OPTIMUM SEISMIC PROTECTION FOR NEW BUILDING CONSTRUCTION IN EASTERN METROPOLITAN AREAS

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Internal Study Report No. 26

IN SITU SHEAR WAVE VELOCITY MEASUREMENTS ON MIT CAMPUS

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16. Abstract (Limit: 200 words)
Seismic field measurements were made to determine in-situ velocity values and elastic moduli of the overburden materials at the westerly end of the Massachusetts Institute of Technology campus. A seismic refraction line was also operated to measure the depths to bedrock and to provide velocity control for measurement intervals for the in-situ velocity studies. Field work was completed during the month of March, 1972. Three orthogonal geophones, two horizontal and one vertical, comprising a detector unit capable of measuring in three different directions, were used. One such unit was placed at each of three boreholes. The signals from these three-directional geophones, enhanced by amplification and filtering, were displayed on a photographic recording oscillograph employing 12 channels of a portable seismograph. Seismic energy was generated with small charges of explosives in a fourth hole. Timing lines were provided across the photographic records at two millisecond intervals. For the seismic refraction line, single geophones, vertical component only, were used at approximately 100-foot spacings along the line of investigation. These geophones were connected to a multi-conductor cable which in turn was connected to the recording instrumentation.

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Preface

This is one of a series of reports prepared for staff use as part of the study of optimum seismic protection and damage statistics under NSF Grants. The measurements described in this report were contributed by Weston Geophysical Engineers, Inc. of Weston, Massachusetts, through the courtesy of Mr. Vincent J. Murphy. The bore holes work for the measurements were contributed by the American Drilling and Boring Company of Providence, Rhode Island, through the courtesy of Mrs. Charles Guild. These contributions are very gratefully acknowledged.

SEISMIC VELOCITY AND ELASTIC MODULI MEASUREMENTS

MASSACHUSETTS INSTITUTE OF TECHNOLOGY CAMPUS

CAMBRIDGE, MASSACHUSETTS

for

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

WESTON GEOPHYSICAL ENGINEERS, INC.
WESTON, MASSACHUSETTS

SIESMIC VELOCITY AND ELASTIC MODULI MEASUREMENTS
MASSACHUSETTS INSTITUTE OF TECHNOLOGY CAMPUS
CAMBRIDGE, MASSACHUSETTS

INTRODUCTION

Seismic field measurements were made to determine in-situ velocity values and elastic moduli of the overburden materials at the westerly end of the Massachusetts Institute of Technology campus.

A seismic refraction line was also operated to measure the depths to bedrock and to provide velocity control for measurement intervals for the in-situ velocity studies.

The location used for the in-situ cross-hole measurements and the position of the single refraction line are shown on Sheet 1 and 2 of this report.

Field work was completed during the month of March, 1972.

FIELD PROCEDURES

Instrumentation

Three orthogonal geophones, two horizontal and one vertical, comprise a detector unit capable of measuring in three different directions. Three such units or "three-directional" geophones were used; each unit was placed in a separate borehole. The signals from these three-directional geophones, enhanced by amplification and filtering, were displayed on a photographic recording oscillograph employing twelve channels of a portable seismograph. Seismic energy was generated with small charges of explosives (usually blasting caps) in a fourth hole. Timing lines were provided across the photographic records at 2 millisecond intervals.

For the seismic refraction line, single geophones, vertical component only, were used at approximately 100-foot spacings along the line of investigation. These geophones are connected to a multi-conductor cable which in turn is connected to the recording instrumentation; the same as for the borehole measurements.

Seismic Measurements

Four cased holes drilled by the American Drilling and Boring Company to a depth of approximately 175 feet below ground surface were provided for our use. Seismic energy was generated in one hole and recorded in the three remaining holes with the seismic source and geophones at the same elevation. Readings were obtained at various intervals up and down the total depth of the boring array except for the bottom section of the hole (which was plugged with material that had forced its way in from the bottom) and the topmost section of material (which is above the water table).

At each recording depth, geophones and recording holes were interchanged and data collected using a variety of combinations of filter settings and amplification. This procedure is necessary to obtain the repeatability of events and to optimize the results by enhancement of the desired seismic wave "arrivals".

For the seismic refraction line, a single hole (No. 4) was used as the shot-hole; the shot was placed at a depth of approximately 50 feet below ground surface.

It should be noted that the very small seismic shot for the refraction line resulted in very high quality recordings, whereas some of the cross-hole recordings were of only fair and in some cases poor quality. Recordings of good quality in the cross-hole work were obtained at the maximum available depth of about 122 feet below ground surface. It appears that the casings were tightly emplaced at the lower depth, whereas for shallower recording depths some or all of the casings were loose; that is, some "rattle" space existed between the casing and the naturally occurring overburden materials.

GENERAL CONSIDERATIONS

The seismic wave normally used in a seismic refraction survey for depth calculations and material identification is called a compressional ("P") wave. This wave is transmitted through earth materials as a series of compressions and rarefractions. As a compressional wavefront passes a point in the earth (particle motion), the point moves to and fro, in the direction of wave propagation.

A second type of seismic wave motion, the transverse or shear ("S") wave, travels through the interior of an elastic medium at a lower velocity than the compressional wave. As a transverse wavefront passes a point in the ground (particle motion), the point moves at right angles or transverse to the direction of wave propagation.

In order to determine the velocities of compressional (V_p) waves and transverse (V_s) waves, field measurements are made along various azimuths in both vertical and horizontal directions. The compressional (V_p) wave and the transverse (V_s) wave velocities are used to calculate the values of Poisson's Ratio (σ):

$$\sigma = \frac{\frac{1}{2}\left(\frac{V_p}{V_s}\right)^2 - 1}{\left(\frac{V_p}{V_s}\right)^2 - 1}$$

The V_p wave and V_s wave velocities are also used with the in-place unit weight (d) to compute Young's Modulus (E) and the Shear (or Rigidity) Modulus (G) in lbs./in.^{2}.

$$G = \frac{V_s^2 \, d}{g}$$

and

$$E = 2\,(1 + \sigma)\,G$$

where g is the gravitational acceleration.

The unit weight, d, must be assumed in cases where it has not been measured.

The above relationships are based on the assumption that the actual earth materials may be represented by a homogeneous, isotropic medium within each layer.

RESULTS

The orientation and location of the cross-hole array is shown on Figure 2 of this report. Presented on Figure 3 is a tabulation of cross-hole velocity and corresponding dynamic moduli values. Also noted on this table is the depth to high-velocity rock ("P" wave velocity = 12,000 ft./sec.) at a depth of 300 feet. The geologic correlations that are shown on this table were obtained from the boring logs provided for our use.

DISCUSSION OF RESULTS

It should be noted that the data of this survey are the results of a reconnaissance type of investigation. Although several levels were chosen for measurement in materials that are generally uniform, the recorded data quality is in some instances less than satisfactory. However, the uniformity of the values that were determined increased our confidence level for their validity. It should be observed that the shear wave velocity values were slightly higher than were previously anticipated for the clay material at this site; it appears that the clay is somewhat stiffer than was anticipated.

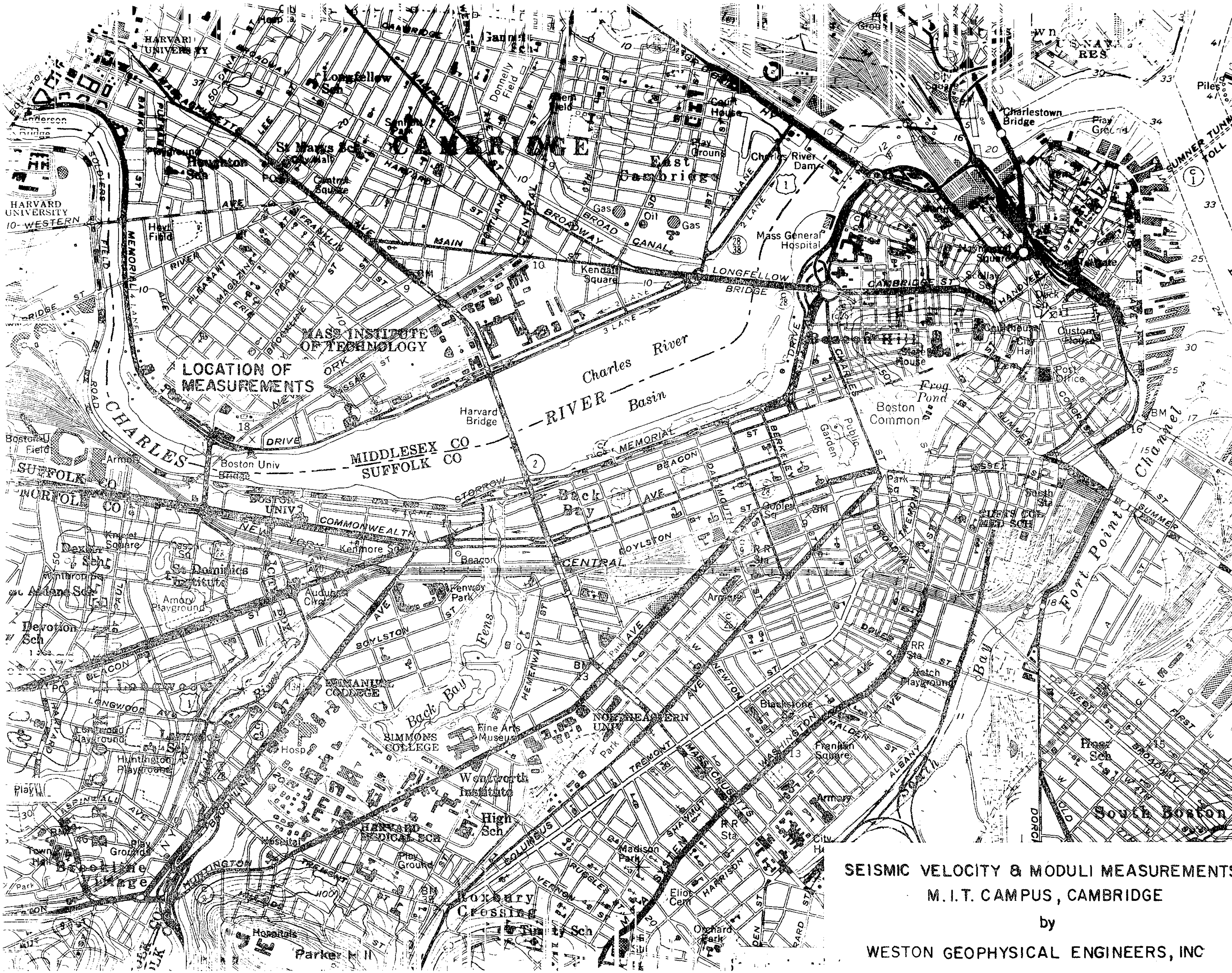
At two levels within the sand-clay layered section of the zone of measurements, at 122 feet and 142 feet below ground surface, anomalously late wave arrivals are evident on the seismic field recordings. The corresponding low velocity values are in the order of 400 feet/second which may indicate conditions for thin (5' ±) layers that are much different from the bulk of the subsurface material at this location.

In the event that a dynamic analysis of the materials at this site requires the use of shear wave or shear moduli data for rock, we have estimated a shear wave value of approximately 6,500 ft./sec., corresponding to the measured "P" wave velocity of 12,000 ft./sec. It is reasonable to assume that these velocities will increase with depth; it is doubtful that any rock layer with a velocity lower than 12,000 ft./sec. exists at this site.

RECOMMENDATIONS

1. If another array of boreholes can be made available for our use, they should be chosen on a similar pattern as the borings of this study with the qualification that an additional or fifth hole be added and that the amount of "rattle" space be minimized by either using a larger casing or a driven casing.

2. A further objective of additional measurements would be surface work to determine the shear wave velocity of surface and near-surface materials at this site.

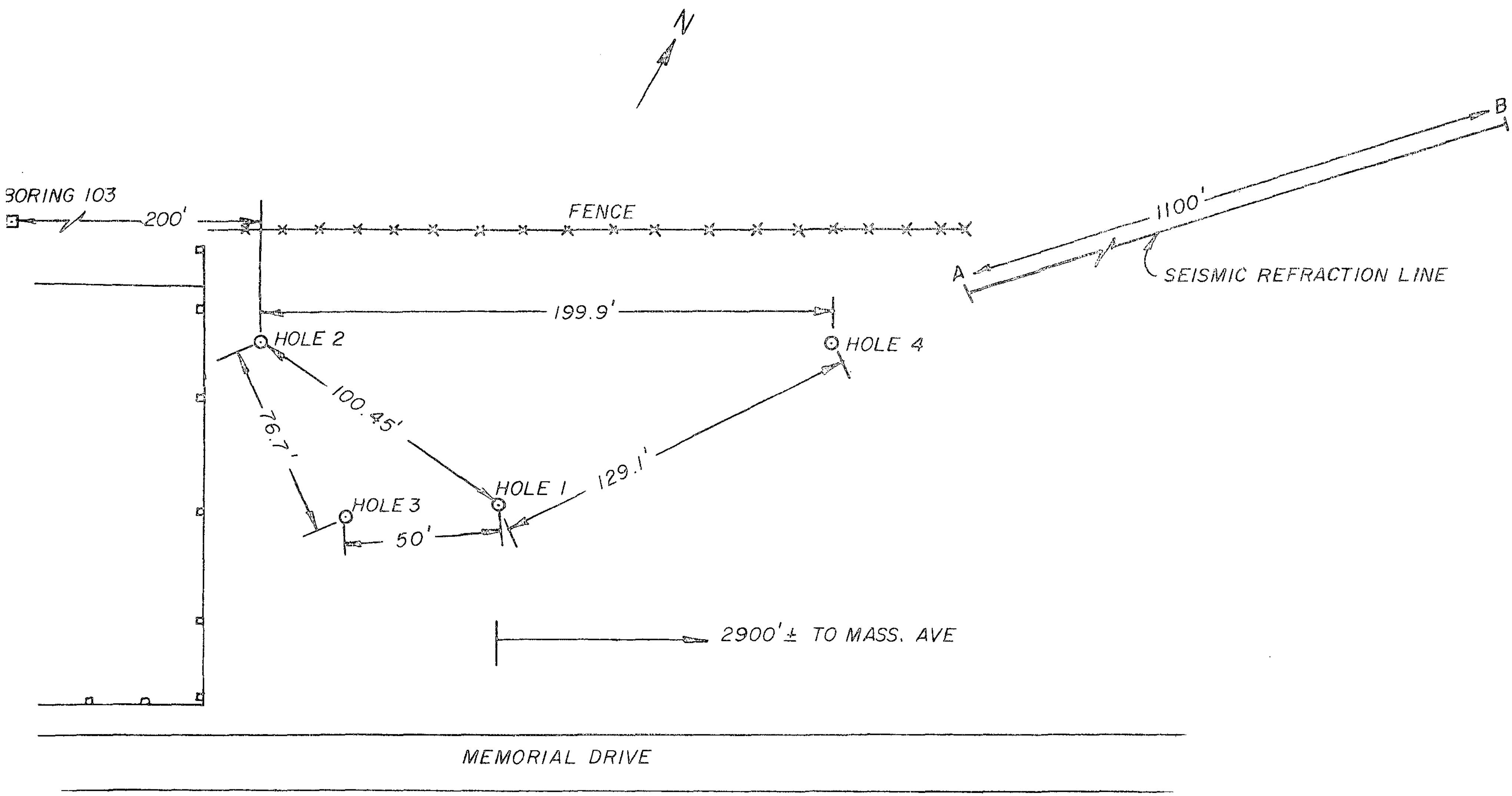


SEISMIC VELOCITY & MODULI MEASUREMENTS

M.I.T. CAMPUS, CAMBRIDGE

by

WESTON GEOPHYSICAL ENGINEERS, INC



SEISMIC VELOCITY & MODULI MEASUREMENTS
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Sheet 2 of 3

TABLE I

SEISMIC VELOCITY AND DYNAMIC MODULI DATA (Based on Cross-hole Measurements)

MASSACHUSETTS INSTITUTE OF TECHNOLOGY CAMPUS, CAMBRIDGE, MASSACHUSETTS

Depth (feet)	Material Identification (based on drill logs)	"P" Wave Velocity (ft./sec.)	"S" Wave Velocity (ft./sec.)	Poisson's Ratio	Shear Modulus* (psi)	Young's Modulus* (psi)	Bulk Modulus* (psi)
40	Clay, medium gray	5,200	850	.486	1.79×10^4	5.33×10^4	64.73×10^4
50	Clay, medium gray	5,000(?)	800(?)	.487	1.59×10^4	4.72×10^4	59.93×10^4
60	Clay, medium gray	4,700	840	.484	1.75×10^4	5.20×10^4	52.50×10^4
80	Clay, medium gray	4,700	900	.481	2.01×10^4	5.96×10^4	52.15×10^4
100	Clay, medium gray	4,900	800	.486	1.59×10^4	4.72×10^4	57.48×10^4
112	Layers of fine sand, and clay	5,000	800	.487	1.59×10^4	4.72×10^4	59.93×10^4
122	Layers of fine sand, and clay	5,000	820	.486	1.67×10^4	4.96×10^4	59.83×10^4
132	Layers of fine sand, and clay	4,800	840	.48	1.75×10^4	5.20×10^4	54.86×10^4
142	Layers of fine sand, and clay	4,800	850(?)	.48	1.79×10^4	5.32×10^4	54.80×10^4
(300)	(Rock) (Based on Refraction profiling)	(12,000)	(6,500) (estimated)	(.29)	(12.77×10^4)	(33.00×10^4)	(26.49×10^4)

NOTE: * Based on unit weight of 115 lbs/ft^3.

Weston Geophysical Engineers, Inc.