Surveying for Expo 67

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The survey work for Expo 67 has provided an opportunity for a broad application of the various surveying techniques. Firstly, the site itself is made up of three principal areas all separated from one another by water and linked by four major bridges, two of which were recently erected to provide access to the site. (Fig. 1). These three areas also presented different problems in planning, and consequently they have had some distinctive features created into them which present something of a challenge to the surveyor. The various sites could be classified as follows:

MacKay Pier — an area of land belonging to the city of Montreal and the National Harbours Board.

Ile Ste. Hélène — an existing island in the middle of the St. Lawrence River owned by the city and used as a park.

Ile Verte — a newly created land mass adjacent to the south portion of Ile St-Hélène.

La Ronde — a newly created land mass adjacent to the north part of Ile St-Hélène.

Ile Notre Dame — A large man-made island adjacent to the Seaway entrance.

There are three artificial lakes in the reclaimed island sites in addition to the various bridges required both for vehicles and pedestrians, the various transportation systems, curved streets and canals, other streets that intersect at odd angles or flare into large plazas, lots and buildings of every conceivable shape and siting arrangement. Needless to say this is all very different from the prosaic rectangular grid type of street pattern with buildings set back in conventional fashion. Yet a relatively simple and accurate method was adopted to position all these features on the sites. A rectangular Cartesian system was selected whereby required points could be established from known stations by line intersection. In other words, the entire horizontal control survey was done by triangulation, thus eliminating the need for constant chaining which is time consuming and often a source of error. The necessity of an efficient and reliable method of surveying particularly during the peak construction period could not be overstressed. Precise chaining particularly in bridge layouts would also have required such adjustments as sag, temperature and slope.

There are three broad categories of survey work involved in building Expo 67. These are:

1. The Control Survey
2. Topography and Other Site Information
3. Construction Layout

Control Survey

a) Purpose

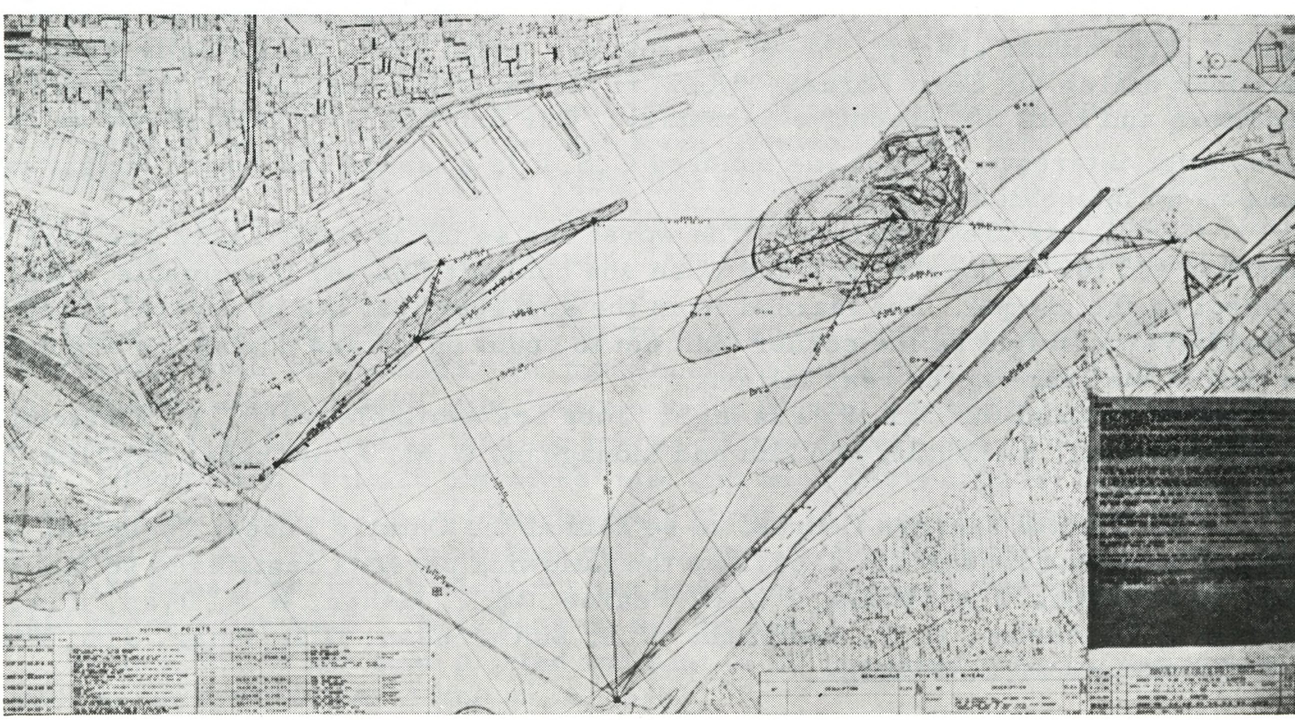
At the very beginning some basic reference points were required upon which to base primary control survey. The purpose was twofold:

1) To form a network from which secondary control stations could be established for all aerial photogrammetric topography, street and lot geometry and finally construction baselines.
2) To establish a number of reference points and features accurately in relation to one another and in relation to a rectangular reference grid drawn on all site plans.

b) Existing Grid and Monuments

Several grid references were available in

Fig. 1.



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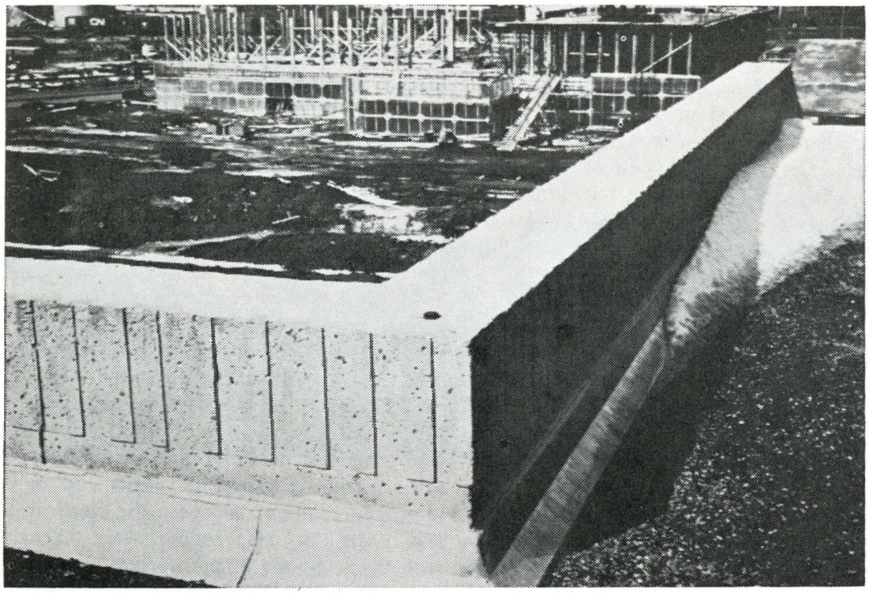


Fig. 5.

e) Computations

A program was arranged whereby traverse and triangulation computations were carried out on an IBM 1620 computer. Using all the adjusted angles at all times and the measured distances one at a time, the remaining distances were calculated 5 times. The results indicated a consistency in distances within an accuracy of 1:90,000 for all measured distances compared to calculated values. Yet in certain instances, depending on field conditions, manual computations were necessary, whereby through various adjustments to certain segments of the traverse or stations acceptable results were obtained.

f) Vertical Control

Vertical control was based upon 3 Geodetic Benchmarks, one in each of the 3 major site areas. Precise levelling was carried out between the two island stations and between the St. Helen's Island station and MacKay Pier in Montreal Harbor. This was done with the use of targets and was intended to serve only as a check on the precise inter-relation of the 3 Geodetic Benchmarks which are thousands of feet from one another and initially were separated by the St. Lawrence River. In order to establish precise vertical control for the construction of the inter-site bridges and other marine structures it was important that the relationship between these benchmarks be checked. The primary control stations and then secondary benchmarks were established within each of the 3 major site areas with each system tied in to its own Geodetic Benchmark.

g) Survey Monuments

Physically the control stations consisted of monuments made up of steel pins set in concrete piling driven to rock. Temporary monuments consisted of steel pins set in concrete below the frost zone to insure protection against movement during the Winter. These were used in the initial stages of development. As the construction operations evolved, additional monuments were established on top of building walls at roof level, on bridge abutments, or on other permanent structures which would provide easy access (Fig. 5).

Topography and Other Site Information

The second general category of work was the task of gathering available site information from such agencies as the St. Lawrence Seaway Authority and National Harbours Board who in the past have been active in this area. This information was supplemented by fieldwork which was a necessary part of the pre-engineering phase. The fieldwork included the establishing of control points for topographic surveys, location of soil borings, taking of river soundings, and determining "as-built" locations of existing structures, dykes and shores of artificial lakes.

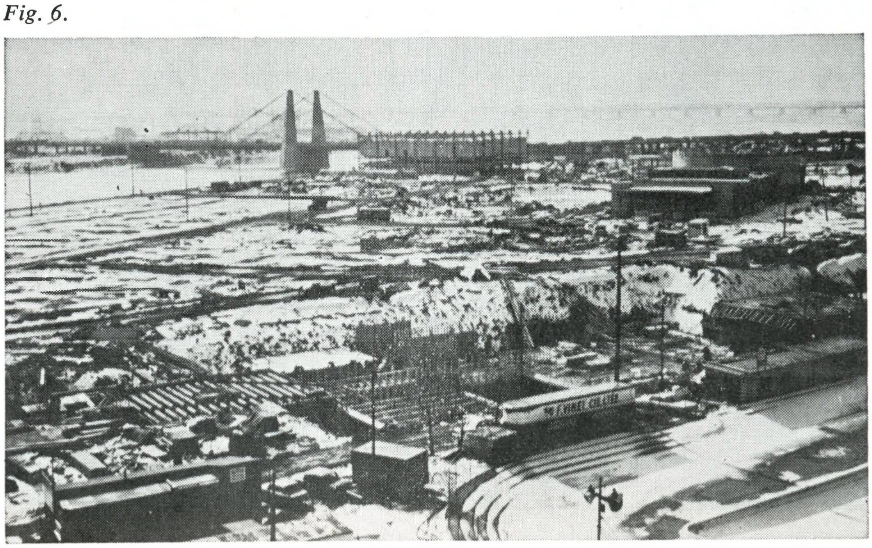
Much existing topography was available for the MacKay Pier Area and St. Helen's Island, but all of the reclaimed land involved in extensions to MacKay Pier and St. Helen's island and the newly created Ile Notre Dame had to be surveyed either by Stadia or by taking a grid of levels. For ground control of aerial photogrammetry (used extensively) ground targets or aerially identifiable landmarks were tied in to the control network. Elevations were also determined at strategic locations so as to provide the necessary vertical control. The line intersect method was employed extensively to determine co-ordinates of existing building corners, church spires or other structures which would readily appear on aerial photographs. These distances between the determined co-ordinates served as baselines for photogrammetric purposes thus providing the necessary horizontal control. To ensure an accurate plan of the sites it was required that these control lines be at the extremities of the overall area. Where services or expressways were planned near existing structures, aerial photogrammetric locations were supplemented by further ground surveys. In most cases no chaining was involved. Topography had to be taken and mapped either for planning purposes or to provide "before and after" maps of earthworks for which yardages could be computed by cross sectioning so as to determine payment of unit price operations carried out by numerous excavation and grading contractors.

Construction Layout

The third general category of survey work and certainly the most serious from the standpoint of consequence of errors was the construction layout (Fig. 6).

The layout of baselines or reference points was required for earthworks, for construction of bridges, roads, canals, utilities, lots, buildings, rapid transit systems, and for the location precisely on

Fig. 6.



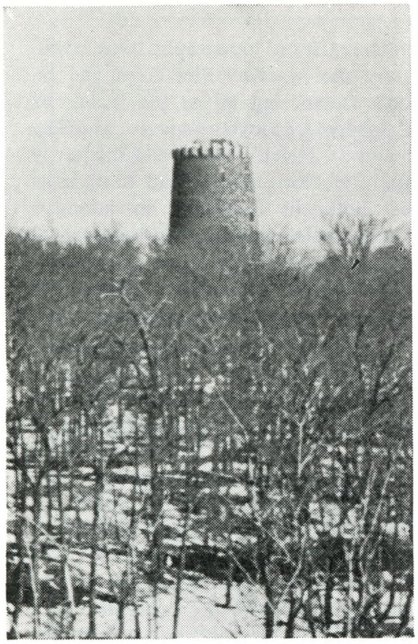


Fig. 2.

the vicinity of the Exhibition site. These were as follows:

The National Harbours Board grid
The St. Lawrence Seaway grid
The City of Montreal grid
Two geodetic points established by the Department of Mines and Technical Surveys of Canada.

The National Harbours Board and St. Lawrence Seaway Grids were independent of each other although almost parallel. The Seaway Grid was based on the Geodetic points mentioned previously. One of these points was on St. Helen's Island proper, the other atop Mount Royal a distance of 4487.75 meters away. The co-ordinates assigned to Point "Royal" by the Seaway had a northing of 50,000 and an easting of 50,000. The East 50,000 meridian through this point has therefore an orientation of true north. The City of Montreal grid was not based on a true north but rather on a city north which in reality was almost East-West.

c) Selection of Grid

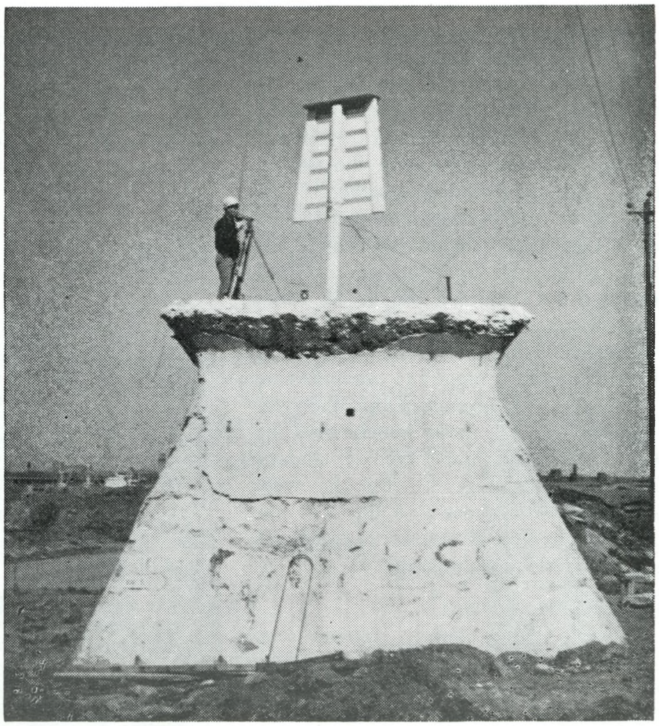
Since the City Grid was based on a local artery while the National Harbours Board Grid was a local grid relevant to Harbour property and would have had negative values within the Exhibition site, the seaway grid was selected. A by-product of the selection of this grid was that one of the goedetic points on it was Station Hélène situated on St. Helen's Island proper and located at the top of the stone clad water tower on the highest ground. Since this station towers some 150 feet over the exhibition area it has been invaluable both for triangulation and construction (Fig. 2).

d) Primary Network

Having chosen the seaway grid as a reference, additional survey monuments were provided in order to expand the primary system so as to have a network which would cover the various sites. It was necessary to tie in the control survey or to include in the primary network 2 existing stations with established co-ordinates onto this grid. These stations were as previously mentioned "Royal" and "Station Hélène", the bearing of the line between them was given by the Department of Mines and Technical Surveys. As these two points were not intervisible due to years of tree growth on Mount Royal an intermediate point was used to establish this line which fixed the grid orientation and provided a base line to which the primary control stations could be referred. The given terms of reference were that primary stations had to be within an accuracy of 1:50,000, and all primary and secondary stations have bettered this requirement. The expanded primary system was then surveyed by precise angle and distance measurement. All angles were measured using wild universal T-2 Theodolites, taking 8 sets, each set with 2 readings. To safeguard against possible sources of error arising from an imperfect vernier and an improper relation between the vertical and horizontal axis, readings were taken with the telescope in the upright and inverted position covering the various quadrants each position being 180° out of phase. At all stations angular closure was within one second. Angular closure of triangles was within 3 seconds. Angular errors at all stations and within triangles were either distributed equally among the angles or adjusted only at certain stations where field conditions made observation difficult. Seven selected distances between primary stations were measured with a geodometer, with 2 sets of 3 readings for each distance. The discrepancies between sets of readings were less than 0.06 ft. in distances ranging from 4400 to 11,150 feet. The largest discrepancy shows an accuracy of 1:66,000 (Figs. 3 & 4).

Fig. 3.

Fig. 4.



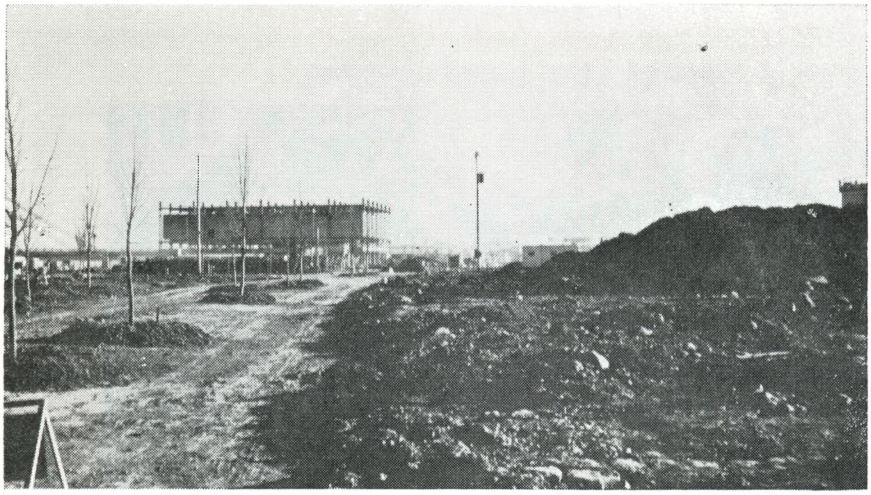


Fig. 7.

the sites of everything created on hundreds of site plans. Bridge centerlines for instance were set down by line intersection from three reference points established on the primary network. The triangle of error was less than ½ inch from projected distances of several thousand feet. The baselines were referenced onto targets set on frames built along the seaway dyke, and onto targets placed on the roofs of sheds in the harbor. All the bridge piers were also targeted on existing parallel river crossings such as Victoria Bridge in order to provide the necessary control in sinking the caissons of the new bridge at 90° to its axis. Curved roads atop the curved dykes along Ile Notre Dame and Ile Ste-Hélène were referenced to offset baselines established by driving stakes located by intersecting angles bearing from control stations. Established in this manner were all curved baselines for the lining of canals with stone filled gabions, the shorelines of artificial lakes, waterlines, sewer lines, ductbanks for power and communication lines, rapid transit lines, etc. These layouts also include tree plantings (Fig. 7).

Participant lot corners were established by means of a standard self-verifying procedure which was followed throughout all the sites. These points were quite important in that they not only served to locate precisely the boundaries of each exhibition lot, but also served to establish the rights-of-way of streets, plazas or other public areas. They were also used as baselines for the siting of all buildings and pavilions. The procedure in each case was to set the corner monuments by two intersecting angles bearing from visible control stations, then measure all the angles between the monuments themselves, and then chain between the monuments for the entire perimeter of the lot (Fig. 8). Through this method a check was made on the positions of all lot corner points. It should be noted that the geometry of all road centrelines and lot corners was established as pairs of grid co-ordinates on the drawings, all determined by electronic computer. The computer runs incorporated an automatically and precisely correct closure on all the geometry, and at the same time provided correct closure lot areas together with true lengths of all the sides of lot configurations. The pairs of grid co-ordinates were then transformed in the field office into bearings from the control stations with the use of a desk calculator. The angles were finally turned off from T2 Theodolites set up on the control stations (Fig. 9).

The invar bar has proven to be an invaluable instrument since it provides a high degree of accuracy for horizontal distances without the necessity for any corrections due to adverse conditions. It was used extensively on short span bridges and in measuring across the canals where precise chaining would be extremely difficult.

Conclusion

From a standpoint of general interest, one might mention some of the pitfalls that are ever presenting themselves in the survey work for an international Exhibition. Firstly the tight schedule required to cram all the planning, designing, layout and construction into a 3½ year period where in other exhibitions seven years were available resulted in frequent changes in the geometry of streets, lots, utilities and other structures. This meant that many points had to be changed—removed and repositioned. Many points were inevitably knocked out by trucks and earthmoving equipment and had to be reset. To get an appreciation of the amount of work involved, the field office records contain two cabinets full of files and upwards of six thousand pages of computations, many of which had to be made in evenings and on weekends along with the actual fieldwork. The work was carried out by an average of 15 to 20 men, working out of three office trailers —two on Ile Ste Hélène and one on MacKay Pier. Along with all of the above work the survey team generally served as an extension to the field offices of the Exhibition Corporation.

Fig. 8.

Fig. 9.