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BATHYMETRY, CONTROL POSITIONS AND ASPECT
OF PROPOSED SOFAR STATIONS IN THE PACI-
FIC OCEAN.

George P. Woollard
24 July 1946

MEMORANDUM FOR FILE

BATHYMETRY, CONTROL POSITIONS AND ASPECT OF
PROPOSED SOFAR STATIONS IN THE PACIFIC OCEAN

by

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BATHYMETRY, CONTROL POSITIONS AND ASPECT OF PROPOSED SOFAR STATIONS IN THE PACIFIC OCEAN

PREFACE

The purpose of this memorandum is to present the available information on the nature of the bottom off the coasts of California and Hawaii adjacent to the proposed SOFAR stations in the Pacific Ocean, the best probable locations for the hydrophones, the probable arcs of reception, the positions of fixed land control points, and other information that will facilitate the establishment of an efficient monitoring system.

The writer is indebted to the Director and personnel of the U. S. Coast and Geodetic Survey for copies of boat sheets containing soundings, data on the deflection of the vertical, and triangulation station data in the areas involved.

INTRODUCTION

From the results obtained at the prototype SOFAR station on Eleuthera Island, B. W. I., it was found that the topography of the ocean bottom governed the arc of reception at the station, the completeness of coverage within the receiving arc, and to a certain measure, the reverberation received. The presence of submarine valleys over 1000 feet deep off Eleuthera made it necessary to determine their position and place the hydrophone on a spur between valleys so as to obtain a favorable aspect. Despite this precaution the presence of a submerged point of land up the coast limited the western reception boundary so that it did not extend beyond a line drawn between the station and Newfoundland. This meant that a large area off eastern North America was in shadow and could not be

monitored. It was also found that sea mounts such as that capped by the Bermuda Islands give rise to pronounced shadow zones. That for Bermuda was 700 miles long.

Another observation at Eleuthera was that there appeared to be a quite pronounced velocity discrepancy when shots from known positions were triangulated in. This phenomenon is believed to be related to errors in position rather than actual velocity discrepancies, and to result from deflections of the plum line. Although the exact degree of error due to this cause at Eleuthera is not known, quite appreciable errors have been reported for other islands in the Atlantic. At Bermuda the discrepancy between astronomic and triangulated positions amounts to 1/4 mile in 18 miles. In Puerto Rico a discrepancy of 1 mile in 60 miles has been reported. Even with the difference known, it is not possible to say which position is correct without information on the gravitational field.

In contrast to the Bahamas there are existing bathymetric surveys for the California Coast which show all the major topographic features out to about 2000 fathoms. Similarly, there are estimates of the departure of the vertical at locations very close to the proposed hydrophone sites. Off Hawaii, the data are not nearly so complete, and additional surveys will have to be made to supplement the existing ones which, for the most part, do not extend beyond 100 fathoms. However, there are sufficient random data to permit the selection of probable hydrophone sites for further investigation.

BATHYMETRY OF AREA TO BE MONITORED

The proposed test installation in the Pacific consists of four stations, two in California and two in the Hawaiian Islands.

Although this installation is primarily a research installation, it also will be used to monitor the principal air-ways between the Islands of Hawaii and California. The bathymetry of this part of the Pacific Ocean is for the most part uncomplicated by known sea mounts. However, five such potential obstacles to SOFAR transmission are known, two of which have been reported in the last two months. Erben Bank at Lat. $33^{\circ}00'$ N. and Long. $132^{\circ}40'$ W. has a reported minimum depth of 244 fathoms. Independence Bank* Lat. $30^{\circ}44'$ N. and Long. $139^{\circ}19'$ W. has a reported minimum depth of 800 fathoms and may rise to much shoaler depths. Twin Banks*, two peaks about 60 miles apart at about Lat. $32^{\circ}00'$ N. and $127^{\circ}30'$ W., are mapped as having depths of 240 fathoms and 750 fathoms respectively. Sumner Bank* Lat. $35^{\circ}08'$ N., Long. $130^{\circ}25'$ W. has a minimum depth of 8 to 18 fathoms. The locations of these sea mounts are shown in Fig. 1, p. 16.

Sumner, Erben and Independence Banks are the greatest potential threats to SOFAR transmission since they lie on the great circle path from California to Hawaii. The Twin Banks lie pretty well to the south and off the direct path between stations.

Until surveys of these sea mounts are made for their width and minimum depth, it will be impossible to estimate the probable extent of the shadow zones that they will cast.

* Independence Bank was reported by the U. S. S. Independence.

The name is not official, but has been adopted for use in the SOFAR reports to facilitate identification. Similarly, Sumner Bank is used to describe the bank discovered by the U. S. S.

Sumner, and the name Twin Banks coined for ease of description.

BATHYMETRY OF STATION LOCATIONS

At all of the station locations in the Pacific the continental or island shelf is narrow, and at no location does it appear that more than 15 miles of cable will be required. Although the exact depth at which the hydrophone should be placed to be on the sound channel axis will not be known until local hydrographic surveys are made, it will probably be around 300 fathoms.¹ Figs. 2, 3, 4 and 5 (pp. 17-20) are bathymetric maps for the various stations. On each are indicated probable hydrophone sites with the anticipated areas of reception at two depths, 300 fathoms and 500 fathoms. Although the control for the bathymetric charts shown in Figs. 2, 3, 4 and 5 is good off the California Coast, that off the Hawaiian Islands is very poor beyond the 100 fathom line. Since the survey ship or cable ship may want to use the original surveys made by the U. S. Coast and Geodetic Survey, the location of these surveys for each station area along with the probable hydrophone positions are shown in Figs. 6, 7, 8 and 9 (pp. 21-24). The numbered areas in these figures refer to the original hydrographic survey "boat sheets" and not to published surveys. Both BuShips and Woods Hole have copies of these boat sheets.

In general the near shore surveys (out to 50 fathoms) are quite detailed, whereas the offshore surveys are more limited in coverage. Since all the proposed hydrophone sites lie in the

¹Long Range Sound Transmission, Interim Report No. 4. Velocity Structure in the Northeast Pacific, O. W. Schreiber. W. H. O. I.

offshore areas, additional detailed hydrographic work will have to be carried out in the area where the hydrophone is to be laid. With a very rough bottom it may be necessary to move further offshore and float the hydrophone to guard against locating it in a gully or other depression which may mask reception.

Statistics on Bathymetry at Stations

Monterey: Monterey Bay and approaches is the most thoroughly surveyed of all the station sites (see Fig. 6, p. 21). In the bay and out to 60 fathoms, the bottom is characterized by a gentle slope except where the head of Monterey Submarine Canyon cuts across the Bay (see Fig. 2, p. 17). In addition to this canyon there are numerous other canyons to the south and northwest of the Bay which makes it imperative that the hydrophone be located on a spur. Such a site lies directly west of Pt. Pinos about 9 miles from Monterey at approximately Lat. $36^{\circ}38'$ N., Long. $122^{\circ}02'$ W. The reception arc at this site appears to be about 110° at a depth of 300 fathoms. Existing surveys do not indicate how rough the bottom is here, and detailed surveys will have to be made prior to choosing the final location for the hydrophone.

Pt. Arena: Off Pt. Arena there is a gentle bottom slope out to about 100 fathoms with a steeper seaward gradient beyond this depth. There are no marked submarine canyons near the most favorable site which is about 14 miles offshore at approximately Lat. $38^{\circ}51'$ N., Long. $123^{\circ}56'$ W. (see Fig. 3, P. 18), although there may be local gullies that do not show up on existing surveys. The station aspect is good, 158° at a depth of 300 fathoms.

Hilo Bay: Although there are no U. S. Coast and Geodetic Survey charts covering the hydrophone site at Hilo Bay, there are sufficient H. O. data to show that there is a marked submarine embayment directly East of the bay and a submerged headland north of the bay. Three hydrophone sites are indicated (see Fig. 4, p. 19). Site 1 is 9 miles offshore and has a reception are of 83° at 300 fathoms. Site 2 is 11 miles offshore and has a reception are of 150° . Site 3 is 14 miles offshore and has a reception are of 204° . Since these stations are to be used for actual air-sea rescue work, site 3 at Lat. $19^{\circ}57'$ N., Long. $154^{\circ}58'$ W. should be used for it will permit the area westward from Hawaii to Oahu to be monitored. Shoal waters at this station are characterized by numerous coral reefs, and it may be advisable to carry the cable through any surf area* in rigid metal conduit to eliminate chafing.

Kaneohe Bay: As at Hilo the U. S. Coast and Geodetic Surveys do not extend far enough offshore to include the proposed hydrophone site, but a rough representation of the bottom can be gained from H. O. data. Two possible sites are indicated in Fig. 5, p. 20. Site 1, 9 miles from shore, has an aspect of 113° at 300 fathoms, and Site 2, 10 miles offshore, has an aspect of 140° at 300 fathoms. This is the western-most station to be established, and Site 2 (Lat. $21^{\circ}35'$ N., Long. $157^{\circ}40'$ W.) is recommended since it has the greatest potential value for air-sea rescue work. Kaneohe Bay is

* If the cable can be brought in through the anchorage behind the breakwater, conduit will not be required, but local regulations may require the cable both here and at Kaneohe to be brought ashore at locations that are not ideal for the cable.

very shoal and characterized by extensive areas of coral, and it may be desirable to lay the shoreward end of the cable in conduit if it has to be brought through surf. Cable maintenance may be a greater problem here than elsewhere.

FIXED LAND CONTROL POINTS FOR SHORAN INSTALLATIONS

In choosing sites for the Shoran installations an attempt has been made to locate these stations at USCGS or USGS triangulation or traverse stations. The advantage of using these sites are that these points have been accurately located which will increase the accuracy of fixes based on them and also will facilitate getting deflection of the vertical data for other studies. Choice of station sites was governed by the following factors: (1) Obtaining a base line 15 to 30 miles long that would permit monitoring of all the offshore areas out to the hydrophone site (2) a base line with no intervening high topography that might cast "shadows" (3) easily accessible and well marked stations. The locations of the stations picked on the above basis and the connecting base lines are indicated in green in Figs. 2, 3, 4 and 5.

Statistics on Proposed Shoran Stations

All of the stations chosen were marked by a standard brass disc set in a concrete monument flush with the ground, and according to the last available information, these markers are still intact.

Monterey:

Soquel Point

Lat. $36^{\circ}57'17.9''$ N.

Long. $121^{\circ}58'32.4''$ W.

To reach the station take the shore road leading from Capitola to Twin Lakes. At 2.5 miles and about 0.2 miles after rounding Soquel Point, turn off the road to the right. The station is about 100 yards off the road. See Fig. 10, p. 25, for a map of the area adjacent to station.

Mt. Torro

Lat. $36^{\circ}31'34.2''$ N.

Long. $121^{\circ}36'35.4''$ W.

To reach the station take the Canyon del Rey road leading from Del Monte to Salinas. At 8.5 miles turn south on the road leading to Washington School. Follow the well traveled road for 1.5 miles, at which point take the left hand fork which skirts the foot of the mountain. Follow this road along the bed of Watson Creek, past Washington School, and Lincoln School. At about $18 \frac{3}{4}$ miles from Del Monte on the crest of the main divide, turn right on the road which runs along the divide. At a point about $3 \frac{1}{2}$ miles up this road on the highest point of the mountain, turn off to the south. The station is on the highest point of the crest about 0.3 miles south of the road and 150 feet above it. See Fig. 11, p. 26, for a map of the area adjacent to station.

Point Arena:

Point Arena Lighthouse

Lat. $38^{\circ}57'17.38''$ N.

Long. $123^{\circ}44'22.4''$ W.

The station is located at the lighthouse which is on the northern end of the projectory known as Pt. Arena. This location is about 4 miles north of the town of Pt. Arena and 2.5 miles west

of the main highway running from Pt. Arena to Manchester. The location of the station is indicated in Fig. 12, p. 27, along with a sub sketch which shows the highway location. There are no USGS topographic or cultural maps for this area, and Fig. 12 is based on USC GS surveys.

Haven's Neck 2

Lat. $38^{\circ}48'31.49''$ N.

Long. $123^{\circ}36'02.98''$ W.

The station is located on Haven's Neck about 1.5 miles north of the village of Fish Rock and 9 miles south of the town of Pt. Arena. The station is on the highest part of the point and near the edge of the bluff. See Fig. 13, p. 28, for the location of the station and sub sketch of Fig. 12 for the relation of this station to Pt. Arena Lighthouse station.

Hilo Bay:

Papaaloa

Lat. $19^{\circ}58'42.0''$ N.

Long. $155^{\circ}13'4.8''$ W.

The station is near the edge of the bluff at the end of the street running NE from the main road about 0.7 miles SE of the main intersection in Papaaloa. See Fig. 14, p. 29, for a map of the area.

Cape Kumukahi

Lat. $19^{\circ}31'7.8''$ N.

Long. $154^{\circ}48'48.6''$ W.

The station is located alongside the Cape Kumukahi lighthouse about $2 \frac{1}{4}$ miles east of the village of Kapoho. For a map of the area see Fig. 15, p. 30.

Kaneohe:

Kahuku

Lat. $21^{\circ}40'42.3''$ N.

Long. $157^{\circ}56'31.8''$ W.

The station is about 1 mile southwest of Kahuku on the road to Makahoa Point. The station is about 1/2 mile west of the end of the point and about 100 yards off the road on the north side. See Fig. 16, p. 31, for a map of the area.

Makapuu Head

Lat. $21^{\circ}18'42.6''$ N.

Long. $157^{\circ}39'21.6''$ W.

The station is on top of the crest at Makapuu Head about 150 yards west of the end of the main road, 0.3 miles south of Makapuu Lighthouse and about 150 yards south of the bluff. See Fig. 17, p. 32, for a map of the area.

DEFLECTION OF THE VERTICAL OBSERVATIONS

The positions given for the proposed Shoran stations are based on the North American 1927 datum which is based on the Clarke Spheroid of 1866. These are geodetic positions; that is, they are referred to a point on the celestial sphere defined by the normal to the ellipsoid of reference. They may differ from astronomically determined positions which are referred to a point on the celestial sphere defined by the plumb line at sea level of the station which is normal to the actual equipotential surface defining the geoid. The degree to which geodetic and astronomically determined positions differ depends on the deflection of the vertical which is the angle between the normal to the ellipsoid and the plumb line or normal to the geoid.

The deflection of the vertical is defined in terms of its two components, one in the meridian and the other in the prime vertical. The difference between the geodetic and astronomical latitudes of a station is the deflection in the meridian, and the difference between the geodetic and astronomical longitudes multiplied by the cosine of the latitude is the deflection in the prime vertical. For the best solution of long range triangulation problems, geodetic coordinates on the same datum are necessary, but since this is not possible, approximations based on astronomic determinations of position are necessary.

Although there are not complete data on the deflection of the vertical at the various stations, there are sufficient data¹ to show the order of magnitude of the deflection that might be expected at each of the proposed SOFAR stations. The known values are given in Table I and the locations indicated in Figs. 2, 3, 4 and 5, pp. 17-24.

Table I

Deflection of Vertical Determinations

<u>Mt. Torro</u>						
Latitude		Defl.		Longitude		Defl.
Astro.	Geod.	Meridian	Astro.	Geod.	Prime Vort.	
36°31'39.88"	33.661"	+6.22"	121°36'36.52"	31.019"	+4.42"	
<u>Pt. Pinos</u>						
36°37'59.48"	58.18"	+1.30"	121°55'-----	30.35"	----	
Pt. Arena						
<u>Pt. Arena Lat. Station</u>						
38°55'10.16"	17.901"	-7.74"	123°43'-----	35.719"	----	
<u>Pt. Arena Long. Station</u>						
38°54'-----	35.139"	-----	123°41'46.26"	23.251"	+17.9"	

¹Deflection of the Vertical in the United States. (1927 Datum).

Table I (con't)

Hilo Bay

<u>Hilo</u>	Latitude		Defl. Meridian	Longitude		Defl. Prime Vert.
	Astro.	Geod.		Astro.	Geod.	
	19°43'11.24"	11.59"	-0.35"	155°05'-----	57.66"	-----

<u>Kohala</u>	20°15'29.33"	14'58.21"	+31.12"	155°46'-----	27.15"	-----
---------------	--------------	-----------	---------	--------------	--------	-------

Kaneohe Bay

<u>Kahuku</u>	21°43'06.07"	42'41.55"	+24.52"	157°58'-----	59.79"	-----
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In connection with the Hawaiian stations¹ it should be noted that in order to reduce the deflection of the vertical values as near to zero as possible, the geodetic latitudes have to be decreased 10 seconds which would raise the deflection values for the above stations by 10 seconds. From the standpoint of the present work, it is important to find out which values tie in best with the North American triangulation net work. This, however, can not be determined except by actual triangulation tests.

RECOMMENDATIONS

Hydrophone Sites:

(1) Since it is probable that the present installation may be used for actual air-sea rescue operations, it is recommended that the sites having the greatest potential value for such operations be used.

(2) Where there are submarine canyons adjacent to the stations, it is recommended that the cable not be laid across such features. If the armoured cable is used, approximately 4 additional miles of cable will be required. If demolition cable is used, there may be failure due to the extra strain on the cable because of (a) the increase in load

Gravity Anomalies and Meridian in Hawaii. J. A. Duerksen. Trans.

from the greater unsupported bight in crossing the canyon and (b) the probable dragging of the cable along the bottom on the laying end after crossing a canyon since the bight in the canyon will probably not have laid itself before that on the adjacent head wall.

Shoran Installations:

It is recommended that all Shoran stations be located at triangulation or transit traverse stations. The advantages to be gained from using these station sites are:

(1) The geographic position of the sites has been accurately determined, and with these as base points, the geographic coordinates of other locations can be more accurately determined than would otherwise be possible.

(2) There are departure of the vertical data available for some of the sites picked.

(3) The stations are marked and described so that they can be easily reoccupied at any time.

With this type of position control not only can more accurate bathymetric and hydrographic surveys be made, but also it should be possible to locate the hydrophone more accurately than has been possible hitherto before. It is suggested that at the time the hydrophone is laid, the survey ship immediately make a continuous fathometer survey of the area and that the intensity of signal received on the hydrophone be recorded. This survey should locate the hydrophone more accurately than is possible using bomb triangulation methods, particularly if the survey consists of two sets of parallel traverses at right angles to each other.

Surveying Sea Mounts:

It is recommended that all known or discovered sea mounts be surveyed in sufficient detail to reveal the minimum depth and the

diameter of the sea mount at the depth of the axis of the sound channel if it extends above that depth, otherwise the diameter of the top which is likely to be a broad, relatively flat area.

This information will be of aid in estimating the number of ray paths that will be obstructed, and (b) the probable width and length of the shadow zone that might be expected.

Station Installation Procedure:

It is recommended that the original investigations at each station be made in the following order:

- (1) Establish the Shoran Installations.
- (2) Make a bathymetric and hydrographic survey of a general nature from the shore out to the recommended hydrophone site. This survey will indicate (a) the location of the axis of the sound channel (b) the accuracy and usability of the charts included in this report (c) the nature of the bottom at the hydrophone site (d) whether the proposed site is satisfactory (e) the degree to which additional surveying appears to be desirable (f) whether the Shoran installation is satisfactory.
- (3) Bathymetric and hydrographic survey along a few traverses to check the probable arc of reception indicated in this report and the thermal pattern within this arc of reception.
- (4) Set up the monitoring equipment.
- (5) Lay a single cable and hydrophone and determine with this installation the following:
 - (a) If local interference permits operations.
 - (b) The geographic position of the hydrophone.
 - (c) The actual arc of reception.

(d) The reliability of the monitoring equipment on continuous operation.

(e) Difference in triangulated positions for offshore vessel using Radar, Shoran and Loran.

(f) Difference in observed travel times and predicted travel times.

(g) Accuracy that range of ship dropping bombs could have been determined from oscillograph records.

(6) With the above investigations in progress, it is then recommended that a new cable or cables be laid to test the preamplifier, two or more hydrophones at different depths, bottom anchored floating hydrophones, change in hydrophone sensitivity with time, variations in bomb signal strength, etc.

(7) For the location of shadow zones due to new sea mounts and a general SOFAR Survey between California and Hawaii, it is recommended that at least three stations be established before this work is undertaken and that a plane be used to drop the bombs. For making the more detailed surveys to determine the width and extent of shadow zones and intensity studies, it appears to be more practical to use the survey vessel.

(8) For studies such as the effect of latitude it is recommended that arrangements be made for other craft stationed in the localities of interest to make the necessary hydrographic measurements and to fire the bombs so that the survey ship can be used efficiently and not have to be detached for long trips from the area of primary interest.

BATHYMETRIC CHART OF NORTHEASTERN PACIFIC

123° 50' 40' 30' 20' 10' 122° 00' 20'

PROPOSED HYDROPHONE SITE
MONTEREY, CALIF.
DEPTH CONTOURS IN FEET
GREEN ○ SHORAN STA.
RED ○ DEPARTURE OF
VERTICAL STA.

PROPOSED HYDROPHONE SITE
PT. ARENA, CALIF.
DEPTH CONTOURS IN FEET
GREEN ○ SHORAN STA.
RED ○ DEPARTURE OF
VERTICAL STA.

Pt. Arena

14 MILES

158°

300 FM. ASPECT
500 FM. ASPECT

FIG. 3

-21-

HYDROGRAPHIC SURVEYS
US COAST & GEODETIC SURVEYMONTEREY, CAL
SOFAR STATION

HYDROGRAPHIC SURVEYS
US COAST & GEODETIC SURVEY
PT. ARENA, CALIFORNIA

HYDROGRAPHIC SURVEYS
US COAST & GEODETIC SURVEY
HILO BAY, HAWAII

HYDROGRAPHIC SURVEYS
US COAST & GEODETIC SURVEY
KANEIOHE, OAHU

37°00' 12.4" 00

R. I. W.

55'

(New Alt SE)

T. II S.

MONTEREY
PROPOSED NORTH
SHORAN STA.

LAT. 36° 57' 17.9" N

LONG. 121° 58 32.4" W

FIG. 14