USE OF TRIANGULATION

by

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TRIANGULATION has been used to settle scientific controversies, to determine the shape and size of the earth, to prove that the earth is in a state of isostatic equilibrium, to fix in geographic position boundaries of nations and states, and to coordinate charts and maps. Eventually it will be used to safeguard the rights of owners of city lots and farms.

Triangulation, as is well known, is a branch of higher surveying that makes use of the mathematical principle that when the length of one side and the angles of a triangle are known, the lengths of the other two sides can be computed. It is an indirect method of measuring distances. Triangulation may be used in the survey of a very small area, such as that of a city, where the curvature of the earth's surface need not be taken into account, but it is usually applied to large areas such as continents or substantial portions of them where the earth's curvature must be considered.

Early Use of Triangulation.

So far as the records show, the first triangulation was done by the famous astronomer, Tycho Brahe, in 1578, when connecting his observatory with the church spires in Copenhagen and other nearby cities. His results were of low accuracy for the work was done before the invention of the telescope which plays such an important part in the triangulation of today.

The first triangulation that may be classed as accurate was made in France by Picard in 1669. The instrument used by him in the measuring of the angles of triangles was fitted with a telescope that had spider threads for making accurate pointings. That was nearly 270 years ago. Great improvements in instruments and methods for carrying on triangulation have been made since that time. One of the most important has been the design of machines for the accurate graduation of the circles of instruments. The graduating machine now at the National Bureau of Standards at Washington is one of the best in existence. It has been used to place the graduations on the circles of the theodolites used by the United States Coast and Geodetic Survey.

Until the beginning of the past century triangulation on extensive scales was used almost exclusively for the determination of the shape and size of the earth. Probably the most famous triangulation was that done in Peru and Lapland by expeditions sent out by the French Academy to determine the lengths of degrees of latitude in high and low latitudes in order to test Newton's theory that the earth is an oblate spheroid, with the radius of the earth shorter at the poles than at the equator. This work was started in 1735. The results proved that Newton was correct in his deductions, and thus was settled a controversy that had raged from the time Newton announced his theory that gravitation required a figure of the earth flattened at the poles.

Other famous arcs were measured along meridians for the determination of the figure of the earth. Since it was impossible to determine the difference of longitude accurately before the invention of the telegraph, near the middle of the last century, it was necessary to confine arc measurements for figure of the earth determinations to the meridians, for along them the astronomical latitudes of triangulation stations could be determined accurately and distances determined astronomically could thus be compared with distances determined by triangulation. At present, the wire and radio telegraphy enables the longitude of a place to be determined with about the same accuracy as its latitude.

Scientific and Practical Uses

By comparison of triangulation data with astronomical determinations of the latitude and longitude of the same stations, it was first determined, nearly a century ago, that there is an outer shell of the earth composed of rock having strength and residual rigidity, but

resting on rock that acts as if it were plastic to long continued stresses and that lacks residual strength and rigidity. Later, values of gravity were used in the investigations of the physical properties of the earth's outer layers. The shell of the earth has been found to extend to a depth of approximately 60 miles below sea level. It has been found that the materials of the shell vary in density, with the densest matter under the oceans and the lightest matter under the highest mountain ranges. If the earth's shell to a depth of 60 miles below sea level could be cut into blocks along vertical planes and the blocks weighed, it would be found that they would weigh nearly the same. Of course the blocks would have to be rather large, say from 100 to 200 miles square, to eliminate the effect of small irregularities. The shell rests on the plastic underlying materials much as ice floats on a lake. This condition of equilibrium of the earth is called isostasy. It is generally accepted as true and is used extensively by geologists and geophysicists in their studies of the earth.

Triangulation is used to determine the extent to which points on the earth's surface move during earthquakes. The size of the area disturbed during an earthquake and the amount of movement in various parts of this area can be determined by this method.

A knowledge of the velocity of light is considered to be of great importance to astronomers who are trying to unravel some of the mysteries of the universe. With an accurate value for the velocity of light they are able to determine more precisely the distribution of matter in the universe and the relative positions of stars and nebulae. The length of the line between San Antonio Peak and Mount Wilson, California, used by Michelson in determining the velocity of light, was obtained by triangulation.

But it is in practical affairs that triangulation is of the greatest usefulness. We need accurate charts of the water area of the earth and reliable maps of the land surface. The total surface of the earth is about 197,000,000 square miles, of which about 57,500,000 is land. It is most important that all areas be mapped and that the maps be accurate in position, area, distance, and direction. This can only be accomplished by triangulation and by the astronomical determinations of the latitudes and longitudes of some of the stations. The triangulation stations, with their fixed latitudes and longitudes, form the basis for mapping.

Triangulation Net of the United States

Although in this country the triangulation net was developed rather slowly at first, we now have the best national net of all countries of the world. It is rigidly connected and ajusted and has been carried on with such accuracy that it is not anticipated that any of it will have to be repeated because of lack of precision. The net consists of nearly 70.000 miles of arcs, which is more than that of any other nation. But the job is not finished The net must be continued until there is a triangulation station within a few miles of every place in the country. When completed the net will bear the same relation to detailed surveying and mapping that the steel framework of a modern office building bears to the rest of the structure. The steel gives shape and strength to the building, and the triangulation gives these same elements to maps, private and public boundary surveys, and the surveys made as a part of engineering construction.

The triangulation of this country is based on the latitude and longitude of a station called Meade's Ranch which is in central Kansas. The computations are made on the Figure of the Earth derived in 1866 by Capt. A. R. Clarke of the Ordnance Survey of Great Britain. Although the Figure of the Earth, called the Hayford or International Ellipsoid, which was derived by officials of the Coast and Geodetic Survey from triangulation and astronomical observations in the United States, is closer to the true dimensions of the earth than that of Clarke, yet the difference is not so great as to make it desirable to make a change.

The Unification of Triangulation Systems

The Canadian and Mexican Governments have also adopted the position of Meade's Ranch as the starting point for their triangulation, charts and maps. Owing to the fact that the three nations of this continent have a single triangulation system, the initial station and its position and the Clarke spheroid are together designated the North American Datum. This is the only continent that has a single datum for its triangulation. In Europe each country has its own datum, with resulting gaps, overlaps and offsets along the boundaries in the maps of the countries involved. There is much sentiment among the geodesists of the European countries in favor of a single datum for the triangulation of their continent. Although it may not be practicable to change over all the national maps of Europe to a single datum, it would be of great scientific importance to have all of its triangulation unified.

Geodesy, or that branch of mathematical surveying which includes triangulation, was considered to be of so much interest and importance that many years ago the European

countries formed a European geodetic association which later became international in scope. This country joined that association in 1889 and continued its adherence until the World War. After the war the Allied Powers, through their academies of science, formed the International Research Council with branches called Unions. One of these is the International Geodetic and Geophysical Union with several branches which includes the present International Geodetic Association. It holds triennal conferences at which the many phases of geodesy are discussed and plans are laid for an attack on problems that extend beyond the confines of a single nation. The last conference of the Geodetic and Geophysical Union was held in Edinburgh, Scotland, in 1936. The next one will be held in Washington, D. C., in September 1939. Invitations to the nations of the world to send delegates to that conference have been sent out by the President.

The International Geodetic Association has urged all adjoining countries to connect their triangulation systems. This has already been done in a number of cases. At its conference held in Stockholm, Sweden, in 1930, it adopted a resolution, addressed to the United States, Canada, and the Soviet Union, recommending and urging that the triangulation of North America be joined with the triangulation of Europe and Asia. This would be one of the most important pieces of geodetic work of all time, for if it is done it will be possible to have all of the triangulation of this country, South America, Central America, Asia, Europe, and Africa computed on the same datum. The results would make it possible to derive a very accurate figure of the earth from the connected system, to learn much more of the isostatic condition of the earth and, for land areas, to derive the shape of the geoidal or sea level surface of the earth.

The triangulation of North America has been carried north by the Coast and Geodetic Survey and the Geodetic Service of Canada to White Pass at the head of Lynn Canal, Southeast Alaska. It can be extended by the Canadians northward to the Yukon River and thence to the 141st meridian, the boundary between Canada and Alaska. From there the Coast and Geodetic Survey could carry the triangulation westward and northwestward to the eastern side of Bering Strait.

It would be the task of the Soviet Government to extend triangulation from the arc across Siberia to the western side of Bering Strait. The connection across the strait would be done by cooperation of the officials of this country and of the Soviet Union. It is entirely feasible to make observations across the strait by using one or more of the islands in it. When this great piece of geodetic work will be done is not known, but it is hoped that its initiation will not be long delayed.

Part Played by Astronomical Stations.

Accurate maps and boundary surveys cannot be made with astronomical stations as the only control for position, distance, and direction. Astronomical observations are necessarily referred to the direction of gravity or the plumb line, and this direction is influenced by the irregular surface of the earth. The plumb line is deflected toward mountains and continents and away from Valleys and Oceans. For instance, the distance north and south across Puerto Rico as shown on the old Spanish chart of the island, and which was based on astronomical determinations of the latitude at Ponce and at San Juan, was found to be one mile greater than the true distance determined later by triangulation. The plumb line at each of the stations is attracted toward the island mass and away from the Atlantic Ocean on one side and away from the Caribbaen Sea on the other. Similarly, a valley in central Asia was found to be one and one-half miles wider by triangulation than by astronomical determinations.

It is true that astronomical observations are required to furnish the latitude and longitude of starting points for extensive surveys. Eventually, however, many astronomical stations are determined and a mean astronomical position is derived for the initial triangulation station. The latitudes and longitudes of the other triangulation stations are then derived by computations and adjustments of the base lines and the observed angles of the triangles forming the triangulation. In this work it is necessary to know with considerable accuracy the dimensions of the earth's surface. As mentioned earlier, the dimensions used for the triangulation, charts and maps of North America are those of the Clarke Figure of the Earth of 1866.

Boundary Determinations and Military Activities.

Triangulation has been used for the determination of the geographic positions of the monuments of international and state boundary lines. This has been done for all monuments along the boundaries between the United States and Canada and between Canada and Alaska. If a monument is accidentally moved or destroyed it will be

possible at any time in the future to find by triangulation the exact spot which was occupied by the lost monument. One can readily realize how this will tend to eliminate controversies and misunderstandings. The monuments along the 100th meridian, the boundary between Oklahoma and Texas, have had their latitudes and longitudes determined by triangulation. The same is true for the boundary between Honduras and Guatemala, and between Guatemala and El Salvador. It is to be hoped that the geographic positions of the monuments along all international boundaries will soon be determined by triangulation as an aid to the peace of the world.

While the shape and size of the earth must be taken into account in national triangulation systems and in the charts and maps of large areas, yet the triangulation stations can be used in local surveys without considering the curvature of the earth's surface. It is possible to treat rather wide strips of the earth's surface as planes without introducing errors greater than 1 part in 10,00 of the distance or at the rate of 6 inches to the mile. Such strips must not be wider than 158 miles to meet this requirement. The difference between the plane coordinate distances and those referred to the curved surface can be computed and applied as a correction if that is desired. The Coast and Geodetic Survey has computed plane coordinate systems for all of our States and it is certain that the plane coordinates of the triangulation stations will soon be extensively used in making the boundary surveys of public and private property and in making surveys for many engineering activities.

Triangulation results have many uses, not the least of which are in connection with military activities. The control stations used in indirect firing by field and heavy artillery should be based on triangulation. Triangulation should also if possible be the basis of the maps used on the field of battle. The officials of the Society of American Military Engineers have frequently expressed the opinion that this country should be completely and accurately mapped. This requires that the maps be based on triangulation.