History of Geodetic Surveying, Part IV

BUILDING THE NETWORKS

By Joseph F. Dracup

At the dawn of the 20th century, a generation of geodesists continued the dramatic expansion of the profession. In the U.S. one man, William Bowie, by virtue of his fine analytical mind and determined nature, emerged early, and, in the same fashion as Hassler, totally dominated American geodesy for more than 35 years. Bowie was born in Anne Arundel County, Maryland, in 1872. He graduated from Trinity College, Hartford, Connecticut, and did additional academic work at Lehigh University. He joined the Coast and Geodetic Survey (C&GS) in 1895.

Geodetic History Resumes

After a break of several issues, the *Bulletin* in this issue continues the history of geodetic surveying by Joseph Dracup. We resume with the beginning of the 20th century. Future chapters include:

- Conclusion of the Age of Bowie: 1900-1940
- Birth of EDMI: the 1940s
- Breaking with the Past: 1950-1970
- The New Age of Geodesy: 1970-1990.

Back issues with the earlier parts of this series are available. Contact ACSM's Publications Order Department for details.

The Geodetic Chief 1909-1936

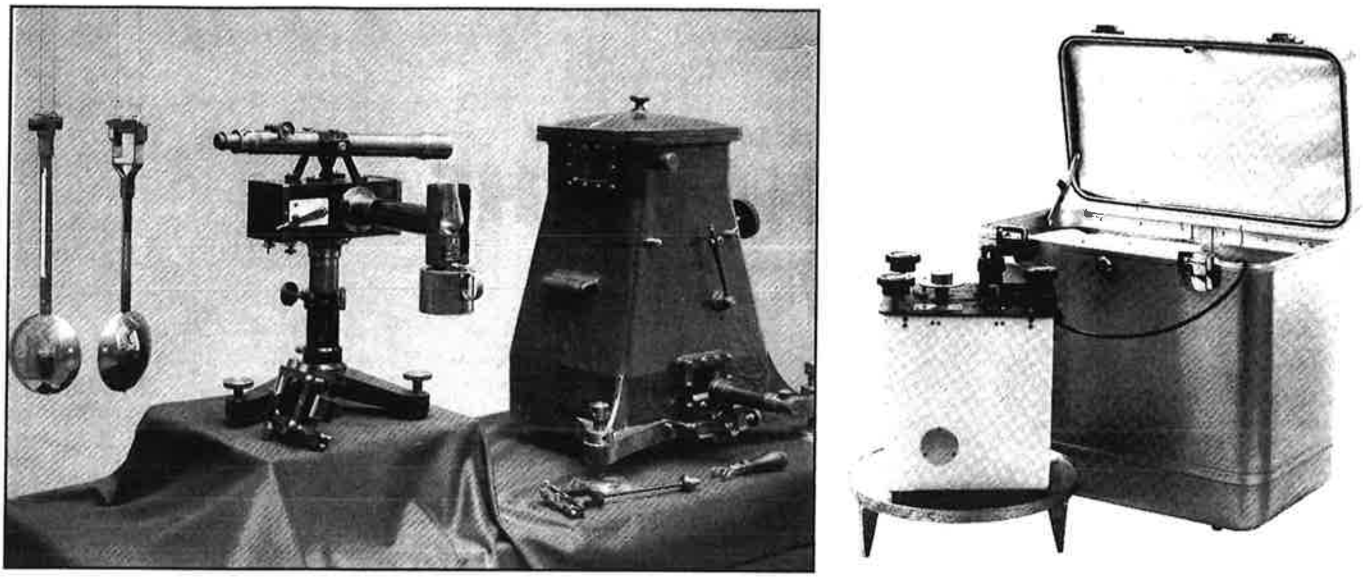

COURTESY NOAA ARCHIVES

William Bowie, Chief of Geodetic Surveys, 1909-1936

During the next 14 years, Bowie demonstrated outstanding abilities in all phases of the bureau's geodetic activities, both field and office, leading to his appointment as Chief of the Computing Division and Inspector of Geodetic Work in 1909 (a position that, in or around 1915 became Chief, Geodesy Division), replacing John F. Hayford, who had moved on to set up an engineering department at Northwestern University. There were several major accomplishments during Bowie's tenure and their success can be attributed primarily to his personal involvement.

In 1913, for example, he persuaded the governments of Canada and Mexico to adopt the U.S. Standard datum for their mapping, resulting in an entire continent being placed on one datum, renamed the North American Datum, a first anywhere in the world. In another case, Bowie pushed for the completion of sufficient primary triangulation in the western half of the country so that a single adjustment could be made. Once Bilby towers were available, he did the same for the eastern U.S. At the same time, Bowie proposed a method to adjust the two halves as separate pieces, yet as a single system.

He supported leveling as well as triangulation with the result that in 1929, a general adjustment for the entire country was made. Also during his tenure, and with his complete support, the state plane coordinate system (SPCS) was created. For the first time, all surveyors could use the network data. Finally, his grand ambition was to complete the nation's primary horizontal and vertical networks. By



BOTH PHOTOS COURTESY NOAA ARCHIVES

Gravity measurements were made by Charles Peirce with European pendulum devices (above left). Later measurements were made with gravity meters (above).

the time of his retirement in 1936, he had virtually succeeded.

One of Bowie's interests was gravity surveys. First introduced in the U.S. by the Coast and Geodetic Survey in 1875, the usefulness of gravity surveys led Bowie to become a strong and vocal proponent of the theory of isostasy. The basic principle of isostasy is that the gravitational effects of the continental masses above the geoid are about equally compensated for by lesser density masses below, the opposite being true in the case of the oceans.

Bowie was recognized nationally and internationally. He was a founder of the American Geophysical Union and an early president. He was also president of the Society of American Military Engineers and of the International Union of Geodesy and Geophysics. Bowie was a captain in the C&GS commissioned corps, but preferred the title major, the rank he earned in World War I. William Bowie died in 1940 leaving behind a record of accomplishments that is not likely to be matched soon, if ever.

Bowie's Lieutenants

Other members of the Geodesy Division making significant contributions during the first half of this century were Walter D. Lambert, Jacob A. Duerksen, and Frederic W. Darling in gravity and astronomy; Sarah Beall in astronomy; Henry G. Avers, Howard S. Rappleye, and Walter F. Reynolds in computations; Clarence H. Swick in gravity, astronomy, and computations; Walter D. Sutcliffe in records and archives; and Hugh C. Mitchell in promoting surveys in metropolitan areas and plane coordinate systems. Mitchell also authored USC&GS Special Publication No. 242, *Definition of Terms Used in Geodetic and Other Surveys,* published after his retirement, the first—and still the best—of geodetic glossaries. Others in the division are cited elsewhere for particular efforts.

Gravity Surveys

Gravity surveys began in the U.S. in 1875 under the direction of Charles S. Peirce following the acquisition of Bessel reversible pendulum apparatus from Europe. The initial measurements with the equipment were made at Hoboken, N.J. after connecting to known gravity values in France, Switzerland, Germany, and England. In 1882 international connections were made with New Zealand, Australia, India, and Japan, and in 1900 again to Europe.

Improvements were made to the apparatus by Peirce, Thomas C. Mendenhall, superintendent of the C&GS (1889-94), and others, the most significant being the replacement of the bronze pendulum with one made of invar in 1920. Work begun on the first national gravity network in 1891 and completed in 1949, involved 1185 base stations, all observed with pendulums.

Meters Replace Pendulums

About the same time, the first geodetic quality gravimeter, the Worden gravity meter, came into use and was adopted by the C&GS in 1952 for differential measurements. Early devices of this type appeared around 1930 for use in oil exploration and were not accurate enough for geodetic work. The long reign of pendulum-measured gravity was coming to a close after about 75 years, albeit the apparatus would continue to be used in absolute determinations for another 25 years.

For most of the period the C&GS was the primary mover with significant contributions made prior to 1900 by Assistants Edwin Smith, Erasmus D. Preston, and George R. Putnam, in addition to Peirce and Mendenhall. After 1900, William Bowie and Walter D. Lambert led the way, with Donald A. Rice coming along after 1950 to continue their work. In or around 1955, plans were laid to complete the long-desired 100-mile spacing network and to expand the existing 900,000 square miles of area coverage at 10-mile intervals over the entire country.

Woollard's Contributions

Beginning in 1954, George P. Woollard began observations using quartz pendulum apparatus and Worden gravimeters to create a nationwide net. The work was completed in 1958 with about 175 stations established, most at regional airports. By 1963, he had extended the net worldwide involving some 1300 points.

Woollard began making gravity measurements in the late 1930s, while at the University of Wisconsin, running traverses across the country and between the Gulf of Mexico and Newfoundland. He also played a part in getting S. P. Worden to build his geodetic gravimeter in 1948.

As the space age began, the need for higher accuracy gravity networks greatly increased. To meet that requirement, the U.S. National Gravity Base Net (NGBN) was established in 1966 in a cooperative effort by the Army Map Service, USAF 1381st Geodetic Squadron, and the University of Hawaii, which placed stations at airports in 59 cities throughout the country. Four LaCoste & Romberg geodetic gravimeters were used and travel was by commercial airlines. In 1971, the NGBN was incorporated in the International Gravity Standardization Net 1971 (IGSN1971) along with observations from various sources connecting stations in 36 additional cities and a number of calibration line pendulum measurements. There are 1854 ISGN stations, with 379 in the conterminous U.S.

As part of the continuing effort to improve the IGSN system, the National Geodetic Survey (NGS), between 1975 and 1979, re-observed most of the NGBN using four LaCoste & Romberg G meters in a simultaneous mode and ground transportation. This new network is identified as the National Geodetic Survey Gravity Network (NGSGN) and includes stations in 54 cities observed in cooperative efforts between NGS and other federal agencies. Calibration lines established by 1990 are East Coast, Blue Ridge, Mid-Continent, and Rocky Mountain.

The general availability of geodetic gravimeters after 1960 and ease of operation have induced other federal agencies including the U.S. Geological Survey (USGS), state and educational institutions, and private companies to carry out observations for several purposes, besides exploration. Marine gravity remains a giant undertaking that continues to be pursued. A safe prediction: For geodesy, the last two decades of the 20th century will be known as the period when the determination of absolute gravity, to a high degree of accuracy, became commonplace.

From Tables to Mechanical Calculators

At the beginning of the American geodetic experience, no mechanical calculators were available and the computations were made using a variety of tables including logarithms, augmented by the individual's arithmetic abilities. In spite of what today would be considered primitive computational means, the work got done.

The method of least squares was introduced in 1847 or 1848 and, as early as 1868, adjustments were carried out involving closures in length, azimuth, latitude and longitude, a formidable task even in later years.

Accuracy estimates determined directly from least-squares adjustments were not routinely computed until the mid 1960s because of the additional effort involved. Other approaches were taken to come up with acceptable substitutes. Charles A. Schott in the Superintendent's Report for 1865, p. 192, explains the problem and the rationale for its solution as follows:

> *The strict application of the method of least-squares in connection with the computation of probable errors of the adjusted parts of a triangulation becomes, in our case, impractical from its laborious nature, and a shorter method must be sought and followed, which, while it is a sufficient approximation of the truth, yet furnishes us with all desirable data to judge the accuracy of our results.*

In spite of what today would be considered primitive computational means, the work got done.

The approximations took several forms depending on the element (length, azimuth, or position) for which the accuracy estimate was desired. Most evolved from the specific condition equation for the element and all included the probable error of the angle (or direction) derived from the adjustment. That for the length eventually became the strength of figure formula, long used to evaluate the strength of triangulation to determine the need for additional base lines.

Doolittle Makes It Less Work

In 1878, Myrick H. Doolittle made a combination of improvements to the Gauss method for solving normal equations. The method, with the improvements, continued in general use for more than 80 years. European geodetic circles insisted on dubbing the method as "Gauss-Doolittle" and it remains so today. In 1924, modifications of Doolittle's procedures made years earlier by a European, F. R. Cholesky, were published posthumously. This method became identified as Cholesky or Cholesky-Rubin. T. Rubin, a European from Sweden, apparently discovered the same approach as Cholesky, but two years later.

Crude and cumbersome mechanical calculators appeared later in the 19th century. Despite their awkwardness, the calculators reduced the task of making multiplications and divisions, the major chore in computations. Later improvements, including small electric motors, resulted in further reductions to the computational effort and made feasible the simultaneous solution of several hundred normal equations.

Azimuths From the South: Why?

From 1850 to the adoption of NAD83 in 1986, azimuths in geodetic surveys were reckoned from the south, clockwise, rather than from the more logical origin—north—used by land surveyors. Walter D. Lambert, in a brief 1946 article and some notes compiled in 1954, gave several explanations. Any of Lambert's reasonings could suffice for the practice.

In his 1954 notes Lambert reported that in Hassler's 1817 work and after 1832, there was no uniformity, sometimes azimuths were reckoned from the north and on other occasions from the south, and furthermore in either direction, without any specific notation whether east or west. The remainder of the notes concluded from various writings of French geodesists of the 1800-40 period that they preferred to measure azimuths from the south around to west and, according to him, so did their American colleagues.

Lambert's 1946 article provides probably the best rationale for the practice. He noted that Charles A. Schott was a German-trained geodesist. While not a student of Karl Friedrich Gauss (1777-1855), Schott was well aware that Gauss followed the general practice of azimuths from the south, clockwise, in his Hanoverian triangulation. Schott joined the Computing Division shortly before 1850, was highly regarded from the beginning and it was very likely he was responsible for the bureau adopting the practice. After 1986, azimuths were measured clockwise from north.

U.S. Horizontal Datums

In 1879 the first national datum was established and identified as the New England Datum. Station PRINCIPIO in Maryland—about midway between Maine and Georgia, the extent of the contiguous triangulation—was selected as the initial point with its position and azimuth to TURKEY POINT determined from all available astronomic data, i.e. 56 determinations of latitude, 7 of longitude and 72 for azimuth.

French geodesists...preferred to measure azimuths from the south around to west and, according to Lambert, so did their American colleagues.

Later the position of the datum was transferred to station MEADES RANCH in Kansas and the azimuth to WALDO by computation through the triangulation. The Clarke spheroid of 1866 was selected as the computational surface for the datum in 1880, replacing the Bessel spheroid of 1841 used after 1843. Prior to 1843, there is some evidence that the Walbeck 1819 spheroid was employed.

The datum was renamed the "U.S. Standard Datum" in 1901, and in 1913 the "North American Datum" (NAD) as Canada and Mexico adopted the system. In 1927 an adjustment of the first-order triangulation of the U.S., Canada, and Mexico began and was completed around 1931. The end result was the North American Datum of 1927 (NAD27).

NAD27 was not a simultaneous solution because it was simply impractical to do this with the available computing equipment. Nonetheless, it was the largest geodetic computation effort at that time. More importantly, the resulting datum was the first to be oriented by Laplace azimuths strategically spaced throughout the triangulation. The azimuth to WALDO in the datum definition was changed by about 5" due to the inclusion of a Laplace azimuth at the nearby SALINA base line. Its inclusion in the NAD27 definition was only for completeness purposes since the datum is actually oriented by 175 Laplace azimuths held fixed in the adjustment as noted previously.

Hayford Ellipsoid

In 1909, John F. Hayford used data from the U.S. triangulation to determine new dimensions for the figure of the Earth, appropriately named the Hayford spheroid. The International Geodetic and Geophysical Union adopted the parameters in 1924 as the basis for the International Ellipsoid of Reference. It is presently used in several countries.

Earlier, Hayford had perfected the strength of figure formula used in deciding where base lines are required in the triangulation. The original concept was developed and used in the U.S. Lake Survey and later improved by William H. Burger (C&GS). Hayford also was the co-author with Thomas W. Wright, formerly of the Lake Survey, of the widely used text *Adjustment of Observations.* He served with the C&GS for 20 years and was Chief of the Computing Division and Inspector of Geodetic Work for about 10 years.

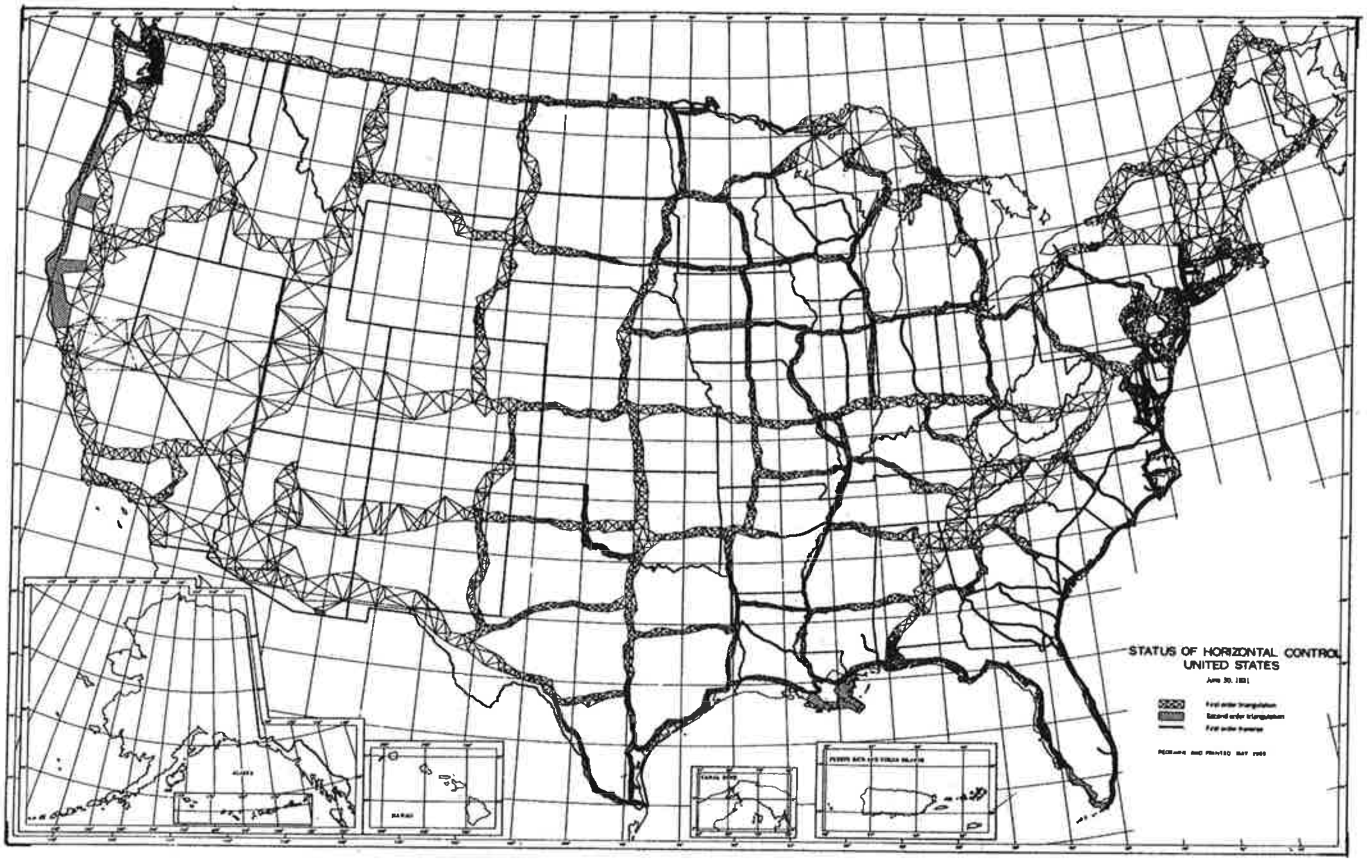
First National Accuracy Standards

In 1921, a committee decided that the C&GS nomenclature for accuracies of geodetic surveys of Primary, Secondary, and Tertiary would henceforth be identified as Precise, Primary, and Secondary. Looking back over more than 70 years, it appears now to have been a political decision, probably some agency objecting to the tertiary classification for their work. As is usual with such edicts, it created nothing but confusion.

In 1925, the Federal Board of Surveys and Maps adopted the now familiar standards of first-order, second-order and third-order, accompanied by the also familiar 1:25,000, 1:10,000 and 1:5,000 length and position closures that were reaffirmed in 1933 and remained in place until 1957.

Traverse Replaces Triangulation 1917-1927

By 1900 the C&GS had observed about 5150 miles of first-order triangulation and the USLS about 1,650 miles. Between 1900 and 1925 about 13,000 miles of the same class triangulation was measured in the western half of the country including the 1460 mile 49th Parallel arc straddling the U.S.-



COURTESY NOAA ARCHIVES

Geodetic control used for the 1927 adjustment (NAD27).

Canada border from the Lake of the Woods, Minn. and the Pacific Ocean observed jointly with the Geodetic Survey of Canada (GS of C).

Due to the high cost of building wooden towers, little or no triangulation was observed from 1900 to 1927 in the eastern part of the country. First-order traverse was substituted because routes could be selected along railroads, with the measurements facilitated by utilizing the rails to support the tapes throughout and then projecting the distances to the stations offset from the tracks. Between 1917 and 1927 some 3300 miles of traverse were observed in 13 states, all east of the 98th Meridian arc except for about 100 miles in South Dakota.

After the development of the Bilby tower in 1926, survey methods for the eastern half of the country reverted to triangulation and between 1927 and 1931 about 9000 miles of first-order work was accomplished. Among the major pieces of work completed after 1900 were the 98th Meridian arc, 1720 miles in length observed 1897-1907; 49th Parallel arc, mentioned previously, about 1460 miles long measured in 1924 and the last of the great triangulations, the Atlantic coast arc, perhaps 1600 miles in length from Providence, R.I. to Key West, Fla. completed in 1932.

NAD27

In the adjustment that created NAD27, all the first-order triangulation and about 100 miles of first-order traverse for a total of 15,050 miles were included in the western half computation. For the eastern half adjustment only the triangulation west of the Eastern Oblique arc amounting to 11,850 miles was used including USLS (1650 miles) and GS of C (630 miles) work, but none of the first-order traverses. Other omissions were:

- International Boundary Commission (IBC)-GS of C triangulation observed before 1920 from Lake Superior westward to Namakan Lake (about 200 miles) because the connection to the 98th Meridian arc was a first-order traverse measured on the frozen Rainy River in Minnesota, and
- a 200-mile section of the Mississippi River arc from St. Louis northward completed in 1931, possibly because the records were not yet received.

The work to the east of the Eastern Oblique arc, including the entire Atlantic coast arc and other triangulation in parts of Virginia, North and South Carolina, Georgia and Florida was left out because traverses were involved.

By 1950 it was evident that NAD27 had many problems caused by large loops in the west and an insufficient number of base lines and Laplace azimuths. Estimates made then suggested that half again as much of the 26,900 miles of triangulation included in the computation and twice as many base lines (112 included) and Laplace azimuths (175 included) would be needed.

By 1940, this amount of new work was largely available, made possible by civil works' funds allotted to aid the unemployed, but no one in 1927 saw this happening. Hindsight, of course, is always better than foresight. 🌐