# DYNAMIC TESTS, PROPOSED NAVY X-BAND ANTENNA SITE WALDORF, MARYLAND

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MISCELLANEOUS PAPER NO. 4-617

January 1964





U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
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ARMY-MRC VICKSBURG, MISS.

PREFACE

The investigations described herein were requested by the Area Public Works Office (APWO), Washington, D. C., in letter 11015 (10) 32 DGS:bjt dated 22 March 1963, subject, "Dynamic Soil Tests at Site of X-Band Antenna at Waldorf, Maryland, Site for U. S. Naval Research Laboratory; request for." The field investigations were performed near Waldorf, Md., on 27 and 28 March 1963.

Engineers of the Flexible Pavement Branch, Soils Division, U. S. Army Engineer Waterways Experiment Station (WES), actively engaged in the field investigation, analysis, and report phases of this study were Messrs. A. A. Maxwell, Z. B. Fry, R. F. Ballard, Jr., J. L. Decell, and J. Fowler. The work was conducted under the general supervision of Messrs. W. J. Turnbull and W. G. Shockley, Chief and Assistant Chief, respectively, of the Soils Division. This report was prepared by Messrs. Ballard and Decell.

Col. Alex G. Sutton, Jr., CE, was Director of the WES during the conduct of this investigation and preparation of this report. Mr. J. B. Tiffany was Technical Director.

# CONTENTS

SUMMARY

The tests described herein were conducted to obtain data pertinent to the elastic characteristics of materials underlying a proposed X-band antenna facility near Waldorf, Md. Refraction seismic tests were performed to determine the depths of subsurface interfaces and the compression wave velocities through each soil layer. Vibration tests were also conducted at the site to determine compression and shear moduli of the underlying material. The resonant frequency of the surface material was also determined.

Results of these tests indicate:

a. Three basic layers of soil material underlie the proposed antenna location. The upper layer (0 to 3 ft) exhibited an average compression wave velocity of approximately 1100 fps, average shear wave velocity of 400 fps, and Poisson's ratio $\mu$ of 0.42. The second layer (3 to 14 ft) showed an average compression wave velocity of about 2100 fps, average shear wave velocity of 800 fps, and $\mu$ of 0.42. The third basic layer (14 to 37+ ft) had an average compression wave velocity of about 4500 fps, shear wave velocity of approximately 1170 fps, and $\mu$ of 0.46.

b. Shear moduli increased from about 5000 psi 3 ft below the surface to approximately 32,000 psi from 14 to 37+ ft below the surface. Compression moduli for each respective depth are approximately three times the shear moduli.

c. Resonant frequency of the surface material is approximately 20 to 24 cps.

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## PART I: BACKGROUND, PURPOSE, AND SCOPE OF STUDY

1. This report describes and gives the results of dynamic tests performed at the proposed location of an X-band antenna facility near Waldorf, Md. Prior to this investigation, exploratory borings and laboratory tests had been made by Froehling and Robertson, Inc., for the Area Public Works Office and the Office of Officer in Charge of Construction Chesapeake, Washington, D. C. Therefore, the subsurface conditions, i.e. type of material present and other characteristics that can be determined by conventional laboratory tests, were known. The field investigations described herein were made to obtain data pertinent to the dynamic elastic characteristics of the materials underlying the proposed site of a high-performance radar facility. Specifically, dynamic shear and compression moduli and refraction seismic velocities were to be determined. These data are necessary for the design of foundations with high stability requirements under dynamic loads.

# PART II: THE INVESTIGATION

## Location and Description of Test Site

2. The site investigated is the former Accokeek Nike-Ajax Site A-45, located approximately 5 miles southwest of Waldorf, Md. The area consists of gently rolling terrain and is easily accessible by paved roads.

3. The soil at the site consists of the following successive layers: 1 to 2.5 ft of fill and topsoil, 3 to 5 ft of brown sandy clay, 4 to 8 ft of sand and gravel, 6 ft of firm, tan silty clay, and 8 to 12 ft of soft silty clay with fine sand underlain by a stiff, gray silty clay extending to a depth of 80 ft.

## Test Methods and Computations

4. The primary dynamic investigations were conducted in two phases: seismic tests and vibration tests. Each type of test was designed to reveal specific information relative to the physical properties of the soil underlying the test site.

### Seismic tests

5. Seismic tests were made to determine the compression wave velocity of the soils; this velocity is used in conjunction with other data to determine Poisson's ratio. The seismic data were collected first so that the presence of any unusual subsurface conditions would be revealed, and on the basis of this information the vibration lines could be located to the best advantage. A hammer-type seismograph was used because of its portability, accuracy, and simple and reliable operational features. In practice, a measuring tape is stretched away from a geophone which is implanted in the soil. A 9-lb sledge hammer, incorporating a switch which closes when the hammer strikes a blow, is used as the impulse source. Compression waves are produced by blows of the hammer on a steel plate placed on the ground at regular intervals along the tape. When the hammer strikes the plate, the switch on the hammer closes, setting a binary counter in operation. When the compression wave produced by the hammer blow reaches the geophone, the counter automatically stops, thus indicating the time

required for the wave to travel from the point of impact to the geophone.

6. Data are plotted in graphic form as impulse distance versus travel time. The reciprocal of the slope of the lines drawn to connect the plotted points indicates the velocity of the wave through each subsurface medium encountered. A distinct break in the slope of the line indicates that the wave has probably passed through the interface between two subsurface layers having different velocities. The depth below the surface at which the first interface occurs can be calculated using the following equation:

$$D_1 = \frac{X_1}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}} \qquad (1)$$

where

$D_1$ = depth in feet from the surface to the first interface

$X_1$ = distance in feet from the origin on the abscissa of the plot of impulse time versus impulse distance to the point at which the first change in slope occurs

$V_1$ = compression wave velocity, in feet per second, in first layer of material encountered

$V_2$ = compression wave velocity, in feet per second, in second layer of material encountered.

If a second interface is encountered, its depth can be calculated using the following equation:

$$D_2 = \frac{5}{6}X_1 + \frac{X_2}{2}\sqrt{\frac{V_3 - V_2}{V_3 + V_2}} \qquad (2)$$

where

$D_2$ = depth in feet from the surface to the second interface

$X_2$ = distance in feet from the origin on the abscissa of the plot of impulse time versus impulse distance to the point at which the second change in slope occurs

$V_3$ = compression wave velocity, in feet per second, in third layer of material encountered

If additional interfaces occur, equations are available to determine their depth; however, since a third interface was not encountered in the soil layer pertinent to this investigation, these equations will not be considered here.

Vibration tests

7. Vibration tests were conducted to determine both the frequency and the velocity of shear waves in the soil. The vibration tests were performed with a high-frequency electrodynamic vibrator and a low-frequency counterrotating mass vibrator, in accordance with the procedure outlined in Waterways Experiment Station (WES) Miscellaneous Paper No. 4-577, A Procedure for Determining Elastic Moduli of Soils by Field Vibratory Techniques. That report explains in detail how wavelengths of propagated Rayleigh waves (treated as shear waves) of known frequency are used to determine the shear and compression moduli of subsurface materials.

Computation of Poisson's ratio and elastic moduli

8. The velocity of a wave V is determined by the product of the frequency f and wavelength $\lambda$. It is then employed in the following equations which describe the mathematical relation of Poisson's ratio and the compression and shear moduli.

$$\mu = \frac{1 - 2\left(\frac{V_s}{V_c}\right)^2}{2 - 2\left(\frac{V_s}{V_c}\right)^2} \qquad (3)$$

where

$V_s$ = shear wave velocity, fps
$V_c$ = compression wave velocity, fps
$\mu$ = Poisson's ratio

$$E = 2\,(1 + \mu)\,\rho V_s^2 \qquad (4)$$

where

$E$ = compression modulus, psi
$\rho$ = mass density of soil = $\frac{\gamma}{g}$ (where $\gamma$ = wet density, lb per cu ft, and $g$ = acceleration due to gravity)

$$G = \frac{E}{2(1 + \mu)} \tag{5}$$

where

G = modulus of shear elasticity, psi

9. It may be questioned whether the propagated waves are shear or Rayleigh waves. Richart[3*] cites Miller and Percy and states that in an elastic solid with a Poisson's ratio of 0.25 for the case of a single source of vertical load on a free surface, 67 percent of the energy is dissipated as Rayleigh waves, 26 percent as shear waves, and only 7 percent as compression waves. While the ground does not behave in a purely elastic manner, the preceding values indicate that the predominant waves would be expected to be Rayleigh (surface) waves. Jones[2] also agrees that Rayleigh waves can be expected to be predominant. However, the differences between the velocities of Rayleigh and shear waves with changes in Poisson's ratio are so small as to be of no practical significance in connection with foundation problems; therefore, since shear wave velocities were needed for this investigation, the propagated surface waves were considered to be shear waves. The values of E and G derived from equations 4 and 5 are plotted versus the half-wavelength, and are considered to represent the elastic moduli of the material at that depth. This half-wavelength is approximately equal to the depth of penetration. Although this assumption is arbitrary, it has proved to be empirically satisfactory.[1,2]

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* Raised numbers refer to similarly numbered items in list of references at end of text.

## PART III: TESTS, AND ANALYSIS AND DISCUSSION OF RESULTS

10. The layouts of the seismic and vibration traverses for the X-band antenna facility site are shown in plate 1. The proposed structure will be similar to the RAMPART facility now under construction at White Sands Missile Range, N. Mex. (described in WES MP 4-584, Nondestructive Dynamic Testing of Proposed Radar Sites, White Sands Missile Range, New Mexico). However, the X-band antenna facility will consist of only one pedestal; and while physical dimensions of the two facilities are virtually the same, the total mass of the X-band antenna facility structure will be considerably less in order to permit the structure to be designed for a natural frequency of approximately 16 cps.

### Seismic Tests

11. Four refraction seismic traverses were run at the site. The results indicated that at least three subsurface horizons exist beneath the X-band antenna site. A composite plot of the velocity determinations obtained from the four traverse lines is shown in plate 2. An arithmetic average of the wave travel time for the four traverses was determined for each distance. Since the traverses were run in the same locality and available borings indicate almost uniform subsurface conditions, it was decided that a composite plot of seismic data would give an informative general subsurface interpretation. The three basic horizons as predicted by seismic information and confirmed by boring logs are:

a. 0 to 3 ft, brown clay, sand, and gravel

b. 3 to 14 ft, tan clayey sand and gravel

c. 14 to 37+ ft, tan and gray silty clays

12. The average compression wave velocity through each of the above-listed layers is approximately 1100, 2100, and 4500 fps, respectively. Depth computations from seismic information indicate the interfaces to be approximately 2.7 and 14.8 ft below the surface. The average velocities obtained for the compression waves were used in computations to determine Poisson's ratio, which will be discussed later.

## Vibration Tests

13. Three vibration traverses were run at the site. Several vibrator locations were tried before a satisfactory test location was found. Initial attempts to position the vibrator resulted in scattered and erroneous data, caused by signal interference from underground culverts and conduits. The traverses were finally positioned so that adequate coverage would be obtained for the circular pedestal site (see plate 1). Plate 3 is a plot of typical velocity determinations. A composite plot of shear-wave velocity variation with depth is shown in plate 4. As is indicated in the plot, average shear wave velocity in the 0- to 3-ft horizon is approximately 400 fps. From 3 to 14 ft, the average shear wave velocity is approximately 800 fps, and from 14 to 37+ ft approximately 1170 fps. These values of shear wave velocities, when used with the corresponding compression wave velocities, indicate a Poisson's ratio of 0.42, 0.42, and 0.46, respectively, for each layer.

14. Equations 4 and 5 in paragraph 8 were used to compute the compression (E) and shear (G) moduli for the materials. These values were plotted versus overburden pressure and half-wavelengths. The results of tests with all three vibration lines are shown compositely in plate 5. The data, as presented in this form without the aid of boring logs, could possibly have been interpreted as indicated by the dashed line that shows a gradual increasing trend of E and G with depth. However, since borings were available, a more feasible interpretation could be made, as indicated by the solid lines. The boring log obtained from borehole 1 (which is located in the center of the proposed structure site) is also depicted in plate 5. It is interesting to note that the interfaces of the basic subsurface horizons are clearly indicated by the breaks in the solid line. These data show that the shear moduli increase from about 5000 psi at the 1-ft depth to approximately 32,000 psi from 14 to 37+ ft below the surface. The compression moduli at corresponding depths are approximately three times the shear moduli. Although the values obtained for E and G exhibited some variation, correlation with the available borehole information, relative to the in-situ material types, was considered to be very good.

## REFERENCES

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2. Jones, R., In-Situ Measurement of the Dynamic Properties of Soil by Vibration Methods. Highway Research Board Bulletin No. 277, 1960.

3. Richart, F. E., Jr., Hall, J. R., Jr., and Lysmer, J., Study of the Propagation and Dissipation of "Elastic" Wave Energy in Granular Soil. Prepared by University of Florida under Contract DA-22-079-eng-314, for U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, September 1962.

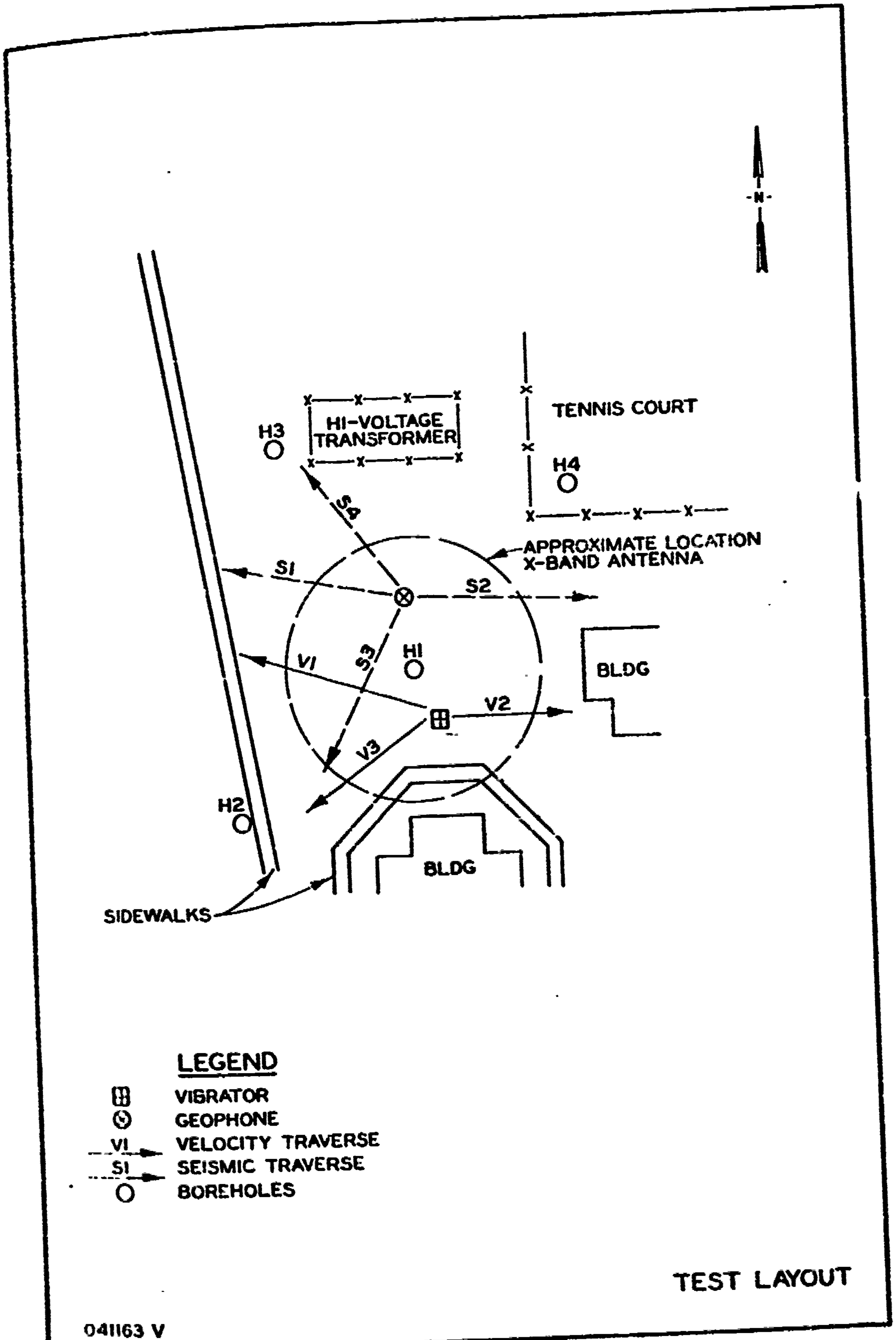
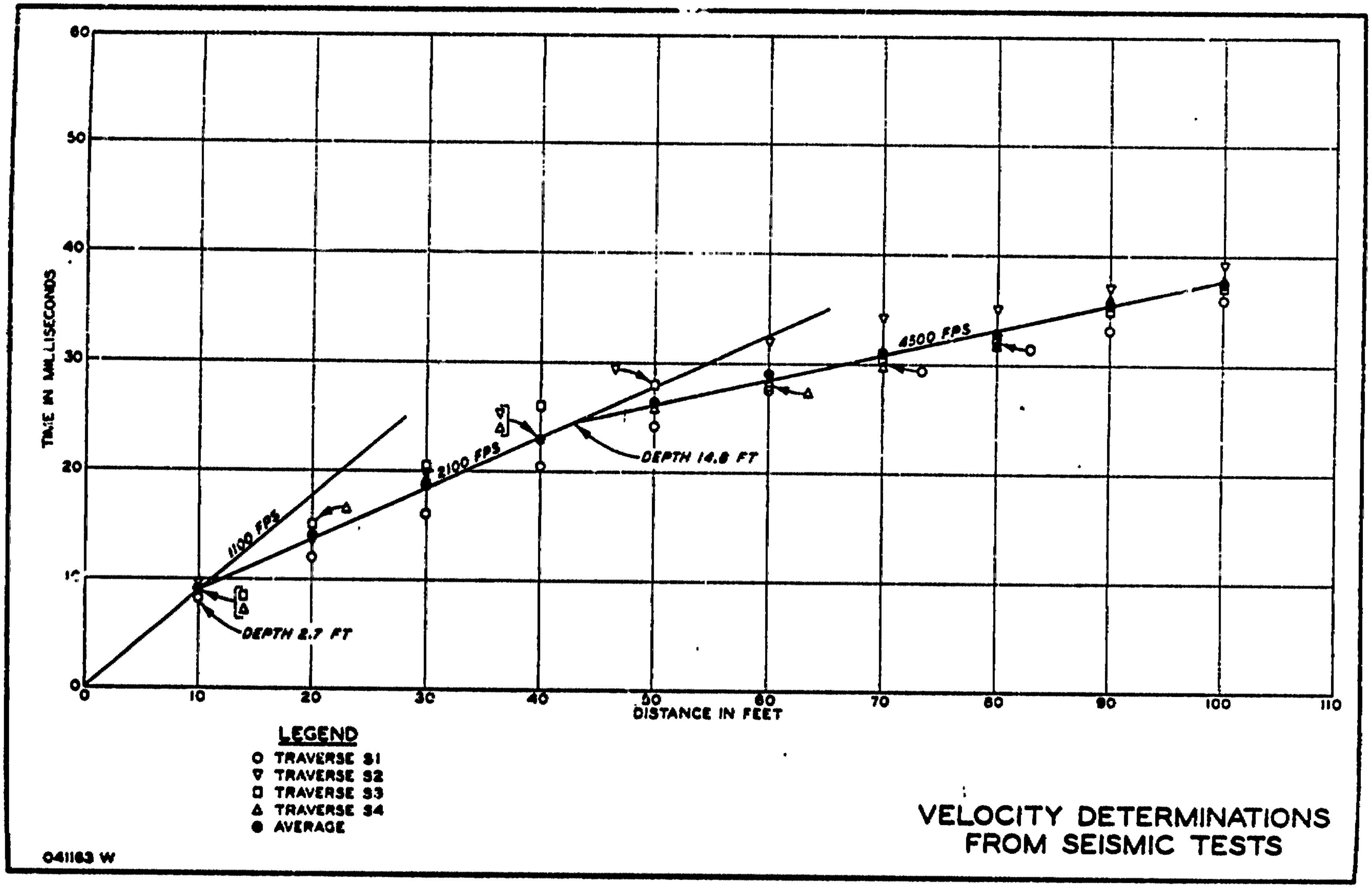
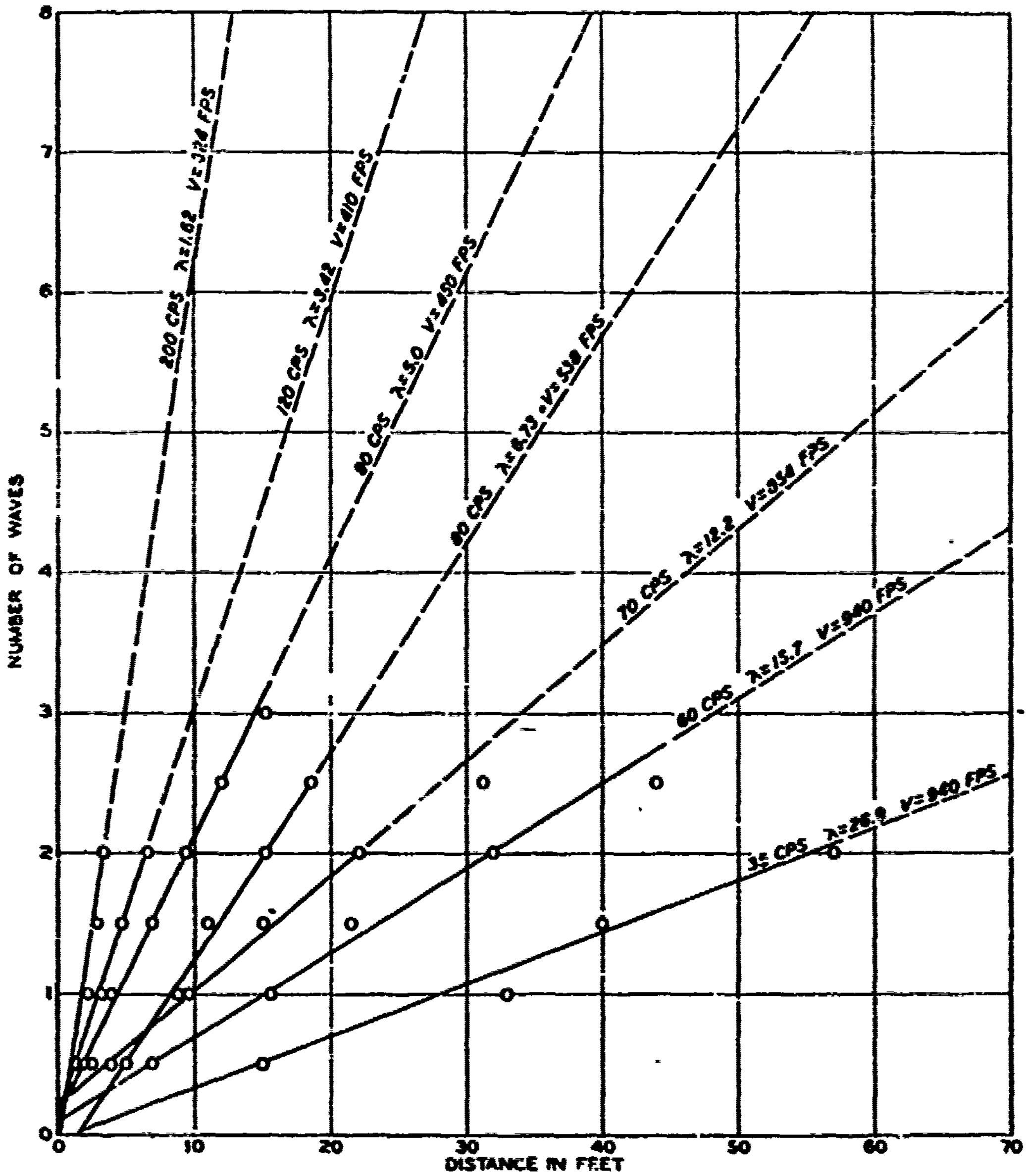

N
HI-VOLTAGE TRANSFORMER
TENNIS COURT
H3
H4
S4
APPROXIMATE LOCATION X-BAND ANTENNA
S1
S2
V1
S3
H1
BLDG
V2
V3
H2
BLDG
SIDEWALKS
LEGEND
VIBRATOR
GEOPHONE
V1 VELOCITY TRAVERSE
S1 SEISMIC TRAVERSE
BOREHOLES
TEST LAYOUT
041163 V

PLATE I




VELOCITY DETERMINATIONS
FROM SEISMIC TESTS

PLATE 2

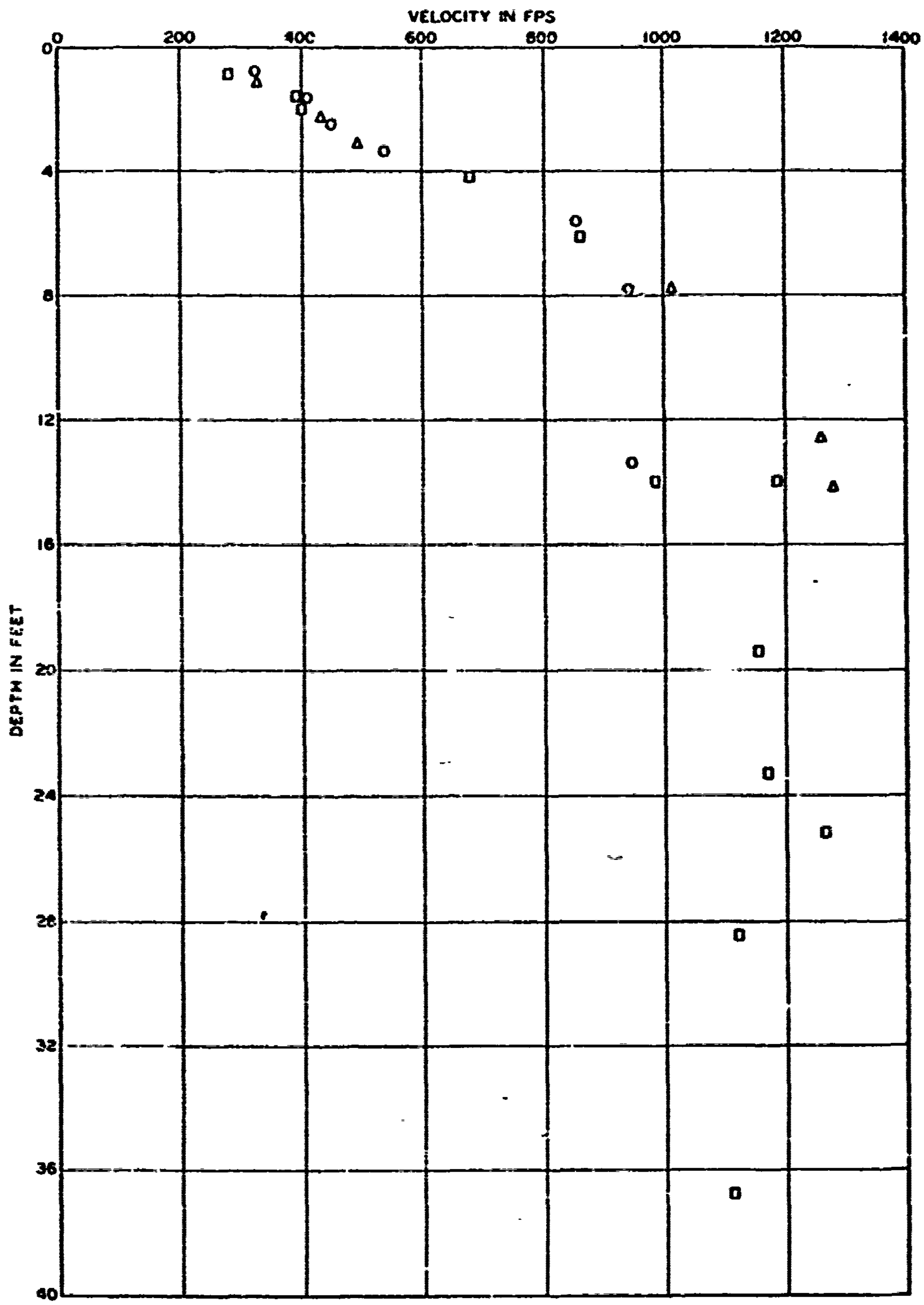



NOTE: V= WAVE VELOCITY
λ= WAVELENGTH

## TYPICAL VELOCITY DETERMINATIONS FROM VIBRATION TESTS

### TRAVERSE VI

041163 X



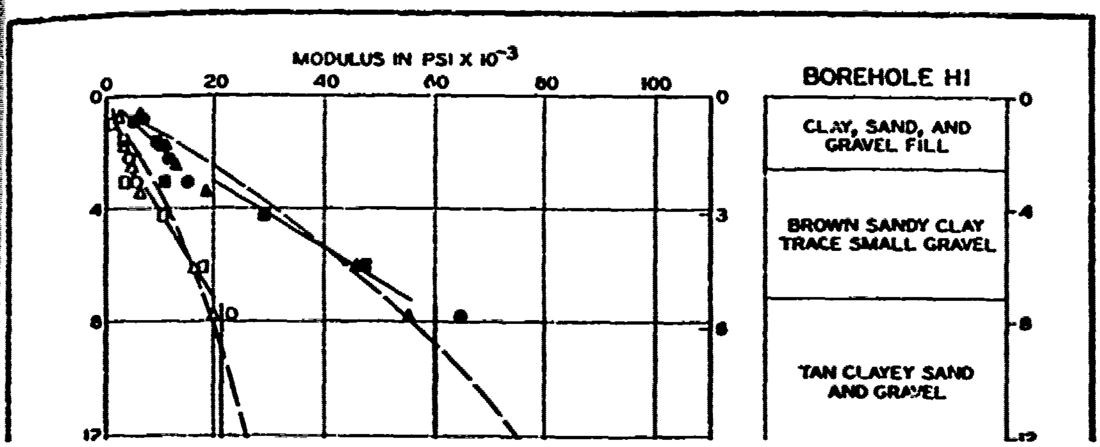

**LEGEND**

- O TRAVERSE V1
- Δ TRAVERSE V2
- □ TRAVERSE V3

041163 Y

## SHEAR WAVE VELOCITY VS DEPTH

PLATE 4




## Errata Sheet

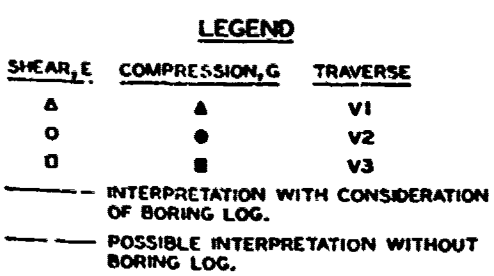
**DYNAMIC TESTS, PROPOSED NAVY X-BAND ANTENNA SITE**

**WALDORF, MARYLAND**

Miscellaneous Paper No. 4-617

January 1964

The horizontal scale in plate 5 of this report should be changed from "Modulus in psi x $10^{-3}$" to "Modulus in psi x $10^{3}$."

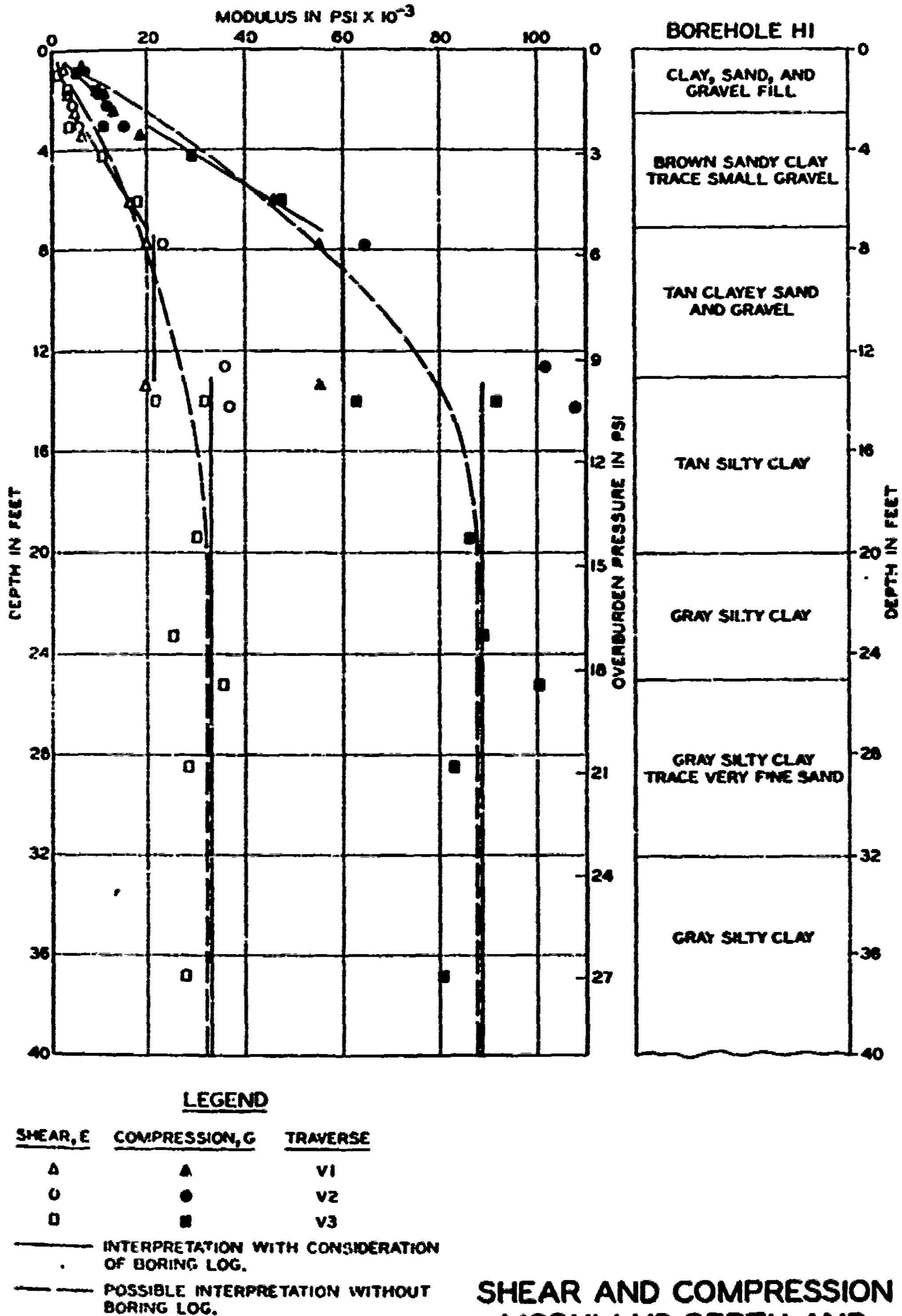



SHEAR AND COMPRESSION MODULI VS DEPTH AND OVERBURDEN PRESSURE WITH SUBSURFACE SOILS DESCRIPTION

041163 Z

PLATE 5

34117




SHEAR AND COMPRESSION MODULI VS DEPTH AND OVERBURDEN PRESSURE WITH SUBSURFACE SOILS DESCRIPTION

041163 Z

PLATE 5

34117