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CORRELATIONS OF SEISMIC VELOCITY WITH DEPTH IN SOUTHERN CALIFORNIA

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This report presents updated correlations relating seismic velocity and Poisson's ratio with depth and various geotechnical parameters for different soil and rock classifications found in Southern California. Such correlations are very useful in earthquake engineering applications. The current study updates previous work by incorporating prior data with 48 new velocity measurements. Data were obtained from borings drilled as a part of geotechnical investigations. In addition to establishing updated velocity correlations, these new data improved and extended a previously developed geotechnical classification system. The report presents new shear-wave and compressed wave velocity together with supporting geotechnical data. Statistics are compared for each classification for surface and near surface velocities of both shear and compressional waves and for Poisson's ratios. Correlations to depth are presented for a few of the classifications for which sufficient data are available. The geotechnical parameters significant to seismic velocity and Poisson's ratio include geologic age, gravel content, water table depth, dry density, and depth of overburden.

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Abstract

Updated correlations relating seismic velocity and Poisson's ratio with depth and various geotechnical parameters are presented for different soil and rock classifications found in Southern California. The geotechnical parameters found to be significant to seismic velocity and Poisson's ratio include geologic age, gravel content, water table depth, dry density and depth of overburden.

Table of Contents

List of Figures

List of Tables

INTRODUCTION

This report presents updated correlations among seismic velocity, depth, and geotechnical parameters in Southern California. These correlations are based on a geotechnical classification system that defines ranges of seismic velocity according to soil or rock type, geologic age, gravel content, water table depth, dry density, and depth of overburden.

Correlations were first introduced by Campbell and Duke[(1)] relating shear-wave velocities and various geotechnical characteristics. These correlations were based on 63 seismic velocity measurements conducted in the greater Los Angeles area since the 1971 San Fernando earthquake (see Duke et. al,[(2)]; and Eguchi, et. al,[(3)]).

This study updates the previous work by incorporating the previous data and 48 new velocity measurements. 37 of these measurements were obtained at sites in Los Angeles and Orange Counties; the other nine measurements included one in nearby Ventura County, one in Kern County, four in San Diego County, and three, although not from Southern California, were from the San Francisco Bay area. Most of these data were obtained from borings drilled as a part of geotechnical investigations. These new data were used to establish updated velocity correlations, and to improve and extend the geotechnical classification system developed by Campbell and Duke.

The previous correlations have proven to be very useful in earthquake engineering applications. Advanced technology in earthquake resistive design has increased the importance of the shear-wave velocity profile beneath the site of interest. Such profiles are required in seismic site response analyses using wave propagation techniques, in the analysis and design of vibrating machine foundations, and in the evaluation of the characteristic site period. The soil-structure resonance coefficient, S, as defined in the Uniform Building Code, 1979 Edition[4], requires the determination of the shear-wave velocity profile to depths where a velocity of 2,500 feet per second or greater are encountered. The shear-wave velocity profile is used in computing the characteristic site period, Ts. In many cases, economical considerations do not allow the measurement of velocities at the depths required for the determination of Ts. In many other situations only estimates of the site period are required. For these applications, available geotechnical data, together with seismic velocity correlations, may be used to estimate velocities with a reasonable degree of confidence.

The increased need for these correlations stimulated the authors to extend the data base with the 48 additional velocity measurements. In subsequent sections, these new shear-wave and compressional-wave velocity data, together with supporting geotechnical data, are presented and the revised geotechnical classification system is discussed. Statistical correlations are presented for each classification for surface and near surface velocities of both shear and compressional waves and for Poisson's ratios. Correlations with depth are presented for a few of the classifications for which sufficient data are available.

VELOCITY DATA

The site information for each of the new 48 velocity measurements is presented in Table 1. The site number for the first site listed in the table begins with number 64 so as to provide continuity with References (2) and (3). The location given by cross-streets is supplemented with the Thomas Brothers map designations for Los Angeles County, Orange County, and locations in other counties (if applicable) for easy reference. See Appendix A for the explanation of the Thomas Brothers map designations.

Table 1 also lists the type of geophysical survey conducted and either the length of the survey line for refraction surveys or the depth of the boring in the case of downhole or crosshole surveys. Ten of the sites were investigated using the refraction technique. Crosshole surveys were used for three of the investigations. The remaining 35 measurements were conducted by downhole surveys.

Refraction survey horizontal traverses ranged from about 150 to 360 feet in length. Depths penetrated by these surveys are on the order of 30 to 80 feet. Depths penetrated by the downhole surveys ranged from about 50 to 135 feet, with most being approximately 75 feet deep. Site 88 was investigated to a depth of 410 feet.

MEASUREMENT TECHNIQUES

The three types of seismic surveys used to determine the velocity profiles presented in this report are those commonly used in geotechnical engineering investigations. Detailed descriptions of these techniques,

TABLE 1

SITE INFORMATION

Site No.	Location	Map Location	Survey	Length/Depth (Ft)
64	Golden Shore Ave., near Shoreline Dr., Long Beach	LA 75B6	Refraction	240
65	Wilshire Blvd. and Malcom Ave., Los Angeles	LA 41E2	Refraction	180
66	Second and Los Angeles Sts., Los Angeles	LA 44D3	Downhole	80
67	Artesia Blvd. near Woodruff, Bellflower	LA 66D5	Refraction	180
68	Century Park East and Galaxy Way, Century City	LA 42B2	Refraction	360
69	Hacienda Blvd. south of Valley Blvd., City of Industry	LA 85E1	Crosshole Downhole	25 50
70	Wilmington Ave. near Sepulveda Blvd., Carson	LA 74C1	Crosshole Refraction	20 180
71	San Antonio and Market St., San Jose	---	Refraction	180
72	Oxnard St. near Canoga Ave., Canoga Park	LA 12C6	Refraction	165
73	West end of El Mirador Dr. Pasadena	LA 26D2	Refraction (Six Surveys)	50-150
74	Mathilda Ave. and Lockheed Way, Sunnyvale	---	Crosshole	30
75	Azusa Blvd. near Temple Ave., City of Industry	LA 92C6	Refraction	110
76	Erringer Rd. and Heywood St. Simi Valley, Ventura County	VE 66A1	Downhole	66
77	North Brand Blvd. and Third St., San Fernando	LA 2E6	Refraction	110
78	Ferndale Ranch, Sulphur Springs Area, Ventura County	---	Refraction (Four Surveys)	0-250
79	San Fernando Rd. and Colorado Blvd., Los Angeles	LA 25B4	Downhole	75

TABLE 1
(Continued)

Site No.	Location	Map Location	Survey	Length/Depth (Ft)
80	Riverside Dr. and Hazeltine Ave., Sherman Oaks	LA 22E3	Downhole	70
81	Truxton Ave. and "L" St., Bakersfield, Kern County	KE 23D5	Downhole	70
82	Wilshire Blvd. and Warner Ave., Los Angeles	LA 41F1	Downhole	72
83	Pier D, Port of Long Beach	LA 75A6	Downhole	85
84	Chandler Ave. north of Garvey Ave., Monterey Park	LA 46B1	Downhole	72
85	Third St. and Sherbourne Dr., Los Angeles	LA 33D6	Downhole	70
86	Chapman Ave. and Lewis St., Garden Grove	OR 16E3	Downhole	64
87	Tiverton Dr. and S. Circle Dr., Los Angeles	LA 41E1	Downhole	85
88	Visitor's Reception Building Jet Propulsion Laboratory Pasadena	LA 19D4	Downhole	410
89	MacArthur Blvd. and Campus Dr., Newport Beach	OR 28B5	Downhole	135
90	MacArthur Blvd. and Birch St., Newport Beach	OR 28B5	Downhole	75
91	Birch St. near Jamboree Blvd., Newport Beach	OR 28C5	Downhole	70
92	MacArthur Blvd. and Jamboree Blvd., Newport Beach	OR 28D6	Downhole	70
93	Normandie Ave. and Sunset Blvd., Hollywood District, Los Angeles	LA 34E3	Downhole	72
94	Van Nuys Blvd. and Osborne St., Panorama City	LA 8D6	Downhole	74
95	Winchester Blvd. near Hamilton Ave., Campbell, Calif. (Santa Clara Co.)	SC 66B2	Downhole	75

TABLE 1
(Continued)

Site No.	Location	Map Location	Survey	Length/Depth (Ft)
96	Third Ave. and H St., Chula Vista (San Diego Co.)	SD 69D4	Downhole	68
97	Ballantyne Ave. and E. Main St., El Cajon (San Diego Co.)	SD 56C4	Downhole	75
98	Lewis St. and Fifth Ave., San Diego	SD 60C3	Downhole	63
99	Miramar Naval Air Station, San Diego	SD 45E1	Downhole	30
100	Broadway and Third St., Santa Monica	LA 49A1	Downhole	50
101	Bristol St. and Anton Blvd., Costa Mesa	OR 28B2	Downhole	72
102	Westwood Plaza and Strathmore Pl., Los Angeles	LA 41E1	Downhole	95
103	Olive and Second Sts., Bunker Hill, Los Angeles	LA 44D3	Downhole	50
104	Imperial Hwy. near Nash St., El Segundo	LA 56C5	Downhole	73
105	Broadway and 21st St., Santa Monica	LA 41B5	Downhole	75
106	Olive and Eight Sts., Los Angeles	LA 44C3	Downhole	72
107	Kenwood and Harvard Sts., Glendale	LA 25D4	Downhole	73
108	Hazard Ave. and Fairmont St., City Terrace Dist. (L.A. Co.)	LA 45D3	Downhole	73
109	Santa Cruz and Newport Center Drs., Newport Beach	OR 32A5	Downhole	74
110	Bristol St. and Town Center Center Dr., Costa Mesa	OR 28A2	Downhole	76
111	Vermont Ave. and DeLongpre Ave., Los Angeles	LA 34F3	Downhole	80

together with their strengths and weaknesses, have been discussed extensively in the literature and will not be repeated here. However, a brief discussion of the methods used to obtain the data used in this study is presented below.

Refraction Survey

Two arrays of geophones, horizontal and vertical, are spread out on a line along the ground surface, usually spaced at equal intervals of 10 to 30 feet. The horizontal geophones are oriented to record motions transverse to the profile, primarily from shear-waves (S-waves). The vertical geophones record motions perpendicular to the surface of the ground, primarily from compressional-waves (P-waves). A long wooden plank, oriented perpendicular to the line of geophones, is placed at one end of the line and weighted down with the front wheels of a truck. Motions rich in horizontally-polarized shear waves (SH) are generated by horizontally striking one end of the plank with a large hammer or mallet. These motions are detected by the horizontal geophones and transmitted to the seismograph where they are amplified and recorded. To facilitate the identification of the shear wave on the record, the process is repeated by striking the opposite end of the plank. Motions rich in P-waves are generated by vertically striking the top of the board or the ground with the hammer. The entire process is then repeated with the plank placed at the opposite end of the line of geophones.

An advantage of the refraction survey is that it does not require the drilling of a borehole; however, it does require an unobstructed line on the order of several hundred feet for placement of geophones and lateral homogeneity of the soil layers within the profile. Typical depths penetrated based on the procedures described above are about 30 to 80 feet.

Downhole Survey

A borehole is drilled to the desired depth and cased with PVC pipe. The annular space between the boring wall and the pipe is backfilled with pea gravel or grout to insure good coupling between the casing and the boring wall. A triaxial borehole seismometer is lowered to the bottom of the hole and clamped tightly to the sidewall of the casing by a spring. A wooden plank is placed on the surface approximately five to ten feet from the hole and weighted down with the front wheels of a truck. Motions rich in shear (SH) waves are generated by horizontally striking the ends of the plank as described in the refraction survey. These motions are primarily detected by two horizontal geophones in the seismometer and transmitted to the seismograph. Motions rich in P-waves are generated by vertically striking the top of the plank or the surface of the ground and are detected by the vertical geophone in the seismometer. The seismometer is then pulled up a distance of five or ten feet to the next desired depth, and a new set of recordings is obtained. This is repeated until the entire range of desired depths has been covered.

Although this survey requires a relatively expensive borehole, the results are more accurate than those obtained by the refraction technique. Very little space is required for this survey, just enough for access by drilling equipment. Great depths can be measured by this technique. One survey that measured shear-wave velocities to a depth of 410 feet has been included in this report (Site 88).

Crosshole Survey

Three boreholes, usually separated by a distance of 10 to 20 feet are drilled to the desired depth. For shallow depths, the boreholes need not be cased. However, for greater depths or when caving is a problem, casing may be required. Borehole seismometers containing two horizontal geophones and one vertical geophone are lowered to the same depth near the bottom of two adjacent boreholes and clamped to the sidewalls with a spring. A hammer device is lowered in the third hole via a rigid pipe or rod to the same depth as the seismometers and it is clamped to the sidewalls with a hydraulic jack-plate assembly. Motions rich in vertically polarized shear (SV) waves and P-waves are generated by striking down on the pipe. The shear-waves are primarily detected by the vertical geophone in the borehole seismometers and the P-waves by the horizontal geophones. These signals are transmitted to the seismograph. To facilitate the detection of shear waves on the records, a second recording made by striking up on the pipe is obtained. The two seismometers and the hammer are then raised five to ten feet to the next desired depth and the next series of recordings is made. This process is repeated until all required depths have been completed.

Although more expensive than the downhole survey, the crosshole technique can be used to measure velocities at extremely great depths, since waves are required to travel only the short distance between boreholes. Since only low gains are required, this technique is valuable even at relatively shallow depths when considerable vibrational background noise is present. Caution must be exercised against misinterpretation due to refractions when surveying near boundaries which have abrupt velocity increases. This is especially critical as the distances between boreholes are increased.

VELOCITY AND GEOTECHNICAL DATA

Techniques commonly used in practice were utilized to compute seismic velocites from the geophysical survey data. These velocity data, together with supporting geotechnical data, are presented in Table 2 for the 48 sites. Multiple surveys were conducted at a few sites, but velocity data were averaged where the results and site conditions were considered similar.

Water levels were established from exploration borings at the site when possible. Where such data were not available or where the water levels were below boring depths, nearby water well data were used to establish the depths. Levels represent the depth to the water table as measured from the ground surface.

S-wave and P-wave velocities represent the average velocities over the depth ranges given. At least two points within the layer were used to establish these velocities. Velocities were not generally computed for layers of less than about five feet in thickness. Exceptions to this were thin surface layers and low velocity layers at depth where the geophone spacing was reduced accordingly.

TABLE 2

SEISMIC VELOCITY AND GEOTECHNICAL DATA

Site No.	Depth (Ft)	S-Wave Velocity (Ft/Sec)	P-Wave Velocity (Ft/Sec)	Poisson's Ratio	Water Level (Ft)	Soil Type	Geology
64	0-10	380	780	0.34	10	Fine Sand with Shells	Hydraulic Fill
	10-60	560	5000	0.49		Fine Sand with Shells	Hydraulic Fill and Recent Estaurine Deposits
	60+	1160	5000	0.47		Fine Sand with Shells	Recent Alluvium
65	0-5	930	1610	0.25	60	Silt	Older Alluvium
	5-20	1310	--	--		Silt, Clay, and Sand (very dense)	Older Alluvium
	20+	2520	--	--		Sand, (very dense)	Older Alluvium
66	0-13	630	1070	0.23	25	Silty Sand	Engineered Fill
	13-25	1770	3170	0.27		Well Graded Sand with 40% Gravel and Cobbles	Recent Alluvium (Gaspur Aquifer)
	25-35	1770	5000	0.43		Well Graded Sand with 40% Gravel and Cobbles	Recent Alluvium (Gaspur Aquifer)
	35-80	2180	3600	0.22		Massive Dark Grey Siltstone	Fernando Formation (Pliocene)
67	0-20	490	880	0.24	33	Fine Sand and Silt with some Organics (grey)	Recent Alluvium
	20+	650	1130	0.25		Fine Sand and Silt with some Organics (grey)	Recent Alluvium
68	0-20	830	1370	0.21	70	Sandy Clay with Gravel	Engineered Fill
	20-70	1500	2960	0.33		Fine Sand and Silty Sand	Older Alluvium
	70+	3080	5020	0.20		Fine Sand and Silty Sand	Older Alluvium
69	0-4	890	--	--	32	Silt, Clay, and Sand	Engineered Fill
	4-12	480	--	--		Moderately Soft Silty Clay	Recent Alluvium
	12-22	1030	--	--		Fine Silty Sand	Recent Alluvium
	22-32	1580	2750	0.25		Fine Sand	Older Alluvium
70	0-15	1050	1530	0.05	54	Fine Silty Sand (very dense)	Older Alluvium
	15+	1210	1940	0.18		Fine Sand	Older Alluvium
71	0-13	480	--	--	24	Fine Silty Sand and Silt with Organics	Recent Alluvium and Bay Deposits
	13-24	670	1280	0.31		Clay, Silt, and Sand with Organics	Recent Alluvium and Bay Deposits
	24-37	670	5000	0.49		Clay, Silt, and Sand with Organics	Recent Alluvium and Bay Deposits
	37+	900	5000	0.48		Clay, Silt, and Sand with Organics	Recent Alluvium and Bay Deposits
72	0-15	480	1170	0.40	15	Moderately Soft Silty Clay	Recent Alluvium
	15-65	1460	--	--		Weathered Brown Siltstone	Pico Formation (Pliocene)
	65+	2670	--	--		Massive Grey Siltstone	Pico Formation (Pliocene)
73	Bed of Ravine						
	0-10	--	1270	--	N/E	Silty Sand with Gravel	Recent Alluvium (Current Channel Deposits)
	10-30	--	1860	--		Silty Sand with Gravel	Recent Alluvium (Current Channel Deposits)
	30+	--	7980	--		Weathered/Fractured Granite	Basement Complex
	Slope of Ravine						
	0-8	--	1200	--		Silty Sand	Recent Alluvium
	8+	--	3260(±)900)	--		Decomposed Granite	Basement Complex
74	10-15	850	5200	0.49	11	Silty Clay	Recent Alluvium
	15-30	950	5200	0.49		Silty Clay and Sand	Recent Alluvium
75	0-15	1480	2650	0.28	N/E	Conglomerate	Puente Formation (Upper Miocene)
	15+	2450	4540	0.29		Conglomerate	Puente Formation (Upper Miocene)
76	0-11	940	1630	0.25	42	Clay and Sand with chunks of Concrete	Engineered Fill
	11-60	780	1800	0.38		Silty Sand with some Peat	Recent Alluvium (River Wash)
	60-66	460	5000	0.50		Soft Silty Clay with some Organics	Recent Alluvium

TABLE 2
(Continued)

Site No.	Depth (Ft)	S-Wave Velocity (Ft/Sec)	P-Wave Velocity (Ft/Sec)	Poisson's Ratio	Water Level (Ft)	Soil Type	Geology
77	0-9	1050	1870	0.27	N/E	Fine to Medium Silty Sand with Gravel and Cobbles	Recent Alluvium
	9+	1690	2940	0.25		Well Graded Sand with 20-30% Gravel, Cobbles, and Boulders	Recent Alluvium
78	Line 1						
	0-28	--	1960	--	28	Well Graded Gravel with 30% Sand and Silt	Older Alluvium
	28+	--	5960	--		Shale	Monterey Formation (Upper Miocene)
	Lines 2-4						
	0-11	--	1600	--		Silty Clay	Older Alluvium
	11-36	--	4230	--		Shale	Monterey Formation (Upper Miocene)
	36+	--	6370	--		Shale	Monterey Formation (Upper Miocene)
79	0-20	1050	1880	0.27	N/E	Fine to Medium Sand with 30% Gravel	Recent Alluvium
	20-60	1320	2500	0.31		Well Graded Sand with 20-40% Gravel	Recent Alluvium
	60-75	1670	3000	0.28		Fine to Medium Sand with 0-30% Gravel	Recent Alluvium
80	0-6	790	--	--	N/E	Clay and Silt	Engineered Fill
	6-30	790	1750	0.37		Sandy Silt and Silty Clay	Recent Alluvium
	30-70	1400	2880	0.35		Silty Sand with Silty Clay	Recent Alluvium
81	0-10	480	910	0.31	N/E	Silty Sand	Recent Alluvium
	10-45	940	1880	0.33		Fine Sand	Recent Alluvium
	45-70	1540	2500	0.19		Fine Sand with some Gravel	Recent Alluvium
82	0-8	670	--	--	24	Silty Clay	Recent Alluvium
	8-48	1050	--	--		Silty Clay with Sand Layers	Older Alluvium (Terrace Deposits)
	48-72	1450	--	--		Silty Clay with Sand Layers	Older Alluvium (Terrace Deposits)
83	0-10	400	830	0.35	10	Fine Silty Sand	Non-Engineered Fill
	10-30	560	4750	0.49		Fine Silty Sand	Hydraulic Fill
	30-85	660	4750	0.49		Silty Sand and Silt	Hydraulic Fill and Recent River Deposits
84	0-8	750	1600	0.36	24	Silt, Clay, and Sand	Engineered Fill
	8-30	1140	2330	0.34		Silt, Clay, and Sand	Engineered Fill
	30-60	950	--	--		Silty Clay	Older Alluvium (Terrace Deposits)
	60-72	1250	--	--		Highly Weathered Shale	Fernando Formation (Pliocene)
85	0-25	560	4700	0.49	10	Grey Silty Clay	Recent Alluvium (Swamp Deposits)
	25-70	1140	4700	0.47		Silty Clay with some Organics	Older Alluvium (Terrace Deposits)
86	0-25	--	1090	--	64	Fine Silty Sand and Sand	Recent Alluvium
	25-64	--	2230	--		Fine Sand	Recent Alluvium
87	0-4	500	1000	0.33	N/E	Fine Silty Sand	Non-Engineered Fill
	4-25	1210	2000	0.21		Clayey Silt and Sand	Older Alluvium
	25-50	2310	4000	0.25		Well Graded Sand with Gravel and Silty Clay	Older Alluvium
	50-74	1230	2080	0.23		Sandy Silt and Silty Sand	Older Alluvium
	74-85	1820	2940	0.19		Silt	Older Alluvium
88	0-5	760	1330	0.26	220	Sandy Silt	Engineered Fill
	5-32	1220	2000	0.20		Gravel (5'-13') and Silty Sand	Older Alluvium
	32-120	2130	3030	0.01		Well Graded Sand with 10-20% Gravel and Cobbles	Older Alluvium
	120-220	2860	3770	-0.18		Well Graded Sand with 35% Gravel and Cobbles	Older Alluvium
	220-270	2500	6300	0.41		Silty Sand with some Gravel	Older Alluvium
	270-370	2970	--	--		Silty Sand and Well Graded Sand with 10-20% Gravel and Cobbles	Older Alluvium
	370-410	3850	--	--		Silty Sand and Well Graded Sand with 40% Gravel and Cobbles	Older Alluvium

TABLE 2
(Continued)

Site No.	Depth (Ft)	S-Wave Velocity (Ft/Sec)	P-Wave Velocity (Ft/Sec)	Poisson's Ratio	Water Level (Ft)	Soil Type	Geology
89	0-4	560	--	--	27	Silt, Sand, and Clay	Engineered Fill
	4-30	980	--	--		Sandy Silt, Fine Sand, and Clayey Sand	Older Alluvium (Terrace Deposits)
	30-55	1040	--	--		Silty Clay and Fine Sand with Seashells	Older Alluvium (Terrace Deposits)
	55-108	690	--	--		Moderately Soft Clayey Silt and Silty Clay	Older Alluvium (Terrace Deposits)
	108-135	1320	--	--		Sandy Silt and Fine Silty Sand	Older Alluvium (Terrace Deposits)
90	0-13	450	900	0.33	13	Silt, Clay, and Sand (Soft)	Recent Alluvium
	13-37	1250	5250	0.47		Silty Clay and Fine Sand	Older Alluvium (Terrace Deposits)
	37-50	1100	5250	0.48		Silty Clay with Organics and Well Graded Sand	Older Alluvium (Terrace Deposits)
	50-75	540	5250	0.49		Blue Grey Soft Fat Clay with Organics	Older Alluvium (Terrace Deposits)
91	0-14	500	1000	0.33	>22	Soft Silty Clay	Recent Alluvium
	14-22	1250	2220	0.27		Silty Clay with Sand	Older Alluvium (Terrace Deposits)
	22-52	900	--	--		Silty Clay and Fine Sand	Older Alluvium (Terrace Deposits)
	52-68	480	--	--		Blue Grey Soft Fat Clay with Organics	Older Alluvium (Terrace Deposits)
92	0-2	500	880	0.26	>40	Sandy Clay	Non-Engineered Fill
	2-40	930	1850	0.33		Fine Sand and Silty Clay, some Organics	Older Alluvium (Terrace Deposits)
	40-58	1070	--	--		Fine Silty Sand and Silt	Older Alluvium (Terrace Deposits)
	58-70	1220	--	--		Fine Sand, Grey	Older Alluvium (Terrace Deposits)
93	0-4	660	1290	0.32	13	Sandy Silt	Older Alluvium
	4-13	--	--	--		Sandy and Silty Clay	Older Alluvium
	13-35	--	6000	--		Sandy Silt and Fine Sand	Older Alluvium
	35-53	1100	6000	0.48		Fine Silty Sand	Older Alluvium
	53-72	1430	6000	0.47		Fine Silty Sand, Sand, and Silty Clay	Older Alluvium
94	0-5	250	490	0.32	N/E	Dry Loose Well Graded Sand	Recent Alluvium
	5-15	--	--	--		Fine Silty Sand and Sand	Recent Alluvium
	15-40	860	1560	0.28		Fine Silty Sand and Sandy Silt	Recent Alluvium
	40-66	1030	1820	0.26		Sandy Silt	Recent Alluvium
	66-74	1430	2750	0.31		Fine Silty Sand	Recent Alluvium
95	5-10	770	--	--	N/E	Sandy Silt	Recent Alluvium
	10-58	1140	--	--		Sandy Silt, Clayey Silt, and Silty Clay	Recent Alluvium
	58-75	1800	--	--		Well Graded Sand with 20% Gravel	Recent Alluvium
96	0-5	480	--	--	N/E	Sandy Clay and Clayey Sand	Fill or Soft Alluvium
	5-28	1110	2220	0.33		Clayey and Silty Fine Sand	Older Alluvium (Terrace Deposits)
	28-68	1540	2860	0.30		Clayey and Silty Fine to Medium Sand	Sweetwater Formation (Eocene)
97	0-25	810	1430	0.26	>25	Clayey and Silty Fine Sand	Older Alluvium (River Terrace Deposits)
	25-52	1270	--	--		Silty Clay	Friars Formation (Eocene)
	52-75	1380	--	--		Silty Clay	Friars Formation (Eocene)
98	0-7	1320	--	--	N/E	Well Graded Sand with 40-50% Gravel, Slightly Cemented	Older Alluvium (Terrace Deposits)
	7-28	--	--	--		Fine Silty Sand	Older Alluvium (Terrace Deposits)
	28-40	820	--	--		Fine Silty Sand	Older Alluvium (Terrace Deposits)
	40-62	1375	--	--		Fine to Medium Silty Sand	Older Alluvium (Terrace Deposits)
99	0-5	1250	--	--	N/E	Clayey Sand with 50-60% Gravel and Cobbles	Engineered Fill
	5-12	930	--	--		Sandy Clay	Older Alluvium (Terrace Deposits)
	12-30	1670	--	--		Fine to Medium Silty Sand with 30-50% Gravel and Cobbles	Stadium Formation (Eocene)

TABLE 2
(Continued)

Site No.	Depth (Ft)	S-Wave Velocity (Ft/Sec)	P-Wave Velocity (Ft/Sec)	Poisson's Ratio	Water Level (Ft)	Soil Type	Geology
100	0-3	600	--	--	50	Silty Sand with Pieces of Brick	Engineered Fill
	3-20	900	1840	0.34		Silty Clay	Older Alluvium (Terrace Deposits
	20-50	1520	2500	0.21		Fine Sand with Some Gravel and Cobbles	Older Alluvium (Terrace Deposits)
101	0-5	360	830	0.38	25	Moderately Soft Silty Clay	Recent Alluvium (Floodplain Deposits)
	5-25	630	1330	0.36		Sandy Silt and Fine Silty Sand	Recent Alluvium (Floodplain Deposits)
	25-72	910	5710	0.49		Fine Silty Sand and Sand	Recent Alluvium (Floodplain Deposits)
102	0-15	640	--	--	47	Sandy Silt	Recent Alluvium
	15-47	920	1630	0.27		Sandy Silt	Recent Alluvium
	47-80	1140	5650	0.48		Clayey Silt with Sand	Recent Alluvium
	80-95	2220	5650	0.41		Well Graded Sand with Some Gravel	Older Alluvium
103	0-30	1090	1860	0.24		Weathered Siltstone, Greyish-Brown	Repetto Formation (Upper Pliocene)
	30-50	1300	--	--		Weathered Siltstone, Some Cemented Layers	Repetto Formation (Upper Pliocene)
104	0-8	400	--	--	N/E	Soft Silty Clay	Non-Engineered Fill and Recent Alluvium
	8-22	720	1480	0.35		Silty Clay	Recent Alluvium
	22-40	1070	2020	0.30		Fine Sand	Recent Dune Sand
	40-65	1400	2500	0.27		Fine to Coarse Sand, Some Gravel	Recent Dune Sand
	65-73	1670	--	--		Sand and Clay	Recent Dune Sand
105	0-15	870	--	--	129	Clayey Silt, layers of Sand and Gravel	Recent Alluvium
	15-30	1180	--	--		Well Graded Sand with 20% Gravel	Recent Alluvium
	30-52	1570	--	--		Clayey Silt	Older Alluvium
	52-75	2290	--	--		Fine Sand	Older Alluvium
106	0-52	1300	2430	0.30	N/E	Gravelly Sand with 10-20% Cobbles	Recent Alluvium
	52-72	2660	--	--		Sandy and Clayey Silt	Older Alluvium
107	0-7	550	900	0.20	160	Silty Sand and Sand	Non-Engineered Fill
	7-40	1150	2250	0.32		Well Graded Sand with 10-40% Gravel	Recent Alluvium
	40-73	2000	4000	0.33		Well Graded Sand with 10-40% Gravel	Older Alluvium
108	0-8	830	--	--	N/E	Sandy Silt and Clay	Older Alluvium
	8-34	1430	--	--		Fine to Well Graded Sand with 10-20% Gravel	Older Alluvium
	34-50	1670	--	--		Fine Silty Sand and Sand	Older Alluvium
	50-73	2200	--	--		Clay, Silt, and Sand	Older Alluvium
109	0-3	700	1400	0.33	N/E	Fine Silty Sand	Engineered Fill
	3-45	1200	2100	0.26		Highly Weathered Siliceous Shale and Siltstone	Puente Formation (Upper Miocene)
	45-74	1500	3300	0.37		Highly Weathered Siliceous Shale and Siltstone	Puente Formation (Upper Miocene)
110	0-18	470	1000	0.36	18	Moderately Soft Silty Clay	Recent Alluvium
	18-42	750	4660	0.49		Clayey Silt	Recent Alluvium
	42-62	1000	4660	0.48		Well Graded Sand	Recent Alluvium
	62-76	1400	4660	0.45		Silt and Sand	Recent Alluvium
111	0-4	600	--	--	33	Fine to Medium Silty Sand with Brick Fragments	Engineered Fill
	4-27	1180	--	--		Clay and Silty Sand	Older Alluvium
	27-70	1220	--	--		Weathered Brown and Grey Siltstone, Uncemented	Pico Formation (Pliocene)
	70-80	2050	--	--		Massive Dark Grey Siltstone	Pico Formation (Pliocene)

Poisson's ratios (ν) were computed from the ratio of the P-wave velocity (V_p) to the S-wave velocity (V_s) by the expression (Richart, et. al,[5]):

$$\nu = 1/2 \frac{(V_p/V_s)^2 - 2}{(V_p/V_s)^2 - 1} \tag{1}$$

Equation (1) was developed assuming that near surface soils can be treated as an elastic medium for the low dynamic shear strains (on the order of 10^{-4}% or less) induced in shallow seismic surveys.

The predominant soil type listed for each layer was obtained from exploration borings at the site of the survey. In most cases, this information was available from the boring in which the survey was conducted in the case of downhole and crosshole surveys. Soils were classified using the Uniform Soil Classification System[6]. The approximate quantity of gravel, debris, and organic content are given when available. Where rock was encountered, a brief description of the rock is given. Materials classified as hydraulic fill, engineered fill, or non-engineered fill represent man-made deposits. The geology of each site was obtained from a geologic investigation which was part of the overall geotechnical investigation. Geologic descriptions and formation names are consistent with established local terminology. A description of the Geologic Time Scale, may be found in Appendix B.

UPDATED GEOTECHNICAL CLASSIFICATION SYSTEM

An increase in the seismic velocity data base to 111 sites and the addition of very detailed geotechnical descriptions permitted the Geotechnical Classification System developed by Campbell and Duke[1] to be updated. Components of this system are diagrammed in Figure 1. The major classifications of Soil, Fill, and Rock essentially remain unchanged.

A description of the components of this system is given in Table 3. Some of the important revisions included the effects of the water table, gravel content, dry density, rock hardness, and rock type. Clay soils became distinguishable from granular soils with respect to Poisson's ratios and the velocities of soft clays at depth.

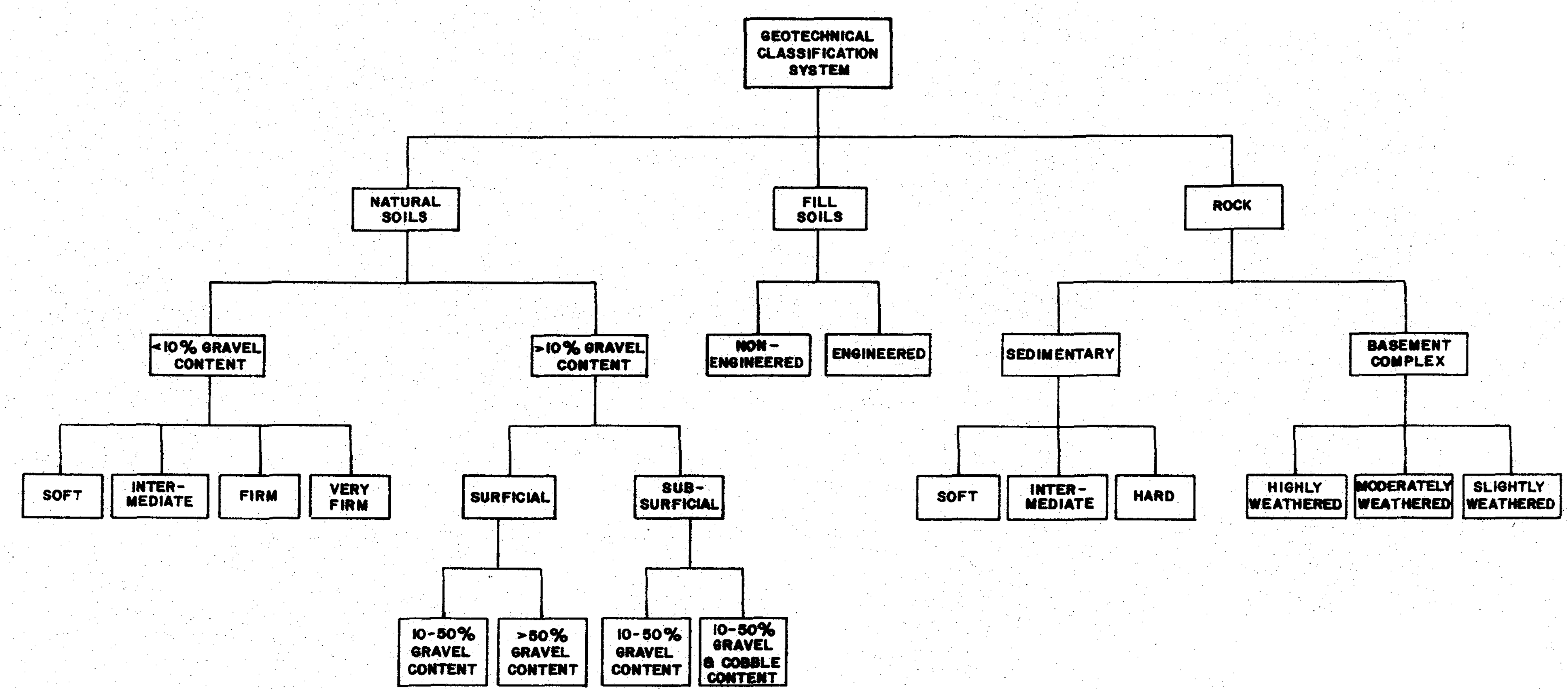

FIGURE 1 UPDATED GEOTECHNICAL CLASSIFICATION SYSTEM

TABLE 3

GEOTECHNICAL CLASSIFICATION SYSTEM

Geotechnical Classification			Description	Dry Density (Lbs./Cu.Ft.)	Depth (Ft.)	Geologic Age and Unit
Natural Soils	<10% Gravel and Cobbles	Soft	Very recent floodplain, lake, swamp, estuarine, and delta deposits, and hydraulic fill soils; may contain organics.	<100	≥0	Holocene
			Saturated Holocene age soils.	90-110	>10-15	Holocene
			Very low density soils; primarily fine-grained.	<90	≥0	Holocene
			Soft to moderately soft clays and clayey silts; generally dark grey to black.	<100 <80	0 ≥10	Holocene and Pleistocene Holocene and Pleistocene
		Intermediate	Unsaturated Holocene age soils of moderate density; may contain moderate amounts of gravel at depths below 30 to 50 feet.	90-110	≥0	Holocene
			Saturated, uncemented Pleistocene and Eocene age soils; may contain moderate amounts of gravel at depths below 10 to 20 feet.	95-115	>10-15	Pleistocene and Eocene (San Diego Co. Sweetwater and Friars Formations)
			Low density Pleistocene and Eocene age soils.	90-100	≥0	Pleistocene and Eocene (San Diego Co. Sweetwater and Friars Formations)
		Firm	High density Holocene age soils.	>110	≥0	Holocene
			Unsaturated, uncemented Pleistocene and Eocene age soils of moderate density; may contain moderate amounts of gravel at depths below 10 to 20 feet	100-115	≥0	Pleistocene and Eocene (San Diego Co. Sweetwater and Friars Formations)
		Very Firm	Pleistocene and Eocene age soils of high density.	>117	≥0	Pleistocene and Eocene (San Diego Co. Friars Formation)
	>10% Gravel and Cobbles	Surficial	Natural soils and engineered fill soils occurring at the surface containing gravel and cobbles or bounders; predominantly coarse grained:			
			10-50% gravel; some cobbles and boulders.	115-130	0	Holocene, Pleistocene and Eocene (San Diego Co. Stadium Formation)
			>50% gravel; some cobbles and boulders.	125-135	0	Holocene, Pleistocene, and Eocene (San Diego Co. Stadium Formation)
		Subsurficial	Natural soils occurring at depth containing gravel and cobbles or boulders; predominantly coarse grained:			
			10-50% gravel; some cobbles and boulders.	115-130 115-130	5-30 5-10	Holocene Pleistocene and Eocene
			10-50% gravel, cobbles, and boulders.	125-135 125-135	5-50 5-20	Holocene Pleistocene and Eocene

TABLE 3
(Continued)

Geotechnical Classification			Description	Dry Density (Lbs./Cu.Ft.)	Depth (Ft.)	Geologic Age and Unit
Fill Soils	Non-Engineered	---	Loose or slightly compacted man-made fill soils (excluding hydraulic fill); containing <10% gravel and cobbles.	100-115	0	---
	Engineered	---	Mechanically compacted man-made fill and natural soils; containing <10% gravel and cobbles.	110-125	0	---
Rock	Sedimentary	Soft	Highly weathered, low density siltstones and shales; usually light brown to light grey; Miocene shales are highly siliceous and diatomaceous.	65-90	15-50	Pliocene (Fernando, Pico, and Repetto Formations) - Miocene (Modelo, Puente, and Monterey Formations)
		Intermediate	Moderately weathered, moderate density siltstones and shales; Pliocene siltstones are primarily massive and dark grey. Miocene shales are highly siliceous and diatomaceous.	90-105	≥0	Pliocene (Fernando, Pico, and Repetto Formations) - Miocene (Modelo, Puente, and Monterey Formations)
		Hard	Moderately weathered, moderate to high density Miocene siltstones, shales, sandstones, and conglomerates.	>95	≥0	Miocene (Modelo, Puente, and Monterey Formations)
	Basement Complex	Highly Weathered	Igneous and Metamorphic rock; highly weathered.	---	≥0	Mesozoic
		Moderately Weathered	Moderately weathered and fractured Igneous and Metamorphic rock.	---	≥0	Mesozoic
		Slightly Weathered	Unweathered or slightly weathered and fractured Igenous and Metamorphic rock.	---	≥0	Mesozoic

See Appendix B for a description of the geologic time scale. Naturally occurring Holocene age soils are generally referred to as Recent Alluvium. Pleistocene age soils of continental origin are generally referred to as Older Alluvium and those of marine origin as Terrace Deposits.

VELOCITY CORRELATIONS

Statistical correlations of seismic velocity have been updated with the addition of the velocity and geotechnical data presented in the first part of this report. Deposits were classified in accordance with the Geotechnical Classification System presented in the previous section.

NEAR SURFACE VELOCITIES

Statistical correlations for surface deposits and a few near surface deposits were performed on both S-wave and P-wave velocities, Tables 4 through 8. Results of the analyses are given in terms of the sample size, the velocity range, the mean velocity, the standard deviation, and the coefficient of variation. The dimensionless coefficient of variation, defined as the ratio of the standard deviation to the mean, represents a convenient means of expressing the statistical uncertainty in the analyses. These coefficients are relatively constant for all classifications, falling generally in the range of 0.08 to 0.14, indicating relative consistency in the measurement and analysis of these data.

POISSON'S RATIO

The results of the statistical analysis of Poisson's ratios is summarized in Tables 9 and 10. Velocity data at all depths were used in establishing these correlations.

New to this study are the significant differences found in Poisson's ratio between clays, silty clays, and clayey silts and the other deposits. For each geotechnical group, these clay soils exhibited Poisson's ratios approximately 20% higher than for deposits containing

TABLE 4

STATISTICAL SUMMARY OF SHEAR-WAVE VELOCITY FOR SURFICIAL SOIL AND FILL DEPOSITS CONTAINING LESS THAN 10% GRAVEL

Geotechnical Description	No. of Data	Shear-Wave Velocity (Ft/Sec) Range	Mean	Standard Deviation	Coefficient of Variation
Soft Natural Soil	12	360 - 560	460	60	0.13
Soft Clay (>10 feet deep)	3	460 - 690	550	-	-
Intermediate Natural Soil	23	520 - 790	620	80	0.13
Firm Natural Soil	31	735 - 1180	940	100	0.11
Non-Engineered Fill	12	400 - 550	490	50	0.10
Engineered Fill	18	560 - 940	710	110	0.16

TABLE 5

STATISTICAL SUMMARY OF SHEAR-WAVE VELOCITY
FOR NEAR SURFACE SOILS CONTAINING MORE THAN 10% GRAVEL

			Shear-Wave Velocity (Ft/Sec)			Coefficient
Gravel Content	Depth (Ft)	No. of Data	Range	Mean	Standard Deviation	of Variation
10 - 50%	0	7	805 - 1150	980	130	0.13
>50%	0	6	1220 - 1430	1320	80	0.06
10 - 50%	5 to 10-30	3	1180 - 1430	1310	-	-
10 - 50% with Cobbles	5 to 20-50	8	1670 - 1980	1780	115	0.06

TABLE 6

STATISTICAL SUMMARY OF SHEAR-WAVE VELOCITY FOR NEAR SURFACE ROCK

Rock Description	Depth (Ft)	No. of Data	Shear-Wave Velocity (Ft/Sec) Range	Mean	Standard Deviation	Coefficient of Variation
Soft and Intermediate Sedimentary Rock	0	5	1040 - 1260	1160	90	0.08
Hard Sedimentary Rock	0	6	1280 - 1480	1360	110	0.08
Soft Sedimentary Rock	15 - 50	8	1220 - 1500	1380	110	0.08
Moderately Weathered Basement Complex	0 - 100	6	3300 - 4610	4040	430	0.11

TABLE 7

STATISTICAL SUMMARY OF COMPRESSIONAL-WAVE VELOCITY
FOR SURFACE DEPOSITS CONTAINING LESS THAN 10% GRAVEL

Geotechnical Description	No. of Data	Compressional-Wave Velocity (Ft/Sec) Range	Mean	Standard Deviation	Coefficient of Variation
Soft Natural Soil and Non-Engineered Fill	13	780 - 1170	930	105	0.11
Intermediate Natural Soil	8	910 - 1750	1290	245	0.19
Firm Natural Soil	9	1250 - 1850	1560	210	0.14
Engineered Fill	9	1070 - 1630	1340	180	0.13
Soft and Intermediate Sedimentary Rock	4	1860 - 2440	2070	270	0.13

TABLE 8

STATISTICAL SUMMARY OF COMPRESSONAL-WAVE VELOCITY FOR NEAR SURFACE DEPOSITS

		Compressional-Wave Velocity (Ft/Sec)			Coefficient
Geotechnical Description	No. of Data	Range	Mean	Standard Deviation	of Variation
Soils Containing >10% Gravel, 0 feet (Unsaturated)	6	1870 - 2430	2070	225	0.11
Soils Containing >10% Gravel, 5 to 10-50 feet	3	2500 - 3170	2870	-	-
Saturated Soil $\geq$0 feet	15	460 - 6300	5330	545	0.10

TABLE 9

STATISTICAL SUMMARY OF POISSON'S RATIO FOR NEAR SURFACE DEPOSITS (UNSATURATED)

Geotechnical Description	No. of Data	Poisson's Ratio			Coefficient of Variation
		Range	Mean	Standard Deviation	
Soft Natural Soil and Non-Engineered Fill	17	0.24 - 0.40	0.32	0.052	0.16
Intermediate Natural Soil	17	0.26 - 0.37	0.31	0.036	0.12
Firm Natural Soil	20	0.18 - 0.43	0.28	0.074	0.26
Soils Containing >10% Gravel	11	0.19 - 0.33	0.27	0.045	0.17
Engineered Fill	9	0.20 - 0.35	0.24	0.045	0.19
Sedimentary Rock	13	0.18 - 0.32	0.25	0.046	0.18

TABLE 10

STATISTICAL SUMMARY OF POISSON'S RATIO FOR NEAR SURFACE CLAY SOILS
(UNSATURATED)

Geotechnical Description	No. of Data	Poisson'S Ratio			Coefficient of Variation
		Range	Mean	Standard Deviation	
Soft Clays	3	0.36 - 0.40	0.38	-	-
Intermediate Clays	3	0.35 - 0.37	0.36	-	-
Firm Clays	2	0.33 - 0.34	0.34	-	-
All Clays	8	0.33 - 0.40	0.36	0.023	0.06

mixtures of sands, gravels, silts, and clays. From the limited amount of data available, it was found that this difference is primarily due to increased P-wave velocities in the clay soils.

The results in Table 9 indicate a trend of decreasing Poisson's ratio with increasing consolidation, age, and density of the deposits. Although based on a limited amount of data, this trend is also observed for the clay soils listed in Table 10.

SHEAR-WAVE VELOCITY VERSUS DEPTH

In the previous study, Reference[1], it was found that the correlation of shear-wave velocity with depth for each of the four classifications considered at that time could be adequately given by the following expression:

$$V_s = Kd^n \quad (2)$$

where V_s is shear-wave velocity, d is depth, and K and n are constants dependent upon the geotechnical classification.

With the addition of more accurate data, equation (2) has been slightly modified to account for the asymptotic behavior of shear-wave velocity at the ground surface. This new expression is given by:

$$V_s = K(d + c)^n \quad (3)$$

where the term c accounts for non-zero values of V_s at the ground surface. Thus, as d approaches zero, shear-wave velocity takes on the value $V_s = Kc^n$.

In order that a regression analysis could be used to estimate the constants K, d, and n for each of eight geotechnical classifications for which sufficient data were available, Equation (3) was linearized by taking the natural logarithm of both sides, giving

$$\text{Ln } V_s = \text{Ln } K + n \text{ Ln } (d + c) \quad (4)$$

A summary of the regression analysis is given in Table 11, with shear-wave velocity in units of feet per second and depth in units of feet. For this purpose, the depth was taken as the vertical distance from the ground surface to the top of the layer, not to the midpoint of the layer as some investigators have used. For the surface layer, the depth was taken as one-third the thickness of the layer. From the statistical summary presented in Table 11, the average correlation coefficient was found to be 0.94 and the average standard deviation to be 0.13. These values suggest that Equation (4) represents the data rather well. The value of 0.13 for the standard deviation of Ln V_s corresponds to a multiplicative factor in V_s of 1.14.

Plots of the data, the regression equations, and the one standard deviation limits for the eight geotechnical classifications are found in Figures 2 through 9. The squares represent data obtained at depth and plotted as the distance to the top of the respective layers. The octagons represent surface shear wave velocity data plotted at one-third the thickness of the layer. In Figure 3, Soft Natural Soils, the triangles represent downhole seismic velocity data from El Centro in Imperial Valley and from Cholame (near Parkfield) as obtained in a study

TABLE 11

SUMMARY OF REGRESSION ANALYSIS FOR V_s

$$\ln V_s = \ln K + n \ln (d + c)$$

Geotechnical Description	Regression Coefficients: Ln K	n	c	Correlation Coefficient	Standard Deviation of Ln V_s	No. of Data
Soft Natural Soils	5.134	0.456	3.9	0.97	0.11	29
Soft Natural Soils including El Centro and Cholame	5.665	0.296	0.30	0.93	0.16	41
Intermediate Natural Soils	5.674	0.408	1.8	0.95	0.12	59
Saturated Firm Natural Soils	5.432	0.460	0.0	0.95	0.14	18
Intermediate and Saturated Firm Natural Soils	5.628	0.413	2.4	0.95	0.13	76
Firm Natural Soils (Unsaturated)	6.251	0.349	2.0	0.93	0.13	50
Intermediate Sedimentary Rock	5.862	0.472	0.0	0.95	0.13	9
Hard Sedimentary Rock	6.607	0.405	0.0	0.87	0.15	13

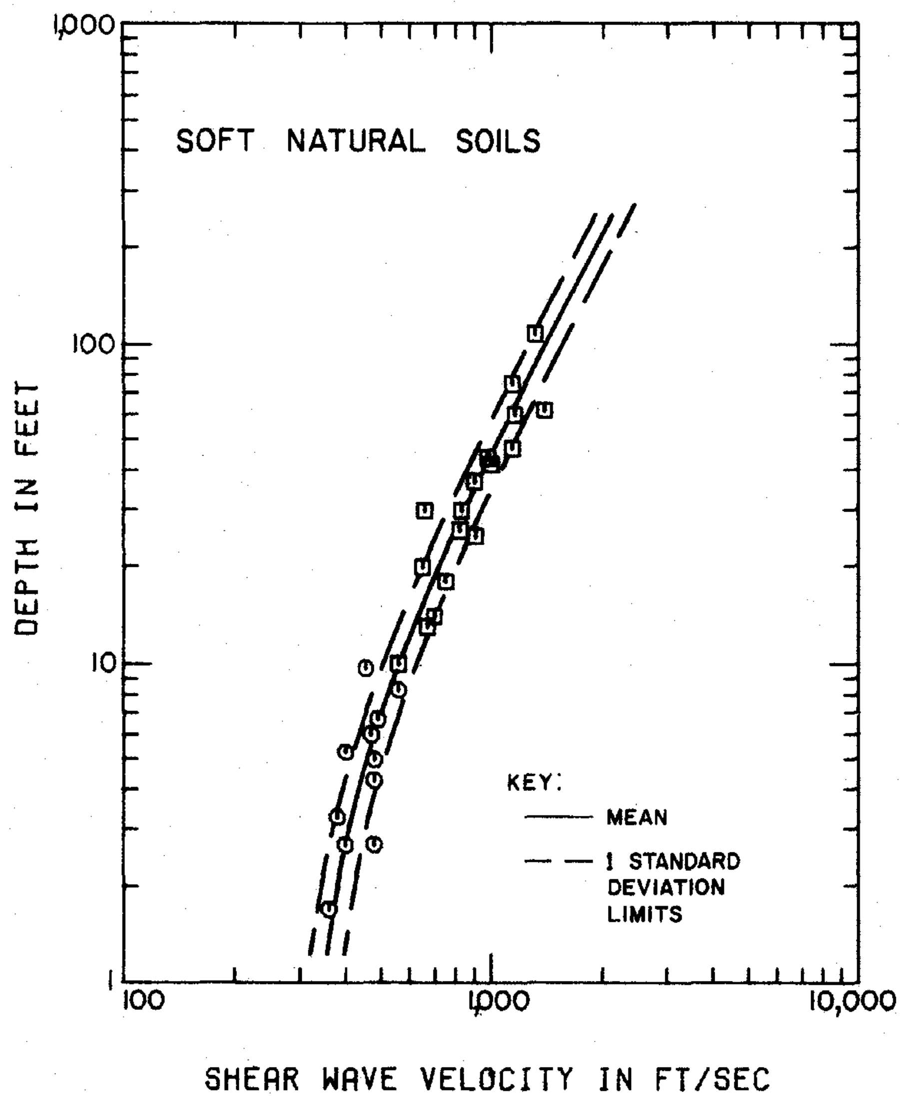

Figure 2. Shear-wave velocity versus depth for soft natural soils.

Key to Figures 2 through 9

⊙ Surface layer velocity data plotted at one-third the thickness of the layer.

⊡ Non-surface layer velocity data plotted at the depth corresponding to the top of the layer.

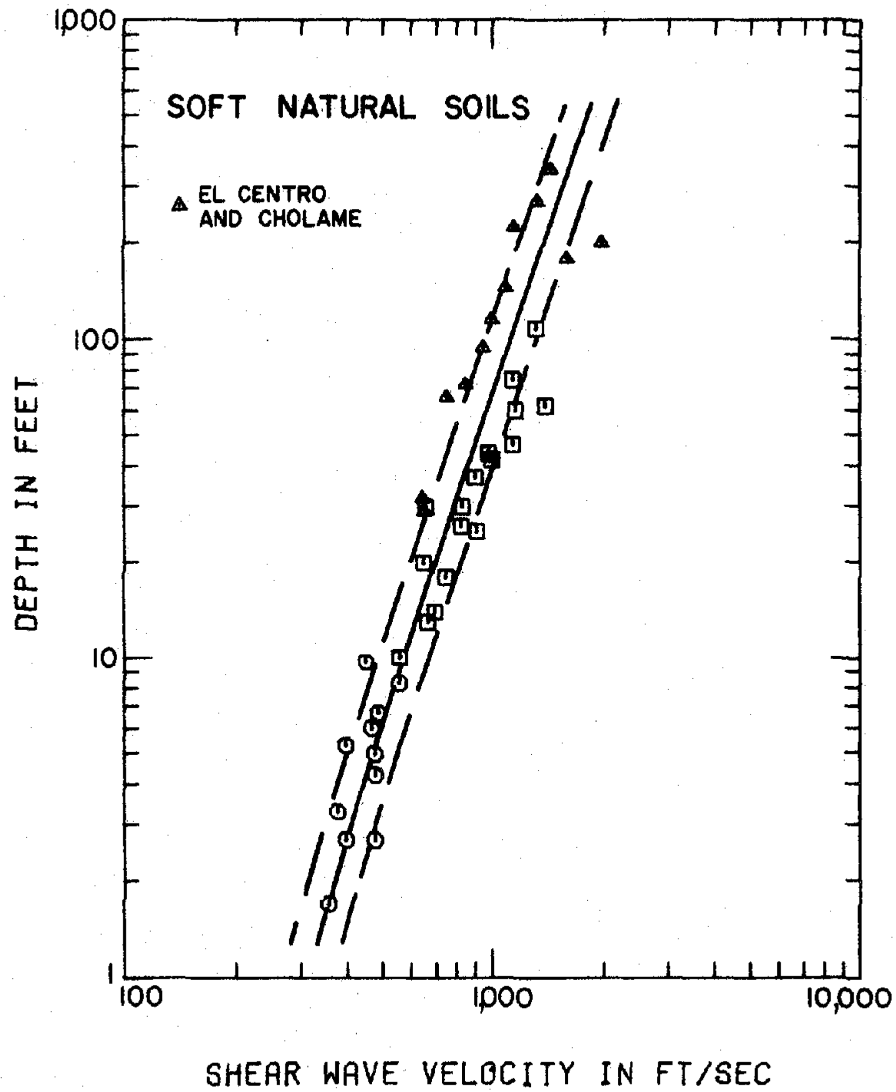

Figure 3. Shear-wave velocity versus depth for soft natural soils including data from El Centro and Cholame-Shandon No. 2 accelerograph sites.

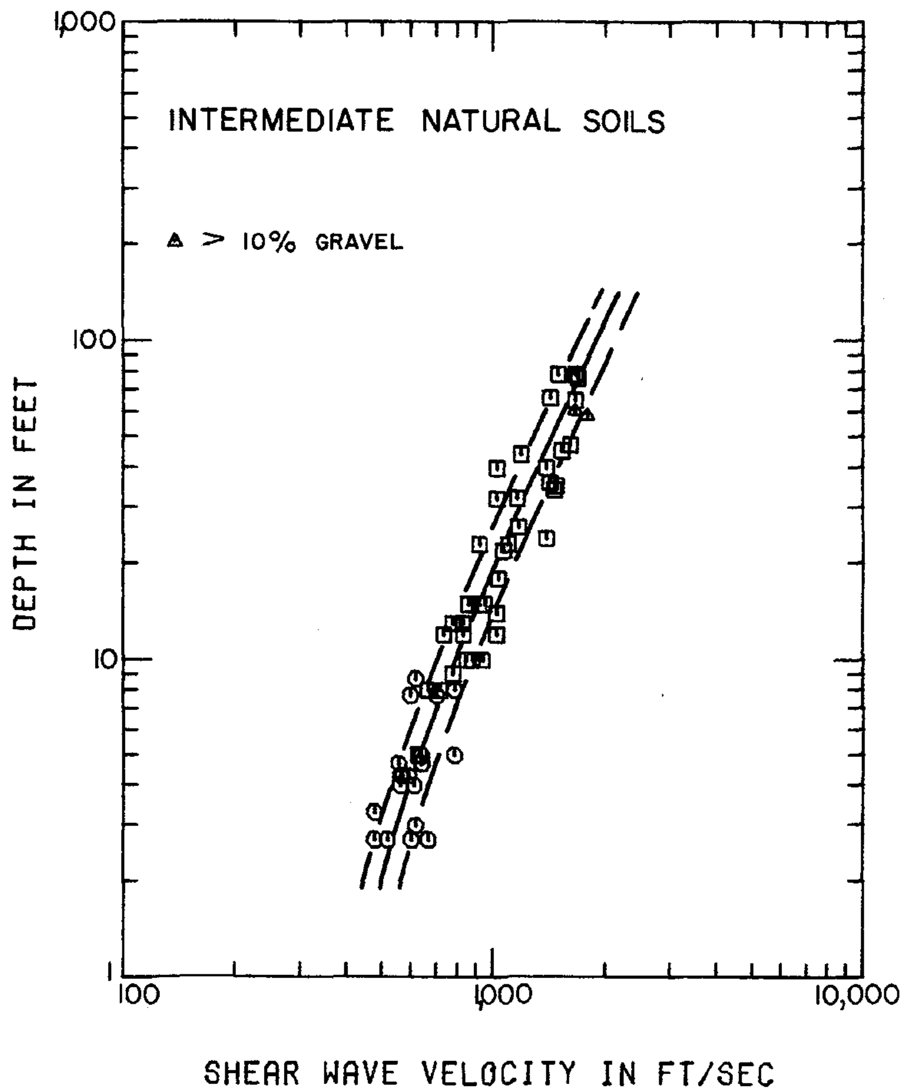

Figure 4. Shear-wave velocity versus depth for intermediate natural soils.

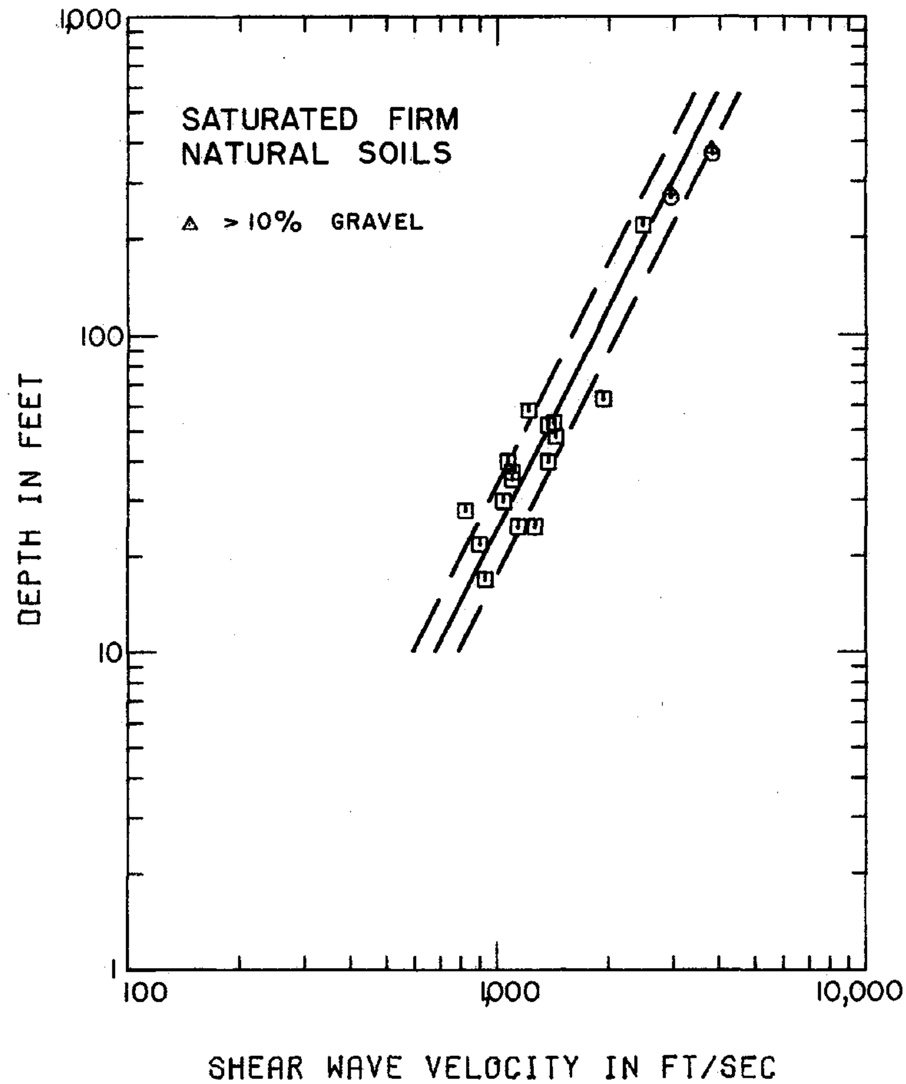

Figure 5. Shear-wave velocity versus depth for saturated firm natural soils.

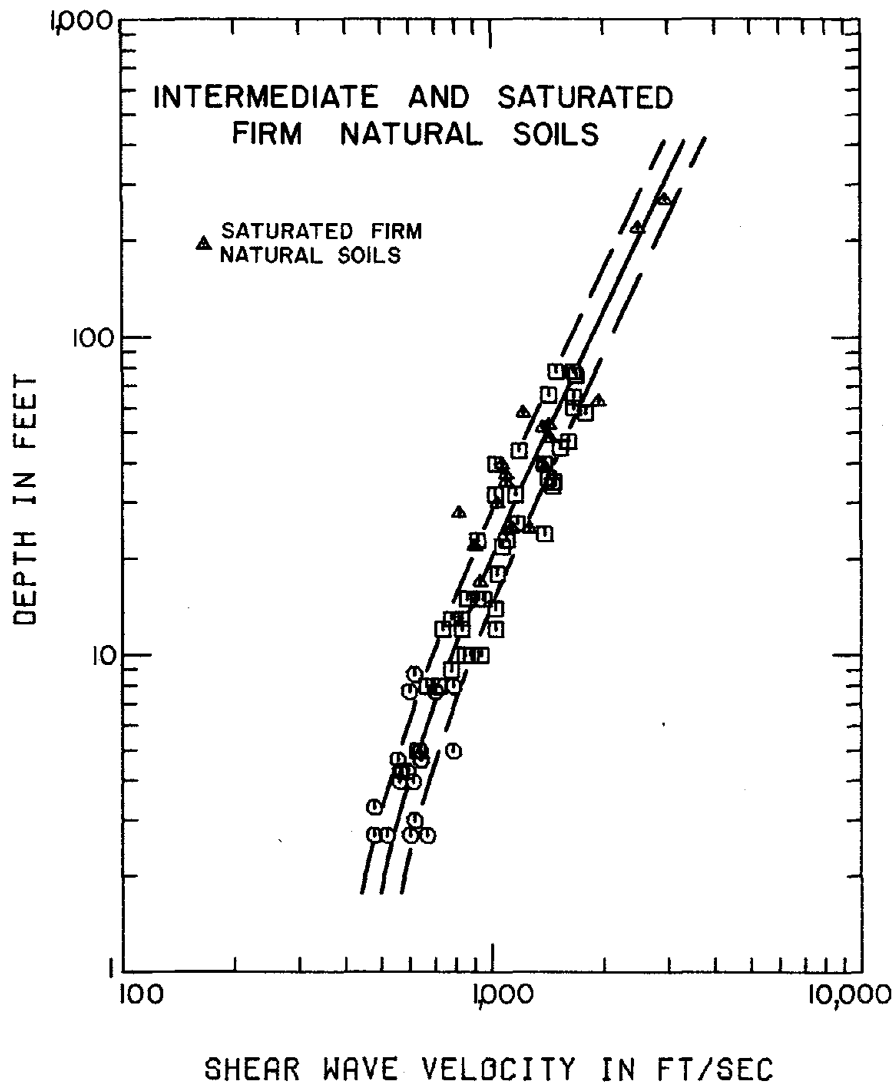

Figure 6. Shear-wave velocity versus depth for intermediate and saturated firm natural soils.

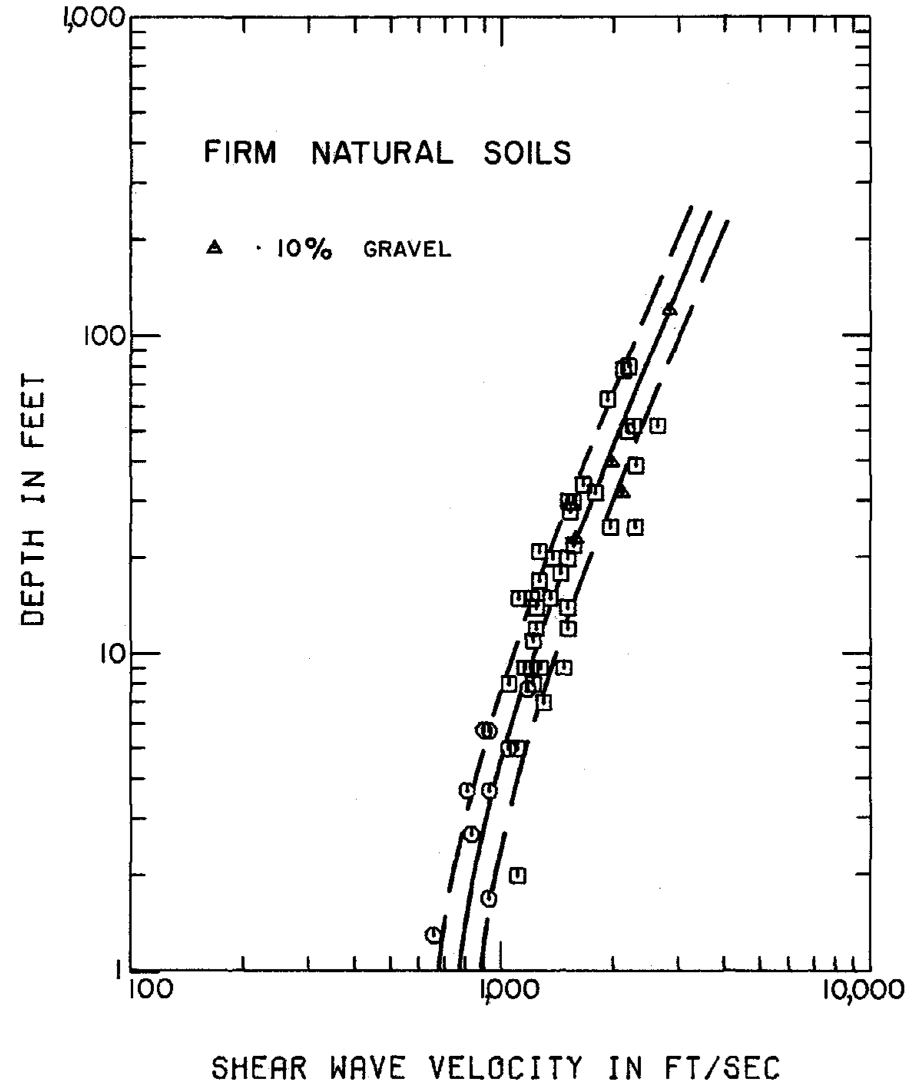

Figure 7. Shear-wave velocity versus depth for unsaturated firm natural soils.

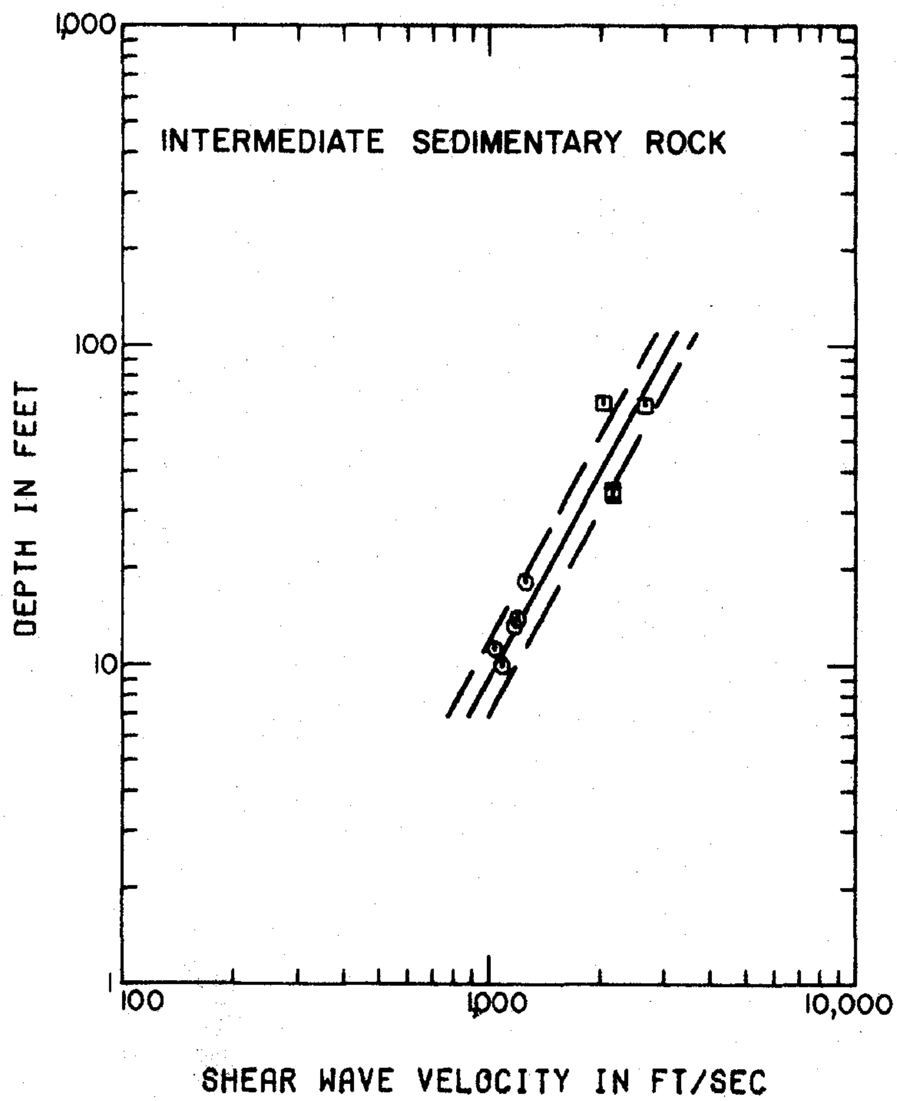

Figure 8. Shear-wave velocity versus depth for intermediate sedimentary rock.

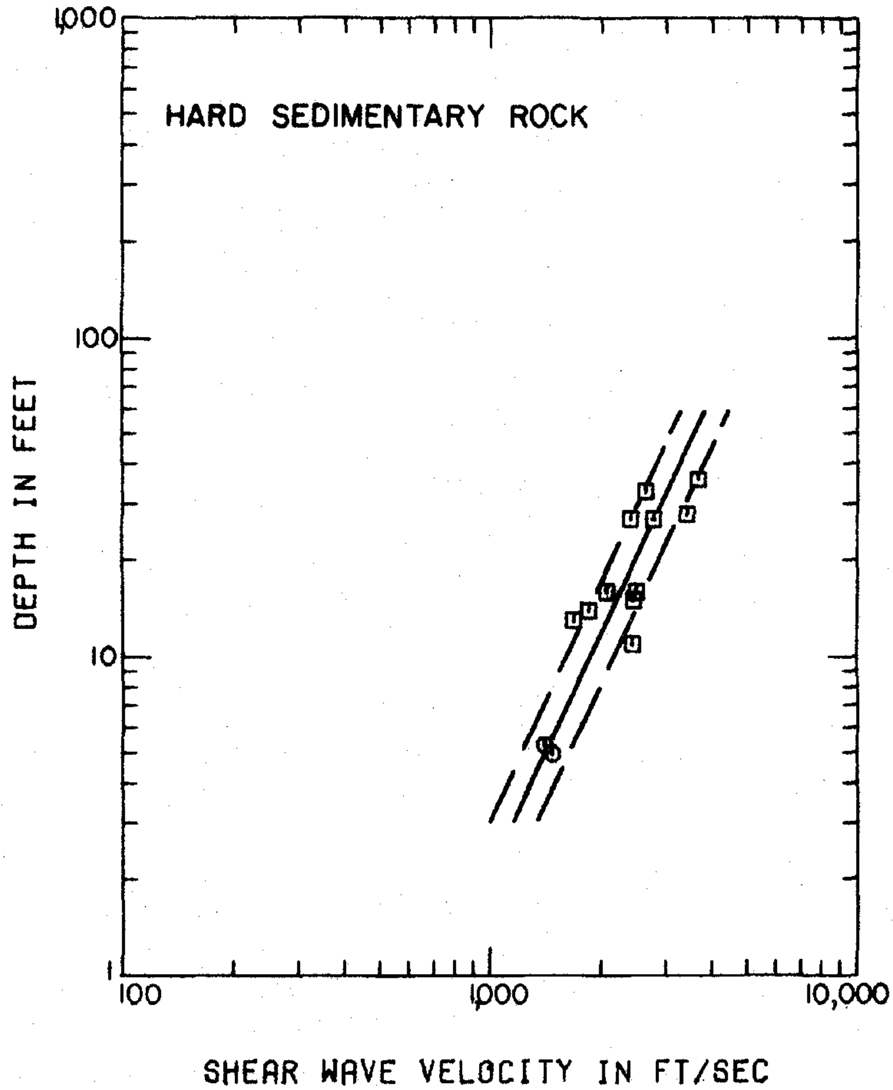

Figure 9. Shear-wave velocity versus depth for hard sedimentary rock.

prepared for the Nuclear Regulatory Commission[7]. These velocities are somewhat lower than those obtained in the greater Los Angeles area. The triangles in Figures 4, 5 and 7 represent velocities obtained in gravelly soils. In Figure 6, the triangles represent saturated Firm Natural Soils. Figure 10 presents comparisons of the mean regression relationships for six of the geotechnical classifications.

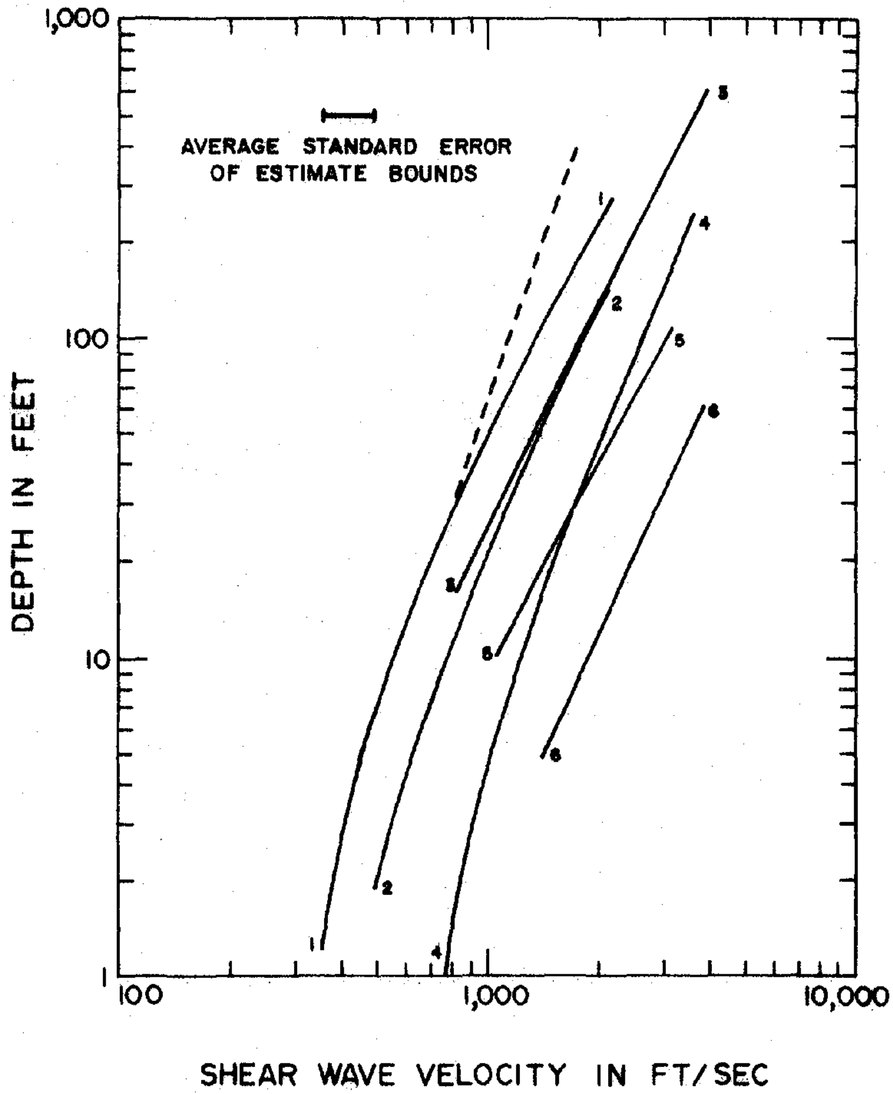

Figure 10. Comparison of mean regression relationships.

Key
1. Soft natural soils (dashed where El Centro and Cholame have been included.)
2. Intermediate natural soils
3. Saturated firm natural soils
4. Firm natural soils
5. Intermediate sedimentary rock
6. Hard sedimentary rock

DISCUSSION AND CONCLUSIONS

The statistical correlations among shear-wave velocity, Poisson's ratio, depth, and the type of soil or rock developed in the previous sections may be used to estimate seismic velocity from only a limited amount of geotechnical data. Geotechnical data considered important for this application are geologic age, rock type, soil type, water table depth, gravel content, dry density, and depth of overburden. Minimum required information includes the geology and depth to the water table. A description of the procedure for generating synthetic velocity profiles illustrated with examples may be found in References (1) and (8).

It should be emphasized that the velocity profiles generated using these correlations are for low shear strains (less than 10^{-4}%). Due to strain softening, the velocities estimated from these correlations should be reduced for strong shaking depending upon the level of shaking. The Uniform Building Code suggests multiplying low-strain seismic velocities by a factor of 0.67 to account for earthquake shaking effects in seismic Zones 3 and 4. A more sophisticated approach taking into account computed stresses and stress-strain behavior of soils is outlined in Reference (1).

The velocity correlations presented here should be used with engineering judgment since they are based on a limited amount of velocity and geotechnical data. The bulk of the data were obtained at depths less than about 100 to 150 feet. Extrapolation of regression equations beyond this depth should be done with extreme caution.

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APPENDIX A

THOMAS BROTHERS MAP LOCATIONS

The Thomas Brothers map designations were used in Table 1 to provide a means of easy reference to locate the sites of the new velocity measurements. The map designations are keyed to the Thomas Brothers Popular Street Atlases which are widely used by governmental and commercial interests in California. An explanation of the map designation is given below:

```
LA    25    F6 ——grid coordinates
|     |
|     |————————— map book page number
|
|——————————————— County
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Key to County Codes -

KE	Kern County
LA	Los Angeles County
OR	Orange County
SC	Santa Clara County
SD	San Diego County
VE	Ventura County

APPENDIX B
ABRIDGED GEOLOGIC TIME SCALE

Era	Period	Epoch	Approximate Duration* in Millions of Years	Millions of* Years Ago
Cenozoic	Quaternary	Holocene	0.01	0
		Pleistocene	2.5	2.5
	Tertiary	Pliocene	4.5	7
		Miocene	19.0	26
		Oligocene	12.0	38
		Eocene	16.0	54
		Paleocene	11.0	65

*After Bolt et. al, Geologic Hazards, Springer-Verlag, New York, 1975.