

Part 2

The Transcontinental Arc

—by Captain Charles A. Burroughs, NOAA (Ret.)

The idea to re-visit the nineteenth century's geodetic feat known as the Transcontinental Arc was born during a consultation on the "Maps in our Lives" exhibit at the Library of Congress in late 2005. The triangulation of the "trans arc" along the 39th parallel is said to have been the beginning of surveying on land over long distances. Captain Burroughs, a retired NOAA Corps officer, took with pleasure the challenge of writing about the work and the people who performed it for the *ACSM Bulletin*. The resulting three-part narrative and timelines, some of them created using drawing equipment of an era long passed, were, according to Burroughs, "labors of love."—The Editor

At the outset of the transcontinental arc of triangulation in 1872, there were only ten states west of the Mississippi River, including Missouri, Iowa, California, Minnesota, Oregon, Kansas, Nevada, Arkansas, Louisiana, and Texas. Both Colorado and Utah, through which the survey was to pass, would not become states until 1876 and 1896, respectively. Then there were the states north of the arc (Washington, Montana, the Dakotas, Wyoming, and Idaho) that would not shed their territorial status until 1889 and 1890. And, finally, Oklahoma, New Mexico, and Arizona, to the south, would retain their territorial status well into the 20th century (1907 and 1912). The Nation's love affair with the railroads also spanned this period, with the surveys for the proposed routes through the mountainous West starting as early as the 1850s and culminating with the completion of the first transcontinental railroad by 1869 and two others, to the north and south, by 1883. There would be many more interconnecting and branch lines added right up to the end of the century and beyond. The transcontinental lines were funded largely by the government through land grants; 131 million acres of public domain were eventually traded for 19,000 miles of railroad. All of this served to open up commerce to and from the Nation's heartland and proved to be of some assistance toward providing for the transport of survey teams to their requisite trail-heads in the West.

The Transcontinental Arc of Triangulation

—by Captain Charles A. Burroughs, NOAA (Ret.)

Ten “Base Nets” of triangulation were established, through time and space, from coast to coast, and eleven “Series” of triangulation arcs between these base nets were conducted over time to complete the work. The bulk of the triangulation field work took place during the years 1878 to 1892.

The total cost of the project, exclusive of salaries of officers, was approximately \$500,000, yielding an average expenditure of about \$20,000 a year. The cost per mile of progress was least in Maryland and Delaware (\$103) and greatest in California, where it was \$463. The average expense of occupying a station in Maryland was \$598, while in California it was \$9,031.

The cost per square mile of territory, strangely enough, was greatest in flat country, where short lines were necessary. The work in Indiana and Illinois cost \$11 per square mile, amounting to an average cost per survey point of \$1,725, while that in Colorado cost about \$2 per square mile, resulting in \$6,131 as the cost of occupying each station.

When making comparisons, one should bear in mind that the lines of observation in mountainous country were considerably longer than those over relatively flat country. The higher station cost was a reflection of the much greater amount of time required for each station occupation, taking into consideration such factors as access, climatic conditions, and procedural matters related to making the requisite observations.

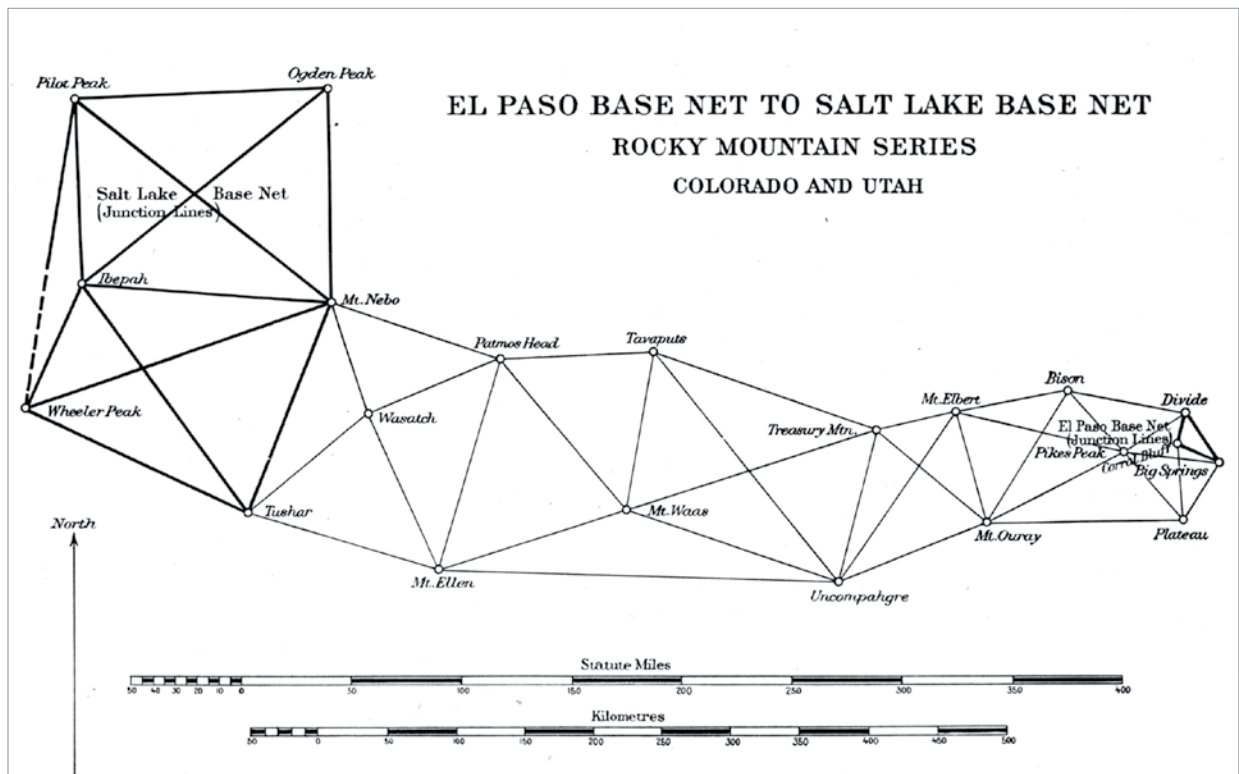
Each base net was first adjusted separately. This gave, at intervals along the arc, certain lines whose lengths depended more directly upon measurement, and which were regarded as absolute. The triangulation intervening between any two adjacent base nets thus established was treated by the method of least squares, so as to reconcile discrepancies between the fixed values and those resulting from the angular measurements connecting them. The operation thus gave a connected homogeneous system of figures throughout, and

opened the way for the final computation of the individual geographic positions.

The credit for compiling the voluminous report that resulted from this survey is attributed largely to its author, Charles A. Schott, who, at the time of the publication in 1900, had been in active service with the USC&GS for more than fifty years. Prominent among the officers who had charge of the field operations—here arranged in the order of linear distance covered over the course of the survey—were William Eimbeck, F.D. Granger, A.T. Mosman, G.A. Fairfield, F.W. Perkins, George Davidson, and O.H. Tittman.

On the whole, but few obstacles were encountered in the execution of the triangulation between the Atlantic and the foot of the Rocky Mountains in what was to become the state of Colorado in 1876. Such obstacles were mainly the presence of lofty trees, necessitating the construction of wooden towers, or of parallel ridges of nearly equal altitude. Transportation and living facilities were sufficiently abundant in this region, except perhaps in that part of the triangulation that passed through the Alleghany Mountains. For the remaining third of the way across the continent the character of the work was totally different, because of the high altitude of the stations, the sparse population, and the deficiency of roads. An appreciation of these conditions can be attested by the information and description about the ninth series (El Paso Base Net to Salt Lake Base Net), furnished by the chief of reconnaissance and observer, Assistant William Eimbeck:

“With but few exceptions, the belt of country between Pikes Peak and Salt Lake traversed by the main triangulation is characterized by stupendous masses of mountains with intricate summit topography. The continental divide in western Colorado, for example, rises as a strongly serrated wall with innumerable defiant peaks. Though



Triangulation work in the Rocky Mountains— El Paso base net to Salt Lake base net [Series 9; 1885, 1890-91; 1893-95].

rugged and often difficult of access, the mountains along the thirty-ninth parallel are nonetheless a favorable feature, inasmuch as they admit of a triangulation on a comprehensive and unusually grand scale; on the other hand, the crossing of the extensive table mountains in eastern Utah necessitated a contracted central figure of triangulation.

The stations comprised within this section rise to an average elevation of about 12,000 feet, and the crossing of the continental divide was effected by the occupation of five peaks, reaching an average elevation of nearly 14,100 feet. We have here the longest side of the triangle, viz. 182.7 statute miles.

As a rule, the country traversed is an arid, barren waste with but a few settlements along the main rivers; within the timber belt, between the 7,000 and 11,000 foot level, there is an abundance of water. The principal drawback to the prosecution of the work was the almost total absence of modern ways of transportation, ordinary freight wagons and pack animals being the only means available.

The Denver and Rio Grande Railway with its Ogden branch, however, afforded much relief. The wagon roads had frequently to be made passable by building bridges across gulleys. Lower camps were established at the end of transportation by wagon, and a pack train was located and opened to the upper camp, usually distant 5 to 10 miles, and involving much cutting of fallen timber, grading, and blasting or quarrying of rocks; the ascent was usually between 3,000 and 7,000 feet. Ordinarily about 10,000 pounds of outfit, instruments, and provisions had to be transported to the upper camp—usually two week's labor—for which purpose from 5 to 7 pack mules were employed, each carrying as a load about 150 pounds—rarely and exceptionally as much as 200 pounds—according to length of trails, steepness, and height of ascent.

The transportation of the "great theodolite," weighing with packing box about 200 pounds, required from one to two days. Sometimes it was carried by hand; at other times it was drawn by a horse and guided by men.



Charles A. Schott
1826-1901

Charles Schott was trained as a civil engineer at the Karlsruhe Polytechnic School in Germany and, upon graduating second in his class, caught the eye of the Survey's second superintendent, Alexander Dallas Bache, in 1848, by whom he was offered his first employment. Throughout his nearly 53-year career with the Bureau, Schott came to appreciate the importance of a thorough knowledge of both field and office work. "The hydrography of harbors, channels, rivers, and oceans, the details of the minute accuracy of base-line measurements, the sources of errors in geodetic triangles, the methods of determining astronomical latitudes and longitudes, the methods of hypsometric determinations, the errors of magnetic and pendulum apparatus, were all known and appreciated and many of them greatly improved by him, to say nothing of the effective systematization introduced by him into all computations and office work."

In addition to devoting some of his early years to field work, Schott was seen as especially well suited to the duties required in the Computing Division and, by 1855, became wholly responsible for that work, a position he retained for the remaining 45 years of his career. He was well known for his energy, adaptiveness, perseverance, both intellectual and physical, as well as for his love of home, drawing, painting, and mathematical precision. At the time of his death in 1901, it was said that "the list of his publications (all in the line of his work) constitutes an impressive monument, built of his own works, better than a marble cenotaph raised in his memory."

[Source: *Biographical Memoir by Cleveland Abbe. Washington: National Academy of Sciences. March, 1915. Vol. VIII of Biographical Memoirs, pp. 87-133.*]

The preparatory work to put the mountain top in condition for occupation was usually very considerable. The instruments were mounted on masonry or rock, the observer stood upon a raised floor, and the whole was walled in and surmounted by a stout canvass tent in order to break the force of the wind. The theodolite stood upon its iron position stand and was effectively protected against direct sunlight and radiant heat by the double-walled and double-roofed observing tent.

As the occupation of a station covered about one month, only two principal stations a year could be disposed of, since the favorable season lasted but four months. The reconnaissance was made by Assistant Eimbeck *pari passu* with the occupation of the station. The party of occupation was composed of three officers and a recorder, with the necessary complement of men acting as packers, drivers, and cooks, the whole party consisting of 12 or 13 persons.

Stationed in pairs at the distant stations, the heliotropers numbered from 10 to 20, according to the requirements of the figure of the triangulation. In consequence of their long connection with the work, the heliotropers had acquired the needful training and familiarity with their duties; they lived in tents or stone cabins or 'dugouts,' close to their stations, and considering the exposure and isolation of their positions it must be conceded that they acquitted themselves well of their trying and responsible duty.

With but few exceptions the horizontal directions and zenith distances were observed upon heliotrope light. As a rule the reflectors were of square shape, varying in dimensions from 1 to 6 inches, and as a matter of experience it was found that a 3-inch mirror sufficed for lines of from 80 to 100 miles, but 4-inch mirrors were needed for lines of 100 to 150 miles; the longest line demanded a square mirror of 6 inches.



William Eimbeck
1841-1909

The signaling or call lights used at the observing station consisted of reflectors from 8 to 12 inches in size; these powerful lights were easily discernable with the unaided eye by the heliotropers, even up to distances of 150 statute miles, and served for directing their mirrors at the beginning of an occupation of a station; they were also used for communication. On long easterly and westerly oriented lines the curious phenomenon of getting the reflected sunlight thrown to the station *at which the sun was already below the horizon*, was frequently observed, and at times lasted several minutes.

The horizontal directions at all stations were observed with the 20-inch theodolite, originally in 19 and later on (since 1893) in but 17 positions of the azimuth circle. The intention was to secure two full sets in each position and to balance the number of observations of the morning and evening but, on account of unavoidable broken series, their numbers had generally to be increased for each position.

Respecting the time of observations, they were made from sunrise till 8 o'clock, and resumed in the afternoon at half past 4 o'clock and continued till sunset. The seeing was usually better in the morning than in the evening; excessive brilliancy of the light was screened off by breathing on the ocular. ...To secure observations under a variety of atmospheric conditions, observations were extended over twenty days or more. ...During the whole work the temperature of the air was never known to fall as low as 0° F.

In conclusion, it may be remarked that the conditions of the weather on these high mountains could not be called unfavorable during the ordinary field season, which lasts from about the first of June to

Born in Brunswick, Germany, William Eimbeck trained as civil engineer under private instruction in St. Louis, gaining practical experience in bridge building, and in the offices of the St. Louis and County Engineers. Thereafter, he taught for two years as Professor of Mechanical and Civil Engineering at Washington University. In 1869, Eimbeck accepted a voluntary position with the Coast Survey to observe the solar eclipse of August 7 of that year. This led to his selection to join the Survey party that went to southern Europe to observe the solar eclipse of December 22, 1870. On July 1, 1871, he was appointed to the Coast Survey and his connection with it continued for the next thirty-five years.

Right at the outset of his distinguished career, Eimbeck was assigned to take up work on one of the triangulation parties initiating work on the Transcontinental Arc with baseline measurements in the Great American Bottom opposite St. Louis. In 1872, he was assigned to the Pacific Coast, performing, for five years, astronomical and primary triangulation work along the California coast. After a year of similar survey work along the East Coast, Eimbeck again took up the western work in 1878, picking up the arc of triangulation in Nevada that would see him so engaged for the next 18 years.

"Stretching from the Sierra Nevada to Pikes Peak and the east line of the Rocky Mountains, including in its list of occupied stations mountain peaks as high as 14,400 feet, in regions where supplies had to be carried for hundreds of miles through deserts and wastes, destitute of roads and almost destitute even of water, the successful conduct of this work called for the endurance of the most rugged pioneers, the undaunted courage of the explorer, while operations represented the highest type of work demanded from the scientist and observer." Near the end of this great triangulation, Eimbek designed the Duplex Base Apparatus, which was constructed in the Instrument Shop of the C&GS and used by him in 1896 in the measurement of the Salt Lake Base. By 1906, however, he felt compelled to resign from the Survey for health reasons, and three years later, on March 27, 1909, he died from a stroke of paralysis.

[Source: *Memoir by Edwin Smith, C&GS astronomer. Bulletin of the Philosophical Society of Washington. Vol. 15. 1913. pp. 127-131.*]



View of Summit Station on Uncompahgre Peak, Colorado. (Altitude: 14,289 ft). The observing tent further back on the right was used for astronomic observations. [Source: *Geodesy: The Transcontinental Triangulation and the American Arc of the 39th Parallel*, U.S. Coast and Geodetic Survey, 1900, plate no. 44.]

the first of November, excepting, however, the period of thunderstorms in midsummer. These thunderstorms, on account of their persistency among the high mountains, have frequently given rise to much suffering, danger, and delay in the progress of the work.

They would envelop or hover around the mountains for days in succession, accompanied by the most violent electrical discharges and thunderbolts imaginable. During such times the whole mountain top fairly hummed or hissed by virtue of escaping electricity, and sparks a couple of inches in length could easily be drawn from any exposed insulated object.

These storms would usually set in about 11 o'clock in the morning and last long after sunset. Though no fatality is, fortunately, to be recorded, they proved, nonetheless, the main discomfort and danger to the party exposed to their fury. The highly attenuated state of the atmosphere, the icy blasts during stormy periods, often accompanied by hail and snow, contributed their share to the depressing and dismal feeling during such exposures.

The experience of the heliotropers would seem to have been more perilous, for three of them were knocked down and rendered partly unconscious, while a tent, several signals, and a theodolite were demolished by lightning. The (so-called) equinoctial snowstorms which annually break over these mountains with surprising regularity were usually borne without concern. They arrive about the beginning of October, and, though sometimes severe and followed by intense cold, they seldom caused other than mere temporary interruption in the communication with the camp below."

So there you have it, the typical mountain station occupation described by one of the principal observers who participated in so much of this work through the mountainous west. Part 3 of this article will deal more specifically with the survey methods employed, to include the requisite astronomic observations, azimuth determinations and corrections for height of station, specifically throughout the mountainous west. There will also be some discussion of "adjustments" required for the completed network and contributions made to the field of geodesy, from the standpoint of "Figure of the Earth" studies.