ILLUSTRATIONS

TRIANGULATION IN HAWAII

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GENERAL STATEMENT

This report covers all the triangulation executed in the Hawaiian Islands up to the end of the year 1928. It includes the triangulation begun in 1871 (see p. 3) while the islands were still a kingdom and carried on through the years during which the islands formed a republic. This is called herein the Hawaiian Government Survey. The triangulation executed by the United States Coast and Geodetic Survey dates from 1899. This report also includes a triangulation of the crater of Kilauea Volcano, executed by an officer of the United States Geological Survey in 1920 and triangulation executed by the United States Engineers on Oahu Island, 1913–1920.

The engineer who wishes to make use of the data in this publication should consult the explanation of tables on page 18, especially the paragraph on "How to find the data desired."

HISTORICAL OUTLINE

The Hawaiian Government Survey was inaugurated to meet, in a scientific manner, a need which arose in the transfer of title from a land system comparable with the feudal system of the Middle Ages, with its lords, overlords, and vassals, to a system of fee-simple titles.

The character of the land lines which had to be described in the legal documents recording titles was such that the ordinary methods of land surveying soon created a condition of chaos and made changes necessary. This will be better understood from a brief description of the land lines, which owed their origin to natural and economic causes. As the needs of the people were supplied by food from the sea and from small patches of cultivated land back from the beach, while from the woods came material for canoes and houses, for fish nets and lines, it was quite natural that the lines delimiting the various parcels of land should run directly back from the shore. The common people were given just about what they could occupy and use under a sort of feudal tenure, while the lands of their masters ran well back into the woods, widening out after passing the upper limits of the tenants' lands, and being terminated by the lands of the higher chieftains and kings, usually three or four in number, which swept around the upland limits of the lands of the lesser chiefs and extended to a common corner at the apex of the island.

This change in system of land titles which occurred in 1845–46 was brought about by the Mahele. This was a convention which has been defined as "an endeavor on the part of the Hawaiian chiefs, and especially of Kamehameha III to secure to all parties what, on the ordinary principles of acquiring property, seemed to b[illegible]ng to them." Under it was secured an equitable division of the lands of the islands among kings, chieftains, and common people, all obtaining fee-simple titles to the lands awarded them.

The boundaries of these lands were very irregular. They followed natural features, such as gulches, streams, and ridges for the larger parcels. The smaller parcels awarded the common people were irregular in shape, bounds being determined partly by occupancy thereof. The survey of such lands to provide description for record titles, and for the compilation of maps, manifestly required stronger controls than those provided by the actual traverse of the boundaries, which because of their very irregular character and short lines would soon, even with the exercise of the utmost caution, accumulate discrepancies which would develop on the plats into overlaps, gaps, and offsets.

In spite of this manifest need, the surveys of these small parcels, or "kuleanas" as they are called, proceeded in almost wholesale lots, and it was not until the government itself got into difficulties—did not know where the lands (grants) to which it had given title were located and therefore could not know what lands still remained of which it could dispose—that the Hawaiian Government Survey came into existence.

In 1870 money was appropriated for a survey of the islands, and Prof. W. D. Alexander, then president of Oahu College, was appointed surveyor general. Professor Alexander continued in this position until 1900, when he became a member of the field force of the United States Coast and Geodetic Survey. To his memory the Hawaiian Government Survey stands as a monument of ability and endeavor.

The purpose of the Hawaiian Government Survey can not be better described than it is in a splendid paper prepared by Mr. Curtis J. Lyons, and published with the report of the surveyor to the Governor of the Territory for the year ending June 30, 1902. Mr. Lyons says in this paper:

> The primary object of the survey, therefore, was to account for all the land in the kingdom by its original title, and indicate such accounting on general maps, and while having no authority to settle such boundaries, to require the surveyors to lay down such boundaries to the best of their ability with the abundant information at their disposal. This was the only means of enabling the government to know what it possessed.
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> To accomplish the object several things were necessary. First, to execute such triangulation of the country as is well known to be the foundation of every good general survey, furnishing points by which to connect together correctly all work, whether cadastral or boundary work; also topographical work, hydrographic work, and engineering work. To make a reliable or in any way a general map by patching together a number of individual maps is simply impossible.
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> Second, to put in the amount of topography necessary to identify localities and land limits.
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> Third, to copy in shape for practical use the individual kuleana surveys of each district to be surveyed, also the surveys of grants. These were indiscriminately contained in large volumes, and were to be found only by means of indexes. It was necessary for a party going into a district to have for use a book containing all the kuleana surveys of said district, arranged according to lands, another containing all grants, and another still of Ahupuaas or ilis that had been surveyed. It was the task to fit all these in place by means of the controlling triangulation. This would practically show the location and limits of the government lands remaining.

While the logical order of executing the survey was recognized at its very inception—that is, to begin with the principal control, then carry out the secondary and detail controls, and finally do the topo-

graphic mapping to serve as the immediate base for the property survey—such an ideal program could not be strictly followed. It was recognized that here as elsewhere the public would demand the production of maps soon after the money for making them was available, and the needs of public business likewise demanded the production of maps at the earliest possible dates.

The survey of the islands was begun in August, 1871, with the measure of a 4-mile base line on the island of Maui, using a 4-meter bar apparatus which had been loaned by the United States Coast and Geodetic Survey. Before entering actively on the execution of the survey Professor Alexander had acquainted himself with the work and methods of the Coast and Geodetic Survey, as well as of other geodetic organizations, including the British Ordnance Survey, the Great Indian Survey, and the New Zealand and Australian Surveys.

In 1871–72 the triangulation was carried by expansion from this first base line over the central part of Maui, and activities were then (1872) transferred to the island of Oahu, where a base line was measured and connected into the triangulation. After this beginning the survey of the islands progressed steadily. In 1875 and the following years, the triangulation of the Maui group was completed and connection made with the already completed triangulation of Oahu. In 1882 the triangulation southward along the western coast of the island of Hawaii was executed, and thence around the entire island. Before 1900 the triangulation of the entire group of islands was completed, with the possible exception of Kauai.

SURVEYS BY THE UNITED STATES COAST AND GEODETIC SURVEY

With the annexation of the islands to the United States in 1898 (the Territory of Hawaii was organized in 1900) a new era in the geodetic survey of the islands was inaugurated. Prior to that time the triangulation had been almost exclusively for the purposes of controlling the topographic and cadastral surveys, but with the annexation of the islands their waters came under the charting jurisdiction of the United States Coast and Geodetic Survey, and at once was begun a program of making hydrographic surveys of the more important harbors and roadsteads, followed by surveys of the deeper inter-island and off-shore waters. In addition to these surveys, which required much revision of and addition to the earlier triangulation executed by the Hawaiian Government Survey, the triangulation of Oahu was completely revised in 1910, and needs arising for an even more accurate triangulation of that island, a complete resurvey of the island, in which many of the older stations were recovered and used, was made in the year 1927. In 1928 a connection was obtained between the triangulation on the island of Oahu and that on the island of Kauai. The triangulation on the latter island had been executed in 1910 by a party of the United States Coast and Geodetic Survey which used some of the stations of an apparently incompleted survey made by the earlier Hawaiian Government Survey. The connection between the islands had been attempted at the time of the 1910 survey, but efforts were fruitless at that time. Improved signal lamps and favorable weather conditions helped in the 1928 determination, but even then it was accomplished with great difficulty.

In the following table are listed the various survey[illegible]cuted in the islands since their annexation to the United States

Hawaiian surveys after annexation to the United States

Date	General locality of survey	Chief of party
1899	Maui, Kahoolawe, and Lanai Islands	F. W. Perkins.
1900	Hawaii Island	Do.
1900	Molokai	Do.
1904	Kauai Island, Hanapepe Bay	H. D. King.
1905	Kahoolawe and Maui Islands	J. F. Pratt.
1909	Hawaii Island, Mahukona Harbor	O. B. French.
1910	Kauai Island, general triangulation	Do.
1910	Oahu Island, general triangulation	Do.
1910	Oahu Island, south coast	W. C. Dibrell.
1910	do	L. W. Smith.
1909	Oahu Island, Honolulu	O. B. French.
1912	Maui Island, north coast	J. C. Gauger.
1912	Hawaii Island, Hilo, and northeast coast	E. R. Hand.
1913	Lanai, Maui, Molokai	J. B. Miller.
1913	Oahu Island, Honolulu Harbor	U. S. Engineers.
1913	Hawaii Island, north and northeast coasts	E. R. Hand.
1914	Hawaii Island, southwest, south, and southeast coasts	Do.
1914	Hawaii Island, east coast	Do.
1915	Molokai	Do.
1914–1920	Oahu Island, western part	U. S. Engineers.
1920	Hawaii Island, Kilauea Volcano	U. S. Geological Survey.
1925	Oahu Island, south coast	E. R. Hand.
1925	Molokai Island, anchorages	R. W. Woodworth.
1926	Oahu Island, southeast coast	E. R. Hand.
1926–27	Kauai and Niihau Islands	C. L. Garner, F. G. Engle.
1927	Kauai	Do.
1927	Oahu Island, general triangulation	L. G. Simmons.
1928	Oahu-Kauai connection	Do.
1928	Kauai Island, Hanapepe Bay	K. T. Adams.
1928	Hawaii Island, west coast	T. J. Maher, K. T. Adams.
1927	Lanai Island, west coast	F. G. Engle.
1928	Hawaii	E. R. Hand.
1928	Oahu-Honolulu	J. H. Peters.

ASTRONOMIC STANDARDS

LATITUDES

In all there were six different standards of latitude connected with the Hawaiian Government Survey, as follows:

1. The original Oahu latitude, begun in 1872 by Professor Alexander, and depending on a determination of D. N. Flitner's observatory in Honolulu.
2. The Tupman latitude, begun in 1879 by Professor Alexander and derived from Captain Tupman's determination in 1874 of the latitude of the Transit of Venus pier in Honolulu.
3. The original Maui Base latitude, begun in 1872 by Professor Alexander from his observations at the Maui Base.
4. The Lahaina Courthouse latitude, adopted by Professor Alexander from the determination of the latitude of Lahaina Courthouse in 1883 by Mr. E. D. Preston.
5. The hydrographic adjusted latitude, calculated by Mr. C. J. Lyons for the United States Hydrographic Office from the determinations of latitude at various points in the islands by Mr. E. D. Preston.
6. The Mauna Kea latitude, a study for which was made by Mr. E. D. Preston. (See United States Coast and Geodetic Survey Report, 1893, p. 639.)

These various latitudes showed that the surveyor general desired to obtain for the projections of the various maps of the islands and lands a latitude which would approach very closely the geodetic latitude. It must be remembered, however, that in the very beginning when the triangulation of the islands was discontinuous necessity compelled the adoption of what might be termed temporary latitude standards for the disconnected portions. It was probably the experi[illegible]

portions of the triangulation, and then endeavoring to harmonize the discrepancies which resulted when unions were effected, that led Professor Alexander to seek the help of the United States Coast and Geodetic Survey. As a result leave of absence for six months, later extended to nine months, was granted in December, 1886, to Mr. E. D. Preston of the Coast and Geodetic Survey, in order that he might undertake latitude and gravity observations at a number of stations in the islands. The expense of making these observations was borne by the Hawaiian government, but the complete instrumental equipment was loaned by the Coast and Geodetic Survey. In this campaign 13 latitudes were determined, which with the 4 stations of 1892 and the station at Lahaina, determined in 1883, makes a total of 18 stations whose latitudes were determined by Mr. Preston. (See p. 21.)

The distribution of these stations with reference to the topographic features of the islands was such as was expected to permit a good determination of the latitude component of a geodetic datum. The hydrographic adjusted latitude (see above) was intended to provide such a latitude.

LONGITUDES

There were four standards of longitude connected with the Hawaiian Government Survey:

1. The original Oahu longitude, a determination of the longitude of Flitner's observatory in Honolulu in 1846 by Prof. C. S. Lyman, using lunar culminations and occultations of stars.
2. The Tupman longitude, a determination in 1874 by Captain Tupman of the longitude of the Transit of Venus pier in Honolulu, using in addition to lunar culminations and star occultations, lunar zenith distances. His first calculations gave results in good accord with those obtained by Professor Lyman, but these were later changed when the true positions of the moon were substituted for its predicted positions.
3. The original Maui longitude, determined in 1872 by Professor Alexander by transporting chronometers between Honolulu and Kahului, using Professor Lyman's original Oahu longitude at Honolulu as a base.
4. The hydrographic adjusted longitude, computed by Mr. Lyons from a study of Captin Tupman's report, M. Fleurian's observations, and from repeated round-trip comparisons of chronometers of the steamers *Mariposa* and *Alameda* between Honolulu and San Francisco.

In 1903 following the completion of the trans-Pacific cable from San Francisco to Manila via Honolulu, Midway, and Guam, first-order determinations of the longitudes of those places were made. (See Appendix 4, Report for 1904.) In 1926 as part of the program for an international belt of longitude stations encircling the earth, a first-order determination of the longitude of a station on the southeastern coast of Oahu was made, using wireless signals from the United States and French Indo-China.

AZIMUTHS

Although a number of azimuths were observed in various parts of the islands, the character of the triangulation connecting these azimuth stations was such that it was deemed advisable to hold the astronomic azimuths and adjust the triangulation to them.

REDUCTION TO OLD HAWAIIAN DATUM

The following table, prepared by Mr. J. S. Emerson and based upon unadjusted values, gives the relationship between the various systems of latitudes and longitudes by stating the [illegible] transfer points on any other system to the standard geodetic datum, called the Old Hawaiian Datum (see p. 9), which was based on the hydrographic adjusted latitude and the Tupman longitude.

Reduction of other latitude systems to hydrographic adjusted latitude

Original Oahu	Tupman	Original Maui	Lahaina Court-house	Mauna Kea
″ +23.33	″ +25.73	″ −20.00	″ +10.40	″ −1.30

Reduction of other longitude systems to Tupman longitude

Original Oahu	Original Maui	Hydro-graphic
′ ″ +3 02.85	′ ″ +1 57.36	″ +13.50

OFFICE COMPUTATION

A special appropriation was made in 1923 and continued through the years 1924, 1925, and 1926, to be used in making a final or office computation of the triangulation of the Hawaiian Government Survey. Under this appropriation Mr. Earl Church was appointed mathematician in charge of the computation and so continued until his resignation in 1924, when his place was taken by the writer. Under Mr. Church's direction the abstracts of horizontal directions made from original records on file in Honolulu were carefully gone over, and lists of horizontal directions prepared and checked. Base-line computations were made; azimuth determinations revised; and a general scheme for the main triangulation around the island of Oahu, across the islands of Molokai, Lanai, Kahoolawe, and Maui, to and around the island of Hawaii was laid out and adjusted. This adjustment was by the angle method, the lengths being controlled by base lines on the islands of Oahu, Molokai, Maui, and Hawaii. There was no connection in length between the triangulation on Oahu and that on Molokai, the connection being through a single closed triangle.

Into this adjusted main scheme were fitted the many adjustments fixing supplementary schemes of triangulation. This involved an unusual amount of preparatory work before the actual adjustments could proceed. It was soon discovered that the computations of these supplementary points could not be standardized. At many stations observations had apparently been made on everything in sight, rather than a concentration of observations on some selected predetermined scheme. This gave a great many more directions than it was advisable to use, and the practice was developed of selecting for adjustment those directions which gave the strongest figures. The not infrequent result was that some of the directions had to be rejected because of too large corrections, and new figures considered. Sometimes several new figures had to be considered essively before one was obtained giving satisfactory results, and in a few cases the lists of directions were exhausted without discovering a satisfactory figure. This proved a great time consumer and therefore very expensive. The probable causes of this condition were several in number: Eccentric occupation of stations, marked perhaps by cairns, without noting the facts, or with erroneous reduction data recorded; erroneous recording of names of stations observed on; confusion of stations, as for instance on the Island of Hawaii, where very symmetrical cinder cones made splended objects on which to point, but which, lacking identification characteristics, were very difficult to recognize from different stations.

The computation of the triangulation of 1910 around the Island of Kauai was made by Mr. H. S. Rappleye, associate mathematician. Mr. Rappleye's computation placed this triangulation on an independent datum, the Kauai Datum. A few years later the connection between Oahu and Kauai made it possible to place this work on the same datum as was used for the other islands, the Old Hawaiian Datum. The magnitude of the shift produced by the introduction of this standard datum may be indicated by the corrections which it induced at station Kikoo, a main station in the interisland triangulation. At that station the corrections to reduce Kauai Datum positions to Old Hawaiian Datum positions were:

	″
Correction to latitude =	+ 9.75
Correction to longitude =	+ 1.10
Correction to azimuth =	−20.5

Among others employed on the computation of the Hawaiian triangulation many worked under temporary appointments, and served but a short time. Among these may be mentioned the following: Mr. C. A. Bowman, Mr. J. R. Powers, Mr. A. Tomelden, and Miss K. Buckingham. For some years past the writer has had the able assistance of Mr. W. E. Wood, junior mathematician, to whom is due no small measure of the credit for whatever value this volume may possess. The sketches at the end of this volume were prepared by Mr. C. A. Bowman and Mr. Harold W. Murray of the division of charts of this bureau.

Mention must also be made of the valuable assistance rendered by the territorial surveyor, Mr. Walter E. Wall, both in connection with the computation of the triangulation of the Hawaiian Government Survey, wherein he was often called upon for notes from original records stored in his office, and because of great help rendered field parties of the United States Coast and Geodetic Survey at work in the islands, particularly in the 1927 resurvey of the Island of Oahu, and in the remarking of the stations of that survey now under way.

CLASSIFICATION OF TRIANGULATION

Triangulation is divided into different classes according to accuracy. The terms applied to these classes have been standardized by agreement of representatives of various map-making bureaus of the Federal Government. Four classes are now prescribed and defined, viz, first, second, third, and fourth orders. The first three of these correspond, respectively, to the classes primary, secondary, and tertiary as formerly defined by the United States Coast and Geodetic Survey.

The ultimate criterion applied in classifying the different grades of triangulation is the actual error in the length of any line. This is indicated by the discrepancy between the measured length of a base line and its length as computed through the triangulation from the last preceding base. In first-order triangulation such discrepancies must not exceed 1 part in 25,000; in second-order triangulation 1 part in 10,000; and in third-order triangulation 1 part in 5,000. Before making the comparison between the computed and measured lengths the adjustment of the triangulation should be carried through to the point where all conditions save that imposed by the length equation have been satisfied. It is also necessary to take into consideration the accuracy of the base lines.

To secure the accuracy indicated above, certain standards have been adopted for the field work, the most important of which relates to the closing error of the triangles or the discrepancy between the sum of the measured angles of a triangle and 180° plus the spherical excess of the triangle. In first-order triangulation the average closing error must not be greatly in excess of 1″; in second-order triangulation it should not be more than 3″, and in third-order triangulation not more than 6″. The shape of the figures in the triangulation scheme, the frequency of the bases, the size and type of instrument, and the number and kind of observations are all selected with due regard to the accuracy desired.

Under certain conditions the proportionate error in the length of line as specified above may be found to be exceeded in any class of triangulation. Where two points are comparatively close together as compared with the size of the triangulation scheme the distance between those points may be in error in excess of that indicated by the class of triangulation of the scheme. In any class of triangulation the subsidiary stations will be located with a less degree of accuracy than the main scheme stations. Special Publication No. 120 of the United States Coast and Geodetic Survey, Manual of First-Order Triangulation, and Special Publication No. 145, Manual of Second and Third Order Triangulation and Traverse, give detailed instructions relating to the field procedure in the execution of triangulation of these grades. Special Publication No. 28, The Application of the Theory of Least Squares to the Adjustment of Triangulation, and Special Publication No. 138, Manual of Triangulation Computation and Adjustment, treat of the methods of computing the results.

ACCURACY OF THE HAWAIIAN TRIANGULATION

The triangulation of the Hawaiian Islands executed under the Hawaiian Government Survey was in advance of the adoption of uniform standards for securing results of given accuracy, even in this country, and classification of its accuracy is almost impossible. It may be stated in a general way that the main schemes have an accuracy, as indicated by closures of loops around islands, of about third-order, represented by closures of about 1 part in 5,000. The work done since 1900 to furnish control for hydrographic and topographic sheets has been done under instructions governing third-order work, but as this work often depends on lines of the older triangulation, it is pro[illegible]ble that its real accuracy, as indicated by accuracy of lines, fa[illegible] below the stated standard.

The triangulation of the island of Oahu executed in 1927 and the connection between the triangulation of that island and the triangulation of the island of Kauai (1928) is of a much higher order of accuracy. The triangulation of Oahu, 1927, was adjusted in two parts: Loop I extends from the base line at Schofield to the northwest side of the island, thence to the north point, down the east side, and along the south side to Pearl Harbor, thence to a closure at Schofield. Loop II extends from a junction with Loop I, along the southwest side of the island, and thence east to a junction with Loop I at Waialua. The two loops are also tied together about opposite Schofield.

The following statistics are an indication of the accuracy of the work:

	Loop I	Loop II
Number of observed directions	175	100
Average correction to a direction	1.0″	2.0″
Probable error of an observed direction	±1.3″	±2.6″
Number of closed triangles	71	41
Average closure of triangle	2.8″	3.1″

In the connection between Kauai and Oahu there were 4 triangles with an average closing error of 2.0″; 12 observed directions with an average correction of 0.7″ and a probable error of ±0.8″; and the length closure between the lines held fixed on the two islands was 1 in the sixth place of logarithms, or 1 part in 434,000.

OLD HAWAIIAN DATUM

The geodetic datum adopted for the triangulation of the islands Oahu to Hawaii was based on the hydrographic adjusted latitude (see p. 4) and the Tupman longitude (see p. 5). In 1928 when a connection was effected between the islands of Oahu and Kauai the datum was extended to the latter island, so that in the present volume all geographic positions of stations from the rock Kaula, southwest of Niihau, to the southernmost tip of Hawaii are on this one datum. This was the datum selected in accordance with a recommendation by Mr. J. S. Emerson, of the Hawaiian Government Survey. Its selection was ratified after the United States Coast and Geodetic Survey took up the adjustment of the triangulation of the islands, and it was given the simpler name of the "Old Hawaiian Datum."

In making the office computation of the Hawaiian triangulation it was first considered computing the ideal geodetic datum, by using the latitude determinations made by Mr. Preston and the 1904 first-order determination of the longitude of Honolulu, and allowing for the computed effects of topography and isostatic compensation. For various reasons this was not done. It was desirable to hold, if possible, the geodetic datum already in use, provided it was shown to be not in too great error as compared with the theoretical best datum. As soon as the computation of this theoretically best datum had progressed to a point where its value could be approximately known, it was found that it differed so little from the datum already in use as to make any change unnecessary.

The first step in the computation of the triangulation of a country is the adoption of a spheroid of reference. For the Hawaiian triangulation the Clarke Spheroid of 1866 as expressed in meters was adopted. This is the reference spheroid used in the geodetic survey o[illegible] North America. After the spheroid of reference has been adopt[illegible] for a country and all angles and lengths in the triangulation [illegible] is still necessary, before we can proceed with the computation of latitudes, longitudes, and azimuths, to adopt a standard latitude and longitude of a specified station, and a standard azimuth from that station as starting data. In present practice in America, however, no one standard azimuth is adopted, but a number of azimuths, systematically placed throughout the triangulation and reduced to their true geodetic values by the application of the Laplace equation, are held and used as standard. In the Hawaiian triangulation, because of certain weaknesses in the triangulation, the observed astronomic azimuths were held and the triangulation adjusted to them.

The starting data from which the computation of geographic positions is carried ahead may be said to define the geodetic datum.

At the time of its adoption the Old Hawaiian Datum was defined in terms of the coordinates of station Oahu west base, as follows:

	°	′	″
Latitude	21	18	13.89
Longitude	157	50	55.79
Azimuth to station Oahu east base	291	29	36.0

When the 1927 triangulation of Oahu was adjusted it was deemed advisable to hold fixed the old position of station Diamond Head (Leahi) and an azimuth from that station for the reason that this station was a base station for the connection with the triangulation of the Island of Molokai, and it was desired to subject that triangulation and the triangulation of the islands beyond Molokai to as little change as possible. Holding the old positions of Diamond Head and Mauna Loa (Molokai) and permitting Mokapu (Oahu) to swing with the 1927 triangulation adjustment, the line from Mokapu to Mauna Loa was changed but 00.1″ in azimuth, and 0.6 meter (1/108 000) in length, thus making it unnecessary to carry any revision into the triangulation outside of the island of Oahu.

It has been noted that in stations most remote from this standard station a discrepancy of appreciable size occurs between the values given in the adjusted work and the corresponding values in the original computation made under the old Hawaiian government. These discrepancies amount to 1.71″ in latitude and 0.94″ in longitude for the station Ka lae on the southern tip of Hawaii. They are not due to a change in datum, but almost wholly to the adjustment of the triangulation. The older computation was carried through unadjusted figures, some of them of no considerable strength and the new computations were so made as to get the best values obtainable from the observations.

The main object in adopting a geodetic datum for the Hawaiian Islands is to secure the full coordination and correlation of the charts of the island waters, as well as of the surveys and maps of the islands themselves. Since two or more islands are sometimes shown on the same chart, it is quite evident that if the surveys of the islands were not on the same geodetic datum, the relative positions of the islands on the chart would not be true, and it is possible that accurate hydrographic surveys would reveal discrepancies. In any engineering or scientific undertakings involving either a single island or a number of islands it is important that the geographic positions of survey stations [illegible]h will form the basis of the maps used in the work shall be in full [illegible]ement, and this can be accomplished only through the use of [illegible]

USE OF HORIZONTAL CONTROL DATA

That horizontal control data should be based on a single standard geodetic datum may be further shown by considering some of the many uses to which accurate maps and charts are put:

(1) **Cadastral surveys.**—The property survey of a body of land requires that its bounds be located accurately with reference to all neighboring bodies of land, and that no matter from what direction a survey proceeds toward a given corner the resulting location of that corner on the ground will be the same. If a corner located with reference to a geodetic survey be completely destroyed it is possible to replace it within certain limits of accuracy from any two or more of the stations of the survey. Geodetic control makes for economy in placing and maintaining cadastral monuments, and is of particular worth in cadastral surveys of city areas.

(2) **Extensive mapping.**—The topographer needs as initial data for beginning a topographic survey the distance and direction between two points and the geographic position of one of them on the standard datum. If he uses local triangulation or traverse based on this control he will prevent the accumulation of excessive errors as he carries on his mapping operations. Expediency may demand the commencement of mapping operations at widely separated points at the same time. The geodetic control will insure that when any of these mapping operations approach each other and effect a junction no discrepancies due to accumulated errors will be found, but instead a perfect agreement may be expected.

(3) **Boundary lines.**—The boundary lines between political divisions such as cities, counties, states, or nations, if mapped on a unified geodetic control are permanently fixed, due to the possibility of the economical and accurate replacement of lost stations in the same manner as is considered under cadastral surveys above.

(4) **Local intensive surveys.**—Such surveys are required most frequently in connection with extensive improvements over a considerable area or as a basis for city planning, where the needs of a city are being anticipated for a number of years. Here a control of inferior order is needed for determining a great many points in the area under study to serve as a basis for the detail maps required, but in order that the extreme limits of the area under study be fully coordinated this subsidiary control must be based on a main control, which is in itself fully coordinated and correlated. This can be done satisfactorily only on a standard datum.

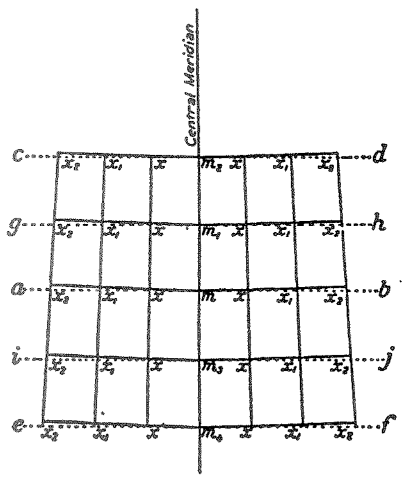
While it is noted in the foregoing that the azimuth and length of one line and the geographical position of one end of that line constitute the essential data in basing a survey on geodetic control, there is always grave danger in depending on this minimum of data. There may be failure to identify the true station mark at one of the stations, or the mark may have been tampered with or otherwise disturbed in position. This will, of course, introduce an error into the new work based on these stations. It is the present practice in this bureau, unless unusual conditions render it unnecessary, to establish the integrity of the recovered points by using at least three old stations as a basis for new work, the third station ser[illegible]g as a check.

In local surveys where the area is of limited extent it is usually desirable to use a system of plane coordinates, the origin being connected to some point of the main-control scheme. This is particularly desirable in city surveys because of the greater simplicity of computations where the plane rectangular system of coordinates is used. Tables for computing plane coordinates from geographic positions are given in United States Coast and Geodetic Survey Special Publication No. 71.

The United States Coast and Geodetic Survey will be glad to give advice on any problem arising out of the use of its control points on any proposed extension of triangulation or traverse from them.

TABLE FOR POLYCONIC MAP PROJECTION

The engineer or surveyor who makes use of the data in this publication may find it desirable to construct a map covering the territory he is surveying. He may wish to show on this map the meridians and parallels so as to be able to plot the positions of the triangulation stations included in the area and show the details of his survey in the correct geographic positions. To enable him to do this with the least possible difficulty the following table, reprinted in an abbreviated form from United States Coast and Geodetic Survey Special Publication No. 5, has been inserted. This table may also be used to interpret in terms of degrees, minutes, and seconds of arc any distance measured along a meridian or parallel. The method of using the table is described below:



NOTE.—In this figure the angle made at the central meridian by the parallels is grossly exaggerated. In an actual projection the parallels appear practically as straight lines.

To make a projection for a large-scale map (1–20,000 and larger) first draw a straight line for a central meridian and a construction line ab perpendicular thereto, each to be as central to the sheet as the selected interval of latitude and longitude will permit. (See fig. above.) On the central meridian lay off the distances, mm_2 and mm_4, using the length of 1′ along the meridian, for the latitude in question as given in the table under "Arcs of the meridian," and multiplying this length by the number of minutes for the interval between the central parallel and the extreme parallels. Through m_2 and m_4 draw straight lines, cd and ef, parallel to the line ab. On the lines ef, ab and cd lay off the distances mx_2, m_2x_2, and m_4x_2 on both sides of the central meridian taking the values from the table under "Arcs of the parallel," corresponding to the latitude of m, m_2, and m_4, respectively. The value of 1′ as taken from the table must be multiplied by the number of minutes out from the central meridian. Draw straight lines through the points thus determined for the extreme meridians—that is, through the x_2 points.

At the two points designated x_2 on the line ab lay off along the meridians the value of Y as given in the table under "Y-Coordinate of curvature," using as argument the interval in minutes between the central meridian and the extreme meridian. Draw straight lines from these points to the point m for the middle parallel, and from the points of intersection with the extreme meridians lay off distances along these meridians, above and below, equal to the distances mm_2 and mm_4 to locate points in the extreme parallels.

Subdivide each of the three meridians and three parallels already determined into parts corresponding with the projection interval and join the corresponding points of subdivision by straight lines to complete the projection.

The method outlined above may be used for all large-scale maps regardless of the number of meridians and parallels shown. For small-scale maps the method is somewhat more complicated and it becomes necessary to make use of Special Publication No. 5, which may be obtained for 20 cents from the Superintendent of Documents, Washington, D. C.

(L)

dif. lat. = [illegible] × cos bearing ÷ arc of meridian.

dif. long. = L sin B ÷ arc of parallel

Oahu Island—Continued

Station	Latitude and longitude	Seconds in meters	Azimuth	Back azimuth	To station	Distance Log (meters)	Distance Meters	Distance Feet
Supplementary points, Honolulu and vicinity—Continued	° ′ ″		° ′ ″	° ′ ″				
Moana Hotel, flagstaff, 1909[1]	21 16 47.17	1,450.7	149 21 53	329 21 23	Punchbowl	3.660952	4,580.9	15,029.2
	157 49 45.76	1,319.1	320 27 23	140 27 42	Diamond Head	3.384921	2,426.2	7,960.0
Royal Hawaiian Hotel, 1927	21 16 50.249	1,545.4	151 29 42.3	331 29 15.9	Punchbowl	3.641227	4,377.5	14,361.8
	157 49 54.270	1,564.4	193 31 58.9	13 32 17.5	Tantalus	3.798294	6,284.8	20,619.4
			317 40 37.7	137 41 00.2	Diamond Head	3.424629	2,658.5	8,722.1
Waikiki latitude eccentric, 1891	21 16 52.384	1,611.0	195 36 50.0	15 37 11.3	Tantalus	3.797705	6,276.3	20,591.5
	157 50 01.856	53.5	315 19 10.3	135 19 35.5	Diamond Head	3.455857	2,856.6	9,372.0
Waikiki, 1927	21 17 15.152	466.0	145 54 30.8	325 54 04.5	Punchbowl	3.570579	3,720.3	12,205.7
	157 49 54.402	1,568.1	195 25 25.4	15 25 44.0	Tantalus	3.743833	5,544.1	18,189.3
			326 42 24.6	146 42 47.2	Diamond Head	3.514252	3,267.8	10,721.1
Kumulae, 1925	21 17 45.166	1,389.0	338 51 02.8	158 51 20.6	Diamond Head	3.593118	3,918.5	12,855.9
	157 49 41.222	1,188.2	131 11 54.1	311 11 23.0	Punchbowl	3.515373	3,276.2	10,748.7
Library, University of Hawaii, 1925	21 18 12.347	379.7	318 49 47.6	138 50 14.8	Kaimuki	3.515481	3,277.0	10,751.3
	157 49 22.540	649.7	348 58 18.6	168 58 29.6	Diamond Head	3.660388	4,575.0	15,009.8
Central Union Church, spire, 1925	21 18 07.238	222.6	332 12 46.1	152 13 14.9	Diamond Head	3.690024	4,898.1	16,069.8
	157 50 11.386	328.2	132 49 31.3	312 49 11.2	Punchbowl	3.337622	2,175.8	7,138.4
Makiki, 1927[1]	21 18 52.06	1,601.1	216 53 42	36 54 05	Tantalus	3.470726	2,956.1	9,698.5
	157 50 04.82	138.9	339 51 55	159 52 21	Diamond Head	3.784157	6,083.5	19,958.9
Lunalilo Home, spire, 1925	21 18 42.286	1,300.5	109 12 00.6	289 11 46.0	Punchbowl	3.086232	1,219.6	4,001.3
	157 50 26.793	772.2	222 06 01.2	42 06 31.6	Tantalus	3.555278	3,591.5	11,783.1
Punchbowl east, 1927	21 18 57.002	1,753.0	233 02 34.5	53 03 11.7	Tantalus	3.565813	3,679.7	12,072.5
	157 50 45.274	1,304.8	330 55 26.5	150 56 07.6	Diamond Head	3.826662	6,709.1	22,011.4
			85 14 39.9	265 14 32.1	Punchbowl	2.793312	621.3	2,038.4
Pauoa, 1927[1]	21 20 15.26	469.3	40 06 53	220 06 27	Punchbowl	3.507070	3,214.2	10,545.3
	157 49 54.90	1,582.0	277 26 43	97 27 02	Tantalus	3.176521	1,501.5	4,926.2
Waolani, 1927	21 21 04.809	147.9	304 23 25.2	124 23 56.9	Tantalus	3.483194	3,042.2	9,981.0
	157 50 30.354	874.6	343 52 55.7	163 53 31.4	Diamond Head	4.008385	10,194.9	33,447.8
			14 45 37.3	194 45 24.0	Punchbowl	3.614682	4,118.0	13,510.5
Wyllie, 1927	21 20 15.651	481.3	273 03 14.3	93 04 03.1	Tantalus	3.587899	3,871.7	12,702.4
	157 51 17.398	501.3	333 11 00.0	153 11 52.7	Diamond Head	3.967556	9,280.2	30,446.8
			352 55 19.6	172 55 23.4	Punchbowl	3.396069	2,489.3	8,157.0
St. Andrews Cathedral, highest tower, 1925	21 18 47.329	1,455.6	253 38 50.9	73 39 01.4	Punchbowl	2.941404	873.8	2,866.8
	157 51 35.850	1,033.2						
Dome, American Factors Building, 1925	21 18 40.894	1,257.7	253 28 12.4	73 28 31.2	Punchbowl	3.193232	1,560.4	5,119.4
	157 51 58.662	1,690.7	314 57 14.5	134 58 22.2	Diamond Head	3.880643	7,597.0	24,924.5
Aloha tower, 1025–1928	21 18 36.751	1,130.2	241 53 06.0	61 54 13.0	Tantalus	3.779420	6,017.6	19,742.7
	157 52 07.419	213.8	251 54 01.5	71 54 23.5	Punchbowl	3.264645	1,839.3	6,034.4
			312 57 08.7	132 58 19.6	Diamond Head	3.885942	7,690.8	25,230.6
Post office, southeast tower, flagstaff, 1925	21 18 32.562	1,001.4	239 19 14.5	59 19 29.4	Punchbowl	3.137443	1,372.3	4,502.3
	157 51 47.709	1,375.0	315 17 14.4	135 18 18.2	Diamond Head	3.856891	7,192.7	23,598.0
Post office, northwest tower, small instrument cupola, 1925.	21 18 33.724	1,037.1	241 07 30.6	61 07 45.8	Punchbowl	3.138594	1,375.9	4,514.1
	157 51 48.564	1,399.7	315 20 51.8	135 21 55.9	Diamond Head	3.859465	7,235.4	23,738.1
Hawaiian Electric Co., southeast stack, 1925	21 18 33.562	1,032.2	246 15 31.1	66 15 50.3	Punchbowl	3.220840	1,662.8	5,455.4
	157 51 59.571	1,716.9	313 35 08.7	133 36 16.8	Diamond Head	3.872644	7,458.4	24,469.8
Hawaiian Electric Co., northwest stack, 1925	21 18 34.299	1,054.8	247 09 32.0	67 09 51.3	Punchbowl	3.221718	1,666.2	5,466.5
	157 52 00.037	1.1	313 38 26.3	133 39 34.5	Diamond Head	3.874118	7,483.7	24,552.8
Judiciary Building, flagstaff, 1909	21 18 31.370	964.8	236 28 39.7	56 28 53.7	Punchbowl	3.125217	1,334.2	4,377.3
	157 51 45.352	1,307.1	315 28 07.4	135 29 10.3	Diamond Head	3.852412	7,118.9	23,355.9
Hackfeld Building, flagstaff, 1909	21 18 40.902	1,257.9	253 28 09.7	73 28 28.5	Punchbowl	3.192973	1,559.5	5,116.5
	157 51 58.632	1,689.8	314 57 36.4	134 58 44.1	Diamond Head	3.880618	7,596.6	24,923.2
Transit of Venus, 1875	21 18 22.738	699.3	235 28 16.7	55 29 16.6	Tantalus	3.760642	5,762.9	18,907.1
	157 51 47.993	1,383.2	313 29 46.6	133 30 50.4	Diamond Head	3.844301	6,987.2	22,923.8
Honolulu Longitude Monument, 1903	21 18 23.719	729.5	236 53 16.7	56 54 19.3	Tantulus	3.772650	5,924.5	19,437.3
	157 51 55.441	1,597.9	312 29 19.5	132 30 26.3	Diamond Head	3.855202	7,164.8	23,506.5
Wireless pole, top, 1909	21 18 23.256	715.2	235 18 11.9	55 18 29.8	Punchbowl	3.238766	1,732.9	5,685.4
	157 51 56.191	1,619.5	312 17 16.7	132 18 23.5	Diamond Head	3.855589	7,171.2	23,527.5
Immigration Building, flagstaff, 1925	21 18 13.669	420.4	231 09 24.9	51 09 44.9	Punchbowl	3.310232	2,042.8	6,702.1
	157 52 01.966	56.7	309 37 27.4	129 38 36.3	Diamond Head	3.851475	7,103.5	23,305.4
Allen and Robinson warehouse, 1925	21 17 53.929	1,658.5	205 13 11.8	25 13 23.0	Punchbowl	3.319585	2,087.3	6,848.1
	157 51 37.618	1,084.3	309 26 25.5	129 27 25.6	Diamond Head	3.790697	6,175.9	20,262.1

[1] No check on this position.

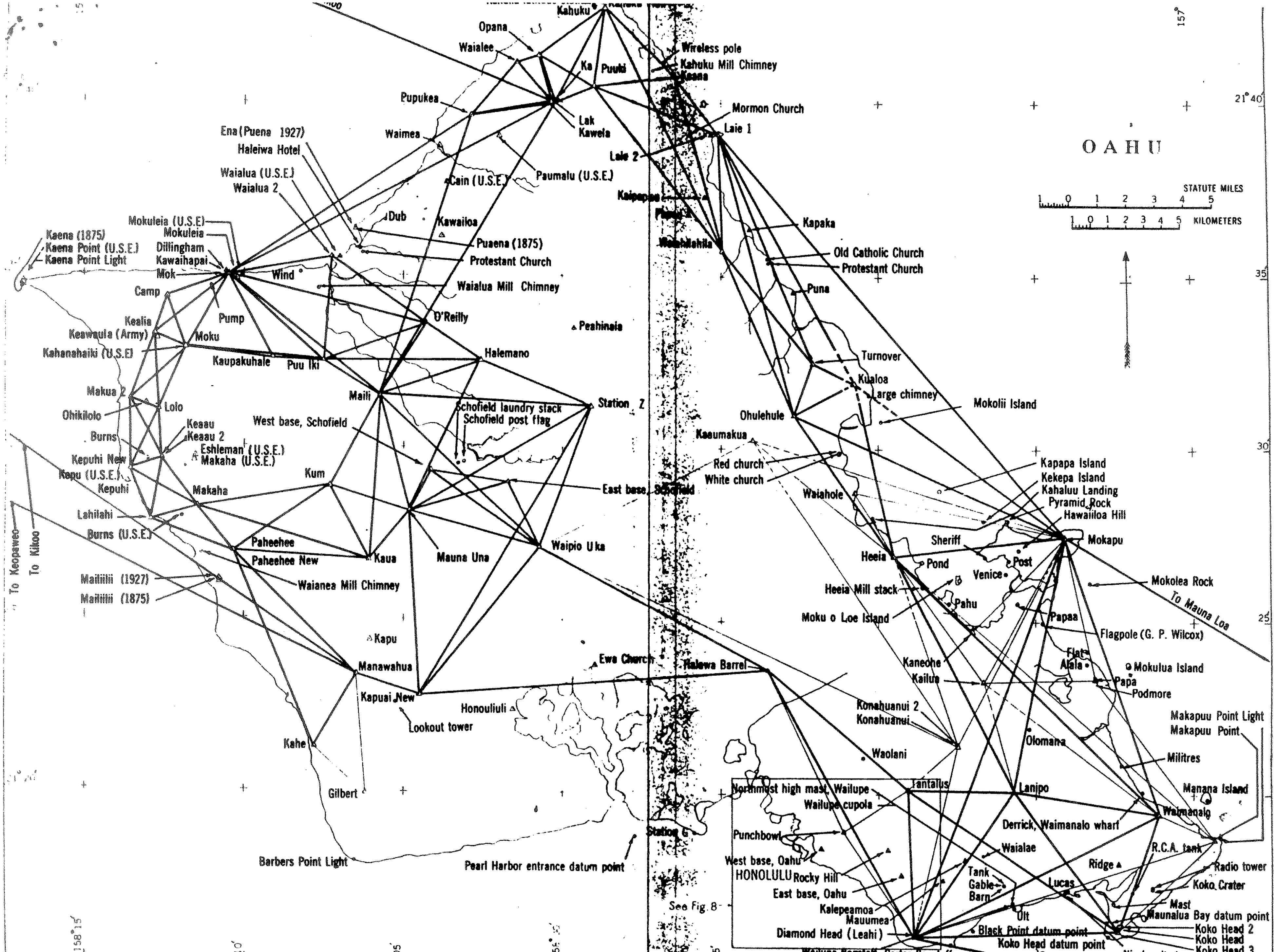


FIG 7 - OAHU ISLAND