether the local system should be referenced to the geographic or State grid system meridian through the point of connection. Should the decision be reached that it is preferable to orient the local network geographically, then the approach as described in (1.a) could be taken and the end result would be identical with one specific and most important exception -- that is, each point in the local net would be directly related to every station in the national network. And as a result, no corner defined by coordinates derived from this system could ever be considered lost in a legal sense. This same condition would exist, of course, if the local net were referenced to the grid meridian.

(c) In the local system described by (1.a) it is assumed that stations of the national network are not readily available. Yet, consideration should be given that one day the national net will be extended into the locality and it might be desirable that the local control system be coordinated with the State grid system. Should this be resolved affirmatively, then to save a great amount of recomputation, it would be best at the very beginning to reference the local net to the State grid system meridian passing through the origin and correct each length for both the scale and sea level reductions. The basic computations would then be carried out as though the tie existed. The positional data necessary to compute the differences between the geographic and grid meridians and the scale and sea level factors can be obtained with sufficient accuracy from USGS quadrangle sheets.

Once the actual connection to the national network is obtained, the simplest solution would be to make only one tie or relate all ties to one point. In this manner, all local coordinates would be changed by a constant in X (departure) and another in Y (latitude). This solution is based on the assumption that the orientation of the original system was of good quality and no great difference exists between this value and that derived through the connection to the national net. On those occasions where there are large differences in orientation, it may be necessary to develop formulae for rotating the local systems. Hopefully, if ties are made to more than one point, the scale differential will not be significant and some sort of a mean value for the State plane coordinates of the origin can be devised. In any case all local coordinates need only be changed by constants for X and Y, but each document should carry, if necessary, the formulae for a more exact rotation and if required, translation of the local coordinates.

In the case of the local system discussed under (1.b), the connection to the national network has been made and it is only necessary to apply the scale and sea level factors to the lengths, orient the net through grid azimuths (bearings) obtained through the connection and compute State plane coordinates for all points based on the value determined at the origin. Should additional connections to national network stations be made in the future some problems may arise which could require a readjustment of the entire net. Such readjustments are not desirable and once it becomes apparent that the expansion of the net will carry it into the vicinity of other national net stations, any further adjustments of extensions to the net should be of a provisional nature.

2. <u>State Plane Coordinates Systems:</u>

(a) Much has been written about the State grids, and the references given at the conclusion of this paper enter into great detail regarding the advantages and procedures involved in using the systems, therefore the comments offered here will be directed to the specific problem under discussion. When possible, it is much better to make the connections to all stations of the national network in the vicinity of the control system as soon as practical. The local net can then be built, piece by piece, but once again it is prudent to establish the segments connecting the national network stations promptly. Once a check has been obtained, the primary concern can then be devoted to determining the proper places for the other pieces in the jigsaw puzzle commonly known as a coordinated control system.

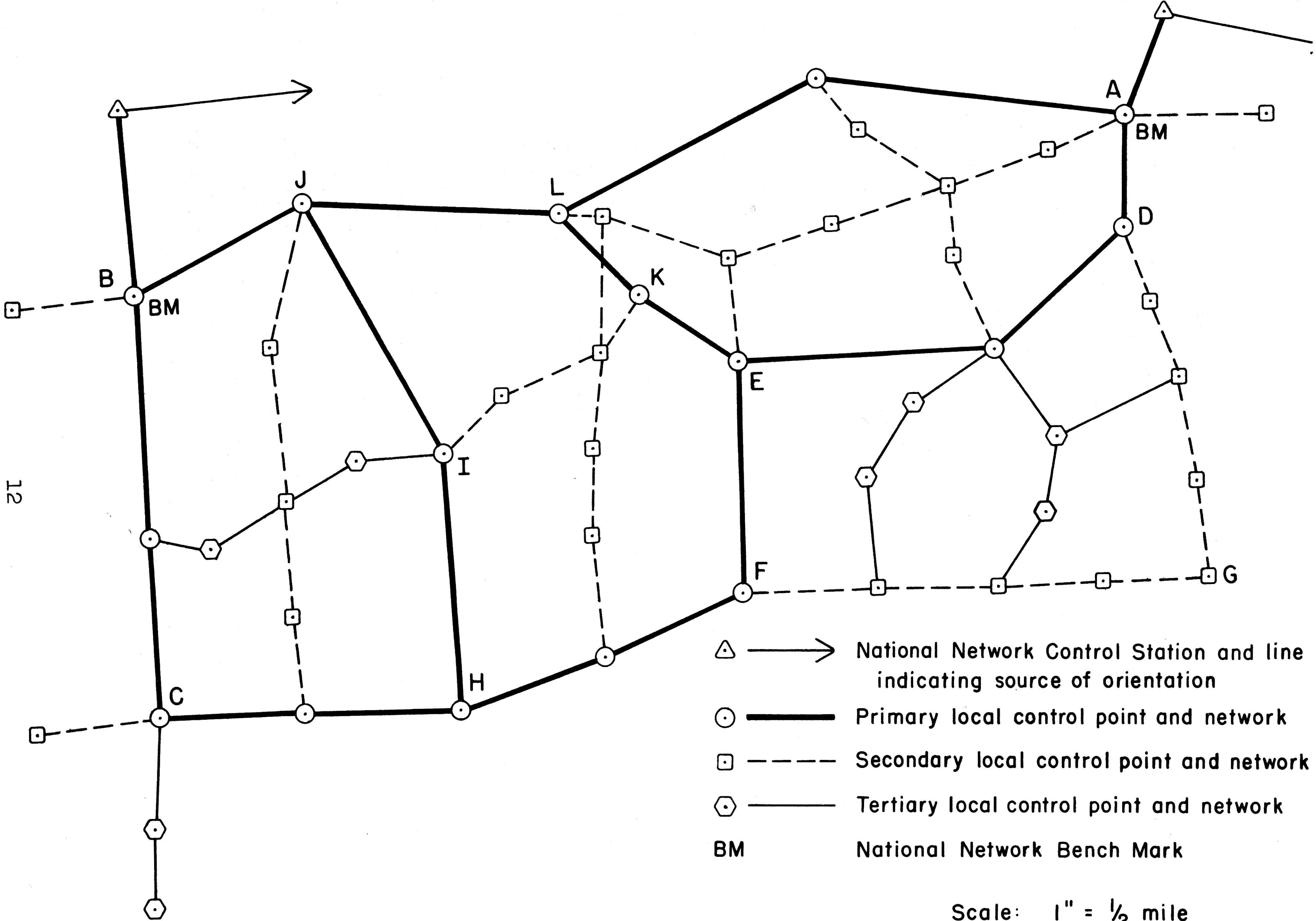
(b) The primary reason for assigning a high priority to completing the national network control connections is rather basic. Stations of this network, as are all monumented points, are subject to destruction from many unforeseen causes, but the replacement of these particular points often requires a large effort and special equipment. There will be occasions, of course, where it will not be practical to promptly perform these connections. In these instances several actions can be taken to lend greater assurance that the control points or substitute points of equivalent accuracy will be available when required.

First, each station site should be visited and the distances and directions to the reference marks and if possible, the direction and azimuth to the azimuth mark verified. Should there be any significant differences in the data as published, the NGS should be immediately notified. Mark maintenance personnel will be dispatched to investigate the situation and check the positioning of the stations. Where a station and its accessory monuments have been verified, it is often wise to establish additional reference and azimuth marks. Intersected objects such as church spires, water tanks, cupolas, etc., whether or not positions have been or will be determined for them adequately serve as additional azimuth points. If electronic distancing equipment is available, one or more satellite points could be positioned some distance from the network station. In these instances at least one and preferably two azimuth marks should be established for each satellite point. Inasmuch as the points may not be connected to the local net for some time, the methods employed to position the satellite stations should contain sufficient built in checks to assure against blunders and care must be exercised throughout the entire operation.

(c) In those cases such as that considered in (2.b) where the national network control is located some distance from the site at which the initial phases of the local system are underway and ties to these stations are not scheduled in the immediate future, the following suggestion is offered. The computations could be carried out using some assumed or observed azimuth (bearing) to orient the system and without having State plane coordinates available for any particular point, but this format for the initial processing of the data is not recommended. Although the lack of State plane coordinates is of little concern at this stage in the progress of the project, the orientation however should be related to the State grid with sufficient accuracy so that large recomputations or rotation formulae are not required when the ties are finally made. In some instances, it may be necessary to initially orient the net as previously noted in this paragraph, but in other cases it is often practical to make the angulation ties between the national control stations prior to connecting the system in scale. These angular connections need not follow the actual proposed traverse scheme and in fact it would be best if the route involved the longest possible lines of sight. The planning, however, must consider the entire system and where practical the points selected to carry the azimuth should be equally spaced throughout the entire net.

(d) The computations should be made using grid distances at sea level and then the adjusted ground level distances can be obtained by dividing the sea level values by the combined grid-sea level factor. Generally, it would be suggested that the coordinates as computed be shown on the plat with the adjusted azimuths (bearings) and ground level lengths. The combined grid-sea level factor should also be shown on the plat. Other data such as the mean elevation above sea level used to derive the sea level factor plus the mean X' (transverse Mercator grid) or the mean latitude (Lambert system) from which the scale factor was determined should be included as well.

Some may wish to divide the adjusted State plane coordinates for the points by the combined scale-sea level factor and show these values on the plat. The adjusted ground level distances would then be exactly compatible with coordinates. This method is entirely satisfactory <u>providing</u> a distinction is made in the coordinates by omitting non essential numbers to the left of the decimal point. The resulting coordinates should be referred to as project datum coordinates with a full documentation included on the plat. All other information noted previously should also be included on the plat. As a matter of fact, for isolated local control systems involving areas of limited extent with little variation in elevation, the coordinates for the basic control points may be given in the project datum form and all further calculations would then be carried out using horizontal ground level lengths. In such cases, however, it must be reemphasized that each document should carry a full explanation of the system including the necessary constants and factors required to reduce the coordinates to their proper datum.



A
BM
B
BM
C
D
E
F
G
H
I
J
K
L
National Network Control Station and line indicating source of orientation
Primary local control point and network
Secondary local control point and network
Tertiary local control point and network
BM National Network Bench Mark
Scale: 1" = 1/2 mile

Figure 1

Example of a Cooperative Control System: For the example shown by Figure 1, the discussion which follows is presented as an actual project history although in reality it is largely fictional.

1. After due consideration by all concerned, it was decided that the primary traverses would be accomplished to a minimum standard of 1:20,000, the secondary breakdown surveys to 1:10,000 and the tertiary system to 1:5,000. The system was to be connected to two triangulation stations and two bench marks of the national control networks, thus assuring an independent check on the horizontal and vertical positioning of the local points and State plane coordinates were to be employed. Leveling over the primary routes was to meet national second-order standards, that is 0.035 ft. $\sqrt{M}$, where M is the distance in miles. All other leveling was to meet at least third-order accuracy (0.05 ft. $\sqrt{M}$).

2. At the present time the community is primarily concentrated in the northeast section as illustrated by Figure 1, bounded on the north by a major east-west State highway, to the east and south by two waterways which intersect at the southeast limits and the western boundary is defined by a gravel road. A County highway passes along the southern limits of the present area of population density, then turns south to the river and westward along the river to the adjoining town. Large scale industrial development is about to take place in the southeast sector with accompanying residential planning underway to the northern and western extremities of the incorporated area. To the east is a larger municipality with a survey system of moderate accuracy, which is also connected to the national network, but a local grid system is utilized. However, this will present no problem in correlating any mapping since both systems are directly related.

All things considered, the primary, secondary and tertiary routes were selected on the basis of available information as outlined in items (3) through (9).

Since annexation of lands to the north and west are scheduled for some future date, it was particularly desired that primary control be established along these present boundary lines. The estimated schedule for completing the basic local framework was within a five-year period. It was also decided to name the local Department of Public Works as the depository for all records and this agency agreed to review all preliminary computations and issue provisional data.

3. As part of an improvement project involving the State highway, the Highway Department agreed to up-grade their normal survey practices in the segment between points A to B to meet local requirements both horizontally and vertically and to make the connections to the triangulation stations. These connections would have been made in any case as all State highways are coordinated with the State grid.

4. A local reservoir is to be located near the westernmost triangulation station with the intake lines from the river pumping station being adjacent to the gravel road bounding the present western limits of the community. The Water Authority agreed to include in the contract for constructing the aqueduct that the necessary surveys between the county road on the south and the State highway on the north must meet the minimum standards as specified for the local primary surveys.

5. The industrial park being planned at the confluence of the two streams involved numerous subdivision and engineering surveys. After several consultations with the various industries, consultants and surveyors, it was agreed that the boundary surveys (D-E-F) along the county road on the north and west sides of the property would be performed to the required standards for local primary surveys. Bounding surveys on the south and east sides (F-G-D) were to be accomplished to prescribed secondary standards and internal subdivisions to tertiary requirements. The connection between A and D was made by local surveyors during the course of work on an urban renewal project (item 7).

6. Contracts for the construction of primary sewers along the county road and the northward extension off this road which would serve the planned new residential areas stipulated that the surveys between points C-H-F and H-I-J were to be of primary quality as described in item 1. of this report.

7. Much of the older section of the community is to be redeveloped in an urban renewal project. Since extensive segments of the area are to be razed and most monumentation would be destroyed, the first thought was to establish a primary system throughout the entire section so that more accurate relocations of the land parcels included could be achieved. However, the initial renewal segment was only about 1/2 square mile in area. It was

then decided to complete the basic loop (L-A-D-E) with a connection of primary quality from E-K-L and to establish traverses of secondary accuracy throughout the urban renewal and adjacent sections. The work was accomplished by local surveyors paid by urban renewal funds with some assistance by Department of Public Works personnel. Establishment of control at some distance from the renewal site using project funds is entirely justified on the basis that monumentation undisturbed by construction activities will be required to accurately relocate the property boundaries and interior land parcels.

8. Inasmuch as land values are increasing in the area bounded by primary traverse E-F-H-I-J-L-K, it was decided that any surveys extending along the preselected routes as shown in Figure 1 would be made to secondary standards. This section of the city is undergoing considerable subdivision for residential purposes and numerous surveyors employed by the developers, utility companies and the Department of Public Works cooperated in establishing the net. Additional surveys to lesser accuracies are underway as further subdivisions are being made and hopefully these data will be forwarded to the depository.

9. The westernmost area has some undesirable terrain features and it was decided that only the north-south route need be to secondary accuracy. It is along this route that development is occurring and the surveys were accomplished by land surveyors and utility crews. The east-west cross connection was performed to tertiary standards in the course of surveys for a feeder line for the water system.

10. A recent ordinance passed by the City Council makes it mandatory to connect to the local control net and to place permanent monuments at all street intersections or junctions with certain specified limitations and exceptions. Eventually, all plats are to contain State plane coordinates for all property corners or sufficient data to compute such coordinates. This ordinance also contains regulations protecting all survey monumentation and places the responsibility for their safety on the contractors, developers and anyone operating equipment in the vicinity of the monuments. A fine of as much as $1,000 may be levied for any monument destroyed and in many instances on major projects, $1,000 bonds for each monument in the vicinity must be deposited with the Department of Public Works prior to initiating any work.

11. With the completion of the project, the city plans to request the assistance of the National Geodetic Survey in simultaneously adjusting the data. In past correspondence with that agency, the subject was discussed, but no firm commitment was obtained for reasons that are given below.

The National Geodetic Survey has adjusted many surveys established by municipalities. These adjustments were made providing the work had been accomplished to acceptable standards, contributed to the national network, properly monumented and described and the data were presented in a format compatible with their computer procedures. Whether this practice will be continued in the future will depend on several conditions. Among them being, the NGS office work load at that particular time but more important, the capability of commercial computer organizations to perform the computations in the manner necessary to obtain the most satisfactory results.

For those who may wish to make their own computations, programs are presently available to adjust rather large traverse networks, but require an IBM 360-30 computer. Within a year or so, programs will be available to adjust any conceivable type of survey system, but these too will be designed for large computers.

<u>Summation:</u> This paper has strayed somewhat from the original intent as inferred by its title, and was done deliberately. To consider only control as needed for land surveys places it in the single purpose category, and there are far too many surveys of this type undertaken each year expending vast sums with little or no residual return.

The cooperative network concept as discussed is not new nor original with the author. Although there is no knowledge available that any control systems on the scale or multiple involvement as described here have been developed, the idea is basically sound. It is known however that at least one state society is considering essentially what has been discussed in this paper. The cost of establishing control networks following the same procedures as employed in the past is constantly increasing and it may very well be that the only solution for many smaller communities will be the cooperative route. In our history we have joined in numerous multiple participation efforts, and there is no reason why a survey control system should be an exception.

In a recent paper (8) Michael C. Kaminski itemized the advantages of adopting the State coordinate systems. Although the benefits listed were attributed to the State grids, they are identical to those that would accrue from any well conceived control net and are particularly directed to land surveyors. The listing follows, and as may be noted some of the advantages apply to both horizontal and vertical control systems:

(1) Places all types of surveys on a common datum.

(2) Provides supplemental identification for property descriptions.

(3) Establishes a relative position value for adjoining surveys and projects.

(4) Provides a common mean to "tie" together Public Works projects.

(5) Provides a common numerical value for survey lines and corners.

(6) Provides a common numerical value for restoration of lost corners.

(7) Provides an easier method to proportion error closures by mathematics.

(8) Helps minimize error accumulation.

(9) Simplifies computation of "cut off" tracts, parcels, and acres.

(10) Provides consistent programming for computer systems.

(11) Provides an instant check on large blunders.

In conclusion, there is one more benefit that may eventually be received from a good control system. That is, at some period of time, photogrammetric techniques will advance to a stage where few surveyors will venture into the field except to extend a system or to remonument previous surveys. Some may think this is a dream, but one needs only to look back just a few years and then it does not take much of an imagination to visualize that the future holds much that cannot even be conceived today.

APPENDIX

CLASSIFICATION DEFINITIONS

Class 1 City Survey - Heavily urbanized sections of any city and many industrial areas. Land has very high value and requires surveys of a high order of accuracy.

Class 2 Urban and Suburban Surveys - Includes property in any thickly settled or built up part of a town. Land used for residential or industrial subdivision of moderate to high value. Rural property for which development is planned or assured in the near future.

Class 3 Suburban and Rural Surveys - Includes any property such as farms and wooded areas or terrain which primarily consists of marshes, mountains, and/or swamps which has little immediate value, but has potential for future development.

The following standards and specifications were primarily designed for surveys in those areas where control is closely spaced (one or two miles, or less) but they could be applied to surveys where the control is more widely spaced providing care is exercised throughout the field operations.

TABLE I - STANDARDS AND SPECIFICATIONS

	CLASS 1	CLASS 2	CLASS 3
POSITION CLOSURE	1:15,000	1:10,000	1:5,000
ANGLES ACCURATE TO	5 sec.	7 sec.	14 sec.
DISTANCES ACCURATE TO (per 100 feet)	0.002 ft. (1:50,000)	0.004 ft. (1:25,000)	0.007 ft. (1:15,000)
REJECTION LIMIT OR SPREADS BETWEEN D & R AND SETS	5 sec.	5 sec.	10 sec.
NUMBER OF POSITIONS OR SETS			
1" Instrument	4 Pos.	4 Pos.	2 Pos.
10" Instrument	1 Set 6DR	1 Set 6DR	1 Set 2DR
20" Instrument	2 Sets 6DR	2 Sets 6DR	1 Set 4DR
30" Instrument	3 Sets 6DR	3 Sets 6DR	1 Set 6DR
1' Instrument			1 Set 8DR
AZIMUTH CLOSURE	$8'' \sqrt{N^*}$	$10'' \sqrt{N^*}$	$30'' \sqrt{N^*}$
AZIMUTH CLOSURE PER ANGLE POINT	3 Sec.	5 Sec.	10 Sec.
NUMBER OF REPETITIONS (distance measurements)	1	1	1
TAPING CRITERIA			
Temperature	Accurate to ±2°F	Accurate to ±2°F	Accurate to ±5°F
Tension	Accurate to ±2# of standard	Accurate to ±2# of standard	Accurate to ±5# of standard
Calibration	**	**	**
TYPE OF TARGET	Fixed	Fixed	Plumb Bob String or Fixed

1. It is recommended that 30" transits not be used for Class 1 & 2 surveys.
2. * N = Number of angle stations carrying azimuth. The smallest value for the azimuth closure criteria will apply.
3. Fractions of a full tape length must be checked.
4. Properly calibrated electronic distance measuring equipment may be used in place of metal tapes.
5. Side points observed from primary traverses shall conform within reason to the required accuracy for the primary traverse. The accuracy of the observations, of course, will depend on the type of point observed. Whenever indefinite points, such as fence corners, tree stumps, etc. are involved, the best approximation of the center or specific point previously described should be observed. Each angle should be oberved 2DR and the spread between the D and R observations should not exceed ±20".
6. Method of taping outlined in paper. Tension applied should be same used to standardize or calibrate tape.

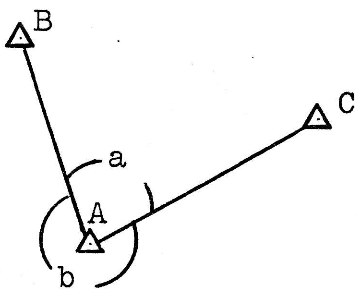
** Standardized tape or one calibrated with a standardized tape.

Angle Observations: With a 1" theodolite, 2 positions and 4 positions, using the recommended rejection limit, an accuracy of within 5 and 3 seconds, respectively, will generally be obtained. The other angle requirements were developed using this criteria and that given previously. As most surveyors are well aware, a large number of repetitions with repetitive (transit) type instruments does not provide the accuracy one might expect. The number of repetitions recommended are based on pointing accuracy of the instruments as related to the accuracy with which the instrument can be read. Should adverse lateral refraction be present, the number of positions and sets should be increased.

When angle observations are made with a transit, one or more sets of direct and reverse angle observations are made. The number of repetitions which compose a set vary with the accuracy required. Regardless of the number of repetitions, the observations with the instrument in direct position will be made of the interior angle, and the observations with the instrument in reverse position of the exterior angle. Figure 2 illustrates the procedures involved with one set of 6 repetitions of direct and reverse observations, the method of recording, and calculation of the angles.

In using a repeating type instrument a constant is determined by the formula 360/n, where "n" is the number of repetitions. For the example given (fig. 2), the constant would be 60° since six repetitions were made. If four repetitions were observed, the constant would be 90°.

When making six repetitions of an angle if the angle is less than 60° the sum of the repetitions divided by six gives the angle directly. When the angle is between 60° and 120° the sum of the repetitions is six times that part of the total angle which is in excess of 60°. Since this is the case in the example (fig. 2), simply add 60° to the angle resulting from the repetitions. Should the angle be between 120° and 180°, 120° would be added. In the example involving the exterior angle, as also shown in figure 2, the angle is about 271° or about 31° greater than the nearest multiple of 60° which would be 240°.



1) observe 6 repetitions of angle "a" with instrument in direct position.
2) reverse telescope and observe 6 repetitions of angle "b" with instrument in reverse.

Obj. Obs.	Tel D or R	Reps.	Angle		A "	B "	Mean "	Angle			
B-C	D	0	00	00	00	00	00				
	D	1	88	59	50						
	D	3	266	59	20	20					
	D	6	173	58	40	40	40	88	59	46.7	
C-B	R	6	00	00	10	20	15			44.2	45.4

Determining the angle B-C from 6 repetitions in direct position.

a)	173°	58'	40"	Last angle read in direct
b)	28	59	46.7	Last angle divided by number of rep. (6)
c)	60			60° x 1*
	88	59	46.7	b + c

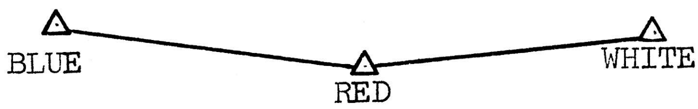
Determining the angle C-B from 6 repetitions in reverse.

a)	00	00	15	6 R value
b)	173	58	40	6 D value
c)	186	01	35	a - b
d)	31	00	15.8	c ÷ number of reps. (6)
e)	240			60° x 4*
f)	271	00	15.8	d + e
g)	88	59	44.2	360° - f = ∠ B-C

* See explanation on p. 20 and at the top of this page.

Figure 2

When direction type instruments are utilized it is strongly recommended that the method of positions be employed rather than sets of angles. A direction theodolite cannot be used in the repetition mode. The recording procedure for this method is shown in figure 3. It is very simple and in the long run will produce results far superior to a helter-skelter method. The observing procedures are described in some detail in ACSM Technical Monograph No. CS-1 (see Bibliography).



Object Sighted	Pos. of Inst.	°	'	"	"	Mean of Dir.	Direction "
BLUE	D	00	00	10	10		
	R	180	00	15	15	12.5	00.0
WHITE	D	176	42	25	25		
	R	356	42	31	31	28.0	15.5
BLUE	R	270	05	33	33		
	D	90	05	38	38	35.5	00.0
WHITE	R	266	47	49	49		
	D	86	47	55	55	52.0	16.5

Mean ∠ at RED - BLUE to WHITE 176° 42' 16".0

Recording procedure for 2 positions observed at RED.

Figure 3

Regardless of whether a theodolite or transit is employed the observer must take precautions to assure that both the instrument and targets are properly centered over the points, leveled, and that parallax has been eliminated from the instrument. When more than one position or set is observed, different portions of the horizontal circle should be utilized to minimize circle errors (see fig. 4). When observing, both direct and reverse pointing should be observed for each position or set to eliminate collimation caused by the cross hairs not being truly centered.

30" Transit
Circle graduated to 20'
Two Sets

Set No.	Setting
1	0° 00' 00"
2	90 10 30

Three Sets

Set No.	Setting
1	0° 00' 00"
2	60 06 30
3	120 13 00

20" Transit
Circle graduated to 20'
Two Sets

Set No.	Setting
1	0° 00' 00"
2	90 10 20

1" Theodolite
One division of circle = 10'*
Two Positions

Pos.	Setting
1	0° 00' 10"
2	90 05 40

Four Positions

Pos.	Setting
1	0° 00' 10"
2	45 02 40
3	90 05 10
4	135 07 40

* Wild T-2 and Kern DKM 2 theodolites are examples of instruments which have circles with a least division of 10'.

Figure 4

Distance Measurements: In determining a distance using metal tapes there are six basic steps: (1) lining in; (2) applying tension; (3) when using plumb bobs in horizontal measurements raising the point to be measured; (4) marking tape lengths; (5) reading the tape; and (6) recording the distance and temperature. Blunders or errors may be introduced into the final distance by not properly performing any of these steps.

To minimize these errors the following methods are recommended for the various type surveys discussed.

Class 1: Direct measurements shall be made with reductions made to the horizontal using differences of elevations obtained from leveling. Vertical angles may be occasionally used when the line of sight either coincides or is reduced to the line of measurement.* Taping benches or equivalent will be used for all measurements.

Class 2: Same as Class 1.

Class 3: On reasonably level ground horizontal measurements may be made using plumb bobs providing great care is exercised and experienced personnel are performing the measurements. However, it is recommended that taping benches or equivalent be used as even the best measurements made using plumb bobs would seldom be accurate to 1:7,500, and more likely would be on the order of 1:5,000. This taping method is also susceptible to the introduction of systematic and compensating errors in measurements. For steeper grades, measurements must be reduced to the horizontal using differences of elevation obtained from leveling or through vertical angles providing the line of sight and the line of measurement coincide.*

* Since each individual measurement must be reduced to the horizontal, the reduction via the cosine of the vertical angle would seldom be recommended unless each measurement had been made from the spindle of the telescope axis. The use of vertical angles to determine the differences of elevations between the tape end points is entirely satisfactory in most cases, however; but generally leveling is easier.

<u>Summary</u>: It must be remembered that these are minimum specifications, and that in many cases it is advantageous to exceed these minimum requirements. For example, observing only two positions with a theodolite utilizing a 10 second rejection limit could introduce a 10 second or larger error into the angle due to a blunder. A third position would have isolated this blunder. For the same reason, double taping of each distance may be worthwhile especially if the measurements are made over difficult terrain. A little more care and effort throughout all field operations may eliminate costly resurveys due to such blunders.

The accomplishment of surveys to these standards will not be achieved by reading the specifications and then implementing only those in the field that are convenient. The licensed land surveyor is a professional and he must perform and insist that his employees perform in a professional manner.

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* Available through the Superintendent of Documents, Government Printing Office, Washington, D. C. 20402.