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DETERMINATION OF SOIL SHEAR MODULI AT DEPTHS BY IN-SITU VIBRATORY TECHNIQUES

by

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Foreword

The investigation reported herein was authorized by the Air Force Special Weapons Center (SWKRB), Kirtland Air Force Base, New Mexico, in Project Order PR630545, 16 August 1963, transmitted by letter to the U. S. Army Engineer Waterways Experiment Station (WES) dated 21 August 1963, subject "Project Order Number AF(29-601)-64-PO-2" (see Appendix A).

Personnel of the Soils Division, WES, who were actively concerned with the investigation were Messrs. W. J. Turnbull, A. A. Maxwell, R. W. Cunny, Z. B. Fry, R. F. Ballard, Jr., J. L. Decell, and J. Fowler. This report was prepared by Mr. Ballard.

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

Contents

Summary

The tests described herein were conducted to investigate the possibility of determining by in-situ field measurements the dynamic moduli of soils at depths approaching or exceeding 100 ft. Tests were performed at several sites representative of various soil materials ranging from sand to rock. During the test program, various mechanical and instrumentation improvements were made in test equipment. Specifically, the hydraulic-powered, fixed-mass vibrator initially used was replaced by a variable-mass vibrator, and a double-amplification technique was utilized in conjunction with a low-frequency band pass filter to increase the amplitude and quality of the transducer signal.

Data were acquired utilizing the fixed-mass vibrator at three sites: Eglin Air Force Base, Fla., in sand; Waldorf, Md., in cohesive soil; and Frenchman Flat, Nev., in cohesive soil. Wave penetration at these sites extended to depths of 20, 37, and 45 ft, respectively.

After construction of the variable-mass vibrator, data were acquired with this vibrator at four sites: U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., in cohesive soil; Sacramento Peak, N. Mex., in rock; and Buckboard Mesa and Area 15 at the Nevada Test Site, Nev., both in rock. Investigational depths attained at these sites were 120, 86, 90, and 170 ft, respectively. Although the variable-mass vibrator with improved instrumentation was not tested on sand, results of tests on other materials indicate that depths greater than the 20-ft depth investigated at Eglin with the fixed-mass vibrator can almost certainly be penetrated with the variable-mass vibrator.

DETERMINATION OF SOIL SHEAR MODULI AT DEPTHS BY IN-SITU VIBRATORY TECHNIQUES

Purpose and Scope of Study

1. The purpose of this study was to investigate the possibility of measuring propagated shear waves at depth from surface-induced vibrations. The desired final product of the research effort was the capability of determining the shear moduli of soil in a continuous profile to depths approaching or exceeding 100 ft. As stated in the "Statement of Work for Vibratory Soil Experiments" prepared by the Air Force Weapons Laboratory (see Appendix A), available equipment, personnel, and field sites were to be used in examining the feasibility of increasing the heretofore comparatively shallow depths of vibratory soil investigations by modifying existing equipment, refining measuring techniques, or both.

Test Sites, Equipment, and Procedures

Location and description of test sites

2. Data collected at several field sites during dynamic soils investigations performed before or concurrently with this study were used in this study when applicable. In addition, tests were made at the Waterways Experiment Station (WES) to check out equipment developed or modified to meet the objectives of this investigation. The sites at which these data were obtained are described below.

3. Eglin. The Eglin test site is located within the confines of the main base at Eglin Air Force Base, Fla., near Building 620. Boring data indicate that the soil material in this location consists of tan and yellow, poorly graded sand to a depth of 16 ft and yellow, poorly graded sand with traces of silt from 16 ft to a depth of 25.5 ft, which is the extent of boring data.

4. Waldorf. This site 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 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.

5. Frenchman Flat. The test site is located approximately 15 miles north of Mercury, Nev., in an area referred to as Frenchman Flat. Terrain in this area is flat and dusty with no vegetation. Borings indicated that the soil is a tan silt, hard and friable, with some variation in soil structure, cementation, and strength to a depth of 55 ft.

6. WES. The WES test site is located within the confines of the reservation at Vicksburg, Miss. Soil at the site is a uniform silty clay (loess) to a depth of approximately 20 ft. From a depth of 20 ft to about 100 ft, a bluish clay is predominant. Limestone is encountered at approximately 100 ft.

7. Sacramento Peak. The Sacramento Peak site is located atop Sacramento Mountain near Cloudcroft, N. Mex. Soil materials at this site consist of a 1- to 2-ft layer of topsoil overlying fractured dolomitic limestone which extends to a depth of at least 236 ft, the maximum depth of borings made at this site.

8. Buckboard Mesa. The Buckboard Mesa site is located approximately 50 miles northwest of Mercury, Nev., within the confines of the Nevada Test Site. Subsurface materials predominant in this area are primarily dense basalt and lenses of vesicular basalt occurring in random patterns. Borings indicate that the base of the basalt is approximately 150 ft below surface level, at which point a light tan tuff is encountered.

9. Area 15. Area 15 is located approximately 50 miles north of Mercury, Nev., within the confines of the Nevada Test Site. The material at this site consists of a relatively homogeneous stratum of granite diorite which extends from the surface to a depth of approximately 800 ft (the depth of available borehole information).

Equipment and test technique

10. Fixed-mass vibrator. The fixed-mass hydraulic vibrator was constructed by the WES in 1962. A complete description of the vibrator

and its auxiliary equipment was presented in a recent WES publication.* After tests with this vibrator had been conducted at several locations, it was evident that the data collected permitted determining shear and compression moduli to depths averaging approximately 30 ft, or nearly double the depth formerly attainable with the electromagnetic vibrator.

11. Variable-mass vibrator. The requirement for greater depth penetration in this study prompted numerous improvements in the fixed-mass vibrator, the design of more sophisticated instrumentation, and led finally to the construction of a variable-mass vibrator. A block diagram of the instrumentation setup and a component listing of the improved and currently used apparatus, which has replaced the fixed-mass vibrator, are shown in plate 1. For comparative purposes, table 1 presents force capabilities of the fixed- and variable-mass vibrators, respectively. Table 1 readily shows the advantages of the variable-mass vibrator in terms of available force capabilities, especially in the lower-frequency range which is associated with long wavelengths and therefore greater depth penetration. The vibrator is trailer-mounted and towed behind an instrumentation van as shown in fig. 1.

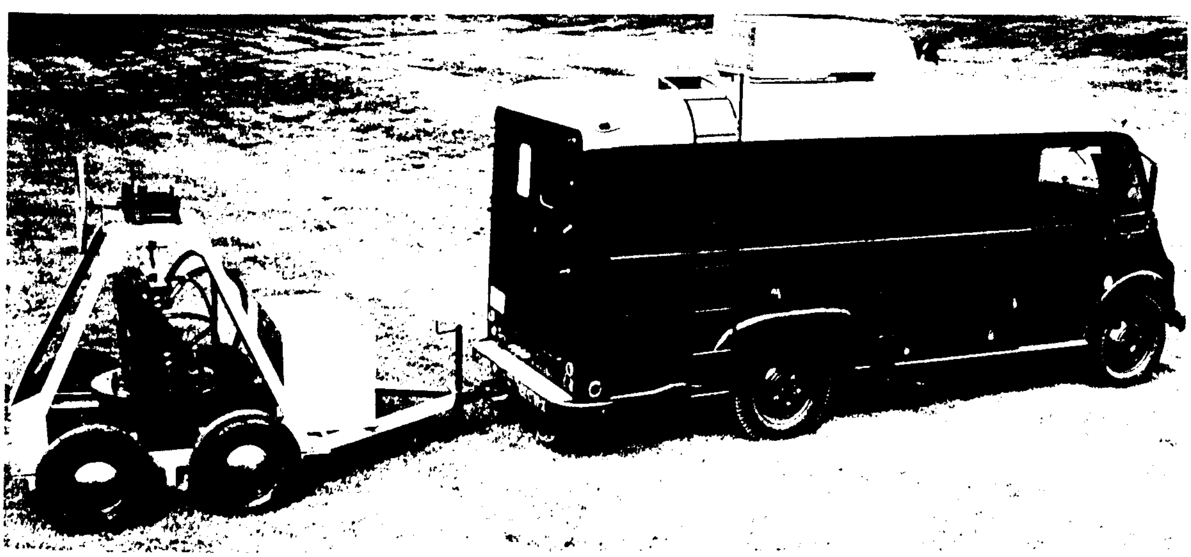

Fig. 1. Hydraulic vibrator and instrumentation van

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* U. S. Army Engineer Waterways Experiment Station, CE, A Procedure for Determining Elastic Moduli of Soils by Field Vibratory Techniques, by Z. B. Fry, Miscellaneous Paper No. 4-577 (Vicksburg, Miss., June 1963).

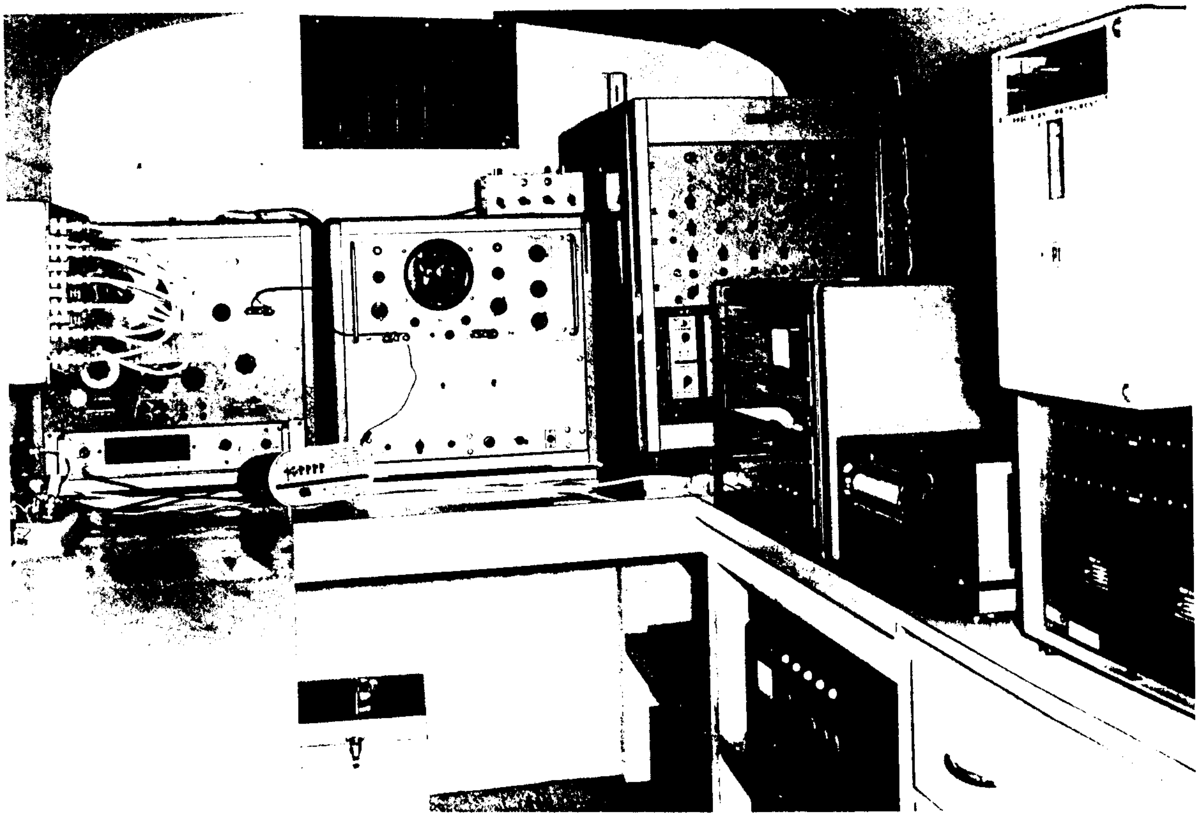

Fig. 2. Interior view of instrumentation van

Fig. 2 is a view of the truck interior showing instrumentation used for dynamic tests. The variable-mass vibrator is shown in detail in fig. 3.

12. Test technique. The method employed to obtain test data was that described in WES Miscellaneous Paper 4-577.* This involves the use of sensitive transducers placed on the ground surface to measure the wavelength increments produced by surface-induced vibrations. Other methods considered to measure the shear-wave increments were (a) placing the vibrator at depths and a transducer on the surface, and (b) placing the vibrator on the surface and the transducers in boreholes. The first method was impractical due to the size of the vibrator and length of control equipment. The second method was attempted in the investigation at Elgin Field, Fla., but did not produce precise information.

Equations Used in Data Reduction

13. The equations used in data reduction were as follows:

* Op. cit.

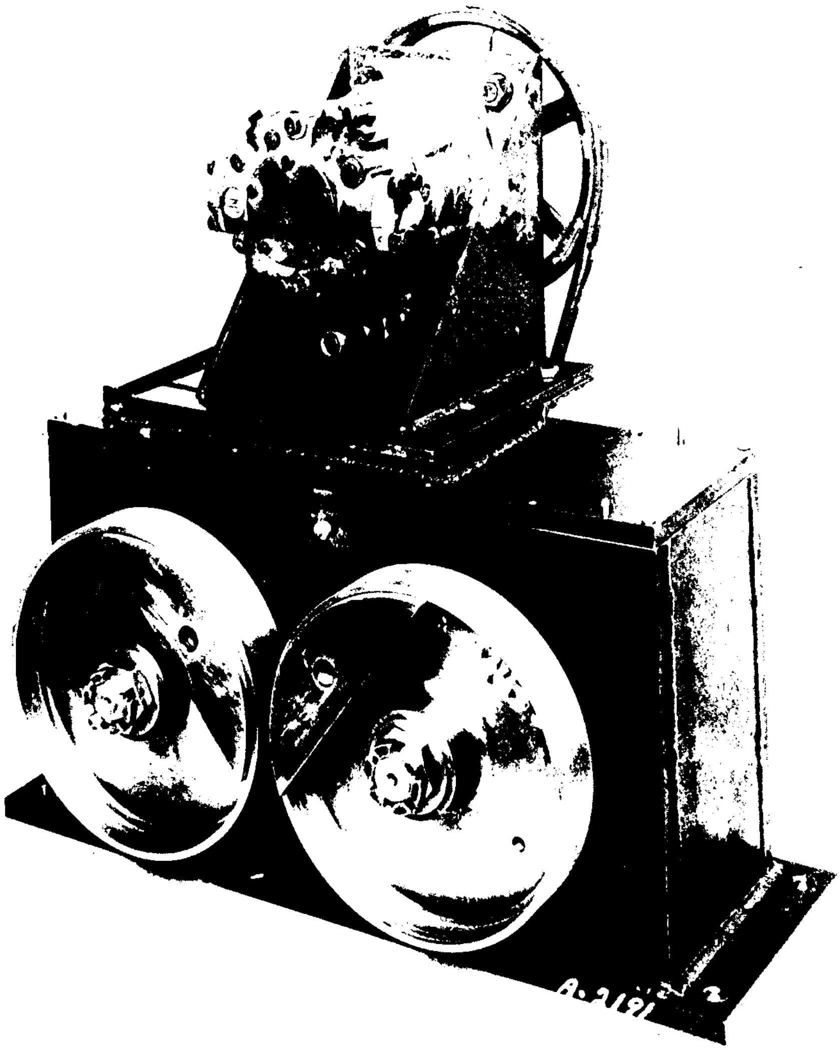

Fig. 3. Variable-mass hydraulic vibrator.

$$\rho = \frac{\gamma}{g} \qquad (1)$$

where

ρ = mass density of soil, slugs per cu ft

γ = wet unit weight of soil, lb per cu ft

g = acceleration due to gravity or 32.2 ft per sec per sec

$$\text{Depth} = \frac{\lambda}{2} \qquad (2)$$

where

λ = wavelength, ft

$$V = \lambda f \qquad (3)$$

where

V = wave velocity, fps

λ = wavelength, ft

f = frequency, cps

$$G = \frac{V^2 \rho}{144} \qquad (4)$$

where

G = shear modulus, psi

V = wave velocity, fps

ρ = mass density, slugs per cu ft

The derivation of these equations is discussed in Miscellaneous Paper 4-577.*

14. It should be noted that the test technique currently used by the WES to determine the dynamic elastic properties of soil materials was developed through the work of many consultants and specialists. Much of the basic theory and analytical work was performed by the Royal Dutch/Shell Laboratorium, Amsterdam, Holland. All but one of the equations presented above are widely used and theoretically correct for homogeneous, isotropic, elastic materials. The assumption which has not been theoretically validated is the use of the half wavelength as the depth of the propagated wave. This assumption, which is generally accepted, has been empirically validated by close correlation of dynamic test results with data obtained from numerous boreholes and test pits. These data are currently being utilized by the WES in a study to establish theoretical validation of the half wavelength as the approximate depth of wave penetration.

Test Results

Fixed-mass vibrator

15. The fixed-mass vibrator was used in tests at Eglin, Waldorf,

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* Op. cit.

and Frenchman Flat. The depth attainable at Eglin was 20 ft, as shown in plate 2, and the shear moduli increased from 3800 psi at a depth of 1 ft to 8800 psi at 20 ft. Soil materials at Waldorf were explored continuously to a depth of 37 ft, as shown in plate 3, and the shear moduli increased from 2000 psi at the 1-ft depth to approximately 30,000 psi at 37 ft. Investigations at Frenchman Flat reached a depth of 45 ft, as shown in plate 4, with shear moduli increasing with depth from 2700 psi near the surface to 23,100 psi at 45 ft. The greatest depths at the three sites were representative of the maximum range of the fixed-mass vibrator.

Variable-mass vibrator

16. The variable-mass vibrator, which was constructed in 1963, and the redesigned instrumentation (viz., a low-frequency band pass filter) significantly increased the depth from which calculations of shear moduli could be made. In initial vibratory check-out tests conducted with this equipment at the WES test site, waves extended to a depth of 62 ft in the clay materials. The device was then utilized on rock materials at Sacramento Peak. During these tests, a second amplifier was added at the output of the pickup. This initial amplification (or preamplification) served essentially to increase the sensitivity of the pickup so that the extremely small amplitudes of the waves propagated through the rock could be detected. The success of this modification is evidenced in the data for Sacramento Peak shown in plate 5. Penetration exceeded 85 ft and the shear moduli ranged from 33,600 psi at shallow depths to about 140,000 psi at a depth of 86 ft. Tests were conducted in areas of the Nevada Test Site in which the preamplification process was used. Investigations at Buckboard Mesa (plate 6) extended to depths of 90 ft, with shear moduli increasing from about 1000 psi at a depth of 1 ft to 144,000 psi at 90 ft. Tests in Area 15 at the Nevada Test Site penetrated to a depth of 170 ft, and the shear moduli ranged from 10,700 psi at 1.3 ft to about 610,000 psi at 170 ft, as shown in plate 7. These latter tests represent the greatest depths of penetration which have been attained by the WES.

17. Additional vibratory tests to further determine the effectiveness of the preamplification technique were made at the same WES test site used in the check-out tests. The results of this investigation are shown in plate 8; note that the second series of tests not only confirmed the

shear modulus values measured in the initial check-out to a depth of 62 ft, but also extended the effective depth of investigation to 120 ft. This was considered to verify the test procedure and technique. Shear moduli at the WES test site increased from 2300 psi near the surface to approximately 24,000 psi at a depth of 120 ft.

Discussion

18. The data summarized in table 2 were selected as representative of each test site, and are presented primarily to illustrate the progress made in extending the range of vibratory data to greater depths. The trend of shear modulus data collected at each site definitely indicated an increase in shear modulus with depth, which is reasonable and possibly attributable to increase in confining pressures at depth.

19. Wave penetration is influenced to some extent by the type of medium through which the wave is propagated. For practical purposes, the materials investigated in this study can be classified into three groups: rock, cohesive soil, and sand. The quality of sinusoidal wave shape and signal amplitude as displayed on the oscilloscope indicates that waves are propagated most easily through nonfractured rock material. Cohesive soil was the next best medium for transmissibility, followed by sand. Weathered materials and uneven or cracked surfaces adversely affect seating of the vibrator and transducer. The effect of these conditions can be minimized by leveling the soil surface and grouting the vibrator in test position, and by careful placement of the transducer.

20. The effect of water-table fluctuation upon data was not determined. However, tests conducted on sand several years ago at Cape Kennedy, Fla., indicated that fluctuation of the water table, if it is near the surface, does appear to slightly affect the transmissibility of vibratory signals through this material. It should be noted that at the test sites referred to in this report the water tables were not near the surface.

Summary of Results and Conclusions

21. The variable-mass vibrator and associated instrumentation developed in this investigation permitted considerable extension of exploratory depths previously limited by the moderate force capabilities of the

fixed-mass vibrator and by less-sensitive instrumentation. In the two types of soil investigated with the new equipment--rock and cohesive soil--test results indicated a shear modulus of 610,000 psi at a depth of 170 ft in the rock material at Area 15, Nevada Test Site, and of 24,100 psi at a depth of 120 ft in the cohesive material at WES.

22. It is concluded from the field test results that the vibratory equipment and associated appurtenances at their present state of development provide a means of determining dynamic shear moduli at depths of approximately 100 ft or more, depending upon site conditions and soil material. The variable-mass vibrator with improved instrumentation has not been tested on sand materials; however, improvements in data acquisition in other materials lead to the conclusion that the shear modulus of sand could almost certainly be determined at depths greater than the 20-ft depth investigated at Eglin with the fixed-mass vibrator.

Table 1

Forces Generated by Fixed-Mass and Variable-Mass Hydraulic Vibrators

Frequency cps	Fixed-Mass Vibrator* Forces, lb	Variable-Mass Vibrator Forces, lb, for Indicated Total Weights of Eccentric Masses, lb**				
		5.0	9.6	14.48	19.0	40.0
1	3.8	2.1	4.0	6.0	7.9	16.6
2	15.6	8.3	13.9	24.0	31.5	66.2
3	34.9	18.4	35.3	53.2	69.8	147
4	62.1	32.6	62.6	94.4	124	261
5	97.0	51.0	97.9	148	194	408
6	140	73.5	141	213	279	588
7	191	100	192	290	380	801
8	248	130	250	378	496	1,043
9	314	165	317	478	627	1,321
10	388	204	392	591	776	1,634
11	470	247	475	716	939	1,977
12	560	294	565	852	1,118	2,354
13	656	345	662	998	1,310	2,758
14	761	400	768	1158	1,519	3,199
15	874	459	882	1330	1,746	3,675
16	994	523	1004	1514	1,986	4,182
17	1123	590	1134	1709	2,243	4,722
18	1257	661	1269	1914	2,512	5,288
19	1401	736	1414	2133	2,799	5,892
20	1553	816	1568	2364	3,103	6,532
21	1713	901	1730	2608	3,422	7,205
22	1880	989	1899	2863	3,756	7,909
23	2053	1079	2072	3125	4,101	8,634
24	2236	1175	2257	3404	4,467	9,404
25	2427	1276	2450	3694	4,848	10,207
26	2625	1380	2651	3997	5,244	11,041
27	2832	1489	2860	4312	5,658	11,913
28	3043	1600	3072	4633	6,079	12,799
29	3265	1716	3296	4970	6,522	13,731
30	3495	1837	3529	5321	6,982	14,700
31	3731	1962	3768	5682	7,456	15,698
32	3976	2091	4016	6055	7,946	16,729
33	4228	2222	4267	6434	8,443	17,776
34	4488	2359	4531	6832	8,965	18,874
35	4756	2500	4802	7241	9,501	20,004
36	5032	2646	5081	7662	10,054	21,168
37	5315	2796	5368	8095	10,623	22,364
38	5607	2947	5659	8533	11,197	23,574
39	5906	3104	5962	8989	11,796	24,834
40	6212	3266	6272	9457	12,410	26,128

* Eccentricity of the unbalanced mass e = 0.652 in.; total of eccentric weights = 58.2 lb.

** Eccentricity of the unbalanced mass e = 4.0 in.

Table 2

Summary of Test Results

Test Site	Wet Unit Weight γ lb/cu ft	Type Vibrator	Frequency f, cps	Wavelength λ, ft	Depth ft	Wave Velocity V, fps	Shear Modulus G, psi $\times 10^3$
Eglin AFB, Fla.	110	Electromagnetic	200	2.00	1.0	400	3.8
			125	3.10	1.6	390	3.6
			70	5.40	2.7	380	3.4
			50	8.00	4.0	400	3.8
			40	10.5	5.2	420	4.2
			30	15.2	7.6	455	4.9
			25	20.0	10.0	500	5.9
			20	27.1	13.6	540	6.9
		Hyd fixed-mass	15	40.6	20.3	610	8.8
Waldorf, Md.	105	Electromagnetic	200	1.62	0.8	325	2.4
			150	2.20	1.1	330	2.5
			150	1.87	0.9	280	1.8
			120	3.42	1.7	410	3.8
			120	3.27	1.6	390	3.4
			100	4.27	2.1	425	4.1
			100	4.00	2.0	400	3.6
			90	4.99	2.5	450	4.6
			80	6.72	3.4	540	6.6
			80	6.12	3.1	490	5.4
			80	8.45	4.2	675	10.3
			70	12.2	6.1	855	16.6
			70	12.3	6.2	860	16.7
			65	15.6	7.8	1015	23.3
			60	15.6	7.8	935	19.8
			50	25.3	12.6	1265	36.2
			45	28.4	14.2	1280	37.1
			35	26.9	13.4	940	20.0
			35	28.0	14.0	980	21.7
			30	38.9	19.4	1165	30.7
			25	50.4	25.2	1260	35.9
		Hyd fixed-mass	25	46.7	23.4	1170	31.0
			20	56.0	28.0	1120	28.4
			15	73.7	36.8	1105	27.6

(Continued)

Test Site	Wet Unit Weight γ lb/cu ft	Type Vibrator	Frequency f, cps	Wave-length λ, ft	Depth ft	Wave Velocity V, fps	Shear Modulus G, psi × 10^3
Frenchman Flat, Nev. Test Site	95	Electro-magnetic	200	1.80	0.9	360	2.7
			200	1.88	0.9	375	2.9
			150	2.40	1.2	360	2.7
			150	1.91	1.0	285	1.7
			125	2.66	1.3	335	2.3
			100	4.00	2.0	400	3.3
			100	3.95	2.0	400	3.3
			100	3.75	1.9	375	2.9
			80	5.94	3.0	475	4.6
			75	6.81	3.4	510	5.3
			75	5.74	2.9	430	3.8
			60	9.38	4.7	565	6.5
	89		50	12.5	6.2	625	7.5
	90		50	11.2	5.6	560	6.1
	90		45	14.3	7.2	645	8.1
	84		40	18.2	9.1	725	9.5
	90		40	15.3	7.6	610	7.2
	90		35	20.6	10.3	720	10.0
	90		30	26.0	13.0	780	11.8
	90		30	24.0	12.0	720	10.0
	93		25	34.1	17.0	855	14.7
	90		25	31.1	15.6	780	11.8
	90		25	38.0	19.0	950	17.5
	84	Hyd fixed-mass	30	23.7	11.8	710	9.1
	93		25	31.1	15.6	780	12.2
	100		25	34.1	17.0	855	15.8
	98		20	43.1	21.6	860	15.6
	100		20	45.2	22.6	905	17.6
	102		15	62.2	31.1	935	19.2
	100		15	63.6	31.8	955	19.7
	91		12	90.3	45.2	1085	23.1
Sacramento Peak, N. Mex.	150	Electro-magnetic	300	3.40	1.7	1020	33.6
			250	4.40	2.2	1100	39.1
			200	4.95	2.5	990	31.7
			160	7.18	3.6	1150	42.8
			140	10.8	5.4	1510	73.7
			140	9.59	4.8	1345	58.5
			130	12.0	6.0	1560	78.7
			110	16.7	8.4	1840	109
			100	23.7	11.8	2370	182
			50	45.2	22.6	2260	165

(Continued)

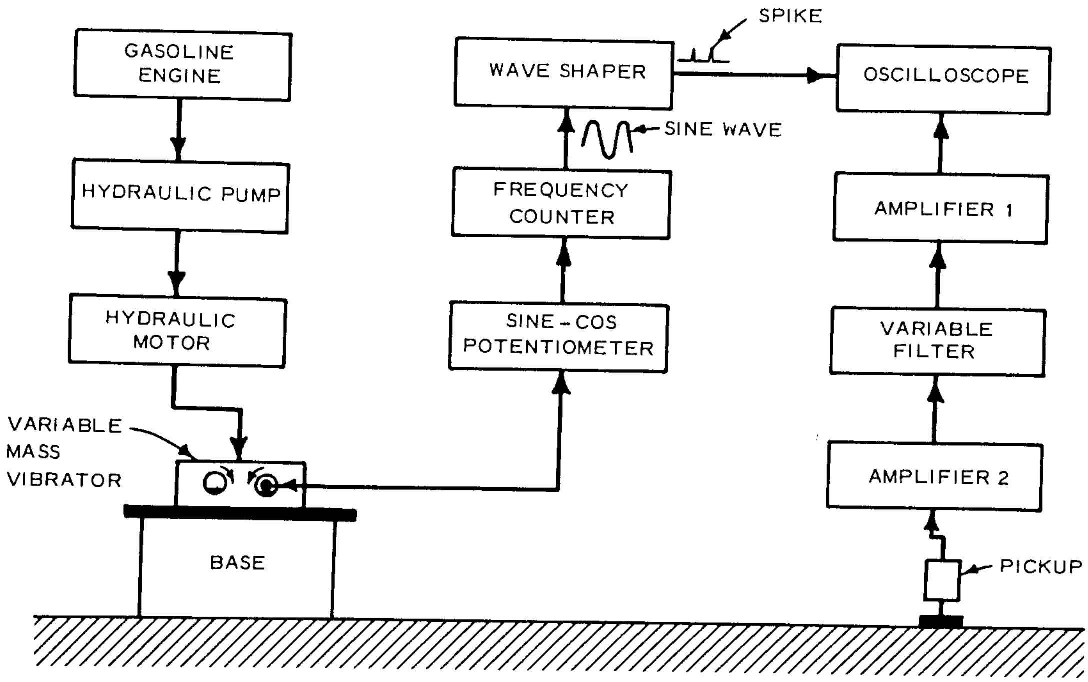
Table 2 (Continued)

Test Site	Wet Unit Weight γ lb/cu ft	Type Vibrator	Frequency f, cps	Wave-length λ, ft	Depth ft	Wave Velocity V, fps	Shear Modulus G, psi × 10^3
Sacramento Peak, N. Mex. (Cont'd)	150	Hyd variable-mass	30	57.5	28.8	1725	96.2
			30	60.0	30.0	1800	105
			25	76.7	38.4	1920	119
			25	92.0	46.0	2300	171
			20	98.6	49.3	1970	126
			20	125	62.5	2500	202
			18	115	57.5	2070	138
			18	138	69.0	2485	200
			14.5	138	69.0	2000	129
			14	153	76.5	2140	148
			12	153	76.5	1835	109
			12	172	86.0	2065	138
Buckboard Mesa, Nevada Test Site	95	Electro-magnetic	120	1.84	0.9	220	1.0
			80	4.34	2.2	345	2.4
			73	6.79	3.4	495	5.0
			65	9.40	4.7	610	7.6
	145		60	12.1	6.0	725	10.8
			55	15.9	8.0	875	15.7
			50	19.7	9.8	985	19.9
			45	23.8	11.9	1070	35.8
			40	29.8	14.9	1190	44.3
			35	38.7	19.4	1355	57.4
		Hyd variable-mass	25	38.9	19.4	975	29.7
			20	50.0	25.0	1000	31.3
			18	73.7	36.8	1325	54.9
			15	93.3	46.6	1400	61.3
	170		13	108	54.0	1405	72.3
			12	140	70.0	1680	103
			11	180	90.0	1980	144
Area 15, Nevada Test Site	170	Electro-magnetic	200	2.69	1.3	540	10.7
			100	7.62	3.8	760	21.2
			80	9.93	5.0	795	23.2
			70	11.7	5.8	820	24.6
			60	15.7	7.8	940	32.4
			50	19.3	9.6	965	34.1
			40	25.4	12.7	1015	37.8
			30	32.8	16.4	985	35.6
			25	43.6	21.8	1090	43.5
		Hyd variable-mass	25	43.6	21.8	1090	43.5
			20	63.0	31.5	1260	58.2
			13.3	200	100.0	2660	259
			12	340	170.0	4080	610

(Continued)

Table 2 (Concluded)

Test Site	Wet Unit Weight γ lb/cu ft	Type Vibrator	Frequency f, cps	Wave-length λ, ft	Depth ft	Wave Velocity V, fps	Shear Modulus G, psi $\times 10^3$
WES, Vicksburg, Miss.	120	Electro-magnetic	400	0.75	0.4	300	2.3
			200	1.87	0.9	375	3.6
			100	4.20	2.1	420	4.6
			75	5.70	2.8	430	4.8
			50	9.40	4.7	470	5.7
			40	12.2	6.1	490	6.2
			35	17.1	8.6	600	9.3
			30	19.8	9.9	595	9.2
			25	22.2	11.1	555	8.0
		Hyd variable-mass, first series	20	27.0	13.5	540	7.5
			10	57.0	28.5	570	8.4
			9	67.0	33.5	605	9.5
			8	85.6	42.8	685	12.1
			7	109	54.5	765	15.1
			6	124	62.0	745	14.4
		Hyd variable-mass, second series	10	58.8	29.4	590	9.0
			9	70.2	35.1	630	10.3
			8	83.3	41.6	665	11.4
			6	111	55.5	665	11.4
			5	140	70.0	700	12.6
			4.5	174	87.0	785	15.9
			4.25	189	94.5	805	16.8
			4	241	120.5	965	24.1

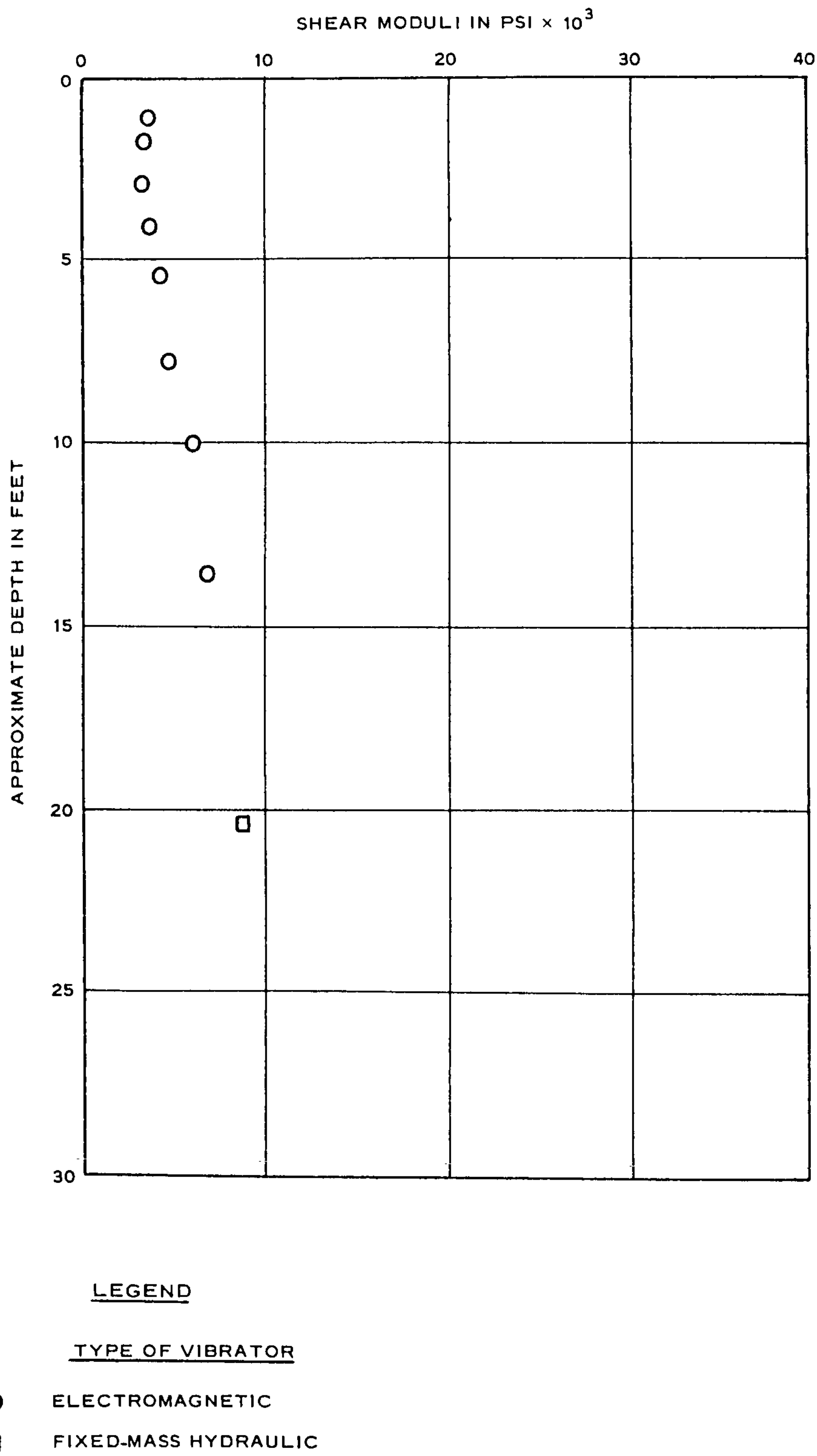


BLOCK DIAGRAM

EQUIPMENT LIST

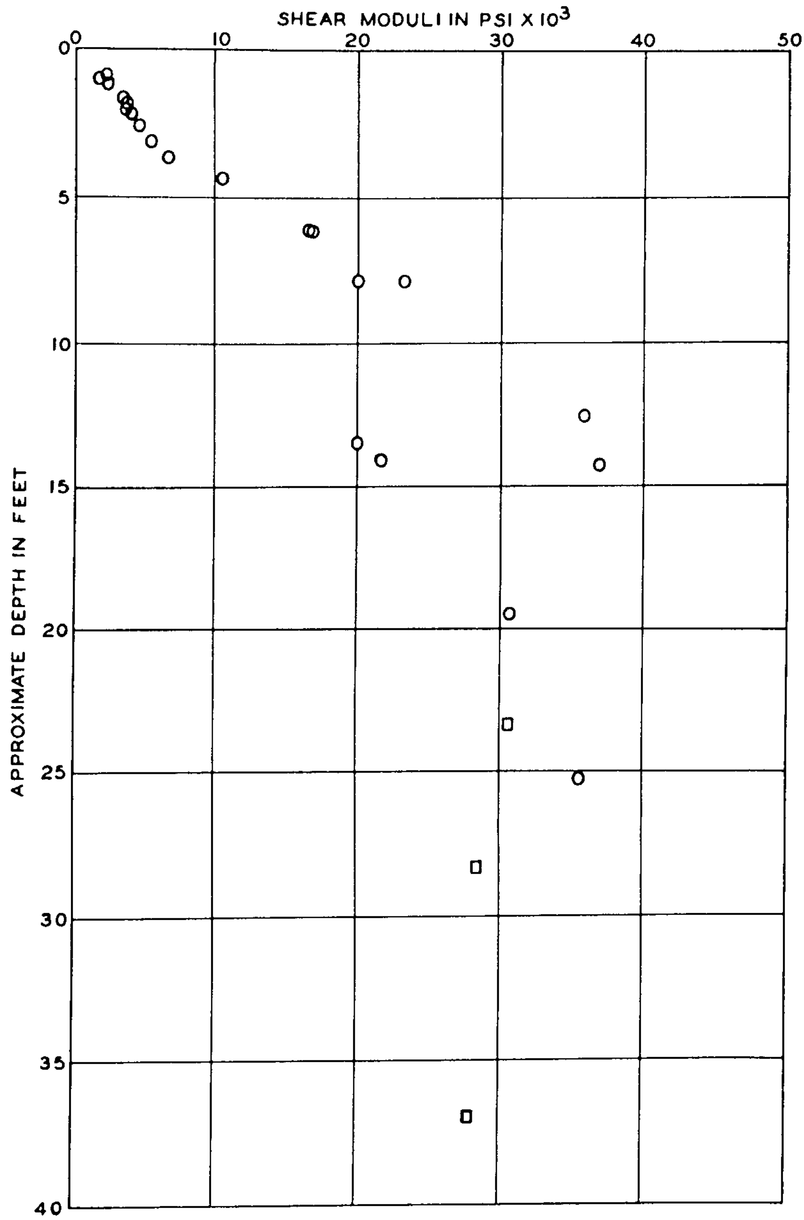
ITEM	MAKE AND MODEL
VIBRATOR	WES-CONSTRUCTED COUNTERROTATING VARIABLE MASS ECCENTRIC WEIGHTS
HYDRAULIC TRANSMISSION POWER	NEW YORK AIR BRAKE COMPANY "DYNAPOWER"
SINE-COSINE POTENTIOMETER	COMPUTER INSTRUMENTS CORPORATION 206
FREQUENCY COUNTER	HEWLETT-PACKARD 5512A
WAVE SHAPER	WES-CONSTRUCTED
OSCILLOSCOPE	HEWLETT-PACKARD 130BR
AMPLIFIER NO. 1	ALINCO 516-A
VARIABLE BAND PASS FILTER	ALLISON 201
AMPLIFIER NO. 2	ALINCO 516-A
VELOCITY PICKUP	PHILLIPS PR9260

BLOCK DIAGRAM FOR LOW-FREQUENCY VARIABLE-MASS VIBRATOR AND ASSOCIATED EQUIPMENT



SHEAR MODULI VS DEPTH

EGLIN AFB, FLORIDA



LEGEND

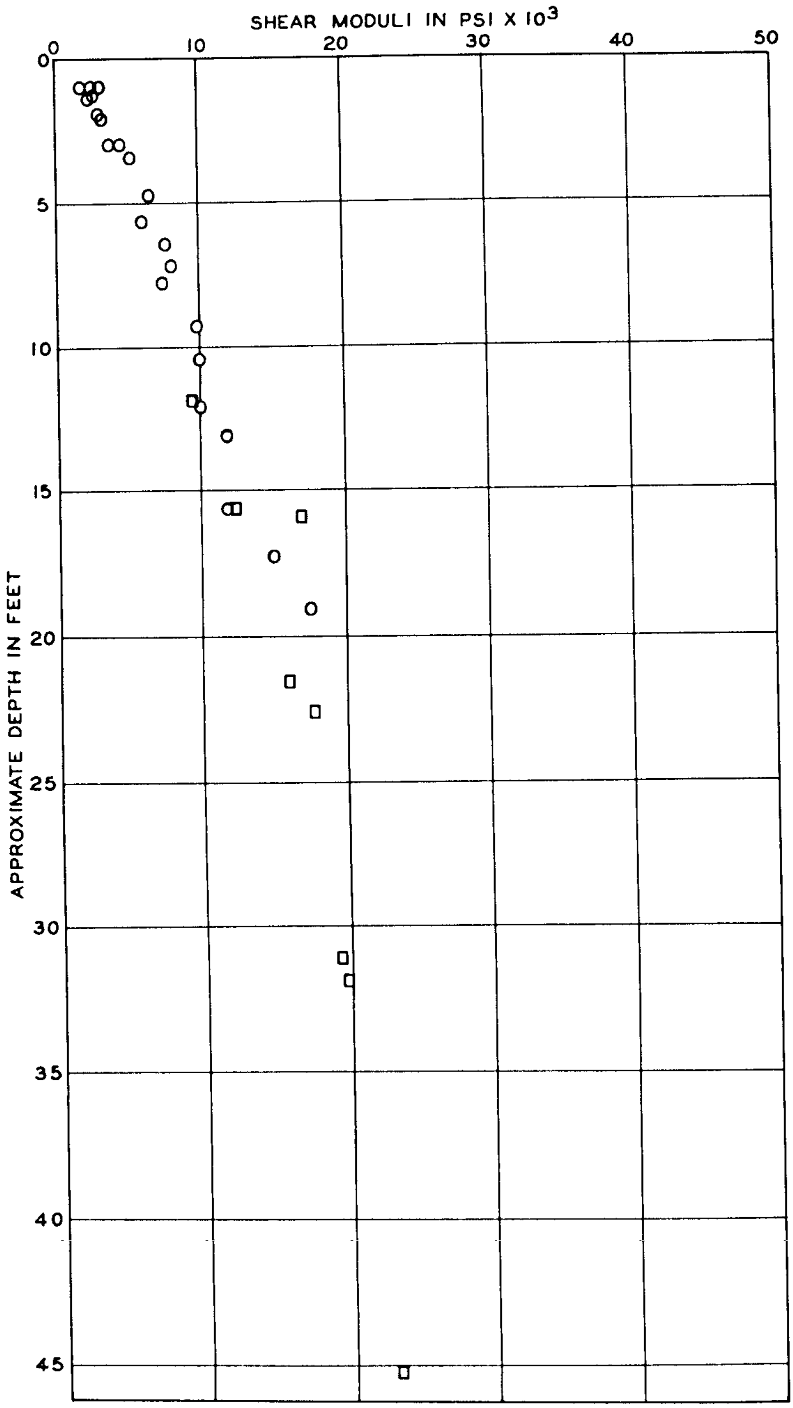
TYPE OF VIBRATOR

O ELECTROMAGNETIC

▫ FIXED-MASS HYDRAULIC

SHEAR MODULI VS DEPTH

WALDORF, MARYLAND



LEGEND

TYPE OF VIBRATOR

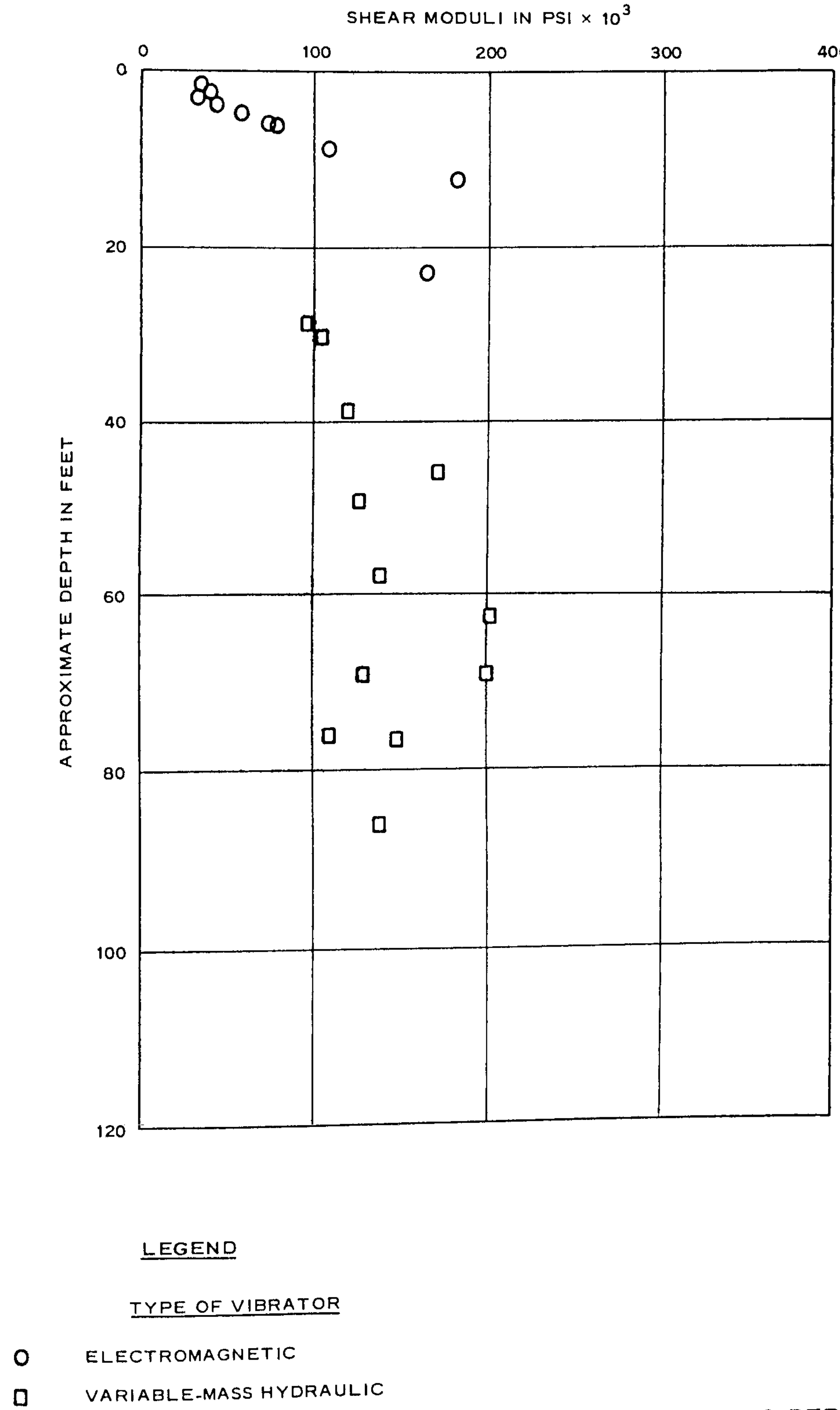
○ ELECTROMAGNETIC

□ FIXED-MASS HYDRAULIC

SHEAR MODULI VS DEPTH

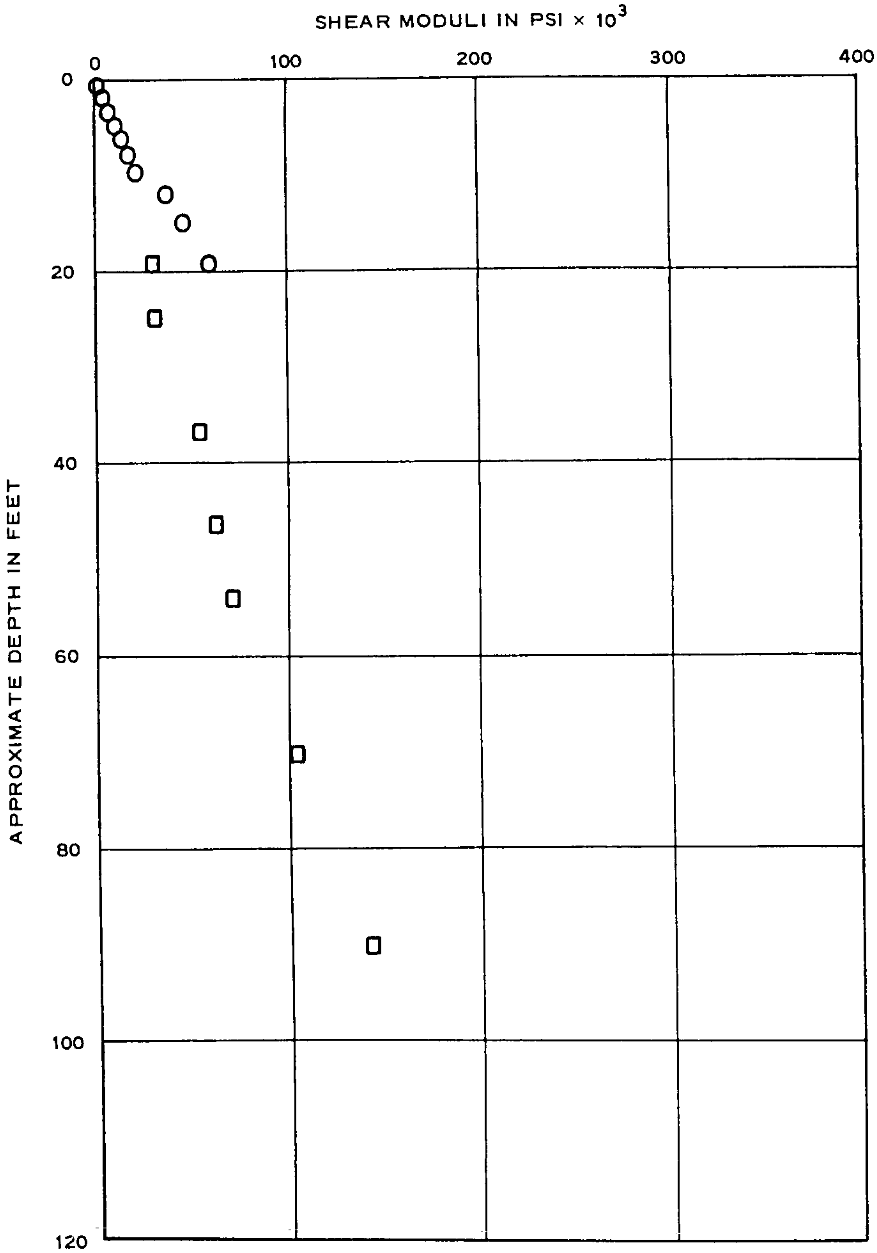
FRENCHMAN FLAT, NEVADA TEST SITE

PLATE 4



SHEAR MODULI VS DEPTH

SACRAMENTO PEAK, NEW MEXICO



LEGEND

TYPE OF VIBRATOR

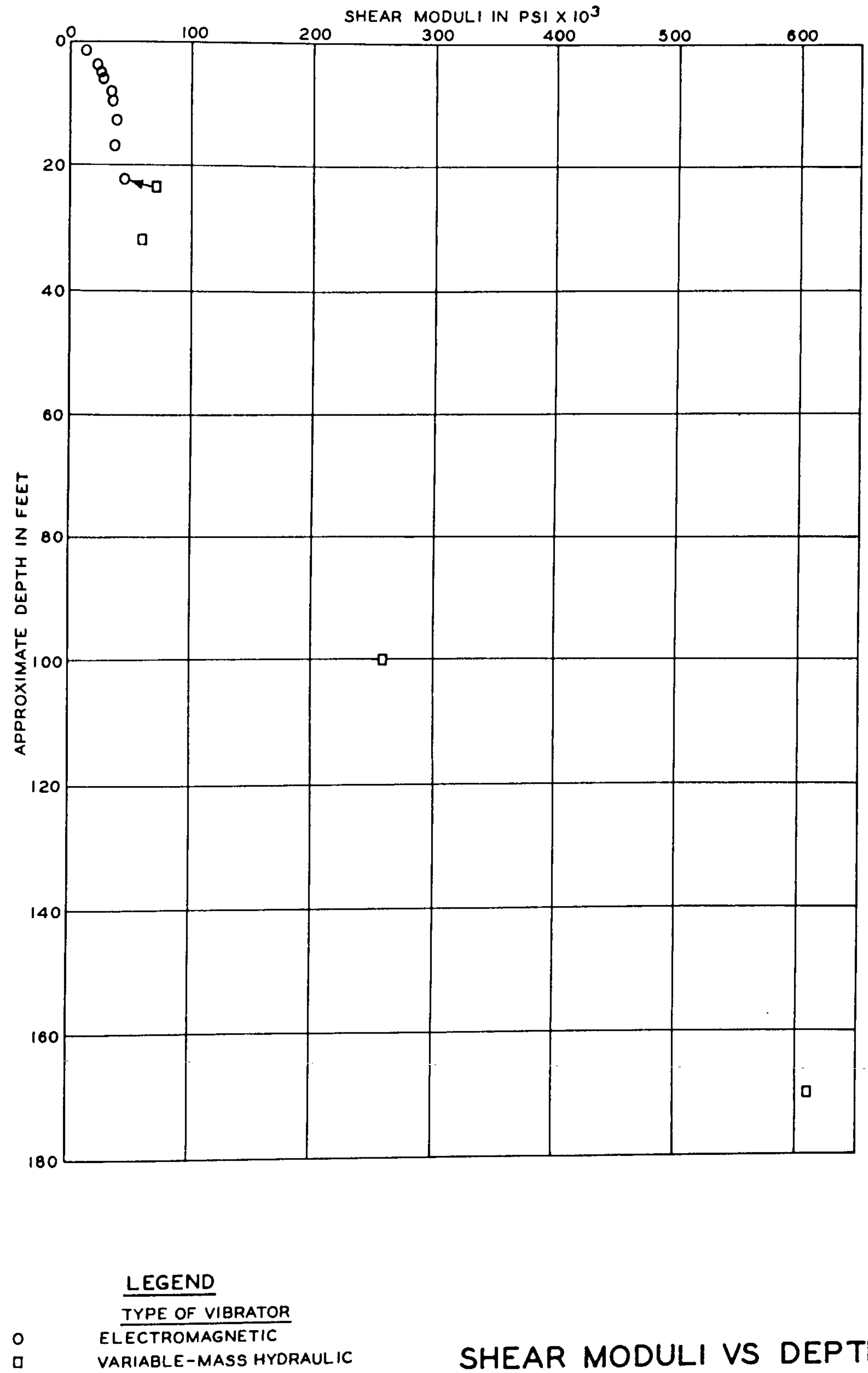
○ ELECTROMAGNETIC

□ VARIABLE-MASS HYDRAULIC

SHEAR MODULI VS DEPTH

BUCKBOARD MESA, NEVADA TEST SITE

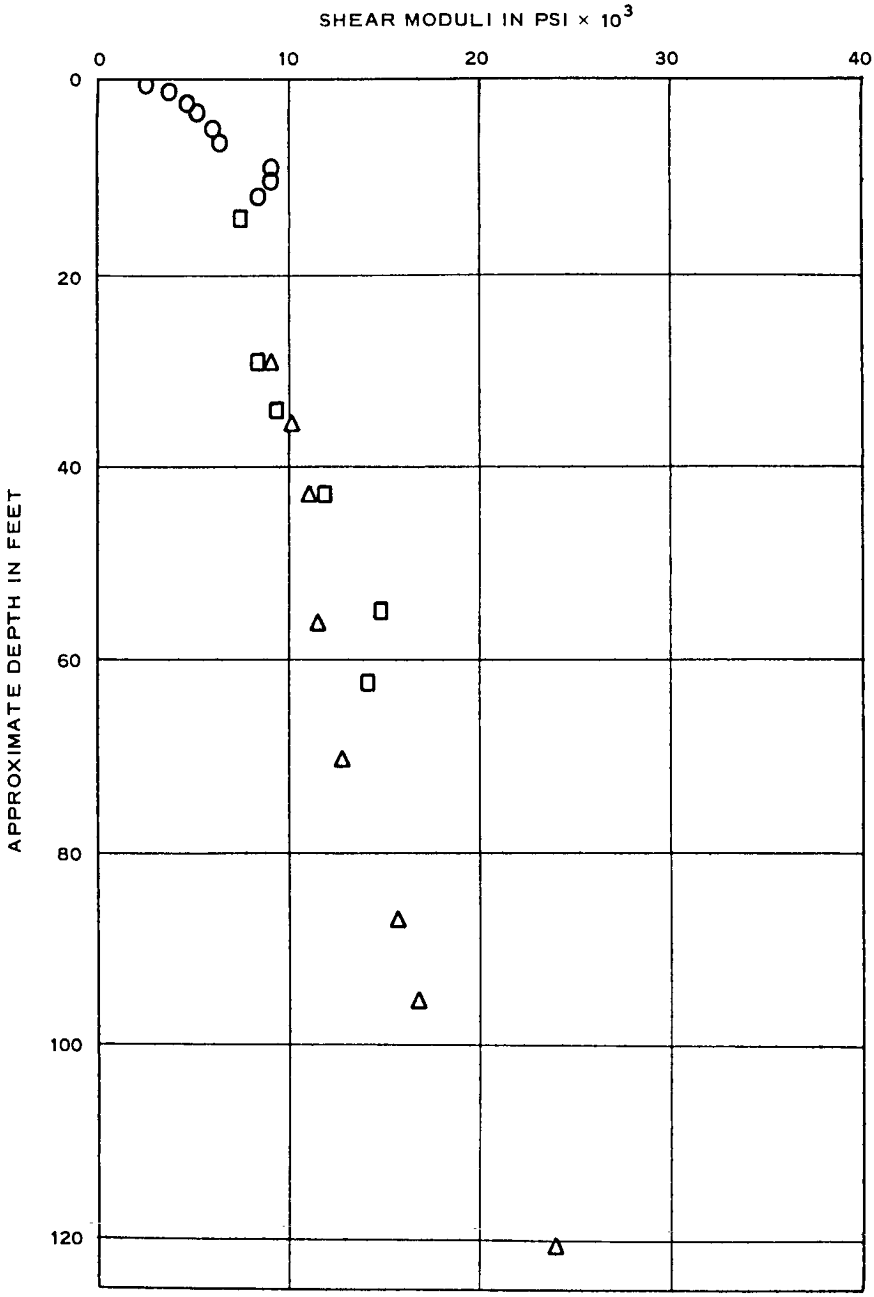
PLATE 6



SHEAR MODULI VS DEPTH

AREA 15, NEVADA TEST SITE

PLATE 7



LEGEND

TYPE OF VIBRATOR

FIRST SERIES

○ ELECTROMAGNETIC

□ VARIABLE-MASS HYDRAULIC

SECOND SERIES

△ VARIABLE-MASS HYDRAULIC

SHEAR MODULI VS DEPTH

WES, VICKSBURG, MISSISSIPPI

APPENDIX A

PROJECT ORDER

PR 630545 **PROJECT ORDER**

(See Reverse Side for Instructions for Issuing Project Order)

1. ☐ FIXED PRICE ☒ COST REIMBURSEMENT

2. DATE: 16 AUGUST 1963

3. ORDERING COMPONENT

NAME	ADDRESS
AIR FORCE SPECIAL WEAPONS CENTER (SWKRB)	KIRTLAND AIR FORCE BASE, NEW MEXICO

4. PROJECT ORDER NO.: AF(29-601)-64-PO-2

5. AMENDMENT NO.:

6. PERFORMING ESTABLISHMENT

NAME	ADDRESS	STATION NUMBER
U.S. ARMY ENGINEERS WATERWAYS EXPERIMENT STATION CORPS OF ENGINEERS	VICKSBURG, MISSISSIPPI	

7. DELIVERY INSTRUCTIONS

PLACE	DATE	METHOD
SEE 8A2 BELOW	30 DEC 1963	PREPAID MAIL

8. DESCRIPTION OF WORK TO BE PERFORMED AND OTHER INSTRUCTIONS *(If additional space is required, use Supplemental Data Section on reverse side hereof or attach additional sheets)*

A. THE WATERWAYS EXPERIMENT STATION WILL FURNISH QUALIFIED PERSONNEL, FACILITIES, AND SUPPLIES NECESSARY TO PERFORM THE RESEARCH INVESTIGATION AND TESTING EFFORT AND FURNISH THE REPORTS CALLED FOR HEREIN, IN ACCORDANCE WITH THE FOLLOWING EXHIBIT, ATTACHED TO AND MADE A PART OF THIS PROJECT ORDER:

1. EXHIBIT "A" TO PURCHASE REQUEST NUMBER 630545, DATED 21 JUNE 1963.

B. THE WES WILL SUBMIT THE RESULTS OF ALL THE RESEARCH EFFORT IN INFORMAL LETTER FORM ON OR BEFORE 30 DECEMBER 1963, IN THE NUMBER OF COPIES AND TO THE ADDRESSEES INDICATED BELOW:

THREE (3) COPIES: AIR FORCE WEAPONS LABORATORY (WLPC)
KIRTLAND AIR FORCE BASE, NEW MEXICO
MARKED FOR: PROJECT OFFICER
PROJECT 1080, TASK 108014
PROJECT ORDER NO. (29-601)-64-PO-2

ONE (1) COPY: AIR FORCE SPECIAL WEAPONS CENTER (SWKRB)
KIRTLAND AIR FORCE BASE, NEW MEXICO
MARKED FOR: PROJECT 1080, TASK 108014
PROJECT ORDER NO. (29-601)-64-PO-2

C. DURING THE PERFORMANCE OF THIS PROJECT ORDER, THE WES AGREES TO SUBMIT INFORMAL MONTHLY PROGRESS LETTERS IN SUFFICIENT TIME TO REACH THE ADDRESSEES WITHIN TEN (10) CALENDAR DAYS FOLLOWING THE END OF THE REPORTING PERIOD, WITH THE FIRST LETTER TO COVER THE PERIOD ENDING 26 SEPTEMBER 1963. THESE LETTERS WILL BE SUBMITTED IN THE SAME NUMBER OF COPIES AND TO THE ADDRESSEES INDICATED IN PARAGRAPH B ABOVE.

9. a. ACCOUNTING CLASSIFICATION	b. AMOUNT
SEE ACD ATTACHED	$5,000.00

10. THIS ORDER IS PLACED IN ACCORDANCE WITH THE PROVISIONS OF 41 USC 23, AND DEPARTMENT OF DEFENSE DIRECTIVE 7220.1. WORK TO BE PERFORMED AND MATERIAL TO BE PROCURED PURSUANT TO THIS ORDER ARE PROPERLY CHARGEABLE TO THE APPROPRIATION OR OTHER ACCOUNTS INDICATED ABOVE UNTIL 30 DEC 1963 (DAY - MONTH - YEAR) THE EXPIRATION DATE OF THIS PROJECT ORDER. FUNDS IN THE AMOUNT INDICATED ABOVE HAVE BEEN COMMITTED AND WILL BE OBLIGATED UPON RECEIPT OF ACCEPTANCE COPY.

TYPED NAME AND TITLE OF AUTHORIZING OFFICER	SIGNATURE
RICHARD M. JUSTUS, CONTRACTING OFFICER	Richard M Justus

11. THE ABOVE TERMS AND CONDITIONS ARE SATISFACTORY AND ARE ACCEPTED.

DATE ACCEPTED	TYPED NAME & TITLE OF ACCEPTING OFFICER	SIGNATURE
9/3/63	C. G. EVANS, Comptroller	C G Evans

INSTRUCTIONS

This form is intended for use by components of military departments in placing project orders with Government-owned and operated establishments within and outside the Department of Defense.

ITEM 1 - Check appropriate box indicating type of project order; i.e., fixed price or cost reimbursement.

ITEM 2 - Date of project order or amendment.

ITEM 3 - Name and address of ordering component.

ITEM 4 - Number assigned to project order by ordering component for control purposes.

ITEM 5 - Number assigned to project order amendment by ordering component for control purposes. Formal amendments shall be numbered consecutively.

ITEM 6 - Name, address, and station number of performing establishment.

ITEM 7 - Instructions for place, date and method of delivery, if applicable. If additional space is required, use Supplemental Data Section below.

ITEM 8 - Full description of the work ordered *(this may be incorporated by reference)* and such other instructions as conditions of inspections, shipping, packing and marking, etc. Use Supplemental Data Section or attach additional sheets if necessary. Limitations, if any, applicable to the appropriations or other accounts relevant to this order are shown in the Supplemental Data Section below.

ITEM 9 - Insert the complete accounting classifications chargeable and the amount of the project order or amendment.

ITEM 10 - Insert in the spaces provided, the expiration date of the project order, the name, title and signature of officer or his authorized representative controlling or having responsibility for the administration of the funds cited on the project order or amendment. If authorizing officer is other than one having fiscal responsibility, the ordering department must have on file as support to the certificate, a written statement by such an officer substantiating the fiscal portion of the certificate.

ITEM 11 - The performing establishment shall indicate acceptance in this space. Duplicate,bearing acceptance date, name, title and signature of accepting officer shall be returned to the ordering component. If the performing establishment is unable to accept the project order, it shall return promptly the original project order form to the ordering office with appropriate explanation.

SUPPLEMENTAL DATA SECTION

D REIMBURSEMENT WILL BE MADE ON A MONTHLY BASIS, AND WILL BE BASED ON SUBMISSION OF SF 1080. SF 1080'S WILL BE SUBMITTED FOR PROCESSING TO:

AFSWC (SWKRB)
KIRTLAND AIR FORCE BASE, NEW MEXICO

E. THE COGNIZANT AIR FORCE ADMINISTRATIVE OFFICE FOR THIS PROJECT ORDER IS:

AFSWC (SWKRD)
KIRTLAND AIR FORCE BASE, NEW MEXICO

F. THE COGNIZANT AIR FORCE TECHNICAL OFFICE FOR THIS PROJECT ORDER IS:

AFWL (WLRS)
KIRTLAND AIR FORCE BASE, NEW MEXICO

G. PAYMENT FOR SERVICES PERFORMED UNDER THIS PROJECT ORDER WILL BE MADE BY:

AFSWC (SWCAT)
KIRTLAND AIR FORCE BASE, NEW MEXICO

H. ACCEPTANCE. FINAL ACCEPTANCE OF THE WORK CALLED FOR UNDER THIS PROJECT ORDER WILL BE MADE UNDER THE GUIDANCE AND SUPERVISION OF THE AIR FORCE WEAPONS LABORATORY PROJECT SCIENTIST. FORMAL ACCEPTANCE (ISSUANCE OF DD FORM 250, "MATERIAL INSPECTION AND RECEIVING REPORT," WILL BE BASED ON ACCEPTANCE OF THE ITEM CALLED FOR IN PARAGRAPH B OF THIS SCHEDULE.

UNCLASSIFIED

Exhibit "A" to Purchase Request 630545

Air Force Systems Command
Research and Technology Division
Air Force Weapons Laboratory

21 JUNE 1963

Statement of Work
for

Vibratory Soil Experiments

1. SCOPE: The scope of the work includes the use of available equipment, personnel, and field sites to investigate the determination of shear moduli at depths from surface induced vibrational energy.

2. OBJECTIVE: The objective of this work is to investigate the possibility of measuring cyclic shear wave energy at depth from surface induced vibrations. The final product of this research effort will be the determination of soil shear modulus in a continuous profile to 100 feet depths.

3. DETAILED OUTLINE OF WORK:

3.1. The contractor shall use existing equipment to investigate the measurement of cyclic shear energy by either:

3.1.1. Placing geophones in boreholes to measure shear wave length increments.

3.1.2. Placing the vibrator at various depths and record with geophones on the ground surface.

3.1.3. Use sufficiently sensitive geophones to make surface measurements of wave length increments from surface induced vibrations.

3.2. The final produce of this research effort shall be a letter type report which summarizes the techniques and results.

UNCLASSIFIED

4-10

ADMINISTRATIVE COMMITMENT DOCUMENT

TO:	DATE	CONTRACTUAL INSTRUMENT NO. / CONTRACTOR
SWKSS: ADMIN. OFFICE: AFSWC (SWKRD) KIRTLAND AFB NMEx	13 AUG 1963	PROJECT ORDER AF(29-601)-64-PO-2 / CONTRACTOR US ARMY ENGINEER, WATERWAYS EXP. STATION, VICKSBURG, MISSISSIPPI

PR ITEM NO.	CONTR ITEM NO.	CONTRACT QUANTITY	PR OR MIPR NUMBER AND ACCOUNTING CLASSIFICATION	UNIT PRICE	TOTAL COST
			PURCHASE REQUEST NUMBER 630545 PROJECT 1080 TASK 108014 VIBRATORY SOIL EXPERIMENTS 57X3600 284-4785 6899 710A 1080 S662300 (DASA MIPR 537-63) 76006015		$5,000.00

PREPARED BY (Typed Name, Org Code, Telephone No., and Signature)

DANIEL SANCHEZ
PROCUREMENT OFFICER, SWKRB
PROCUREMENT DIRECTORATE, EXT 2383

The supplies and services to be obtained by this instrument are authorized by, are for the purpose set forth in, and are chargeable to allotments enumerated above, the available balance of which is sufficient to cover the cost in an amount not to exceed $ $5,000.00

15 AUG 1963
DATE

R.J.ALLEN FOR M.L.COOPER,MAJ,USAF
SIGNATURE (Accounting Officer)
ACCTG & FINANCE OFFICER

AFPI FORM 27 JAN 54 6 REPLACES AMC FORM 434, 24 JUL 53, WHICH IS OBSOLETE. PAGE OF