MUNICIPAL COORDINATE CONTROL*

by Lorne Pelton

INTRODUCTION Coordinate control surveys have been established in many Canadian cities during the past four years and it might be of some benefit to describe what a plane coordinate system is. Briefly, a plane coordinate system consists of two axes which intersect each other at right angles at a point called the origin. If two city streets intersect each other at ninety degrees they could be considered as the X and Y axes of a plane coordinate system and all points in the four adjoining blocks, or quadrants, could then be referenced to these axes by an x distance along one street and a y distance measured perpendicular to the X axis. Most cadastral surveys are carried out on areas which are considered as plane surfaces. The error introduced by neglecting curvature only amounts to about 1 part per million at a distance of ten miles from the origin and therefore a plane rectangular coordinate system is ideal for surveys of areas up to about 25 miles in diameter. However, when an adjoining coordinate area is met the two systems clash. The bug-bear here is of course, that our globe is not a cube and we have to concern ourselves with the spheroidal curvatures of meridians, parallels, geodesic lines and the like. Nevertheless, if we take into account a certain area, its shape, its east-west and north-south dimensions and the scale distortions that we can allow it is possible to come up with good projection systems that will give x and y coordinate references that are related to the geodetic latitudes and longitudes for the points. It is then possible to give any point in the area an x, y coordinate value and if greater accuracy is desired, known scale corrections can be applied to give geodetic values for the positions, angles and distances. It would be possible, for instance, to pick a projection system that would give scale errors up to 1 foot in 3000 feet. These projection errors are known and the coordinate system could still be used for highly accurate surveys. With today's precision distance measuring instruments it is relatively easy to obtain traverse closures of 1 foot in 10,000 feet. It would seem advisable therefore, to pick a projection system that would allow plane angles and distances to be used and still attain accuracies of 1 part in 10,000. Small scale corrections would then only be required for a few specialized surveys. Since angles are very important in any survey a conformal projection is desirable. This means that there is no differential angular distortion between angles calculated on the projection and corresponding angles measured in the field.

HISTORY The importance of a system of rectangular coordinates is slowly but surely becoming apparent to most people connected with surveying. The survey data is of benefit to federal, provincial and municipal organizations as well as to private land surveyors and engineers. Officials of the Department of Mines and Technical Surveys feel it is a responsibility of the federal government to encourage and assist municipalities to establish networks of good survey control. The Surveys and Mapping Branch has been able to provide such assistance by establishing first and second order control to which other municipal surveys can be referenced. Trained personnel, precise survey instruments and modern computational equipment and methods, have been made available to carry out a limited program of municipal control surveys.

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In 1961 discussions were begun between Mr. C.A. Boileau, Superintendent Engineer with the Montreal Department of Public Works, and Mr. S.G. Gamble, Director of the Surveys and Mapping Branch of the Department of Mines and Technical Surveys. This resulted in an agreement to establish first and second order horizontal control to supplement a network of first order levels that had been put in previously by the levelling section of the Geodetic Survey. Inquiries soon followed from officials of the Metro Toronto Department of Roads. Field surveys began in these two metropolises during the summer of 1962. Since that time the Surveys and Mapping Branch has assisted twenty-three separate municipalities in establishing an integrated control network for their particular areas. Two of these areas are in British Columbia, four in Alberta, three in Saskatchewan, one in Manitoba, eight in Ontario, two in Quebec, two in Prince Edward Island and one in the Yukon. I understand that Sydney, Halifax and Dartmouth are scheduled for next summer.

FIELD WORK FOR MUNICIPAL CONTROL The field work connected with municipal control is very interesting to me and I would like to go into this aspect in a little more detail. Reconnaissance is one of the most important steps to a good second order net and if at all possible the party chief should look after this phase of the work in cooperation with the municipal officials. He should try to determine which roads are to be widened in the immediate future and which side is to be widened. All schools, churches, parks, municipal grounds and hydro lines should be located. He should build up a mental picture of prominent landmarks, and ground locations that are intervisible with the first order control stations. The second order points must be accessible and relatively permanent and the network should be dense enough to be practical for a surveyor to use. Whenever possible neat orderly loops should be laid out and redundant lines across numerous loops should be avoided. The method of using temporary stations with side-shots to main coordinate control stations should be avoided as check measurements or future relocations will be difficult to make after the temporary marks have disappeared. Signal mirrors, binoculars and walkie-talkie radios are essential to good reconnaissance. Underground utilities should be located and utility companies should be advised even if a monument is only to be located near their lines. This is in the area of public relations which I believe is very important. In fact, the utility companies should be urged to tie their lines in with coordinate references once they become available so that the relative positions of the local utilities can be established. It is a good policy to inform the owner of property adjacent to a proposed monument site as to what the monument is there for and how it can be used and ask him if he sees the monument being tampered with to call the local city surveyor or whoever is in charge of the monuments in that area.

One of the most important prerequisites to a second order network is a strong first order framework. The Geodetic Survey established twenty-four first order stations in and around Metro Toronto which covers an area of 240 square miles. This gives a density of one monument for every 10 square miles. This is essential in order to provide the necessary azimuth and positional control for the second order work. According to the Surveys and Mapping Branch control specifications, the maximum number of courses along the most direct route between azimuth control points is 10 and the probable error of astronomic azimuths should be within 0.3 seconds. This is impossible to achieve with a normal star shot on polaris. Small errors will inevitably occur in the second order work but with a strong first order framework and proper adjustment these errors can be distributed to give an overall uniform system.

The main difference between my last summer's operation in the Burlington-Oakville-Toronto Township area and the 1962 to 1964 surveys of Metro Toronto and Hamilton was that distances were measured by day and angles at night. With the early model Geodimeters it was necessary to make most of the measurements at night. To keep the vehicles and equipment working efficiently on a 24-hour basis it was therefore necessary for the angle work to be carried out during the day. With the coming of the mercury arc lamp and the new model 6 geodimeter it was possible to reverse the scheduling. Last summer using a model 6 Geodimeter with a standard bulb it was possible to measure lines up to 1 1/2 miles in daytime and about 4 1/2 miles at night.

There are many excellent features to the new Model 6 Geodimeter; however I am not here to sell geodimeters so suffice it to say that we found them very reliable and easy to use. As in previous years communication between stations, on both the geodimeter and angulation parties, was by walkie-talkie radios. These were F.M. sets in the V.H.F. band.

Specifications for second order control as outlined by the Surveys and Mapping Branch state that the maximum anticipated error in measured lengths, after reduction to sea level, should not exceed 1 part in 50,000. The closing error for traverses must be better than 1 part in 20,000. Because of an inherent error of about 1 cm. in the geodimeter an attempt was made to keep the distances between successive monuments to a minimum of 1000 feet and preferably 2000 feet. Although ambiguities are unlikely with the model 6 geodimeter we again used a 50 cm. bar at the reflector end and two complete measurements were taken for each line. For the first position the reflector was set 25 cms. in front of the plumb point and for the second position it was set 25 cms. behind the plumb point. The two measurements were then meaned to give the required distance. The two readings give a good check on your work and little time is required to take the extra measurement as only the prism housing at the reflector end needs to be moved. Seven foot tripods were used for sightings over cars, pedestrains, mailboxes and the like. On one occasion the reflector was placed on a four foot extension bar on top of a 7 foot tripod in order to clear some waving grass that was blocking the line of sight. Distances less than 800 feet were chained to maintain accuracy.

A Wild T-2 was used for angle measurements along with the Wild traversing equipment which allows the instrument and target to be interchanged on the tribachs without moving the tripod. Eight sets of horizontal angles were read for each required angle and a maximun deviation of 5 seconds from the mean was accepted. If large spreads were encountered extra sets were taken until a satisfactory mean was achieved. One set of vertical angles was taken at each station in order to reduce the slope distances to horizontal distances at sea level.

Night work was found to give much better results then daytime, and loop closures were generally kept to within $2\sqrt{N}$ where N stands for the number of sides in a closed figure or traverse. The number of sides in any loop was held to a maximum of 16 and preferably around 9, to help isolate angular errors.

Descriptions and horizontal photographs were taken of each monument location for reference purposes. A few stations around the perimeters of the various municipalities were selected as photo reference points and a number of azimuths and distances were taken at each of these stations to photo-identifiable points. The purpose of this was to aid in the preparation of photogrammetric plots for large scale maps should the need arise.

Monumentation varies from place to place. In the "Diamond Horseshoe" area of Toronto and Hamilton, frost seldom penetrates deeper than 4 feet. The majority of monuments consisted of a concrete cylinder 4 1/2 to 5 feet deep and about 1 foot in diameter. These were brought to ground level. Four reinforcing rods were placed vertically in the concrete to avoid breakage of the column. In Metro Toronto all the holes were dug by hand whereas in Hamilton and the various municipalities between Hamilton and Toronto powered augers were used. Many tablets were cemented directly into sidewalks in Metro Toronto. Sidewalks are subject to considerable disturbance due to frost, plows and construction, and in 1964-65 most sidewalk monuments were placed independent of the sidewalk. This involved cutting a section out of the sidewalk, digging a 5 foot hole, pouring the monument and finishing with a steel casing to bring the monument to sidewalk level. In others, oily wallboard material was used to take up any shock between the sidewalk and the monument. In Winnipeg most monument holes were dug to depths of 25 feet to overcome a particularly poor soil condition. Last year, the Ontario Department of Highways in Toronto made tests with numerous types of monuments in different locations and even in Toronto where frost is relatively light they experienced vertical displacements of up to 1/10 of a foot in one year. Precise levelling must be a demoralizing experience! A design that is now being used in Ottawa consists of 2 concentric pipes with a lubricant between them so that the outer cylinder is free to slide up or down without disturbing the inner pipe, which contains the survey tablet. Certainly a good solid footing below frost level should help a great deal to overcome disturbances due to frost.

The adjustment of the second order municipal control is presently being carried out by a computer program known as GROOM. Groom stands for "Generalized Reduction of Observed Material" and is actually a series of programs that gives an area type of least squares adjustment for the survey data. Groom was originally written for the IBM 650 in 1961. It was written in SPS which stands for "Symbolic Programming Systems" and in the fall of 1963 the program was rewritten for the IBM 1620. Now the 1620 is considered inadequate and our programmers are again rewriting GROOM for a newer computer - the CDC 3100. This latest program will be in Fortran which stands for "Formula Translation" and should be adaptable to still newer and more sophisticated computers as they become available.

In carrying out adjustments it is obvious that slope distances must be reduced to give horizontal distances but the reason for a reduction to sea level may not be as apparent. The Clarke Spheroid that is used in Canada assumes that the earth is an ellipse that has rotated about its minor axis to give what some people call an "oblate spheroid" and others an "ellipsoid of revolution". All geodetic measurements are reduced to this mathematical figure and sea level is used as the scaling reference. For rectangular coordinates though, we could just as easily assume a mean elevation for the area in question and then horizontal ground measurements would more closely approximate the grid values. However, this would only hold for relatively flat areas. The sea level correction amounts to about 1 part of 10,000 at an elevation of 2000 feet. A very interesting paper on "Skew Plane Coordinates" was given by Mr. J.E. Lilly, Dominion Geodesist, at last year's American Congress of Surveying and Mapping held at Kansas City, Missouri. This paper deals with coordinate axes that are not north-south and east-west but have been rotated or "skewed". Mr. Lilly has developed the "Mercator Projection" and a projection which he calls a "Geodesic Strip Projection" and has tested both of these projections for an area similar to the Province of Nova Scotia. The Modified Transverse Mercator with 3° zones could easily be used for Nova Scotia. Two zones, with central meridians at longitudes 61° - 30' and 64° - 30', could be used to cover the entire province and would fit into a system that has been proposed for many provinces in Canada. There would seem to be a practical advantage to having the grid north in the general direction of true north rather than having it oriented to the northeast, however these are all considerations that should be thought out before a projection system is selected.

USES OF MUNICIPAL CONTROL There are four basic mathematical problems that can be solved using rectangular coordinates:

First, if the distance and azimuth between two points and the coordinates of one of them are known, the coordinates of the second point can be calculated.

Second, if the coordinates of two points are known, the distance and azimuth between them can be calculated.

Third, if the coordinates of three vertices of a triangle are known the three angles of the triangle can be calculated.

Fourth, if the coordinates of two points A and B are known along with the angle between A B and A C, where C is any other point, then the azimuth of A C can be calculated. With a coordinate system of x and y values a surveyor can set up over a coordinated monument and use an adjacent monument as his plane coordinate reference azimuth. He can then traverse along measuring angles and distances until he comes to another coordinated monument. His angle work can be checked against the plane coordinate azimuth at the end point. Coordinate values can be easily computed for all intermediate stations using his measured lengths along with sine and cosine values. The coordinate and azimuth errors at the end point if within a permissible limit, can be adjusted into the intermediate stations which will then be coordinated with the entire control survey. I have listed seven broad uses for municipal control which may be of interest. These are taken from a list that was prepared by our office last year:

1. A control survey provides an integrated system of monuments which can be used for the orderly development of maps and plans and as a reference for surveys executed in a city.
2. A first and second order control network gives a means of standardizing and checking the accuracies of future surveys. The control is based on a uniform system of observations, computations, and adjustments, and once filed in the local city surveyor's office (or city engineer's office) the survey information should be readily available to the public.
3. It provides control for the production of base maps from aerial photography. Such maps are of value to planning boards interested in parks and recreational areas, urban renewal and zoning and assessment commissions. Route maps for transportation systems can be tied to the control.
4. Street and highway plans developed by a city should be tied to a reference system. Much money is invested in surveys for such projects which usually become of no future value because the survey has left no retraceable evidence on ground or has not been tied to a reference system.
5. Utilities, such as sewage and water works, telephone communications, both overhead and sub-surface, and power commissions, require accurate plans for the development of their interests. Duplication of survey efforts could be avoided if all surveys were tied to a reference system.

6. Property surveys tied to a reference system could be much more readily relocated on the ground and evidence collected with greater certainty. Rectangular coordinates give the possibility of interconnecting points even though they may not be intervisible and may be miles apart.
7. A reference system can cut costs and aid planning. The majority of maps and plans become nothing more than expensive sketches because of the inability to correlate the portrayed material to evidence found on the ground. By the complete integration of surveys, bound to a common reference system, much money and man power would be available for other investment.

Metropolitan Toronto is actually using city control and to give a more detailed idea of how a control survey system can be used I would like to quote a section from the Metropolitan Toronto Department of Roads Biennial Report for 1963-64.

This report lists thirteen uses as follows:

"(1) Provides control for construction projects.
(2) Relates various projects.
(3) Relates property surveys to engineering surveys.
(4) Provides ground control for aerial surveys.
(5) Co-ordinates Departmental work with private developers and other Departments.
(6) Relates all engineering data.
(7) Eliminates the need to run closing loops.
(8) Reduces the possibility of survey errors.
(9) Standardizes all measurements.
(10) Provides an easy method of calculating and indexing.
(11) Provides a permanent record.
(12) Provides an easy method of survey maintenance.
(13) Eliminates the need to take astronomic observations.

Many other uses of the co-ordinate network will be made as time goes on. A number of these uses depend upon the Municipality undertaking other projects for which the co-ordinates were prerequisite.

With the co-ordinate systems now established it is possible for the Municipality to proceed with the following projects: -

- The modernizing of the land registration system.
- The transferring of all land in the Metropolitan Area into the Land Titles office (this would include the relating of each parcel of land to the co-ordinate network, the confirming of the boundaries thereof and the confirming of the ownership thereof.
- The modernizing of the land survey and land subdivision system in the area.
- The integrating of engineering records.
- The compiling of basic maps for the area (topographic, cadastral and utility).
- The establishment of a Municipal Data Bank containing all types of information related to a geographic location. (The bank will contain the information from the above projects plus information from many other sources, e.g., Assessment, Planning, Welfare, Housing, Industrial Commissioners, etc.)

When these projects are undertaken then the full potential of the co-ordinate survey system will begin to be realized."

While in Toronto, I discussed this idea of a Municipal Data Bank with Mr. R.A. Smith, Supervisor of Surveys for the Metro Toronto Department of Roads. Although still in the future the possibilities of a computerized city leaves a person somewhat awed. In Philadelphia, a municipal data bank has already been set up. This is a large capacity computer that stores statistics such as population, information on electoral districts, births, deaths and traffic accidents which are broken down by street and date. Any desired information is obtained merely by pushing the right buttons. What is required for a data bank is an accurate system of co-ordinate references for the information being stored. Statistics are already kept by various agencies on motor vehicles, births, deaths, welfare payments and the like so the collection of this tremendous volume of data would not be as great as might be expected.

Once the municipal control monuments have been placed and the survey completed it becomes the responsibility of the municipality to look after the monuments and to make sure that certain standards are maintained for any 3rd order control that might be undertaken in the future. It is advisable for good reference azimuths to be established at each control station in the event that adjacent monuments are destroyed, or the line of sight between monuments becomes obstructed. In addition, accurate ties should be taken to each monument in case it is moved due to construction or vandalism. The Hamilton engineering department hope to have descriptions filed with the Building Department for any monuments located on private lands. If a building permit is applied for and a monument is found to exist on the property, the City Surveyor will be notified and steps can then be taken to protect the monument or ensure that it can be relocated after the construction has been completed.

CONCLUSION There is, at present, a very active interest in rectangular coordinate systems across Canada. New Brunswick has led the way by officially adopting such a system and you have probably heard from Mr. Willis Roberts concerning the progress being made there. British Columbia has adopted a coordinate system and legislated accordingly. Alberta is about to follow suit. The Surveyor-General of Ontario has recently instituted a feasibility study to report on the interest and uses of a provincial coordinate system and to determine the most suitable projection for Ontario. A pilot project covering the Bay de Verde Peninsula in Newfoundland is now under study, and we understand that Quebec is also giving thought to the adoption of a coordinate system.

The establishment of a precise control framework is only a start. The municipality should fill in the framework with 3rd order surveys, thus assuring that a well-established control point is within easy reach of future surveys. All interested agencies, or individuals, should participate in the breakdown into lower order surveys. Only when this stage has been reached will the full benefit of an integrated plane coordinate system be apparent.