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6.2 GEODETIC CONTROL*

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Geodetic Control nets are built over time depending on the resources available. In the U.S. the situation around 1900 looked like Figure 1. You had a translation scheme along the east coast, you had some activity around the great lakes, and the major accomplishment of 25 to 30 years was the Transcontinental Arch of Triangulation. So that was the first time when people even knew how far it was from one coast to the other one. By 1931 (Figure 2), the situation had changed to a rather nicely developed pattern with the arch of triangulation going North, South, East, and West. You see in Figure 2 extremely large triangles, and the basic principle of triangulation observations is that one measures the angles in a triangle and occasionally one measures a distance between two points, a side of a triangle. By that you can compute the coordinates and resolve all the unknowns in the triangle and get coordinates. If you have a starting value, you can build upon that as you go along. The accuracies that are involved depend very much on how frequently you update your distance, because that is the most degrading effect. By 1946 the situation in North America looked like Figure 3: a highly developed system in the conterminous United States with hardly anything in Canada, some attempts to do something in Alaska, and a development in Mexico by virtue of the Inter-American Geodetic Survey. By 1946 the number of points reached over a 100000 in the U.S. The situation as it stands today, looks like Figure 4. In the conterminous U.S. it has grown to an inventory of about 250,000 points. Canada has also made progress; there is significant progress in Alaska, and one should expect much more in Alaska with the current developments in energy. The control net has been pushed all the way through the Central American Republics into the northern part of South America with all of the connections to islands.

The instruments that are used to build a horizontal network have been primarily the theodolites and they are considered part of the classical arsenal of instrumentation. We can measure directions with the theodolites to a standard error of about 6/10 of a second. We now have electronic distance measuring instruments which can measure distances most accurately to 1 part in a million of the distance. We make satellite doppler observations which give us point positions with accuracies of standard deviations of level of less than 1 meter. In recent years, inertial survey systems have been developed and they are primarily used for identification purposes. For the future, there will be Global Positioning Satellites, but in our concept it will come down to standard deviations between 2 and 4 centimeters. That is the difference from the 15-meter and 6-meter deviations mentioned before. The point is we have more time, we don't need it instantaneously. We can sit there at the station for a number of hours and that will improve the accuracy. Furthermore, we will use GPS only in a relative mode because we have 200,000 points already. We can put one receiver at a known point, and then relatively position any other point within 200 km from the first point, to this kind of accuracy.

The relative and absolute accuracies of the U.S. horizontal network are shown in Figure 5. We distinguish between several orders of accuracy. The first order is the most precise one, it has direct accuracy of 1 in a 100,000 and

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the others just decrease to 1 in 5,000. What is more interesting possibly for this audience is the absolute accuracy of the U.S. network which is on the North American datum of 1927. The accuracy in the absolute sense is about 15 meters, and that is due to the existing distortions in the network. We are actively working now on a project that will give the North American Datum in 1983, where all positions will be known to about 1/2 meter. That 1/2 meter refers to the worst; we contemplate just 4-5 centimeters precision for some of the best points in the network.

For the U.S. network on the 1927 datum, all points are related to a mathematical surface which is an ellipsoid placed in space many many years ago, in such a way that there is an offset with respect to the Geocenter of 22 meters in x, 157 meters in y, 176 meters in z. These numbers are not to be looked at as errors, but they are very well known numbers. Still, we will move the mathematical surface from one point to another point becsause when this was done originally no one knew where the earth's geocenter was. But today because of satellites it is very easy to determine where the Geocenter is. The most significant datum defined by the Defense Department was the world generic system of 1972. We know these numbers that relate to the U.S. datum, but we also know these numbers for the other datums. Figure 6 gives an example of the major datums in the world and what these shifts to the Geocenter are, but you see that these numbers vary depending on how these datum were defined to begin with. The thing that needs to be remembered is that one cannot apply one philosophy to all datums and assume that they are all consistent in the same coordinate system. Each of them is a separate coordinate system, and in order to make one earth coordinate we have to take all of these datums and shift them to one common place, and the most logical common place today is the geocenter. International meetings have agreed that the geocenter makes sense. The International Association of geodesy has defined the geodetic reference system of 1980 as a geocentric system.

The availability of geodetic information within the U.S. is the responsibility of the National Geodetic Survey and the information is freely available in this country. That is not the case in general. Other countries have looked at geodetic activities very much in terms of their military establishment. As a consequence the information is generally unavailable because these countries classify the information. However, there are old publications that you can find that show what these datums look like, and give you some idea of what the accuracy is. There are international units of measure in geophysics national reports that one can consult, and one can read between the lines and see for example the Peoples Republic of China has a network that is similar to ours in terms of accuracy or you can obtain it from the geodetic organizations that are inclined to make that information available. For the accuracies that we can estimate relative between two points, the worst that you can find is 1 in 5,000. That is due to the instrumental errors because you are dealing with an accuracy only from one point to another 2-3 miles away. However, when you look at these in terms of an absolute reference (where is this vis-a-vis the geocenter?) then of course you can have errors as high 200 meters. Some of the datums in other continents are much weaker in terms of the way they were constructed, and the instrumentation that was used, so you may very well get to that number.

In general, if one gets some coordinates, either latitude or longitude or some other types of coordinate system derived from latitude and longitude any place on the Earth, one cannot immediate assume that that's part of the same coordinate system that we have in the U.S. The Doppler Survey System today is allowing us to make exact determination of what these changes and what the errors actually are. An example of this problem is the Universal Transverse Mercator projection. The UTM coordinate system is a way to represent coordinates if you don't want to deal with latitudes and longitudes. Basically the system divides the Earth up into sixty zones and the center meridian for Zone 1 is at longitude 180° east. The scale along the central meridian assumes a false easting of 500,000. Now what's important is that this is not a universal transverse Mercator in an absolute sense. Its universal within a particular datum. It should be possible to compute, if you know the information world-wide, all your coordinates and put all them into one datum, a Geoscentric Datum and then you can transform all these points a given projection. Then you have indeed a universal projection. All of this is done by the military, but I don't know of an inventory of coordinates world-wide that is consistent from all these points of view. The problem is not only in the position of the mathematical surfaces, but also the size and shape. When you bring in the size and shape, the semimajor axis of the reference elipsoid and the flattening, you get just as many combinations of datums; there are hundreds of datums world-wide each of which look at the problem from their own point of view. Basically, the characteristic of geodetic control is that it is in direct proportion to the technological development of the countries involved [1,2]. World-wide you find good coverage in terms of geodetic control in the U.S., in western Europe, and in Japan. You find less than full coverage even in the Soviet Union and South America, and Asia and so forth in other large areas.

References:

1. NASA, Directory of Observation Station Locations, GSFC, Greenbelt, MD.

2. NAD Symposium, Proceedings. The Canadian Surveyor, vol. 28, No. 5, 1974.

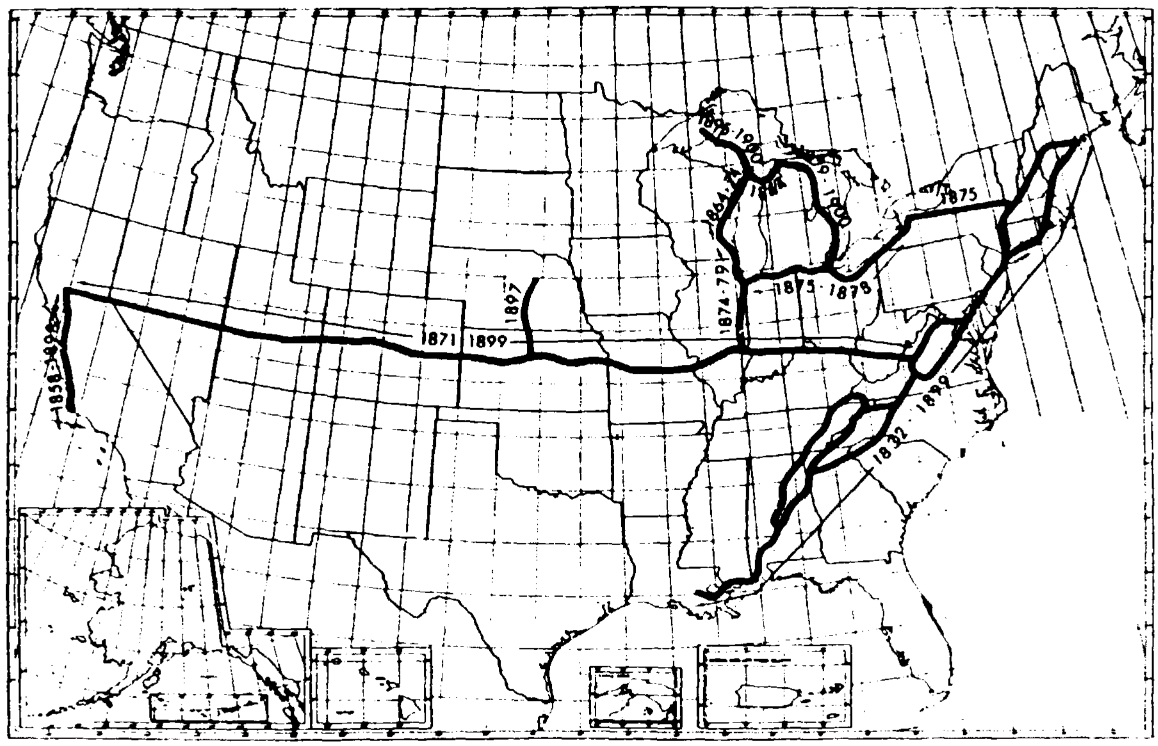

Figure 1. U.S. Horizontal Network 1900

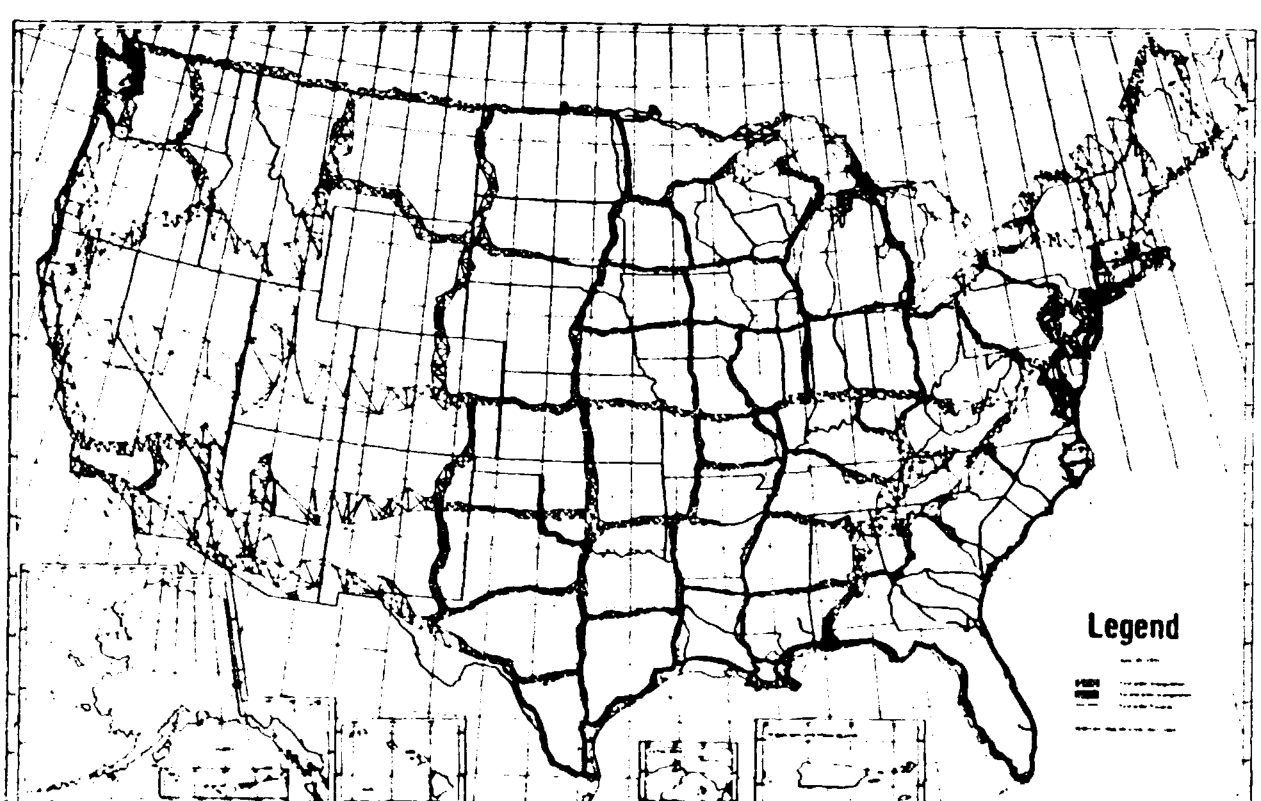

Figure 2. U.S. Horizontal Network 1931

Figure 3. North American Datum 1946

Figure 4. North American Datum 1981

Relative Accuracy
between directly connected adjacent points

First order	Second order		Third order	
	Class I	Class II	Class I	Class II
1:100,000	1:50,000	1:20,000	1:10,000	1:5,000

Absolute Accuracy

- NAD27 15m
- NAD83 0.5m

Figure 5. U.S. Horizontal Network

Shifts to Geocenter

	ΔX(m)	ΔY(m)	ΔZ(m)
1. North American	− 22	157	176
2. European	− 84	− 103	− 127
3. Tokyo	− 140	516	673
4. Arc 1950	− 129	− 131	− 282
5. Indian	293	697	228
6. Australian	− 122	− 41	146
7. South American	− 77	3	− 45
8. Pulkovo	—	—	—
9. South Asia	21	− 61	− 15

Figure 6. Major Geodetic Datums