

# Moisture and Strength Variability in Some Arizona Subgrades

SANDRA L. HOUSTON, WILLIAM N. HOUSTON, AND TIMOTHY W. ANDERSON

A series of cone penetrometer tests was performed on subgrade materials at 18 sites along Arizona highways. At each site, water content and cone penetration data were obtained at two locations, 10 m apart, along the right-wheel path of the right lane and at a third location along the adjacent shoulder. The cone penetration and water-content data indicate pronounced variations in subgrade properties over distances of only a few meters horizontally. Variations in subgrade properties were also significant over small vertical distances. Soil profiles at the 18 test sites contained a wide range of soil types; however, most upper subgrade materials were classified as silts or sands with silty fines. Relationships among soil water content, soil suction, and shear strength are explored, and the effect of highly variable subgrade properties on pavement design is discussed.

Variations in subgrade materials can lead to variable performance of pavement systems over a fairly short length of highway section. Pavement and subgrade properties vary because of differences in material type but may also vary with seasonal moisture fluctuations (1). Often subgrade variabilities that occur over short segments of highway go undetected because it is prohibitively expensive to perform highly detailed geotechnical investigations for the long stretches of roadway typical of most transportation projects. In addition, many projects involve upgrading and maintaining existing sections of highway, and it is generally not considered practical to perform the destructive testing that would normally be done to produce detailed information on subgrade variability. Therefore, a reliance on nondestructive testing (NDT) has become very common for most pavement upgrading and maintenance projects. In some cases there is an attempt to capture seasonal variations by conducting nondestructive tests at different times of the year.

The focus of this study is to evaluate the typical subgrade property variation for several Arizona highway sections. The investigation of subsurface profiles and spatial variability involved soil testing to determine basic characteristics and classifications. Water-content and cone penetrometer profiles were obtained at three closely spaced locations at each of the test sites. Although direct field suction measurements were not obtained, at some locations soil suction was qualitatively assessed by using typical soil-water characteristics curves and relating suction to water content. Variations in NDT deflection basins were available at each of the test locations. The details of the NDT studies are not given in this paper but have been reported elsewhere (2).

## SITE CHARACTERISTICS

The test sites are located on in-service Interstate systems, U.S. highways, and state routes. Twelve of the eighteen sites are on the Inter-

state system. A wide range in subgrade material was encountered, including clayey, silty, and sandy soils as well as gravelly material. A summary of the upper subgrade characteristics, showing Unified Soil Classification, is given in Table 1. Most of the upper subgrade materials were classified as sands with silty fines or silts, but materials ranged from gravel to clay.

Complete boring logs were obtained at each site to a depth of approximately 9 m or refusal (3). The geologic settings of the test sites are summarized in Table 1. During the site-selection process geographical distribution was an important concern for ensuring that the entire range of geological and climatic conditions was included in the data base to be developed in the study. Previous work by the Arizona Department of Transportation identified nine climatic zones in the state of Arizona. On consideration of all selection criteria, eight of the state's nine climatic zones were represented in the test sites. Thus, there was an attempt to remove data bias based on geological setting or climatic conditions.

## CONE-PENETRATION DATA

Cone-penetration testing (CPT) was performed at three locations at each test site. In general, these locations corresponded to (a) Station 1, located on the right-wheel path of the right lane, (b) Station 4, located approximately 10 m from Station 1 and on the right-wheel path of the right lane, and (c) Station 1S, located on the shoulder adjacent to Station 1. The CPT consisted of advancing an electric friction cone penetrometer attached to a truck-mounted CME 55 drill rig unit. The CPT was performed according to ASTM procedure D3441-86. The cone data were obtained to depth of 9 m or at refusal. In some cases (if the boring logs indicated feasibility) when refusal was met at relatively shallow depth, the cone penetrometer was removed, the hole was augered down to softer material, and then the cone was readvanced in the softer material beneath the hard layer.

Normal output from the CPT consists of a digital readout of the friction sleeve resistance and cone tip resistance. These values are displayed every 10 cm and represent an average over a 10-cm zone. Although sleeve resistance was obtained, cone tip resistance only will be reported here because it is the cone tip resistance for which most correlations with soil shear strength and modulus have been successfully made (4,5). In addition, the sleeve resistance values are somewhat temperature sensitive. Moisture-content data were obtained from disturbed samples taken from the boring log holes drilled at the sites. The moisture-content data were obtained very near the time of the CPT testing because water content profiles vary seasonally.

A summary of the cone penetrometer tip resistance,  $q_c$ , and the water content,  $w$ , profiles for each site is given in Table 2. In most

S. L. Houston and W. N. Houston, Department of Civil Engineering, Arizona State University, Tempe, Ariz. 85287-5306. T. W. Anderson, Force and Vann, Inc., 9013 North 24th Avenue, Phoenix, Ariz. 85021-2851.

TABLE 1 Summary of Upper Subgrade Characteristics Showing Unified Soil Classification

Site	Subgrade Characteristics		Geologic Setting
	Depth Below T.O.P.	USCS	
1	0.75 m	SM & SC	Quaternary & Tertiary Alluvium, very thick and coarse grained
2	1.4 m	ML & SM	Quaternary Alluvium, fine grained and thick
3	1.4 m	CL	Thin Quaternary Alluvium (derived from the Chinle Formation) overlying early Triassic Moenkopi Sandstone
4	1.0 m	CL	Same as for Site 3
5	1.0 m	SM	Thin Quaternary Alluvium overlying the Bidahochi Formation (sedimentary in nature, most likely sandstone)
6	0.75 m	ROCK	Permian age Kaibab Limestone
7	0.6 m	SM	Recent Alluvium overlying the Bidahochi Formation
8	0.75 m	SM	Same as for Site 7
9	1.25 m	CL-CH	Thin Alluvium (detritally weathered) overlying Tertiary Basalt
10	1.0 m	CH	Same as for Site 9
11	1.0 m	GC-CL	Quaternary Alluvium (fine grained) overlying Granite of early Proterozoic age
12	0.75 m	SM & SC	Same as for Site 1
13	0.30 m	SC	Thin Alluvium (detritally weathered) overlying Kaibab Limestone of Paleozoic age
14	0.30 m	SC-CH	Thin Alluvium (detritally weathered) overlying Kaibab Limestone and the Toroweap Formation (sandstone)
15	0.6 m	SM	Very thick Quaternary Alluvium, predominantly comprised of coarse grained sands and gravels
16	0.30 m	SM-ML	Very thick Quaternary Alluvium, predominantly fine grained sands and clays
17	0.15 m	ML	Thin Alluvium (detritally weathered) overlying the Naco Group (sedimentary rocks of Permian & Pennsylvanian age)
18	0.75 m	SM & GM	Thin Quaternary Alluvium overlying Tertiary aged Conglomerate
19	0.6 m	SC-CL	Thin Alluvium overlying Quaternary and Tertiary Basalt
20	1.0 m	GM & GP	Thick to very thick Quaternary Alluvium

Notes: T.O.P. - Top of Pavement

USCS - Unified Soil Classification System

cases data were obtained at Stations 1 and 4, located 10 m apart. However, as indicated in Table 2, occasionally the cone data were obtained at 20-m (Stations 1 and 7) or 12-m (Stations 1 and 5) spacings. The cone penetrometer data demonstrate the great variations in material properties that are possible, vertically and laterally. As an example, Site 1 exhibits a very hard layer in the 1- to 2.5-m depth range at Station 1, whereas the material in the 1 to 2.5-m depth range at Station 4, 10 m away, exhibits a much lower cone resistance, indicating a less stiff layer. It can also be noted that, because

of natural vertical and lateral profile variations, cone penetrometer data along the shoulder of the road may not accurately represent subgrade properties and layering for material beneath the pavement. In general, it is difficult and expensive to capture vertical and lateral variations by using field or laboratory tests on relatively small sample volumes.

The vertical and lateral variations of cone resistance and water content are more clearly seen in Figures 1, 2, and 3 top, showing profiles of  $q_c$  and water content for three typical sites. The layering

TABLE 2 Summary of Cone Data and Water Content

Site	Depth(m) (m)	Station 1		Station 1S		Station 4/7	
		qc(MPa)	w(%)	qc(MPa)	w(%)	qc(MPa)	w(%)
1	0.8	2.9	4.5	7.0	6.9	2.1	4.3
	1.2	11.2	8.5	7.4	6.8	8.9	3.0
	1.8	13.9	7.3	22.7	8.3	7.5	7.0
	2.4	22.3	7.5	9.9	5.9	3.2	10.9
	3.0	4.4	10.7	10.6	7.3	28.5	11.1
	3.7	7.7	9.4	23.4	7.3	N/A	13.9
	4.3	9.7	15.1	N/A	9.5	N/A	11.1
2*	0.8	19.6	5.9	8.6	8.6	34.8	6.0
	1.2	16.0	7.1	11.2	5.6	N/A	8.0
	1.8	1.9	6.4	8.2	5.8	2.5	8.2
	2.5	15.5	5.4	N/A	5.2	3.4	5.0
	3.0	N/A	4.8	N/A	5.1	7.3	6.4
	3.7	N/A	5.1	N/A	5.3	10.0	4.9
	4.3	18.7	3.5	N/A	4.6	22.0	3.1
	4.9	25.1	2.4	N/A	4.8	28.2	1.9
3*	0.8	N/A	11.8	4.5	12.6	N/A	11.6
	1.2	15.4	9.0	8.5	12.2	16.8	9.7
	1.8	2.5	17.1	2.5	17.6	2.8	18.5
	2.4	2.2	14.3	1.5	20.4	2.7	13.4
	3.0	2.4	17.2	3.0	17.8	2.6	17.4
	3.7	4.6	10.7	2.4	9.7	3.0	10.5
	4.3	2.7	9.0	3.7	9.7	3.7	12.7
	4.9	5.3	6.3	4.3	7.7	6.4	11.7
	5.5	4.6	9.8	2.3	7.7	5.1	10.0
	6.1	3.2	10.6	4.6	7.6	2.9	7.5
	6.7	3.2	15.4	2.0	8.0	3.7	7.5
	7.3	2.1	23.1	3.0	19.2	6.8	7.5
	7.9	3.6	23.1	6.9	23.1	10.1	7.5
4	0.8	6.0	22.8	1.4	19.6	19.4	9.8
	1.2	0.9	20.5	0.8	23.4	3.4	12.8
	1.9	0.7	27.1	0.6	25.4	0.5	27.5
	2.4	0.8	26.5	1.1	25.2	0.8	23.9
	3.0	1.3	25.1	1.3	26.2	1.2	27.8
	3.7	1.7	sat'd	3.4	sat'd	8.1	sat'd
	4.3	4.0	sat'd	5.1	sat'd	7.5	sat'd
	4.9	8.6	sat'd	9.0	sat'd	6.3	sat'd
	5.5	6.8	sat'd	7.6	sat'd	4.0	sat'd
	6.1	11.4	sat'd	1.0	sat'd	2.3	sat'd
	6.7	5.6	sat'd	7.1	sat'd	1.3	sat'd
	7.3	3.1	sat'd	7.4	sat'd	2.2	sat'd
	7.9	3.6	sat'd	11.0	sat'd	7.0	sat'd
5	0.8	9.6	12.0	8.7	10.0	12.8	11.6
	1.2	10.8	10.8	6.3	9.9	14.5	7.7
	1.8	37.3	6.4	7.4	15.1	12.2	7.0
	2.4	N/A	15.8	7.9	20.6	N/A	9.1
	3.0	N/A	19.3	6.1	20.0	N/A	16.1

NOTES: N/A - Not Available

\* - Data under Station 4/7 applies to Station 7

sat'd - saturated, no water content samples taken

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is significantly different at the three locations at Site 12 (Figure 1), indicating high lateral variation in properties. On the other hand, Site 3 profiles, Stations 1 and 7 (Figure 2), show consistent cone resistance profiles, demonstrating that pavement subgrades can be uniform in properties at some locations. Figure 3, Site 15, demonstrates the potential for significant vertical soil layering over short distances as well as lateral variability.

#### CORRELATIONS OF WATER CONTENT AND CONE RESISTANCE

The observed water-content variations are often indicative of material-type variations because some soils, such as clays, have a higher affinity for water than do granular materials. In addition, for a given material type, the lower water content would be expected to corre-

TABLE 2 (continued)

Site	Depth(m) (m)	Station 1		Station 1S		Station 4/5	
		qc(MPa)	w(%)	qc(MPa)	w(%)	qc(MPa)	w(%)
7	0.8	7.1	11.0	14.1	10.2	13.6	9.0
	1.2	3.7	16.1	1.3	10.3	7.2	8.9
	1.8	1.8	16.1	1.0	18.3	1.9	16.9
	2.4	2.0	18.4	1.0	22.5	1.2	20.3
	3.0	1.3	25.8	1.1	26.8	2.3	24.5
	3.7	1.6	26.7	1.1	28.6	2.8	24.5
	4.3	2.2	26.0	1.8	28.6	7.4	22.2
	4.9	3.4	17.1	6.1	11.8	10.8	5.7
	5.5	7.9	11.5	5.6	11.8	N/A	5.7
	6.1	9.1	15.0	N/A	19.0	N/A	12.1
8	0.8	6.4	8.9	7.1	7.1	9.6	10.6
	1.2	6.0	10.6	1.5	13.9	2.3	17.5
	1.8	6.4	18.0	N/A	14.0	6.2	21.4
	2.4	N/A	12.8	N/A	14.5	7.1	16.0
9	1.0	5.3	10.3	1.7	8.4	N/A	3.3
	1.5	29.1	19.3	1.3	21.0	2.1	20.2
	2.1	N/A	N/A	21.8	21.0	2.4	21.0
10	0.8	27.6	17.8	13.8	8.8	28.5	17.3
	1.2	2.4	19.2	1.7	26.7	2.2	25.6
	1.8	N/A	N/A	19.6	24.3	2.5	24.6
	2.4	N/A	N/A	N/A	24.2	8.7	27.6
	3.0	N/A	N/A	N/A	24.2	11.1	20.4
	3.7	N/A	N/A	N/A	16.3	17.3	20.4
11*	0.2	45.9	1.2	0.6	3.3	N/A	1.9
	0.5	45.4	1.9	21.8	5.7	42.5	2.8
	0.8	N/A	2.5	7.3	10.1	16.1	4.2
	1.1	N/A	5.3	11.8	8.5	34.1	8.2
	1.4	25.8	6.8	N/A	8.9	N/A	7.6
	1.7	13.8	6.8	N/A	8.9	N/A	9.7
12	0.6	35.5	4.2	5.4	7.4	26.9	4.3
	1.2	11.4	6.8	25.8	5.5	14.8	7.1
	1.8	19.5	6.9	16.2	6.3	16.3	9.2
	2.4	N/A	4.6	N/A	4.9	22.7	5.5
	3.0	24.9	3.8	N/A	4.9	5.1	4.8
	3.7	7.1	3.8	N/A	2.6	2.3	9.2
	4.3	11.7	3.8	N/A	2.6	7.2	9.2
	4.9	18.9	2.6	N/A	2.5	11.1	6.3
	5.5	4.6	4.2	N/A	2.7	12.5	5.0
	6.1	10.2	4.1	N/A	2.7	12.5	4.1
	6.7	9.8	3.7	N/A	3.0	15.5	3.0
	7.3	21.7	3.7	N/A	4.0	14.4	3.0
13	0.3	14.3	7.5	1.6	12.4	23.0	6.9
	0.6	2.8	9.0	9.9	17.2	10.8	6.6
	1.0	14.4	8.4	24.0	12.2	22.2	6.6

NOTES: N/A - Not Available

\* - Data under Station 4/5 applies to Station 5. Without \* the data applies to Station 4.

sat'd - saturated, no water content samples taken

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spond to higher cone resistance because soil suction (negative pore-water pressure) increases with decreasing water content. It was observed during the hole logging operation that, in many cases, the high cone-penetration values corresponded to materials that appeared cemented. Soil cementation arises both from soil suction and from cementing agents such as dried clay and calcium carbonate.

In general, whether the change in water content is due to a difference in material type or variations in soil suction for the same material type, the expected trend would be to observe increasing cone resistance with decreasing water content. The role of soil suction can be evaluated only by studying the effect of water content on cone resistance for a given material type.

TABLE 2 (continued)

Site	Depth(m) (m)	Station 1		Station 1S		Station 4/5	
		qc(MPa)	w(%)	qc(MPa)	w(%)	qc(MPa)	w(%)
14	0.3	15.5	7.2	11.3	9.3	22.6	5.0
	0.6	10.6	15.7	5.6	17.4	8.6	11.5
	1.0	5.2	17.4	4.1	19.9	14.4	16.3
	1.2	35.0	19.0	18.5	19.9	8.3	15.2
	1.5	N/A	18.5	12.3	17.6	9.1	22.8
	1.8	N/A	9.5	N/A	16.6	15.1	14.6
	2.1	N/A	9.4	N/A	11.7	26.0	10.9
15	0.3	3.9	5.8	4.1	6.0	2.4	5.3
	0.6	1.4	6.2	1.1	5.5	8.7	5.3
	1.0	3.8	5.4	2.4	5.5	3.0	5.1
	1.2	2.5	5.4	4.7	5.5	5.0	3.6
	1.5	3.7	5.4	4.1	3.8	6.3	12.4
	1.8	5.2	5.4	4.7	8.9	4.9	9.3
	2.1	28.7	6.7	15.2	4.3	12.0	4.7
	2.4	23.3	4.4	18.4	8.1	33.1	4.7
16	2.7	N/A	8.2	N/A	9.2	32.8	6.8
	0.6	10.9	5.9	6.2	5.9	20.5	6.4
	1.2	1.4	5.6	2.1	5.1	2.0	4.5
	1.8	2.4	8.7	4.6	6.5	2.3	8.9
	2.4	12.5	6.9	5.4	5.8	12.2	10.7
17*	3.0	N/A	6.9	38.2	6.8	20.5	10.3
	0.6	2.8	18.8	45.3	13.0	9.7	3.1
	1.2	5.1	18.6	14.9	13.2	11.7	13.9
	1.8	5.6	30.5	10.7	15.3	2.4	15.2
	2.4	2.9	21.5	N/A	22.0	1.3	22.9
	3.0	1.7	17.9	N/A	21.2	1.1	23.0
	3.7	10.9	N/A	N/A	N/A	0.7	22.6
18	4.3	9.9	N/A	N/A	N/A	1.0	22.6
	0.3	34.5	3.5	16.3	4.6	N/A	4.5
	0.6	N/A	4.6	32.5	5.4	N/A	4.6
	1.0	N/A	7.0	N/A	6.0	N/A	5.1
	1.2	N/A	7.4	N/A	6.9	N/A	6.7
	1.5	N/A	6.8	N/A	11.1	N/A	9.3
	1.8	11.7	7.5	N/A	9.0	N/A	10.7
	2.1	15.0	9.5	N/A	8.0	N/A	10.0
	2.4	11.4	13.8	N/A	5.9	N/A	10.5
19	2.8	21.7	9.5	N/A	5.4	N/A	7.3
	0.3	31.4	9.9	6.3	13.0	18.6	8.8
	0.6	19.1	13.1	1.8	22.5	4.7	9.2
	1.0	5.9	24.4	1.2	29.2	28.3	16.5
	1.2	2.8	30.2	0.7	28.7	N/A	21.2
	1.5	6.5	24.6	16.8	29.4	N/A	20.0
	1.8	1.0	25.4	N/A	N/A	N/A	23.5
19	2.1	34.5	N/A	N/A	N/A	N/A	N/A

NOTES: N/A - Not Available

\* - Data under Station 4/5 applies to Station 5. Without \* the data applies to Station 4.

sat'd - saturated, no water content samples taken

In an attempt to eliminate some of the sources of data scatter in the cone-resistance/water-content correlations, the sites having subgrade materials consisting primarily of silt or silty sand were studied alone. The gradation of the materials has an effect on the variation in  $q_c$  that is not completely accounted for by the variation in water content. Therefore, inclusion of the primarily clayey and gravelly sites in the predominantly silty soil data base would add to the scatter. The average cone resistance and the average water content for each of the silty sites were computed. A plot of average  $q_c$  versus average water content for the silt and silty sand subgrades is shown in Figure 4. Although averaging the values for each site, and including only the silty soils, tends to decrease some of the scatter

in the data, significant scatter still exists in the data given in Figure 4. Variations in gradation within the predominantly silty soils still exist, no doubt, and cause some variation in water content. In addition, some of the scatter in the data results from the presence of rock or gravel fragments. When rock fragments are encountered, this can lead to inconsistently high cone resistance values for the reported water content. Presence of rock or gravel fragments also leads to more apparent variability in subgrade materials than might actually be exhibited in situ. The appropriate dimensions for averaging for pavement applications are typically much greater than the dimensions of the CPT cone or the pebbles and rock that sometimes yield erratically high CPT values.

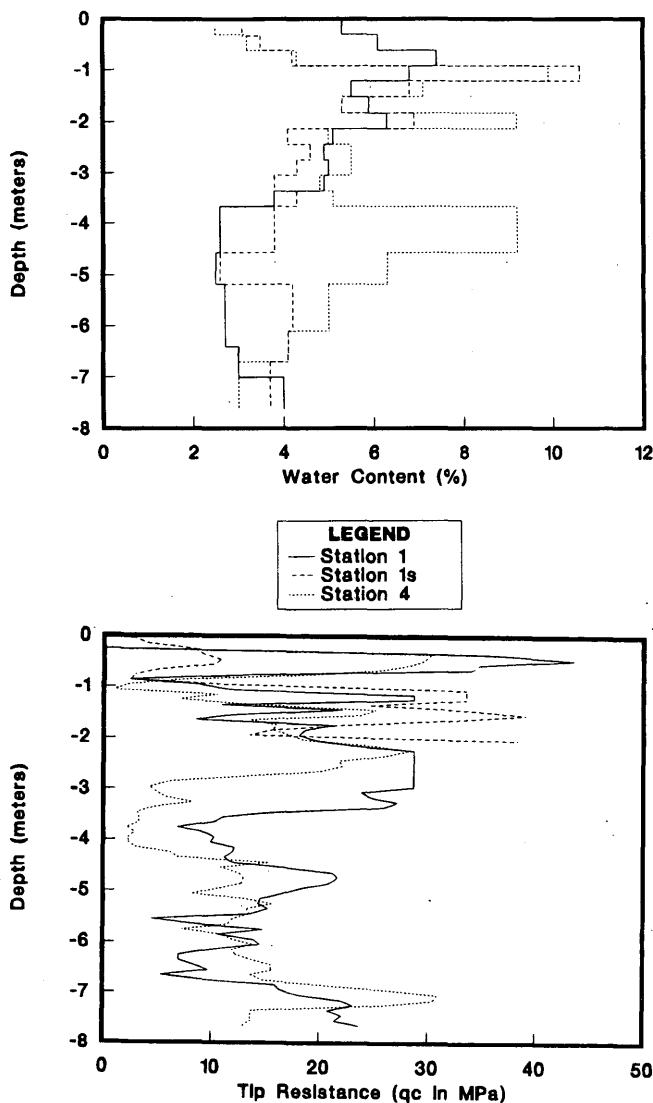


FIGURE 1 Cone tip resistance and water content profiles for Site 12.

### ROLE OF SOIL SUCTION

The relationship between soil shear strength and soil suction has been well established (6). For a given soil gradation and density, the higher the soil suction, the higher the effective stress, and therefore the greater the soil shear strength and cone tip resistance. For a given soil type and density, the soil suction can be correlated directly to water content and degree of saturation (7). The increase in shear strength associated with decreasing water content is apparent from the direct shear data obtained for a silty soil, shown in Figure 5 (8).

Because soil suction is not dependent on density, a relationship between soil suction and soil water content is often established for a given material type. A soil-water characteristic curve, showing the relationship between water content and soil suction for a typical silty sand, appears in Figure 6. A typical curve, such as that depicted in Figure 6, can be used to obtain qualitatively correct suction data for the silty soils in this study. By using the soil-water characteristic curve shown in Figure 6 an approximate relationship between

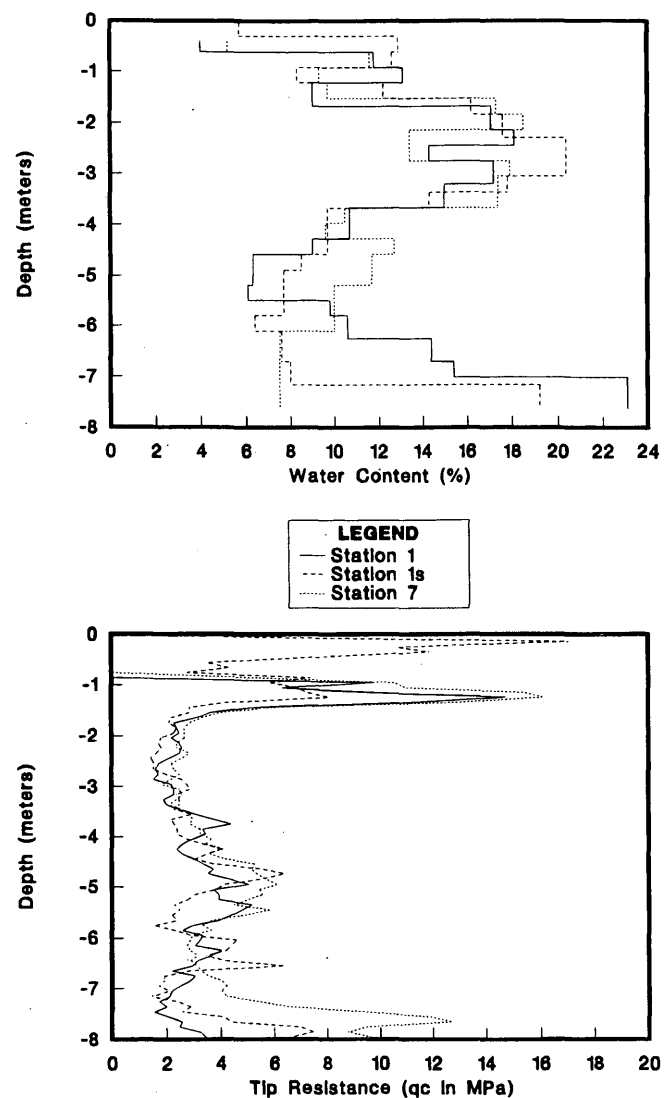


FIGURE 2 Cone tip resistance and water content profiles for Site 3.

average cone tip resistance and soil suction, shown in Figure 7, was established for the sites with silty subgrade materials. Although there is significant scatter (most likely resulting from vertical non-homogeneities), a clear trend of increasing cone resistance with increasing suction exists.

### EFFECTS ON PAVEMENT DESIGN

The cone penetrometer data demonstrate the potential for a high level of variation in subgrade material properties. This observation affects pavement and overlay design because the subgrade materials play a significant role in the pavement surface deflections exhibited during pavement loading and during NDT tests, such as the falling weight deflectometer tests. Pavement surface deflections are of primary consideration in the design of new pavements and overlays for existing pavements.

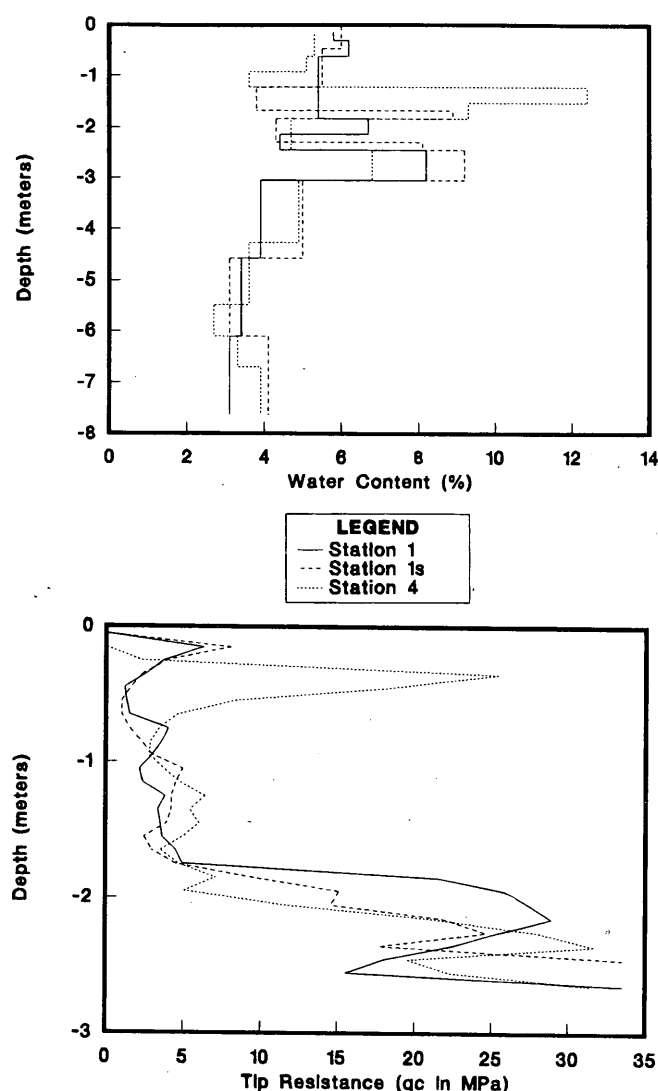


FIGURE 3 Cone tip resistance and water content for Site 15.

If the modulus of the subgrade was constant all the way down to firm (or bedrock) material, then NDT deflection basins should be consistent at a given site. Even if the subgrade were highly layered in the vertical direction, provided that there was little or no lateral variation at the site, the deflection basin should be repeatable over short distances because the deflection basin provides a weighted average or "lumped" indicator of the subgrade modulus. Thus, for laterally uniform subgrade, variations in deflection basins from the falling weight deflectometer test would not be expected to be significant over distances as small as a few feet. However, the NDT deflection basins at the test sites considered in this study did, in fact, show significant variation over distances of approximately 3 m. Data from falling weight deflectometer (FWD) tests indicate pavement and subgrade nonhomogeneities, as shown in Figure 7. A statistical analysis of the variability of NDT deflection basins was previously reported for the same sites considered in this paper (3). In general, the NDT deflection basins at the 18 test sites were found to vary significantly over fairly short distances. Although there are

certainly material property differences in the pavement surface and subbase materials, especially when poor construction quality control is implemented, these differences are unlikely to occur over very short distances. In addition, variations in material properties of the engineered surfaces and subbase materials are very small in comparison to variations in subgrade materials. Therefore, it is probable that the variations in the deflections, especially at the outer sensors, are caused by natural vertical and lateral variations in subgrade material properties. The outer sensor (geophone) has been shown to have a very strong correlation to the subgrade modulus (9). The subgrade materials to a significant depth (i.e., 8 to 10 m) below the pavement surface can also be shown to contribute to the outer sensor deflection measurements.

Given the significant influence of subgrade materials on the surface deflections and the tremendous variabilities detected for the subgrade materials from cone penetrometer, water-content, and boring log data, it appears plausible the variations in subgrade are predominantly responsible for much of the variability in NDT deflection basins. Therefore, any pavement overlay design procedure that is based on the deflection basin data or moduli backcalculated from these deflection basins would be sensitive to subgrade material property and water-content variations.

A great deal of subgrade material variation should be expected over short spans of highway. Even with good quality control of the construction methods, variations in deflection basins from NDT should be anticipated. The subgrade material variability is usually out of the control of the design engineer, because the materials are not engineered. Therefore, the design engineer must be aware of the potential of significant variability in subgrade response over short distances and its potential effect on the design selected. Because of the relationship among soil water content, soil suction, and soil shear strength, seasonal and spatial variability in water content must also be taken into consideration. Test intervals and length of design sections are best selected on the basis of statistical characterization and on the basis of local experience with subgrade variability.

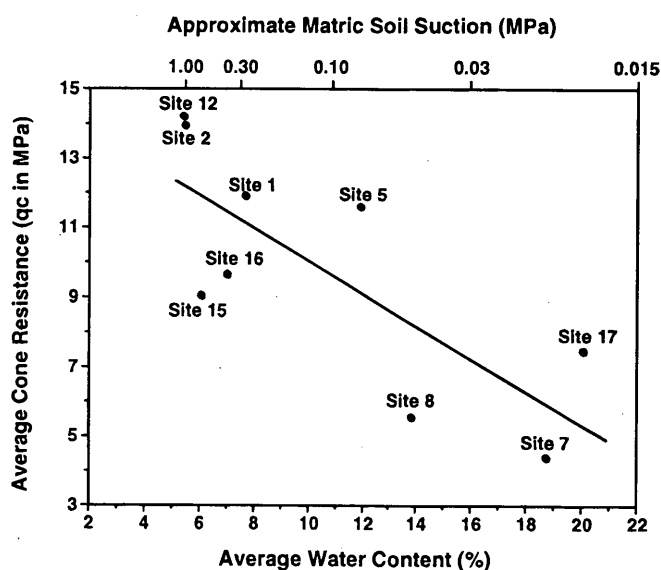


FIGURE 4 Average cone resistance and water content for sandy silts and silty soil profiles.

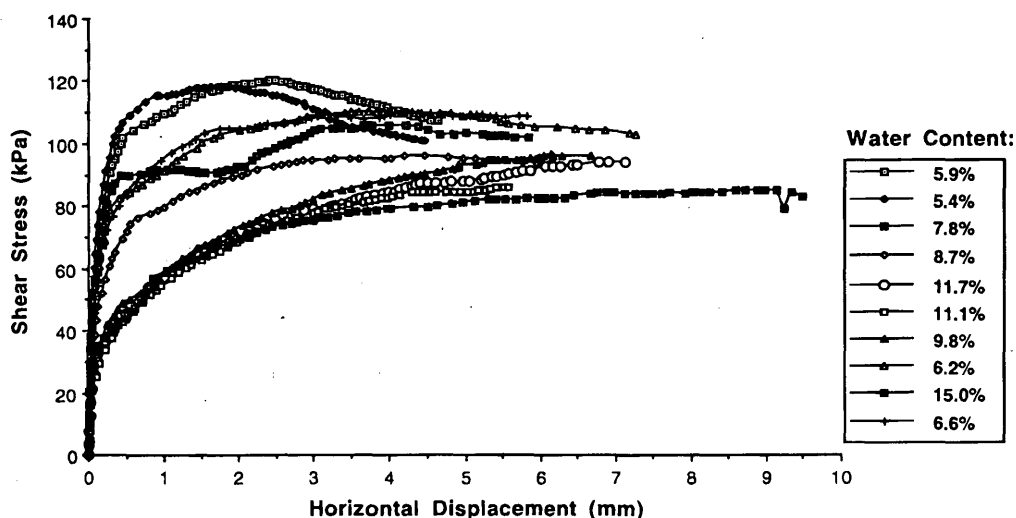


FIGURE 5 Direct shear test results for silt at various water contents.

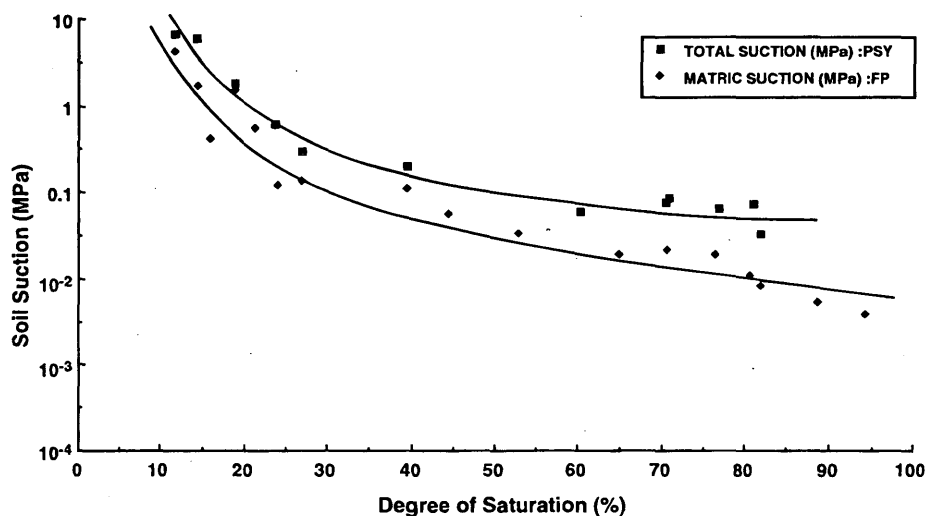


FIGURE 6 Typical soil suction versus degree of saturation for silt.

## CONCLUSIONS AND RECOMMENDATIONS

Because of the considerable length of highway involved in new roadway or overlay construction and because of the huge volume of material that must be characterized, an assessment of the degree and effect of natural subgrade variations is of considerable importance. The decisions regarding the frequency of sampling and boring, NDT testing, and length of design section clearly should be related to the degree of nonhomogeneity at any given site. Cone penetrometer data from 18 sites in Arizona demonstrated the potential of many subgrade materials to exhibit significant variability both vertically and horizontally over distances of a few meters or less. Large

variations in subgrade water content were also observed over short spans of highway. Water-content variations could be indicative of material type changes, negative pore-water pressure differences, or both. In any case, the lower the soil water content and the higher the soil suction, in general, the greater will be the cone resistance and subgrade stiffness.

The deep CPT and borings were useful as research tools to quantify the subgrade property variations and identify their sources. However, the CPT and borings are not practical for routine design applications. NDT with an FWD or similar apparatus is much more practical and useful for characterization of pavement structure properties for routine design.



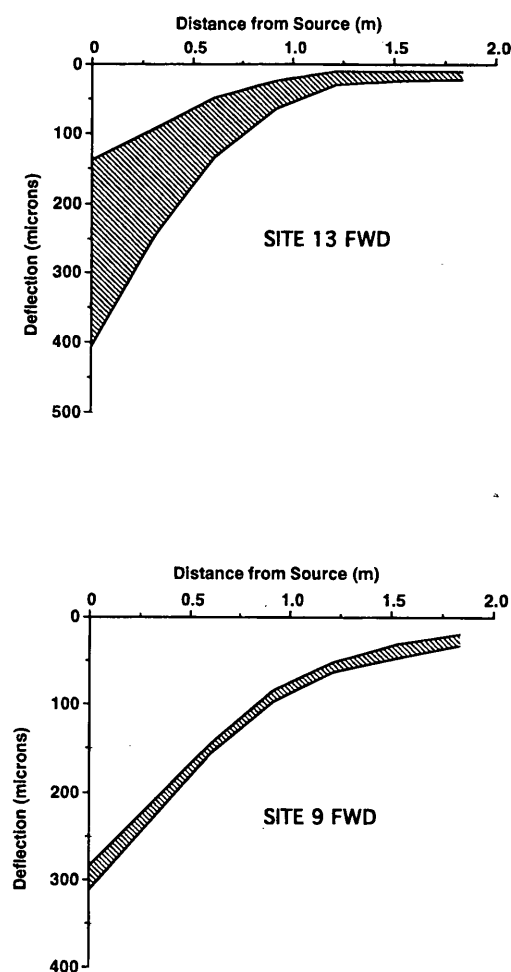


FIGURE 7 Deflection basins for: *top*, relatively high variability site and *bottom*, relatively low variability site (3).

## ACKNOWLEDGMENT

The research presented in this paper was sponsored, in part, by the Arizona Department of Transportation through the Arizona Transportation Research Center.

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*Publication of this paper sponsored by Committee on Environmental Factors Except Frost.*