A CENTURY OF GEODETIC SURVEYING IN CANADA and the USA

Early Decades, Classical Geodesy (1900-1927)

Geodetic Concepts

The "figure of the earth", was generally accepted during (and before) this period by geodesists as approximating an ellipsoid of revolution, with the Earth's rotational axis corresponding approximately to the semi-minor axis. Following significant efforts in the USA to determine the size and shape of the best fitting ellipsoid for the geoid in the conterminous USA, the Clarke Spheroid of 1866 was chosen, and a datum point or origin chosen called Meades Ranch in Kansas, the approximate center of the USA. The geometry of the ellipsoid and algorithms for computing distances and coordinates on this surface were refined and documented (Hosmer, 1930). The gravity field of the earth was measured and theories concerning it were developed (Bowie, 1912).

Instrumentation and Methods

Triangulation, a technique dating back to the 1600s, and traversing were the principal methods employed during this period. Theodolites, zenith telescopes, various astronomic telescopes and leveling instruments were used to make geodetic observations. Baselines were taped using high-quality steel and invar tapes, and precise methods.

Network beginnings

Most of the geodetic surveying in the USA in these early days was accomplished by federal agencies, principally by the U.S. Coast and Geodetic Survey. This agency was a successor to the first surveying organization established in the USA by President Thomas Jefferson in 1807, originally named the "Survey of the Coast". The instruments, methods and scope of geodetic surveying activities were too specialized, complex and costly for other government or private organizations to undertake. By 1927 triangulation arcs supplemented by some traversing spanned the USA but these were widely spaced, and coverage was sparse.

Geodetic surveying in Canada began in 1905, with triangulation in the Ottawa area carried out by the Astronomical Branch of the Department of the Interior, (renamed Geodetic Survey of Canada (GSC) in 1909). By 1908 two leveling parties were also active (Thompson, 1967). As the Canadian triangulation network was extended it was joined to the USA network, and Canada recomputed their networks on the North American Datum of 1927 (NAD 27), thereby maintaining compatibility with the USA networks. In 1927, the Canadian network included only an arc along the 49th parallel, area triangulation in southern Ontario and Quebec and a triangulation loop in New Brunswick (McLellan, 1974).

Mid-Century Transitions, Beginnings of EDM and Space Geodesy (1927-1975)

From 1927 to about 1965 both national geodetic agencies were involved in adjustments of their horizontal (NAD 27) and vertical control (NAD 29) networks and in densifying these networks with additional monuments. In the early 1960s they participated in initial "space geodesy" efforts to determine geodetic positions of points around the world and a refined figure of the earth.

Control Networks

The geodetic control networks consisted of thousands of mostly concrete monuments placed in Canada and the USA in organized patterns. The spacing and configuration of these points were determined by the requirement for intervisibility between adjacent points for the observing of horizontal angles and leveling lines, by geometric conditions required for strong networks, and by regional population densities. Instruments had improved and the networks were extended and densified with many new monuments. While the NAD 27 horizontal and NAD 29 vertical adjustments served the nations well until the mid-1960s, they contained a number of problems that grew worse during the decades between 1930 and 1970 (Schwarz, 1989).

Instrumentation Changes

A very important development occurred in geodetic surveying instrumentation with the invention of electronic distance measuring (EDM) devices in the 1950s, using visible monochromatic light or microwave frequencies. Improved leveling instruments and processes along with better theodolites and the introduction of the Bilby (portable steel) tower in 1926, also made geodetic surveying more accurate and efficient, but of these, the introduction of EDM was most significant. It reduced the time needed to measure baselines and to measure them with greater accuracy, and made it possible to measure the lengths of triangulation sides directly, thus opening the way to more accurate, faster, and less expensive network configurations. Electronic ranging techniques from aircraft, (Shoran and Aerodist), were developed and used along with new triangulation and traversing designs in extending the geodetic network to Canada's northern mainland and Arctic islands, mainly in support of their National Topographic Series mapping program. Automatic, self-leveling levels were also introduced during this period which streamlined leveling procedures.

After the first Russian satellite was launched in 1957, scientists at the Applied Physics Laboratory at Johns Hopkins University in the USA realized that the Doppler effect on signals from the satellite could be used to derive geodetic coordinates. This spawned a revolution in geodetic positioning methods. Also, photographic techniques using BC-4 cameras to photograph satellites in the background of the stars were used to position geodetic points around the world, connecting networks separated by oceans. However, it was the satellite Doppler technique that inspired the development of other space-electronic techniques, the most important being the Global Positioning System (GPS), which revolutionized both horizontal and vertical geodetic surveying. Because of the accuracy and global capability of the space systems, the departments of defense in both countries played major roles in geodetic positioning in North America and the world in the four decades 1960-2000. This was particularly true in the USA where the Defense Mapping Agency and the Naval Surface Weapons Center developed new techniques and instrumentation.

A New Era, Network Redefinition, Development of Positioning from Satellites (1975-2000)

Geodetic Networks and Datum Redefinition

As a result of the addition of thousands of new observations and control stations to the networks in Canada and the USA, the impact of newer technologies such as EDM and satellite Doppler, it was generally agreed that the horizontal and vertical networks on the continent needed to be redefined and readjusted. These efforts were the focus of geodetic surveying efforts in the USA and Canada in the period 1975-1985.

The North American Datum 1983 (NAD 83) Project

NAD 83 was a very large international effort involving the digitizing and accuracy evaluation of geodetic observations for horizontal networks in Canada and Denmark (Greenland), the USA and Mexico and Central America. In the USA it also involved the digitizing of large amounts of other data related to the control stations such as station descriptions. To prepare for the readjustment, numerous new measurements were made to strengthen existing networks. These included additional EDM measurements, triangulation, and in the USA, high-precision transcontinental traverses. It also included the satellite Doppler positioning of many points in the Canadian and USA networks which strengthened them and enabled the realization of a new geocentric datum, (which in future years would facilitate accurate positioning with GPS). Because GPS was then a nascent technology, only eight GPS positions in the U.S. were included in the adjustment. The geocentric reference system chosen for NAD 83 is known as the BIH Terrestrial System 1984 (BTS84) produced by the Bureau International de l'Heure, together with the global reference ellipsoid of the Geodetic Reference System 1980 (GRS80) adopted by the International Association of Geodesy. A simultaneous adjustment of some 1,785,772 observations involving 928,735 unknowns was completed in 1985 (Schwarz, 1989). Canada contributed the influence of their 8000-station primary network in this adjustment, and followed it with the integration, internally, of Canadian federal/ provincial secondary networks for a total of 105,000 points (Pinch 1990). Because of the need for computing the geoid for purposes of the adjustment, the gravity field in both countries underwent a similar revitalization.

North American Vertical Datum 1988 (NAVD 88) Project

As with horizontal networks, significant errors in the vertical networks in North America had become apparent by the mid-1970s. In the USA, for example, the National Geodetic Vertical Datum (NGVD) had been added to and forced to fit in many areas of the country, which distorted the network. Therefore in about 1980 a similar redefinition and revitalization of this network began. This effort included the same countries, as did the horizontal datum. Over 500,000 permanent benchmarks were included. The datum surface was defined to be an equipotential surface passing through a point on the Great Lakes. This surface closely corresponds with mean sea level on the coasts of the USA. Canadian participation took place in two stages. A Canadian Basic Net comprising 76,000 km of post-1960 leveling was adjusted simultaneously in 1991 with the U.S. networks, with readjustment of the remaining Canadian networks to follow (Babbage, 1999). Canada has yet to adopt NAVD 88, partly because of unexplained discrepancies in the order of 1.5 meters from east to west coasts, and because the urgency for change was not as great as in the USA. The Canadian Geodetic Vertical Datum of 1928 (CGVD28) is still in use, and consideration is being given to the feasibility of a new height reference system based on geoid modeling (Véronneau et al., 2006), a system more suited to Canadian needs and conditions.

Geodetic Surveying with GPS

The single most important breakthrough in geodetic surveying in the 20th century was the development of methods for using GPS to position points relative to one another with centimeter accuracy, and without the need for intervisibility between them. This provides far more flexibility in placing points where they are easily accessible and of greater use. GPS also provides vertical positioning, thereby supporting developments towards an accurate geoid model which in turn provides the capability for using GPS to derive elevations above sea level. Canada and the USA began using GPS as *the* method for geodetic surveying starting in the 1980s.

The USA established a network of Continuously Operating Reference stations named the CORS network in the 1990s (Stone, 2006). The concept is that GPS receivers (rovers) can be placed at points whose coordinates are needed and used to interrogate the CORS stations. The CORS stations are then used as highly accurate differential stations. This results in what is known as first-order geodetic control (NOAA, 1997). Similar developments took place in Canada at about the same time. Federal and provincial agencies in Canada have cooperated to put in place The Canadian Spatial Reference System (CSRS) comprising “active” networks of Active Control Points (ACPs) somewhat similar to CORS stations in the USA, along with the standard “passive” monumented control points, (Craymer, 2006). Monumented stations in the USA and Canada still provide geodetic control for those who wish to use them. High-accuracy monumented stations are needed for the monitoring of tectonic plate motion, which is important for geophysical purposes as well as for maintaining the accuracy of geodetic control networks.

GPS combined with other technologies in the 1990s has produced a quantum leap in the period of a decade in geodetic positioning capabilities world-wide. Canada and the USA participate in continuing international projects to improve GPS satellite tracking, modeling of the geoid, and monitoring the accuracy and stability of positional reference frames. The NAD 83 in the USA and Canada is accurately related to the International Terrestrial Reference Frame, based on stable directions observed by radio telescopes to very distant radio sources which appear motionless from the Earth over long periods of time. The use of GPS for accurate, low-cost geodetic positioning of points on the surface of the earth is now commonplace, passed along from the specialized expertise of geodetic surveyors into the hands of people in other position dependent, land measurement and geographical disciplines such as geophysicists, cartographers, land surveyors, and geographical information system experts.

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