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Technical Report No. 14

Shot Refraction Profiles in the Atlantic Coastal Plain 6 Miles East of Ambrose Lightship

by

R. O. Carlson and M. V. Brown

W. A. Nierenberg
Director

Research Sponsored by
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SHOT REFRACTION PROFILES IN THE ATLANTIC COASTAL PLAIN 6 MILES EAST OF AMBROSE LIGHTSHIP

by

R. C. Carlson and M. V. Brown

ABSTRACT

Two mutually perpendicular profiles were obtained by reversed refraction shooting across a point at 40°27'55"N and 73°41'40"W, about 8 miles south of Long Beach, Long Island, and 6 miles east of Ambrose Lightship. Three ground layers were detected with slopes of less than 1° along either profile. The seismic velocities and thicknesses of the layers are as follows: water-4905 ft/sec, 80 feet; unconsolidated sediment-5630 ft/sec, 750 feet; semi-consolidated sediment-6750 ft/sec, 1040 feet; rock basement-18,600 ft/sec. The velocity values and rock basement depth are in agreement with previous seismic refraction results for nearby ocean areas.

INTRODUCTION

During the month of June, 1953, two mutually perpendicular reversed refraction profiles were made in a shallow water area 8 miles south of Long Beach, across a point designated as X-Ray, 40°27'55"N and 73°[illegible]1'40"W. The purpose of this experiment was to determine several of the physical parameters of the area such as the thickness of sediment layers underlying the water, the velocity of sound in the water, and the velocity of sound in the sediment layers and the rock basement. Previous shot refraction profiles to the east of point X-Ray[1,2] and fresh-water well log data on nearby Long Island[3] made it possible to estimate beforehand that we could expect one or two sediment layers overlying a rock basement at a depth of about 1700 feet (measuring from the ocean surface). One profile was chosen to be along the direction of expected maximum basement slope.

LOCATION

The position of point X-Ray was marked by the Coast Guard with an anchored buoy. The depth of water near X-Ray is about 80 feet. Fig. 1 is a chart of the area involved in this shot refraction project showing point X-Ray, previous shot refraction stations,[1] and well positions on Long Island.[3] The four shot receiving stations are indicated as ABLE, BAKER, CHARLIE, and DOG. The first reversed refraction profile was fired along the line joining ABLE and BAKER, making an angle of 58° with True North. The second reversed refraction profile was fired along the line joining CHARLIE and DOG at an angle of 148° with True North. The four receiving stations were selected to be one nautical mile from point X-Ray.

APPARATUS

The shot firing ship for this experiment was the USS ALLEGHENY (ATA-179). A 40 foot Navy Retriever boat was used as the listening station. The shot arrivals through the water and various ground layers were received by a Brush AX-58-C hydrophone lying on the ocean bottom at a depth of about 80 feet, were amplified by a geophysical amplifier with a gain of the order of 40 to 60 db, filtered, and then recorded on a Southwestern Industrial Electronics Oscillograph Camera. Eight channels were used on the recording camera: three for the low frequency filtered hydrophone signal (up to 60 cps), three for the high frequency filtered and rectified hydrophone signal (above 500 cps), and two for the radioed shot signal. To give the firing time of the shot, the shot signal picked up by holding a microphone against a bulkhead of the firing ship was transmitted to the Retriever. The speed of the firing ship was known and the interval of time between the throwing of the charge over the ship's side to the explosion was measured. From this data the correction for the time of travel of the shot sound wave through the water to the firing ship was easily made.

PROCEDURE

The procedure followed in obtaining a refraction profile is illustrated by Event ABLE. The firing ship proceeded to position X-Ray and, using its radar and pelorus, moved out one nautical mile on the bearing of 238° T to station ABLE. The Retriever came up alongside and anchored. The firing ship then moved away and stood by until the Retriever had lowered its hydrophone and was ready to receive shot sound arrivals. The Retriever requested that a charge be fired at a given distance from it on the line joining ABLE and X-Ray. The firing ship maneuvered until it was on a course at right angles to the ABLE-X-Ray line and then steamed at five knots or more to intersect the line at the prescribed distance from the Retriever, as measured by the ship's radar. The charge was dropped as the firing ship crossed the ABLE-X-Ray line. Distances and charges for each event were chosen so as to give a number of first arrivals (or definite later arrivals) from each suspected sediment layer or the rock basement. The distances specified for each event were 1000, 2000, 3000, 5000, 7000, 9000, and 12,000 feet, although additional shots were fired at intermediate ranges in some events. In the case of a dud, the charge, which was tied to hang about 30 feet below a five gallon can float, was towed to a seaward disposal point and sunk. After each shot, the camera record was developed and the shot arrivals plotted. In this way, it was possible to study the travel time graph immediately.

WATER WAVE ARRIVAL

The rectified high frequency camera traces were used to detect the arrival of the sound wave traveling entirely through the water. The temperature of the ocean water from the surface to the bottom was measured each working day using a bathythermograph. The salinity of the water around X-Ray, as obtained from reports by Stockton,[4,5] was approximately 31 parts per thousand for the bottom half of the water layer. In Table I, the temperature data and the velocities obtained from tables of sea water sound velocity [6] are presented. Since the first arrival water wave travels in the region from 30 feet deep down to the ocean bottom, the average velocity for this region was used. For Events ABLE and BAKER, this average velocity was almost exactly 4900 ft/sec, while for Events CHARLIE and DOG, it was 4910 ft/sec.

In Table II, a comparison is made of the radar range of the Retriever at the time of each shot, with the range computed from the water wave arrival time and average sound velocities in water as given in Table I. Since the travel times can be measured to thousandths of a second, the estimated error in "computed" ranges due to an error in measured travel time should be about 0.8% for the shortest range diminishing to less than 0.2% for the longest range. The spread of differences between radar and "computed" ranges can be accounted for by the difficulty in reading the radar screen in the short time available and by the fact that there were several radar observers, each with slightly different radar scope reading habits.

It is striking, however, that for Events ABLE and BAKER and shot 1a of Event CHARLIE (carried out on June 23rd and 25th) the radar range is always less than the "computed" range with only one exception. For Events CHARLIE and DOG the opposite is true, i.e., the radar range is always greater than the "computed" range. It was noticed after one event that the ship's radar scope was not accurately centered, i.e., the center of the radar sweep beam did not coincide with the center of the scope grid. Such non-centering could lead to a recurring error during the course of an event in which the listening boat was always on the same bearing from the firing ship. If the radar beam were left the same in both Events ABLE and BAKER, the radar "error" should be of opposite sign in the two cases since their true bearings would be 180° apart on the radar screen. Since this was not true, it means that if the radar "error" in Event ABLE were due to non-centering of the radar beam, the radar beam must have been readjusted before Event BAKER two days later. No note was made whether such radar adjustments were made or not.

RECIPROCAL RANGES

In drawing the travel time graphs, it is helpful to have the range between the two stations comprising the reverse profile (reciprocal range) so that the reverse points can be plotted. The firing ship located each listening station with respect to the anchored buoy at a radar range of one mile. From Table II, it appears that for a radar range of 2027 yards, the corrected range would be 125 yards greater for Event ABLE, 120 yards greater for Event BAKER, 80 yards less for Event CHARLIE, and 90 yards less for Event DOG. Carrying out these radar range corrections, the distance between ABLE and BAKER or reciprocal range is 12,900 feet, corresponding to a water travel time of 12900/4900 = 2.633 seconds. The distance between CHARLIE and DOG is 11,650 feet, corresponding to a water travel time of 11650/4910 = 2.373 seconds.

BUBBLE PULSES

Since the charges used in this experiment, ranging from 1/2 lb to 12 1/2 lb, were not fired on the water surface, bubble pulses were obtained on each shot record. The first bubble pulse intervals were measured and the data fitted to the first bubble pulse interval equation

$$T = 4.19\, W^{1/3} \Big/ (H + 33)^{5/6},$$

T being the first bubble pulse interval in seconds, W the charge weight in pounds, and H the depth of the charge in feet.[7] It was found that the pulse intervals corresponded to a depth of about 30 feet only for the heavier charges, those over 4 lbs. The

1/2 lb charge intervals were of the order of 0.147 seconds (average value), corresponding to a depth of only 9 feet. The 1 lb charge pulse interval correspond to a firing depth of 13 feet, 1 1/2 lb charges a depth of 25 feet, and 2 lb charges a depth of 20 feet. The conclusion drawn from these calculations is that the lighter charges may not have had sufficient time (approximately 36 seconds) to sink 30 feet below the float before they exploded. The sinking rate for free falling 1/2 lb demolition blocks can be obtained from a report by Officer and Wuenschel.[8] Their curve indicates that a free falling 1/2 to 1 lb block should sink 60 feet in 36 seconds, which is considerably more than the experimental bubble pulse interval would indicate. However, it may be that the cord used to tie the charge block to the oil can float retarded the sinking rate to such an extent that the block only sank 9 feet in 36 seconds. All travel time calculations were made on the assumption that the shots actually were fired 30 feet below the water surface since the corresponding difference in travel time through the water is negligible.

THEORY

The theory involved in the derivation of travel time equations has been covered in considerable detail by Ewing[9] and in geophysical books such as that of Dobrin.[10] The wave paths for our particular case are shown in Fig. 2. Since these wave paths are slightly different from the standard arrangement in which the shot and hydrophone are both on the ocean surface, the travel times will be derived in this section. The velocities, depths, and angles are as defined in Ewing's paper. We shall assume a uniform velocity in the water.

For path (1) entirely in the water, $t_1 = \frac{\sqrt{x^2+y^2}}{V_1} = \frac{x}{V_1}$,

where we have for our case ($y \sim 50'$, $x \sim 1000'$, $V_1 = 4900$ ft/sec) neglected the term in y.

For path (2) through the water and along the water-unconsolidated interface:

$$t_2 = \frac{y}{V_1 \cos i_{12}} + \frac{x - y\tan i_{12}}{V_2} = \frac{x}{V_2} + \frac{y}{V_1 \cos i_{12}} - \frac{y \tan i_{12} \sin i_{12}}{V_1}$$

where we have used $\frac{V_1}{V_2} = \sin i_{12}$. Combining, $t_2 = \frac{x}{V_2} + \frac{y \cos i_{12}}{V_1}$

For path (3) through the water, across the unconsolidated layer, and along the unconsolidated-semi-consolidated interface:

$$t_{3a} = \frac{y}{V_1 \cos q_{13}} + \frac{h_{2b} + y \tan q_{13} \sin \omega_{23}}{V_2 \cos i_{23}} + \frac{h_{2a}}{V_2 \cos i_{23}}$$
$$+ \frac{x \cos \omega_{23} - (h_{2b} + y \tan q_{13} \sin \omega_{23}) \tan i_{23} - h_{2a} \tan i_{23} - y \tan q_{13} \cos \omega_{23}}{V_3}$$

Using $\frac{V_2}{V_3} = \sin i_{23}$, the y terms become

$$\frac{y}{V_1 \cos q_{13}} + \frac{y \tan q_{13} \sin \omega_{23}}{V_2 \cos i_{23}} - \frac{y \tan q_{13} \sin \omega_{23} \tan i_{23} \sin i_{23}}{V_2}$$
$$- \frac{y \tan q_{13} \cos \omega_{23} \sin i_{23}}{V_2}$$

The second and third y terms combine as:

$$\frac{y \tan q_{13} \sin \omega_{23} \cos i_{23}}{V_2}$$

This term then combines with the fourth y term to give:

$$-\frac{y \tan q_{13} \sin (i_{23} - \omega_{23})}{V_2}$$

Using $\frac{V_1}{V_2} = \frac{\sin q_{13}}{\sin(i_{23} - \omega_{23})}$, this term then combines with the first y term to give:

$$\frac{y \cos q_{13}}{V_1}$$

The h_{2b} term can be replaced by h_{2a} - x sin ω_{23} so the h_{2a} terms give: $\frac{2 h_{2a} \cos i_{23}}{V_2}$

The x terms are:

$$-\frac{x \sin \omega_{23}}{V_2 \cos i_{23}} + \frac{x \cos \omega_{23}}{V_3} + \frac{x \sin \omega_{23} \tan i_{23}}{V_3}$$

and with $\frac{V_2}{V_3} = \sin i_{23}$, the first and third term combine and the x expression becomes:

$$\frac{x}{V_2} (\cos \omega_{23} \sin i_{23} - \sin \omega_{23} \cos i_{23})$$

$$= \frac{x}{V_2} \sin(i_{23} - \omega_{23}) = \frac{x}{V_{3a}}$$ where V_{3a} is the apparent velocity in the third layer.

Altogether then, one has:

$$t_{3a} = \frac{x}{V_{3a}} + \frac{2 h_{2a} \cos i_{23}}{V_2} + \frac{y \cos \alpha_{13}}{V_1}$$

For path (4), the previous reasoning can be followed to give:

$$t_{4a} = \frac{x}{V_{4a}} + \frac{2 h_{3a} \cos i_{34}}{V_3} + \frac{h_{2a} (\cos \alpha_{24} + \cos \beta_{2i})}{V_2} + \frac{y \cos \alpha_{14}}{V_1}$$

The relations between the various angles in Fig. 2 are given by Snell's Law as:

$$\frac{V_1}{V_2} = \sin i_{12}$$

$$\frac{V_1}{V_{3a}} = \sin \alpha_{13} \qquad \frac{V_1}{V_2} = \frac{\sin \alpha_{13}}{\sin (i_{23} - \omega_{23})} \qquad \frac{V_2}{V_3} = \sin i_{23}$$

$$\frac{V_1}{V_{4a}} = \sin \alpha_{14} \qquad \frac{V_1}{V_2} = \frac{\sin \alpha_{14}}{\sin (\alpha_{24} - \omega_{23})}$$

$$\frac{V_2}{V_3} = \frac{\sin \alpha_{24}}{\sin (i_{34} - \omega_{34})} \qquad \frac{V_3}{V_4} = \sin i_{34}$$

RESULTS

The travel time graphs are plotted in Figs. 3 and 4. Several of the lines are poorly determined, such as the semi-consolidated refraction arrivals in Fig. 3 for the ABLE-BAKER profile and the semi-consolidated refraction arrival in Fig. 4 for the CHARLIE-DOG profile. The intercepts for the various refraction arrivals are listed in Table III along with the velocities computed from the inverse slopes of the lines. Since in each case the velocities for the reverse stations are almost equal, the slopes of the sediment and basement interfaces must be very small.

The computed velocities and layer thicknesses are summarized in Table IV. Only the unconsolidated-semi-consolidated interface for the ABLE-BAKER profile has an appreciable slope and even this is somewhat doubtful because of the difficulty of establishing the ABLE and BAKER intercepts. The thickness of the unconsolidated sediment layer at X-Ray, H_2, computed from the two reversed pro-profiles do not agree and it is probable that the depth at ABLE is too small. The maximum basement slope at point X-Ray does not appear to lie along the direction of Station DOG; however, it is difficult to say just what the maximum slope direction is in view of the small angles involved and consequent comparitively large change in slope for a small change in the travel time graph intercepts. The total depth to the basement at X-Ray, 1870 feet, is in agreement with the estimate of 1700 feet.

Figs. 5 and 6 show cross sections through the ABLE-BAKER and the CHARLIE-DOG Stations.

DISCUSSION OF RESULTS

The average velocities for the unconsolidated, semi-consolidated, and basement layers are in good agreement with the average velocities found by Oliver and Drake:[2] 5400 ft/sec for unconsolidated layer, 6500 ft/sec for semi-consolidated layer, and 18,400 ft/sec of the rock basement. They found these three layers at one seismic station southeast of Block Island and two stations south of Shinnecock Inlet near the eastern end of Long Island. At Station 7, shown on Fig. 1, Ewing et al[1] found only an unconsolidated sediment layer of velocity 5600 ft/sec and a rock basement 2100 feet down with a velocity of 18,800 ft/sec. Evidence of a semi-consolidated layer of velocity 10,800 ft/sec appeared only on the south side of Station 7. Since this velocity is so much higher than the semi-consolidated layer velocity found in this experiment, it is probable that the materials comprising the "semi-consolidated" layers are quite different in the two cases.

An extensive study of the underlying geological formations of Long Island has been made by the New York State Conservation Department. Their reports[3,11] show the basement rock and intermediate layer contours based on fresh-water well log data over the whole island. The basement rock surface contour extrapolates very well to cover the results of the present experiment and earlier seismic work. In addition, their north-south cross-sectional profiles indicate that the unconsolidated layer in our seismic work may be identified with the Magothy layer known to exist under the top glacial deposit of western Long Island. The semi-consolidated layer may be identified with the Raritan and Lloyd layers. It is probable that the Raritan layer runs out as one proceeds southeasterly from New York harbor so that at Station 8 it has been replaced by other deposits of higher sound velocity.

PRECISION OF RESULTS

It is impossible in a shot refraction experiment to give more than crude estimates of the precision of the results for the following reasons:

(1) The reading of the camera records involves personal judgment in the selection of the ground arrivals. Even though a selected point on the camera record can be measured to ± 0.001 second, in many cases the actual start of the ground wave arrival on a record (especially a second or third arrival) may be difficult to estimate within ± 0.01 or even ± 0.1 second. Hence, the considerable number of questionable points on the travel time graphs.

(2) Except for several of the basement refracted arrivals and the semi-consolidated layer refracted arrival at Station CHARLIE, only two to four points can be counted on for determination of the travel time graph lines. With so few points to determine a line, it is difficult to assess the possible errors in the slope and intercept values of Table III.

(3) For the computation of the velocity of sound in sea water at the time of the experiment in late June, it was necessary to use sea salinity data taken several years earlier at another month of the year. The estimate of salinity as 31 parts per thousand for the near bottom sea layers may be in error by several parts per thousand. This salinity error and the error caused by assuming that the temperature of the sea water remained constant over each working day at the bathythermograph values limit the accuracy of the water sound velocity V_1 to about 1/2%. V_1, of course, enters into the calculation of each of the other layer velocities.

(4) The reciprocal ranges were obtained from "corrected" radar ranges and their accuracy is unknown. The choice of different reciprocal ranges would affect the values of the reverse points and hence the values of the slopes of the travel time graph lines.

(5) The velocities of the various ground layers were assumed to be constant over the length of each profile, whereas there may actually be a change in the material density and sound velocity in the ground layers over the two mile ranges of the reversed profiles.

(6) Errors in the calculation of layer thickness are cumulative since each layer intercept calculation involves a term for the previous layer thickness.

(7) A low velocity sediment layer (i.e., with sound velocity lower than that in water) would not be detected in this experiment.

Taking into account the sources of error listed above, and weighting the results of the two reversed profiles, we estimate that the set of velocities in Table IV has a precision of ± 2% while the ~~set~~ set of layer thicknesses at X-Ray has a precision of ± 5%.

CONCLUSIONS

From this experiment, several of the physical parameters have been determined at Point X-Ray. Since the layer interface slopes are small, a parallel sediment layer model is a good approximation for this area. Somewhat better values and certainly better internal data consistency would have been possible if more shots had been fired and recorded on each profile. The velocity and depth values obtained for each seismic refraction layer are in good agreement with previous experiments, including both seismic work offshore of Long Island and fresh-water well log data on the island itself.

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TABLE I

CALCULATION OF VELOCITY OF SOUND IN SEA WATER

		Water Temperature (Degrees Fahrenheit)					Calculated Velocity[6] in ft/sec		
EVENT	DATE	Surface Thermometer	Surface BT	30' Depth BT	Bottom BT	Depth of Water (ft)	At 30'	At Bottom	Average
ABLE	6/23	-	68	60	48	95	4935	4860.5	4898
BAKER	6/25	65	65	59	49.5	85	4929.5	4871	4900
CHARLIE	6/30	70	70	65.5	47.5	85	4966	4857	4911
DOG	7/1	69	~ 69	60.5	51	80	4938.5	4881	4910

Salinity 31 parts per thousand for water near the bottom.[4,5]

BT refers to bathythermograph measurement.

Depth Factor + 0.0182 ft/sec per ft. of depth.

TABLE II

COMPARISON OF RANGE COMPUTED FROM
WATER WAVE TRAVEL TIME WITH RADAR RANGE

Event ABLE - 23 June 1953

SHOT NO.	WATER WAVE TRAVEL TIME	COMPUTED RANGE	RADAR RANGE	DIFFERENCE
13	0.464 sec	2370 ft	1950 ft	420 ft
6	.524	2560	1950	610
7	.680	3330	2850	480
10	1.079	5290	4950	340
11	1.491	7310	6900	410
12	2.535	12,400	12,150	350

Shots 1,2,3,4,5,8,9 were either duds, not recorded, inside radar range, or radio signal was lost. Sound velocity used for ABLE was 4898 ft/sec (see Table I).

Event BAKER - 25 June 1953

SHOT NO.	WATER WAVE TRAVEL TIME	COMPUTED RANGE	RADAR RANGE	DIFFERENCE
2	0.496 sec	2430 ft	1980 ft	450 ft
3	.686	3360	3000	360
4	1.099	5380	4975	505
5	1.464	7170	6975	195
6	1.878	9190	9030	160
10	2.165	10,600	10,050	550
9	2.329	11,400	12,000	-600

Shots 1,7,8 were either inside radar range or not recorded. Sound velocity used for BAKER was 4900 ft/sec.

TABLE II (cont'd)

Event CHARLIE - 26 June (Shot 1a) - 30 June (Shots 1-8)

SHOT NO.	WATER WAVE TRAVEL TIME	COMPUTED RANGE	RADAR RANGE	DIFFERENCE
1a	.286 sec	1405 ft	1125 ft	280 ft
1	.383	1880	1950	- 70
2	.531	2610	2850	-240
3	1.000	4910	5025	-115
4	1.138	5590	5850	-260
5	1.392	6850	7050	-200
9	1.515	7450	7650	-200
7	1.735	8520	8700	-180
8	1.957	9610	9900	-290

Shot 6 - lost radio shot signal. Sound velocity used for CHARLIE was 4911 ft/sec.

Event DOG - 1 July 1953

SHOT NO.	WATER WAVE TRAVEL TIME	COMPUTED RANGE	RADAR RANGE	DIFFERENCE
2	0.394 sec.	1940 ft	2100 ft	-160 ft
3	.567	2790	3000	-210
4	.938	4610	4950	-340
5	1.130	5550	5775	-225
6	1.355	6660	6990	=330
7	1.546	7600	8070	-470
8	1.740	8550	9000	-450
9	1.966	9660	10,140	-480
10	2.337	11,500	12,000	-500
11	3.059	15,030	15,450	-420

Shot 1 was within radar range. Sound velocity used for DOG was 4910 ft/sec.

TABLE III

TRAVEL TIME GRAPH INTERCEPTS

STATION	LAYER	INTERCEPT at $t = 0$	INTERCEPT at $t = 2.633$	Velocities in ft/sec from Reciprocal Slopes
ABLE	Unconsolidated	0.006	2.277	$V_{2A} = 5686$
	Semi-consolidated	0.118	2.075	$V_{3A} = 6590$
	Rock basement	0.521	1.236	$V_{4A} = 18040$
BAKER	Unconsolidated	0.005	2.277	$V_{2B} = 5679$
	Semi-consolidated	0.144	2.075	$V_{3B} = 6680$
	Rock basement	0.548	1.236	$V_{4B} = 18750$

STATION	LAYER	INTERCEPT at $t = 0$	INTERCEPT at $t = 2.373$	Velocities in ft/sec from Reciprocal Slopes
CHARLIE	Unconsolidated	0.011	2.103	$V_{2C} = 5570$
	Semi-consolidated	0.167	1.861	$V_{3C} = 6880$
	Rock basement	0.545	1.171	$V_{4C} = 18700$
DOG	Unconsolidated	0.010	2.103	$V_{2D} = 5570$
	Semi-consolidated	0.165	1.861	$V_{3D} = 6670$
	Rock basement	0.551	1.171	$V_{4D} = 18800$

TABLE IV

SUMMARY OF LAYER VELOCITIES, THICKNESSES, AND SLOPES

Profile	V_1 ft/sec	V_2 ft/sec	V_3 ft/sec	V_4 ft/sec	h_1 ft	$\bar{h}_2$ ft	ω_{23}	$\bar{h}_3$ ft	ω_{34}	$\bar{h}_{total}$ ft
ABLE-BAKER	4900	5680	6640	18390	80	680	0°38'	1050	0°22'	
CHARLIE-DOG	4910	5570	6870	18800	80	775	-0°7'	1035	0°26'	
Weighted Average	4905	5630	6750	18600	80	750		1040		1870

V_1 = Velocity in water

V_2 = Velocity in unconsolidated layer

V_3 = Velocity in semi-consolidated layer

V_4 = Velocity in rock basement

h_1 = Water depth or depth to unconsolidated layer

$\bar{h}_2$ = Thickness of unconsolidated layer at X-Ray

$\bar{h}_3$ = Thickness of semi-consolidated layer at X-Ray

$\bar{h}_{total}$ = Vertical depth to rock basement at X-Ray

ω_{23} = Slope of interface between unconsolidated and semi-consolidated layers

ω_{34} = Slope of interface between semi-consolidated layer and rock basement

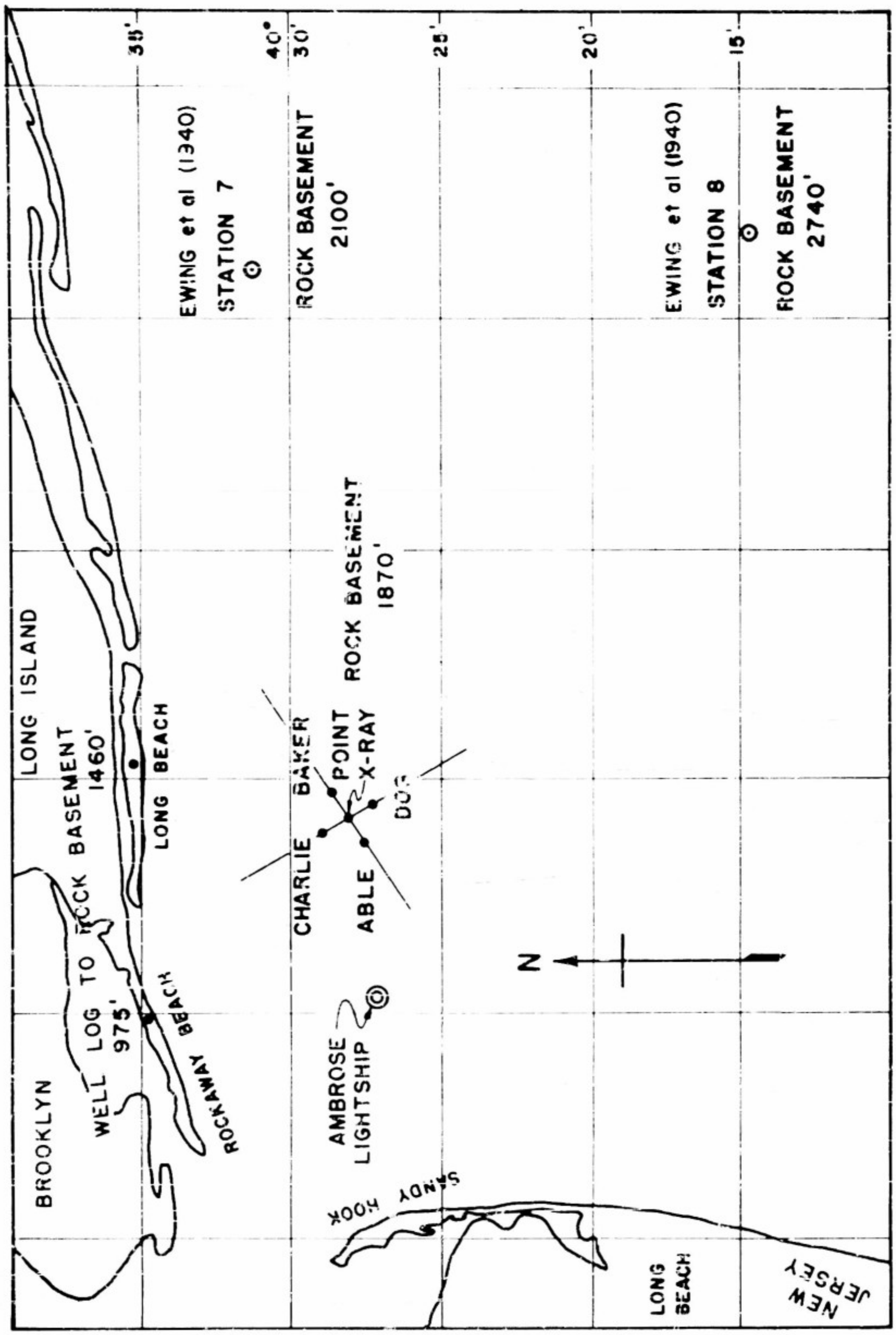
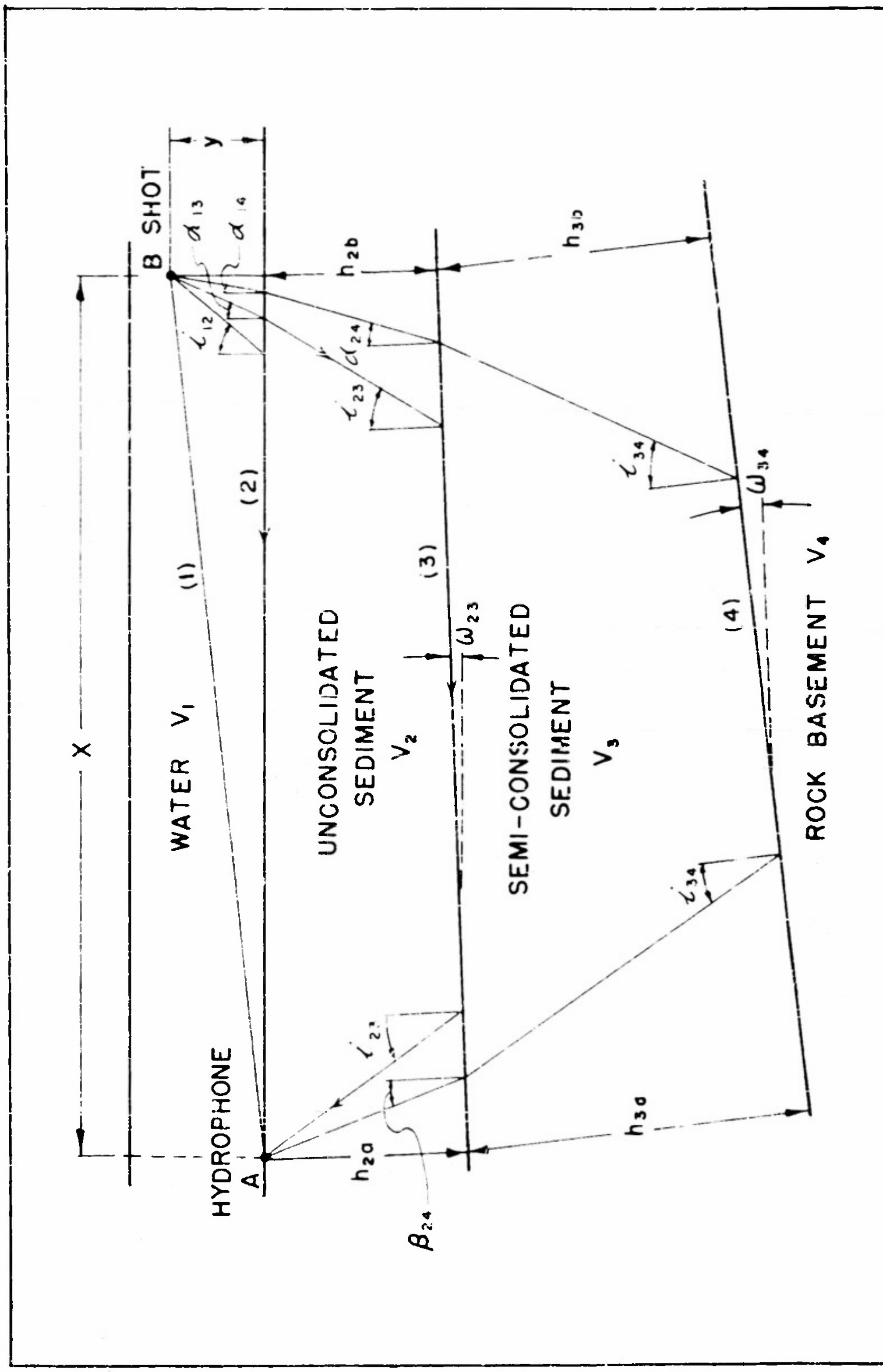


CHART OF POINT X-RAY AREA

FIG. 1

RESTRICTED
SECURITY INFORMATION



CHARACTERISTIC WAVE PATHS THROUGH THE WATER AND THE GROUND LAYERS

FIG. 2

RESTRICTED

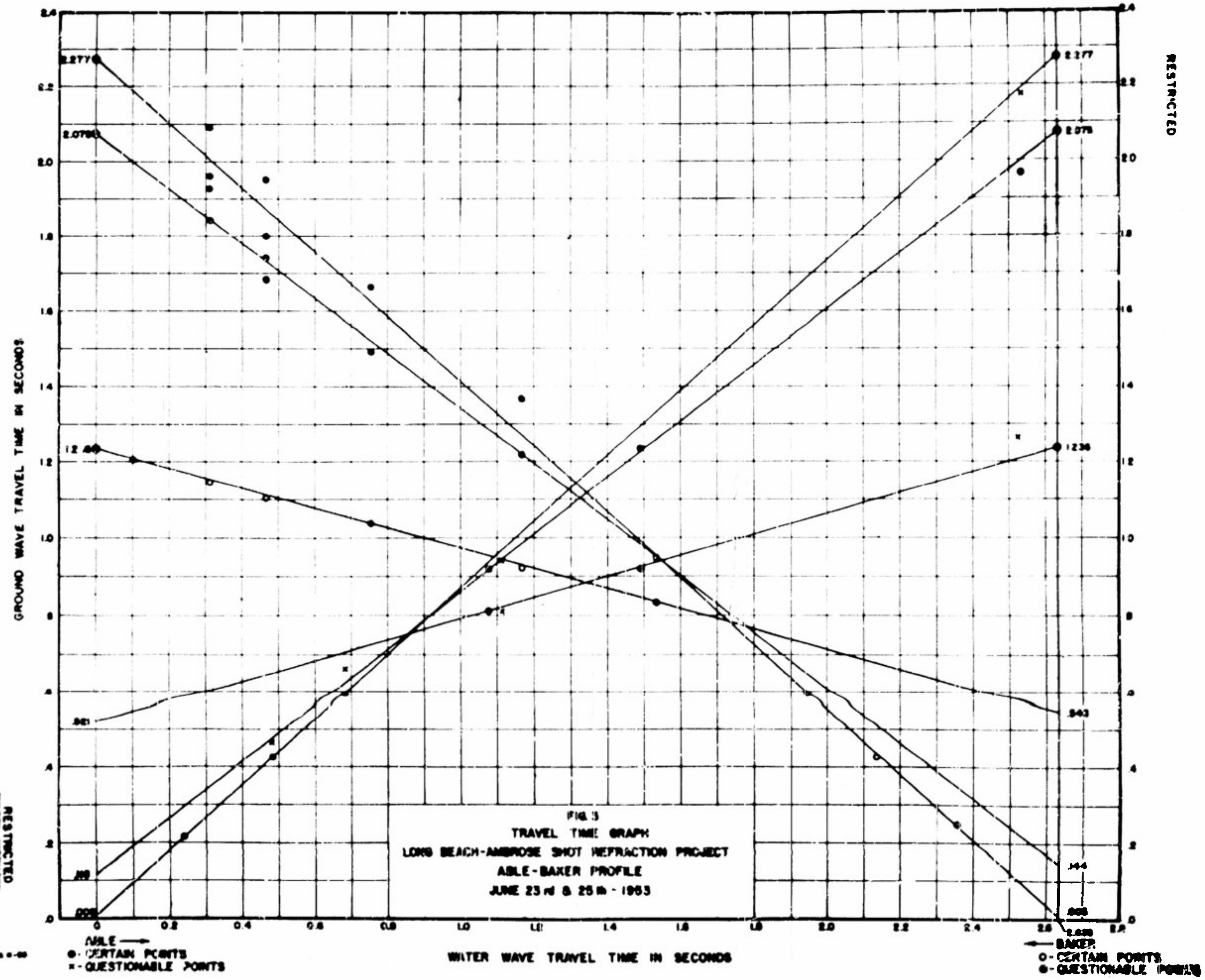


FIG. 3
TRAVEL TIME GRAPH
LONG BEACH-AMBROSE SHOT REFRACTION PROJECT
ABLE-BAKER PROFILE
JUNE 23rd & 25th - 1963

RESTRICTED
SECURITY INFORMATION

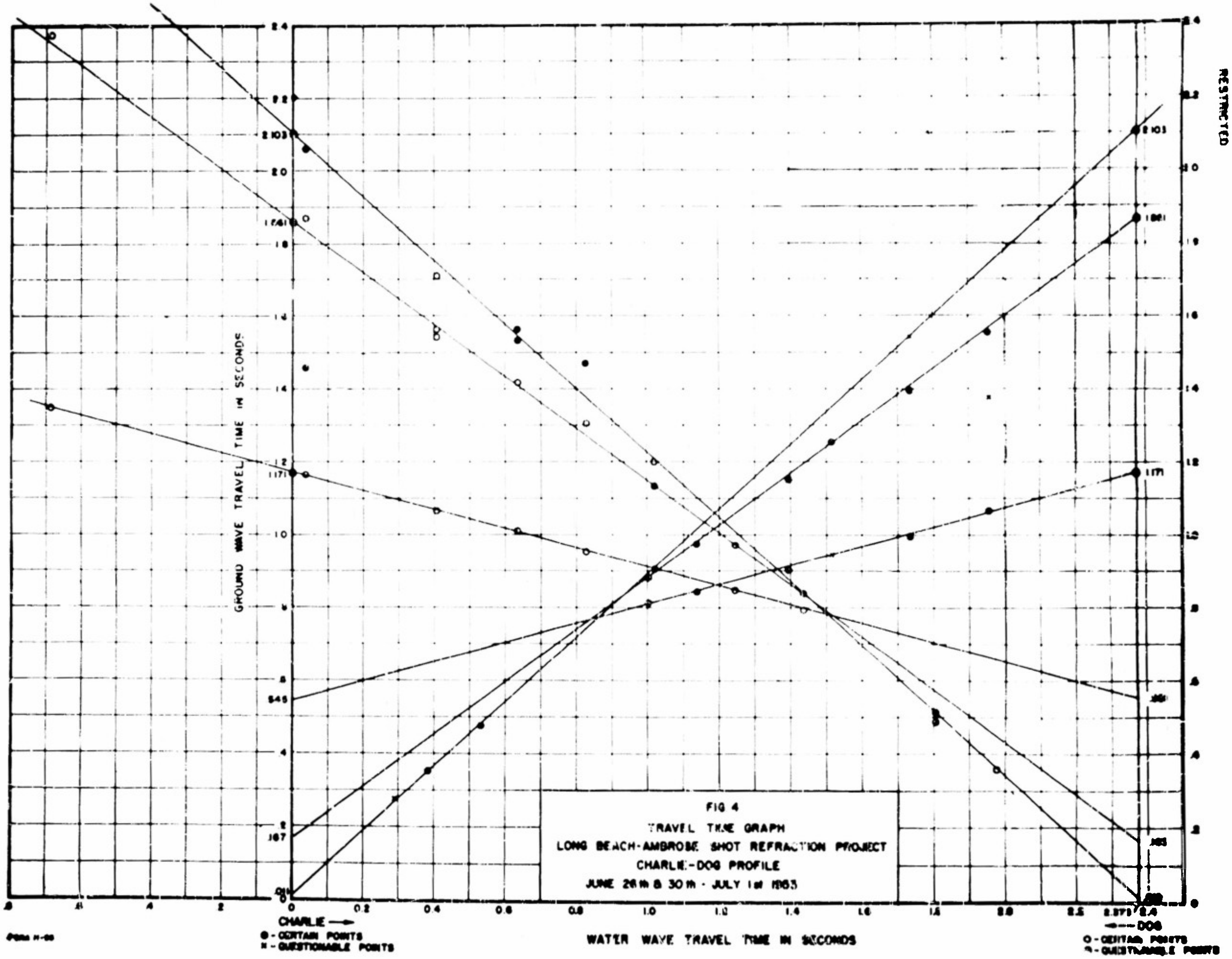


FIG 4
TRAVEL TIME GRAPH
LONG BEACH-AMBROSE SHOT REFRACTION PROJECT
CHARLIE-DOG PROFILE
JUNE 26th & 30th - JULY 1st 1953

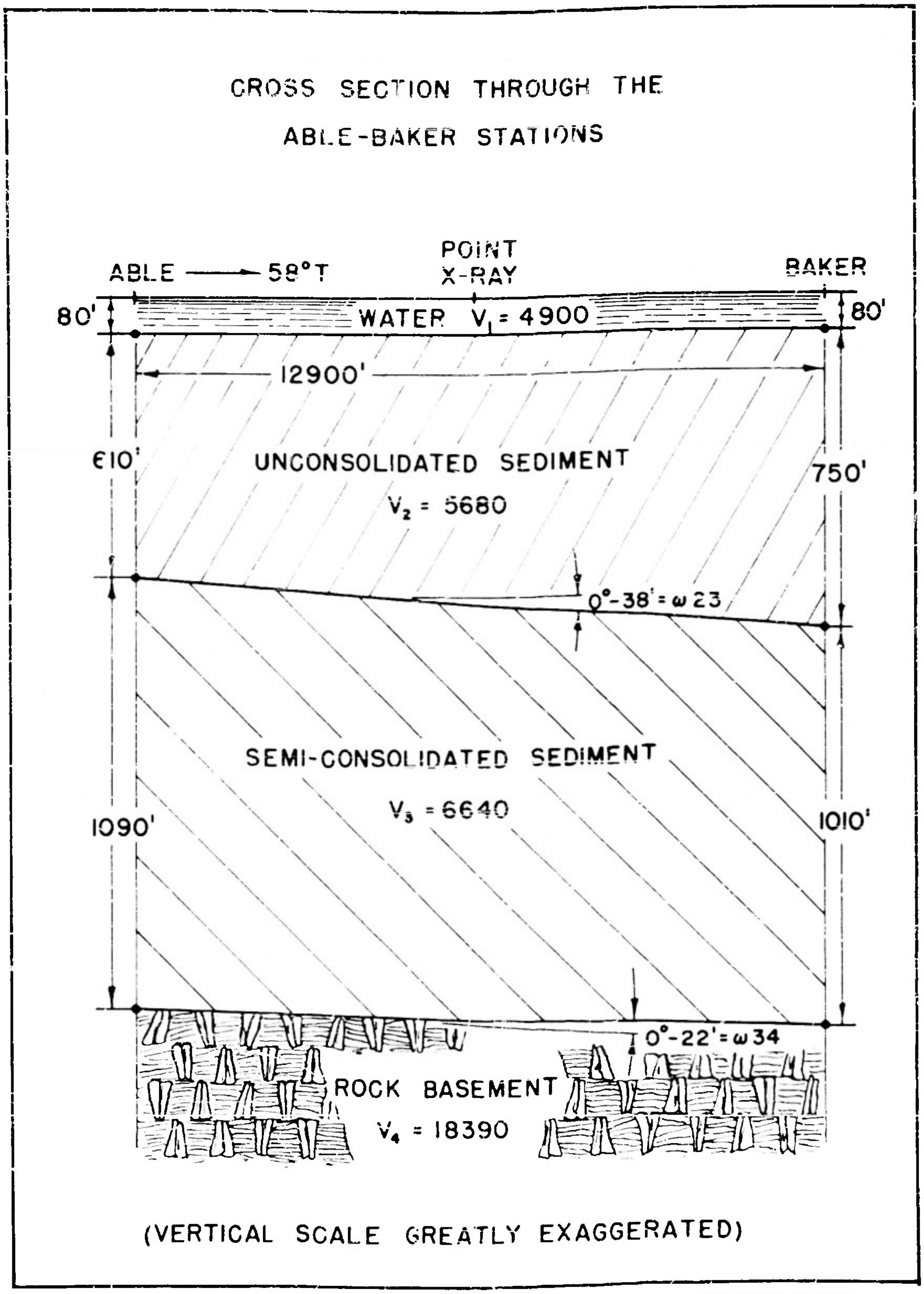

CROSS SECTION THROUGH THE
ABLE-BAKER STATIONS
ABLE ——→ 58°T
POINT
X-RAY
BAKER
80'
WATER V1 = 4900
80'
12900'
610'
UNCONSOLIDATED SEDIMENT
V2 = 5680
750'
0°-38' = ω 23
SEMI-CONSOLIDATED SEDIMENT
V3 = 6640
1090'
1010'
0°-22' = ω 34
ROCK BASEMENT
V4 = 18390
(VERTICAL SCALE GREATLY EXAGGERATED)

FIG. 5

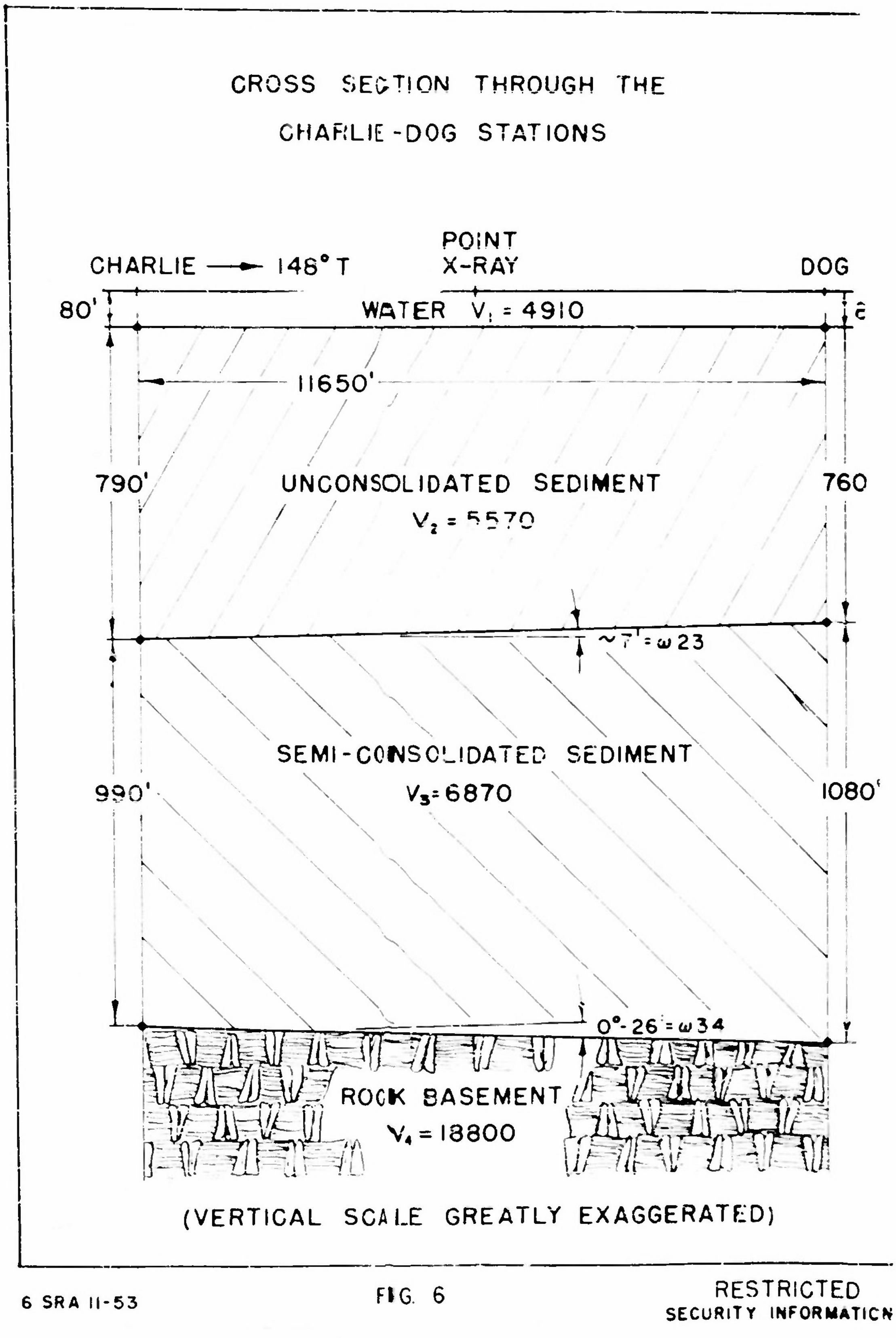

CROSS SECTION THROUGH THE
CHARLIE-DOG STATIONS
CHARLIE → 148° T
POINT
X-RAY
DOG
80'
WATER V_1 = 4910
11650'
790'
UNCONSOLIDATED SEDIMENT
V_2 = 5570
760
~7' = ω 23
SEMI-CONSOLIDATED SEDIMENT
V_3 = 6870
990'
1080'
0°-26' = ω 34
ROCK BASEMENT
V_4 = 18800
(VERTICAL SCALE GREATLY EXAGGERATED)

FIG. 6