SIDEWALK UNDERMINING STUDIES
PHASE II — SOIL STUDIES

by

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and

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways & Transportation and the University of Virginia)

Charlottesville, Virginia

September 1976
VHTRC 77-R20

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INTRODUCTION

The Fairfax Residency of the Virginia Department of Highways & Transportation spent $3.6 million between FY71 and FY76 replacing or repairing deteriorated and undermined sidewalks, curbs, and gutters.(1) Of this total, $3.4 million was spent for replacement or repair along secondary roads in Fairfax County alone.(1) At present, residency personnel estimate that as much as $7.0 to $8.0 million would be needed to correct the existing sidewalk problems throughout Fairfax County.(2)

While other problems associated with sidewalk maintenance in the area are severe, the most difficult to handle is represented by the many sidewalks that have been undermined through erosion of the immediately underlying soil. Undermining removes the support from under the sidewalks and results in faulting of the joints and the creation of peripheral drainage and siltation problems. More importantly, the faulted joints and other sidewalk distortions create hazardous conditions which need immediate attention.

Because of the policy of accepting sidewalks into the secondary system concurrent with acceptance of the adjacent subdivision pavements, the sidewalks become a maintenance responsibility of the Department. The Department accepts, on the average, 30 miles (48 km) of Fairfax County roads into its secondary system each year. Almost all of these roads have sidewalks on both sides. Thus, maintenance problems will continue to multiply unless changes are made in the design standards and specifications for sidewalk construction to prevent undermining and early deterioration.

A previous report from this study dealt with interim maintenance recommendations and the hydrological considerations involved in sidewalk undermining. The present report describes the procedures used to correlate sidewalk undermining with particular soil types. It should be pointed out that this connection has long been suspected, but never fully proven through technological means. A later report will present recommendations for changes in sidewalk construction specifications and final recommendations for maintenance replacement.

DESCRIPTION OF PROBLEM

Undermined sidewalks are generally located on longitudinal grades of 3% or more, and usually are located downgrade from drainage areas comprising one or more blocks of subdivision development. Yards typically slope upward from the sidewalks, so that all water from roofs as well as the rest of the drainage area must travel over or along the sidewalks to reach storm drain systems located under the edge of the roadways.

The presence of undermining where longitudinal grades are more than 3% is probably related to the fact that unless longitudinal grades are flat, there will always be some longitudinal drainage, either on top of the sidewalk or beneath them, if voids are present. Although some of the problem sidewalks were constructed on the flat, most have cross-slopes of approximately 2%. When longitudinal grades exceed this 2% cross-slope, the preponderance of drainage will be longitudinal.

Furthermore, undermining is aggravated by the presence of a sodded utility strip from 1 to 12 feet (0.3 to 3.6 m) wide between the sidewalk and the roadway curb. Because of normal growth, the sod in both the utility strip and the adjacent yards is higher in elevation than the sidewalks. Thus, the sidewalk functions as a paved ditch to carry much of the drainage longitudinally. If voids are present under the sidewalks, the water will flow under as well as over the concrete slabs.

REVIEW OF PHASE I

The Phase I report discussed the maintenance and hydrology considerations involved in the sidewalk undermining problem.[3] Detailed study by others of several severe undermining situations had led to the conclusion that it would be very difficult to prevent the infiltration of surface water into the area beneath the sidewalks.[4,5] Additionally, an alternative of reducing the undermining potential by reducing the velocity of the infiltrated water is considered by some to be of questionable value. Thus, for maintenance purposes, both the Fairfax County and Fairfax Residency personnel had decided that it would be better to protect the erodible soil by the use of an aggregate base and longitudinal curtain walls under the rebuilt sidewalks, and to remove infiltrated water through the use of a drainage system constructed under the walks and draining into the existing storm sewer system. [4,5] A schematic of this type of construction is shown in Figure 1.

While this method of placement was successful in that no subsequent undermining was found, it was costly and questions were raised concerning the determination of pipe sizes to be used on the various grades encountered in the maintenance program. [6] After much discussion, the use of a sidewalk replacement technique wherein the subgrade soil is protected by polyethylene sheeting and the infiltrated water is carried away by a subsurface drainage system was recommended. [3] A schematic of this type of construction is shown in Figure 2. This revised method realized a 53% cost saving over the previously used system. [7]

Hydraulic considerations yielded a nomograph from which infiltration water and pipe size could be determined for a given set of field conditions. [3] It was concluded that a 7-inch (178 mm) diameter pipe would be adequate for most practical cases. [3]

Several other maintenance replacement methods were suggested as possible alternatives in the Phase I report. These are under consideration and will be reported on at a later date.

SOIL SAMPLING AND TESTING

As was previously mentioned, a direct correlation between undermining and particular soil types has long been suspected, but never unmistakably proven. In fact, the Soil Survey Report for Fairfax County, Virginia, supports this hypothesis. [8] The report lists the Elioak, Glenelg, Glenville, Manor, and Rowland series as being either erodible or highly erodible and, furthermore, confers a poor to fair rating on these soil series for road construction purposes. The mapped locations of these series seem to interconnect extremely well with many areas identified as having sidewalk undermining problems. Thus, the sole purpose of this phase of the research was to define the relationship between particular soil types and sidewalk undermining.

Soil samples were taken from various locations throughout Fairfax County. These represented areas that either undoubtedly or possibly are experiencing undermining problems and areas in which no evidence of undermining could be found.

It should be mentioned that the sampling covered approximately 40% of the county. Most of the remaining portion of the county was not covered by the sampling because of either very flat slopes, no sidewalks in developed areas, or no developments at all.

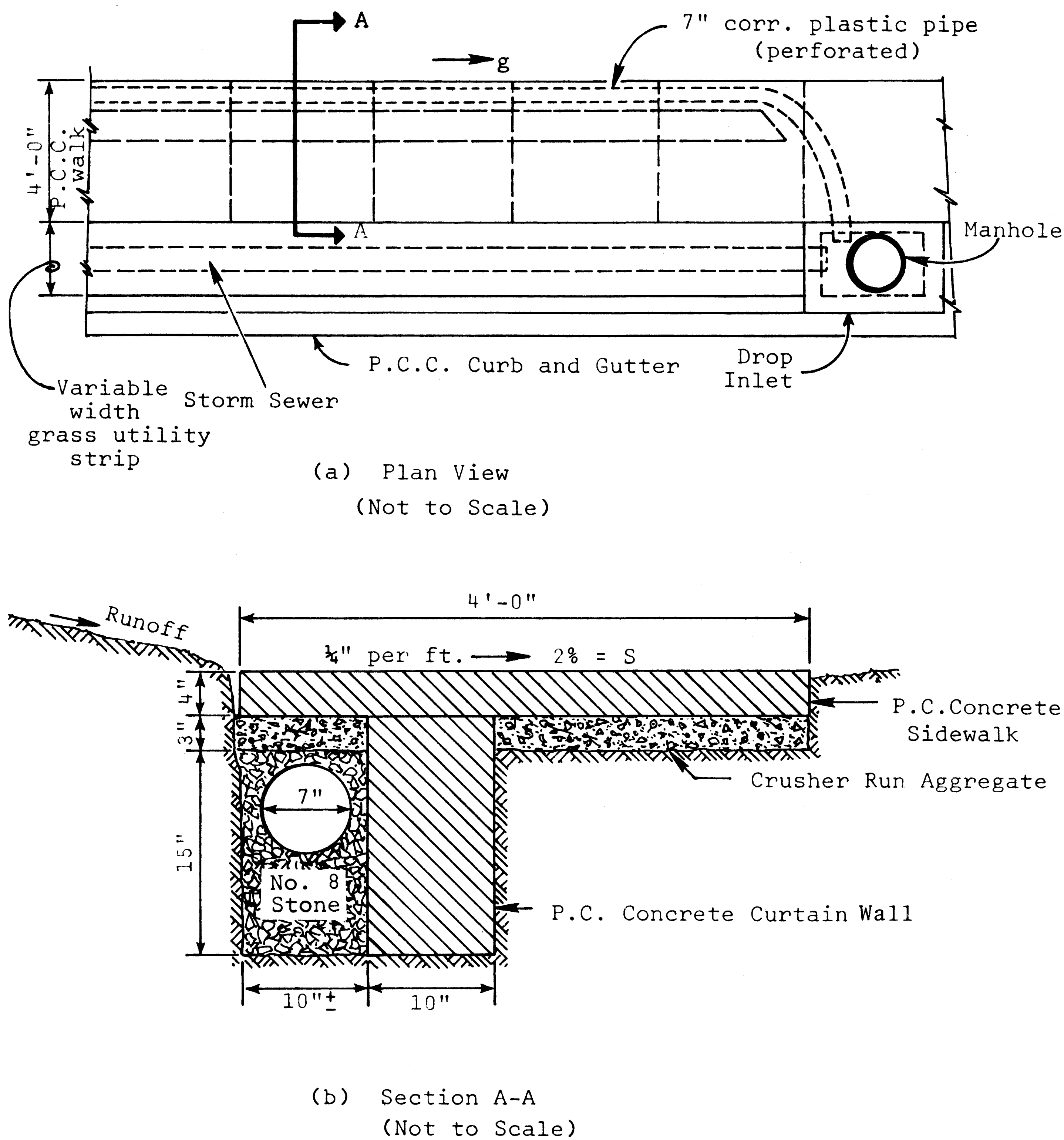

Figure 1. Sidewalk reconstruction with curtain wall and drainage system. (1 in. = 25.4 mm)

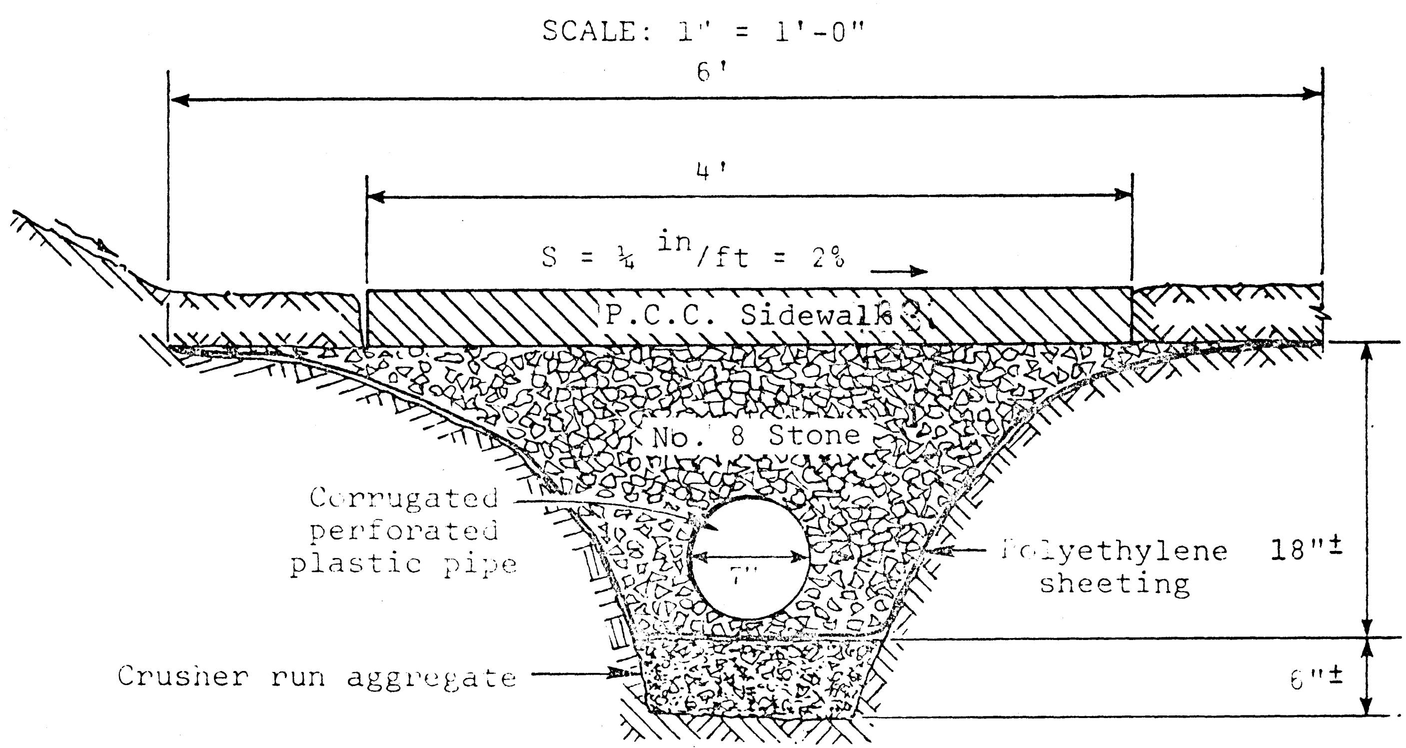

Figure 2. Cross section of experimental sidewalk installation. (1 ft. = 0.3 m)

The samples were taken in the median strip by cutting the sod to a depth of approximately 4 inches (10.2 mm). This was done in order that the samples would be taken from about the same elevation as the subgrade soil under the sidewalk. A sample bag was filled by cutting away the sod from three places for each sample area and removing approximately equal volumes of soil from each of the three holes. This was done to insure that the soil sample was roughly representative of the soil layer immediately underlying the sidewalks.

Standard laboratory procedures were used to determine the coarse and fine gradations, Atterburg limits, optimum moisture content, and the maximum density of the samples, and the soils were classified according to the AASHTO system. In addition, a specific gravity test and a hydrometer analysis were performed on each sample. These final two tests enabled the drawing of a complete grain-size distribution curve, the necessity for which will become evident later on in this report.

The final test on the soil samples was one to determine percentages of organic matter.

ERODIBILITY FACTOR

The soil testing provided the information needed for the establishment of an erodibility factor for each soil sample. The erodibility factors were derived with the use of an erodibility nomograph developed by Wischmeier, Johnson, and Cross. (9) The use of the nomograph (Figure 3) requires that five soil parameters be established: percentage of silt plus very fine sand (from 0.002 to 0.10 mm), percentage of sand (from 0.10 to 2.0 mm), percentage of organic matter, soil structure index and permeability class. (10)

The first two parameters are established by using the complete grain-size distribution curve mentioned previously. Values are read directly from the graph and the ranges are calculated accordingly. The other three parameters are somewhat foreign to the highway engineer and therefore warrant special discussion.

Organic Matter Content

Wischmeir et al. used a slightly modified Walkley-Black method for determining percentages of organic matter. (9) The organic matter content is determined in this method by chemically oxidizing the carbon in the soil and it is approximately 1.72 times the percentage of carbon. Furthermore, a recovery factor in the range of 74% to 77% is necessary for a good correlation with the dry combustion method. (11)

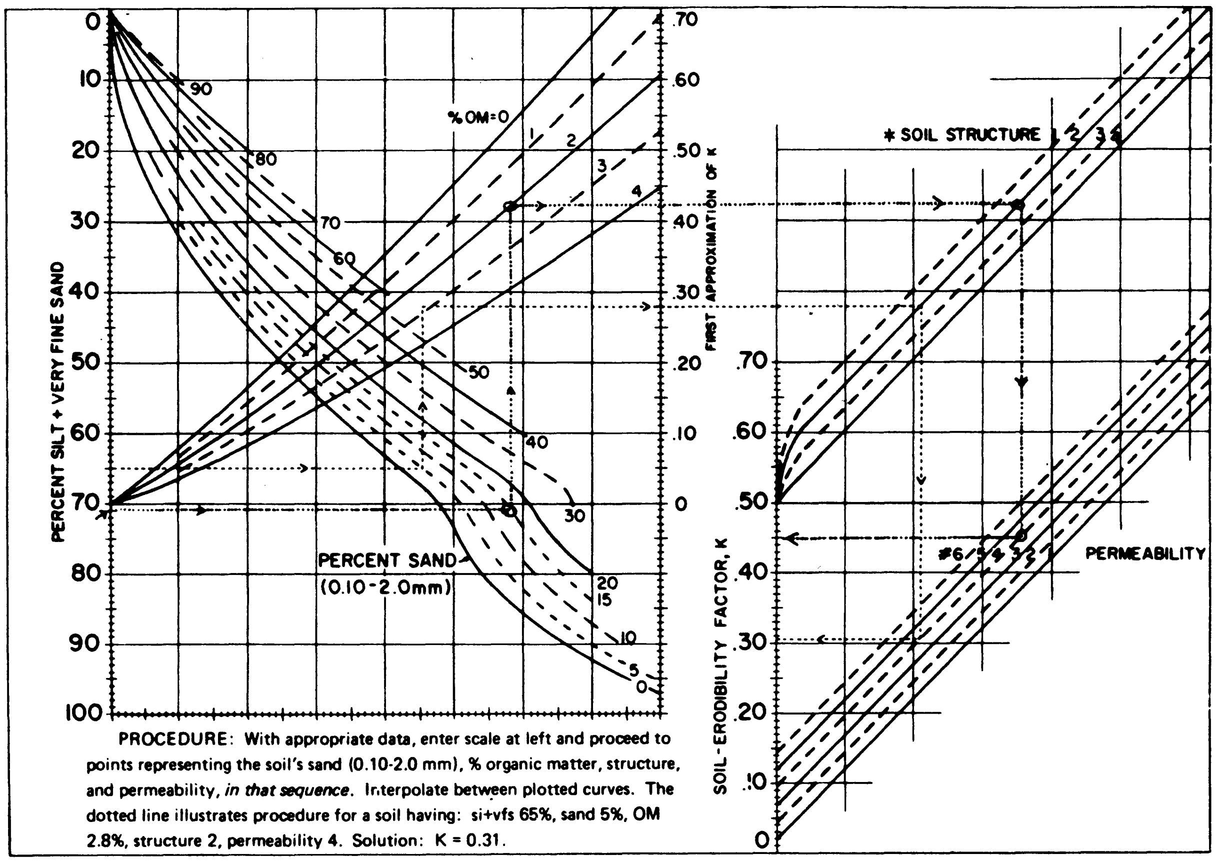

Figure 3. Soil erodibility nomograph.

Because of the unknown recovery factor and because of the time involved in employing the Walkley-Black method, another procedure was used to determine the organic matter in the samples. The technique chosen was one developed by Mitchell and involves the direct oxidation of organic matter at a moderate temperature.[11] The samples were first oven dried overnight at approximately 110^{o}C and then dry weights recorded. The organic matter was driven off by heating the samples at roughly 400^{o}C for 7 to 8 hours. The samples were weighed again, after cooling, and the organic matter content was then calculated as the weight loss divided by the oven dry weight of the sample.[11]

Soil Structure and Permeability

A soil structure index and a permeability class greatly improve the accuracy of a predicted erodibility factor as compared to a measured one. The structure codes are given in Table 1. These indexes are usually established through information noted during the sampling process.[9]

Table 1

Structure Index Codes

Structure Index	Definition
1	Very fine granular
2	Fine granular
3	Medium or coarse granular
4	Blocky, platy, or massive

Source: McElroy et al., "Loading Functions."

Soil permeability is the last parameter needed to derive the erodibility factors of the samples. The permeability codes are given in Table 2. The permeability class is the only parameter that might reflect a soil layer other than the top 6 to 7 inches (152 to 178 mm). The other four parameters represent the layer being analyzed.[9] It is not necessary to test for permeability rates, though, since a reasonably accurate engineering judgment is usually sufficient.

Table 2

Permeability Class Codes

(Conversion: 1 inch = 25.4 mm)

Permeability Class	Rates in inches/hour	
1	Rapid	over 6.0
2	Moderately rapid	2.0 to 6.0
3	Moderate	0.6 to 2.0
4	Moderately slow	0.2 to 0.6
5	Slow	0.06 to 0.2
6	Very slow	less than 0.06

Source: McElroy et al., "Loading Functions."

It should be pointed out that on-site information needed to establish the soil structure codes was not obtained. Nor were borings made to detect underlying layers of appreciable difference from that of the particular soil layer being studied in order to establish the permeability codes. Instead, general guidelines were developed from which the nomograph user may choose the specific code based upon the grain-size distribution already established. These guidelines are fundamentally a replication of the triangular, textural classification chart used by the United States Department of Agriculture.[13]

The chart to be used as guidance in establishing structure codes is shown in Figure 4. Figure 5 gives the necessary guidance for establishing permeability classes for the samples. It is felt that the use of these charts, instead of going to the extra expense and time of taking borings at each site and performing additional field work, did not result in any great amount of error. The chart for the structure codes is logically sound, and therefore should be reasonably accurate. The permeability class chart should also be fairly sound, because only very infrequently would there be an extreme difference in soil layers that would require the use of a permeability code other than the one denoted by the soil layer being studied.

Furthermore, although the organic matter content, the soil structure index, and the permeability class do improve the accuracy of this empirical technique the combination of the grain-size parameters account for 85% of the variance in observed erodibility factors.[10] It should be reemphasized that these charts were developed as general guidelines and should not be used blindly. Often engineering judgment may alter the particular codes suggested by the charts. More detailed information on the structures and permeabilities of soils may be found in reference 13.

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STRUCTURE INDEX	DEFINITION
(1)	Very Fine Granular
(2)	Fine Granular
(3)	Medium or Coarse Granular
(4)	Blocky, Platy, or Massive

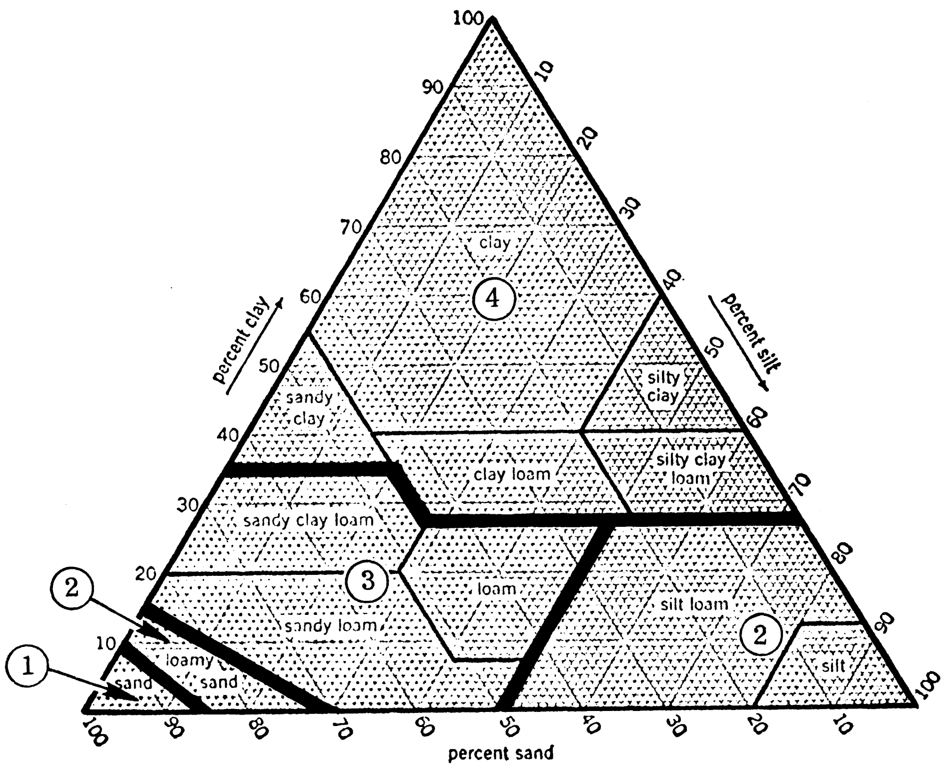

Figure 4. Chart for estimating structure index of soil by using percentages of clay (below 0.002 mm), silt (0.002 to 0.05 mm), and sand (0.05 to 2.0 mm).

PERMEABILITY CLASS	DEFINITION
(1)	Rapid
(2)	Moderate to Rapid
(3)	Moderate
(4)	Slow to Moderate
(5)	Slow
(6)	Very Slow

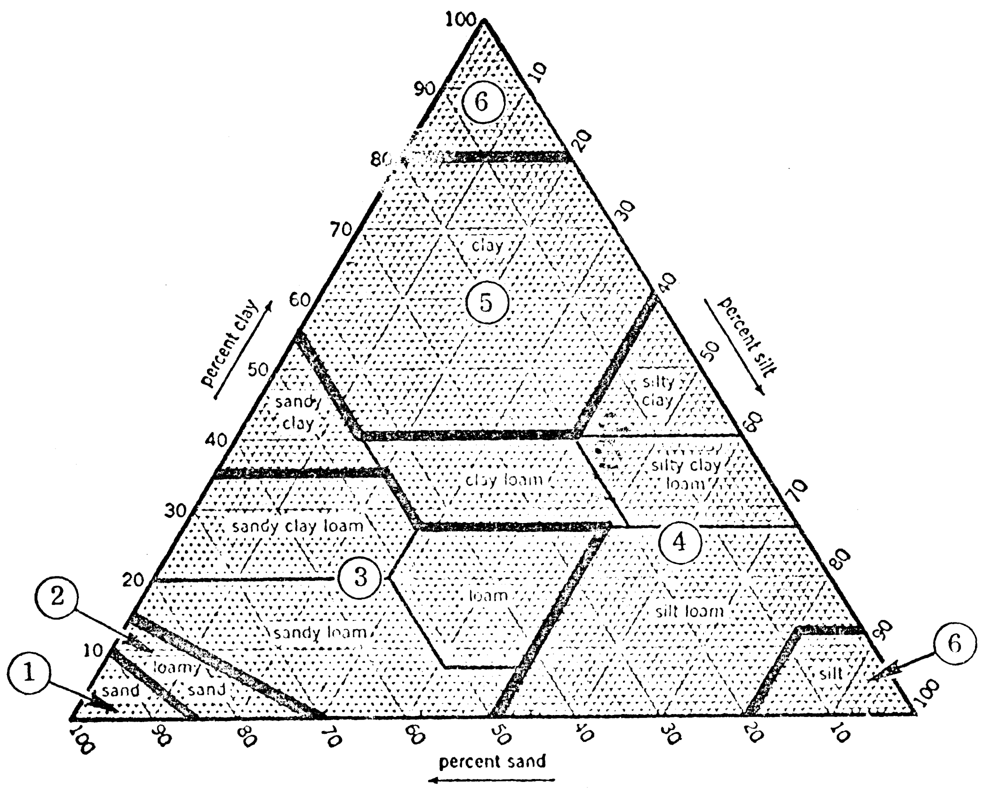

Figure 5. Chart for estimating permeability class of soil by using percentages of clay (below 0.002 mm), silt (0.002 to 0.05 mm), and sand (0.05 to 2.0 mm).

UNDERMINING POTENTIAL INDEX

Preliminary analysis of the erodibility factors developed for each sample showed no direct correlation between undermining and the magnitude of the erodibility factors. Some sample areas which had relatively small erodibility factors were experiencing problems with undermining, while others with larger erodibility factors were not experiencing problems. An examination of precisely what the erodibility factor describes provided the solution to this dilemma.

The erodibility factor is the relative measure of a soil's erodibility characteristic when the other factors that affect erosion are essentially equal. These other factors are rainfall, slope length, slope steepness, type of land cover, and the type of land management practices employed. [10] All of these variables are combined with the erodibility factor in the universal soil loss equation to predict a sediment yield for a particular situation. [10] Sidewalk undermining is fundamentally a sediment yield, which led to the conclusion that at least some of these other factors must be accounted for in order to derive a relationship between undermining and particular soil types. This deduction led to the development of an undermining potential index for each sample area.

The undermining potential index (UPI) is primarily a duplication of the universal soil loss equation with some minor modifications. First, the type of land cover and land management practices were assumed to be approximately equal for each of the sample areas and thus were set equal to unity in deriving the UPI. This assumption is not completely exact and will be elaborated on in a subsequent section of this report. Secondly, a relatively small land area is covered by the research, so the rainfall factor is definitely the same for all of the sample sites. A value of 200 for the rainfall factor would normally be used for computing sediment yields in Fairfax County, but for simplicity a value of 100 was employed in calculating the UPI's. Thus, only three distinct variables enter into the calculation of the UPI: the erodibility factor, the slope length, and the slope steepness.

The effect of the length and the longitudinal gradient of the particular location are combined into a topographical factor designated LS. The mathematical expression for LS for a uniform slope is

$$LS = l^{0.5}(0.0076 + 0.0053s + 0.00076s^2) \tag{1}$$

where l is the length of the slope in feet and s is the percentage of longitudinal slope. [10]

Foster and Wischmeier proved that the effect of an irregular slope can not be computed with the preceding equation, even if an average slope steepness is assumed. [14] They, instead, proposed a technique whereby the section is divided into N segments such that the gradient of each segment is essentially uniform. Their technique compared very favorably with field data. The topographical factor then takes the form of

$$LS = \frac{\sum_{j=1}^{N} \left(S_j l_j^{1.5} - S_j l_{j-1}^{1.5}\right)}{l_e (72.6)^{0.5}} \tag{2}$$

where the term l_j is the length, in feet, from the top of the section to the lower end of any segment j; l_{j-1} is this equivalent length above segment j; and l_e is the total section length.[14] The term S_j is the value of the factor S for segment j, which is defined as

$$S = \frac{0.043\, s^2 + 0.30\, s + 0.43}{6.613} \qquad (3)$$

where s is the percentage of longitudinal slope as previously defined.[14]

Foster and Wischmeier simplified the technique for computational purposes and published equation (2) in graphic form in their paper. Their procedure is also presented and explained in great detail in reference 12. Furthermore, there are computer programs available, such as the one developed by Poche[15] that will compute the topographical factor.

Thus, the undermining potential index reduced to an equation in the form

$$UPI = 100 \cdot K \cdot LS \qquad (4)$$

where K is the erodibility factor of the sample and LS is the topographical effect of the particular sample site.

The development of UPI for each soil sample resulted in very good correlation between soil types and sidewalk undermining. Additionally, the magnitude of the UPI correlated very well with the degree of sidewalk undermining denoted.

ANALYSIS OF DATA

Tables 3 through 6 give the complete information on the soil sample sites. The first letter of the sample number represents a Fairfax County map supplement, and the subsequent number is indicative of a general location involving one or more subdivisions on the particular map supplement. A letter appears at the end of the sample number in instances where there was more than one sample site within a particular numbered location. The other columns, although self-explanatory, give information on the AASHTO soil classification, percent passing the #200 sieve, plasticity index (PI), erodibility factor, length of the site, slope of the site, topographical factor (LS), UPI and whether the site is experiencing undermining problems or not.

A total of 56 sample sites were identified during preliminary field work from which 52 soil samples were taken. Of the samples taken, 2 were discarded because of extreme variations in some of the factors that were assumed to be approximately equal for all of the sample sites. Twenty-nine of the sample sites were concluded to be definitely undermined, 7 others as possibly undermined, and the remaining 14 as definitely having no

Table 3

Data for Sample Sites; Soil Classes A-2-4, A-4(0), A-4(1), and A-4(2)
(Conversion: 1 ft. = 0.3 m)

Sample No.	Soil Class	% Passing #200 Sieve	PI	Erodibility Factor	Length (Ft.)	Slope (%)	LS Factor	UPI	Undermined
C-1-B	A-2-4	23.2	7.8	0.08	340	8.9	2.11	17	No
C-5	A-2-4	35.1	9.6	0.12	560	10.4	3.45	41	Possible
C-9	A-2-4	28.6	9.9	0.07	270	6.3	1.16	8	No
F-3	A-2-4	34.4	NP	0.19	500	4.7	1.10	21	Possible
F-6	A-2-4	34.6	2.8	0.22	580	10.4	3.02	66	Yes
					160	3.1			
G-12-A	A-4(0)	36.3	4.7	0.22	1055	2.1	0.72	16	No
H-3	A-4(0)	35.6	6.2	0.14	340	4.2	0.79	11	No
C-10	A-4(1)	39.7	4.8	0.13	850	9.9	3.94	51	Yes
F-8-A	A-4(1)	39.3	6.7	0.18	315	7.8	1.46	26	Yes
					480	3.6			
F-8-B	A-4(1)	41.3	NP	0.23	360	7.3	1.38	32	Yes
					630	3.1			
F-12-B	A-4(1)	37.5	NP	0.23	600	4.2	1.05	24	Yes
C-8-A	A-4(2)	45.4	6.1	0.17	450	6.8	1.67	28	Yes
H-6	A-4(2)	46.5	2.2	0.25	760	8.3	2.89	72	Yes

Table 4

Data for Sample Sites; Soil Classes A-4(3) and A-4(4)
(Conversion: 1 ft. = 0.3 m)

Sample No.	Soil Class	% Passing #200 Sieve	PI	Erodibility Factor	Length (Ft.)	Slope (%)	LS Factor	UPI	Undermined
A-5	A-4(3)	48.3	6.0	0.17	295	9.4	2.14	36	No
A-6	A-4(3)	52.2	NP	0.23	355	7.8	1.81	42	Yes
					665	3.1			
B-5	A-4(3)	48.8	6.3	0.24	300	1.0	0.98	24	Yes
					195	4.2			
B-10	A-4(3)	48.2	5.9	0.19	360	5.2	1.06	20	No
F-11	A-4(3)	46.6	NP	0.29	295	8.9	1.97	57	Possible
H-4	A-4(3)	50.0	3.0	0.32	300	8.9	1.78	57	Yes
					200	4.7			
A-10	A-4(4)	52.5	6.4	0.22	290	9.9	2.30	51	Possible
B-3	A-4(4)	55.7	5.7	0.34	555	3.1	0.75	26	Yes
B-4	A-4(4)	53.8	NP	0.29	175	4.2	1.35	39	Yes
					220	6.8			
					85	5.2			
B-7	A-4(4)	57.0	NP	0.43	150	8.9	1.48	64	Possible
					70	4.7			
B-9	A-4(4)	55.0	NP	0.33	330	9.4	3.05	101	Yes
					50	16.1			
C-8-B	A-4(4)	54.5	2.7	0.36	250	10.9	2.05	74	Yes
					250	5.2			
G-5	A-4(4)	56.0	NP	0.29	300	6.3	1.22	35	Yes

Table 5

Data for Sample Sites; Soil Classes A-4(5) and A-4(7)
(Conversion: 1 ft. = 0.3 m)

Sample No.	Soil Class	% Passing #200 Sieve	PI	Erodibility Factor	Length (Ft.)	Slope (%)	LS Factor	UPI	Undermined
A-1	A-4(5)	57.5	NP	0.29	200	9.9	1.91	55	No
A-3	A-4(5)	60.7	5.2	0.32	250	4.9	0.83	27	Yes
A-7	A-4(5)	58.1	NP	0.36	395	7.3	1.73	62	Yes
C-6-B	A-4(5)	57.4	10.0	0.22	220	3.6	0.55	12	No
F-12-A	A-4(5)	57.4	7.1	0.26	320	8.3	1.88	49	Yes
F-13-A	A-4(5)	61.1	5.5	0.26	370	6.3	1.36	35	Yes
Andrea	A-4(5)	58.4	7.8	0.41	235	3.1	1.04	43	Yes
Drive					190	5.7			
G-8	A-4(5)	59.9	3.1	0.32	365	5.2	1.07	34	Possible
G-11-B	A-4(5)	61.9	NP	0.33	285	4.7	0.83	27	Yes
A-9	A-4(7)	68.0	NP	0.40	395	9.9	2.68	107	Yes
F-14	A-4(7)	69.6	6.4	0.36	365	8.3	2.01	72	Yes
G-4-A	A-4(7)	69.9	3.7	0.39	365	7.8	1.83	71	Yes

Table 6

Data for Sample Sites; Soil Classes A-4(8), A-6, and A-7-6

(Conversion: 1 ft. = 0.3 m)

Sample No.	Soil Class	% Passing #200 Sieve	PI	Erodibility Factor	Length (Ft.)	Slope (%)	LS Factor	UPI	Undermined
A-4	A-4(8)	72.9	10.0	0.26	370	8.3	2.02	53	Yes
C-6-A	A-4(8)	75.2	8.8	0.30	450	6.3	1.50	45	Yes
G-4-B	A-4(8)	72.9	3.2	0.41	420	5.7	1.29	53	Yes
G-10	A-4(8)	80.7	4.4	0.47	460	6.3	1.52	71	Yes
B-11	A-6(2)	42.6	10.7	0.14	660	5.2	1.44	20	No
F-9	A-6(2)	40.9	12.2	0.13	280	4.7	0.83	11	No
C-1-A	A-6(5)	49.2	13.6	0.14	225	4.2	0.65	9	No
B-1	A-6(7)	50.9	15.1	0.15	800	9.4	3.52	53	No
B-6	A-6(7)	64.1	12.3	0.22	705	8.3	2.79	61	Yes
F-5	A-6(9)	76.9	12.5	0.32	975	3.6	1.16	37	Possible
C-4	A-7-6(9)	61.5	18.9	0.18	400	9.9	2.44	44	No
					180	5.2			
C-7	A-7-6(13)	61.6	27.2	0.20	625	8.3	2.62	52	No

evidence of undermining. All of the conclusions regarding undermining for the sample sites were the result of the examination and deduction by as many as 4 observers and never less than 2, independently.

From an analysis of the tables, it is easily concluded that the dividing line between undermining and no undermining occurs at the point where the UPI is equal to 21. In all instances where the UPI was less than 21 there was no evidence of undermining. In thirty-six of the 41 cases where the UPI was greater than or equal to 21, the undermining was either definite or very possible. These statements are shown graphically in Figure 6. The 5 discrepancies (i.e. samples A-1, A-5, B-1, C-4, and C-7) that are produced by the system can be partially, if not completely, explained.

Samples C-4 and C-7 (Table 6) are in the AASHTO A-7-6 classification, i.e. they are clay soils. Young and Wiersma studied the effect of raindrop impact in soil erosion and concluded that it was the major force in initiating erosion. (16) However, they stated that flowing water played a very important role in erosion initiation with the more noncohesive soils, and an analysis of their data implied that the effect of raindrop impact was more prevalent with the cohesive than with the noncohesive soils. Since raindrop impact is definitely not a factor in sidewalk undermining, the preceding is support of the hypothesis that the more cohesive (clay-type) soils would not be subject to sidewalk undermining, and therefore would not be governed by the same UPI limitations as the noncohesive soils. This hypothesis is further supported by Paaswell in his state of the art review of the causes and mechanisms of cohesive soil erosion. (17) Sample B-1 (Table 6) is a clay-type or cohesive soil also, and its discrepancy in the UPI would therefore be explained in the same manner.

In the case of samples A-1 and A-5(Tables 4 and 5, respectively) the discrepancies could not be accounted for in the foregoing manner since the samples were noncohesive soils. However, the sites from which the samples were taken possess physical characteristics that distinguish them from the others. Both sites have either constant yard slopes that are very flat, or yards that are flat close to the houses and then slope sharply downward at the sidewalk. Most of the other yard slopes were constant and were steeper and thus allowed less infiltration of water. Additionally, the site for sample A-1 is the shortest section and has only two houses draining to the street in the aforementioned fashion, and the site for A-5 has a great many trees in the median strip, which would tend to inhibit undermining. Other sample sites had trees, but none had as many as site A-5, considering its length.

The assumption that the land cover and land management practices on these two sites would be approximately equal to those for the other sites is not accurate. The combination of the physical characteristics described for the sites for samples A-1 and A-5 would make these factors less than the assumed value of unity and, therefore, would reduce the calculated UPI. More extensive research would be necessary to establish the exact value of the land cover and land management practice factors in instances such as these.

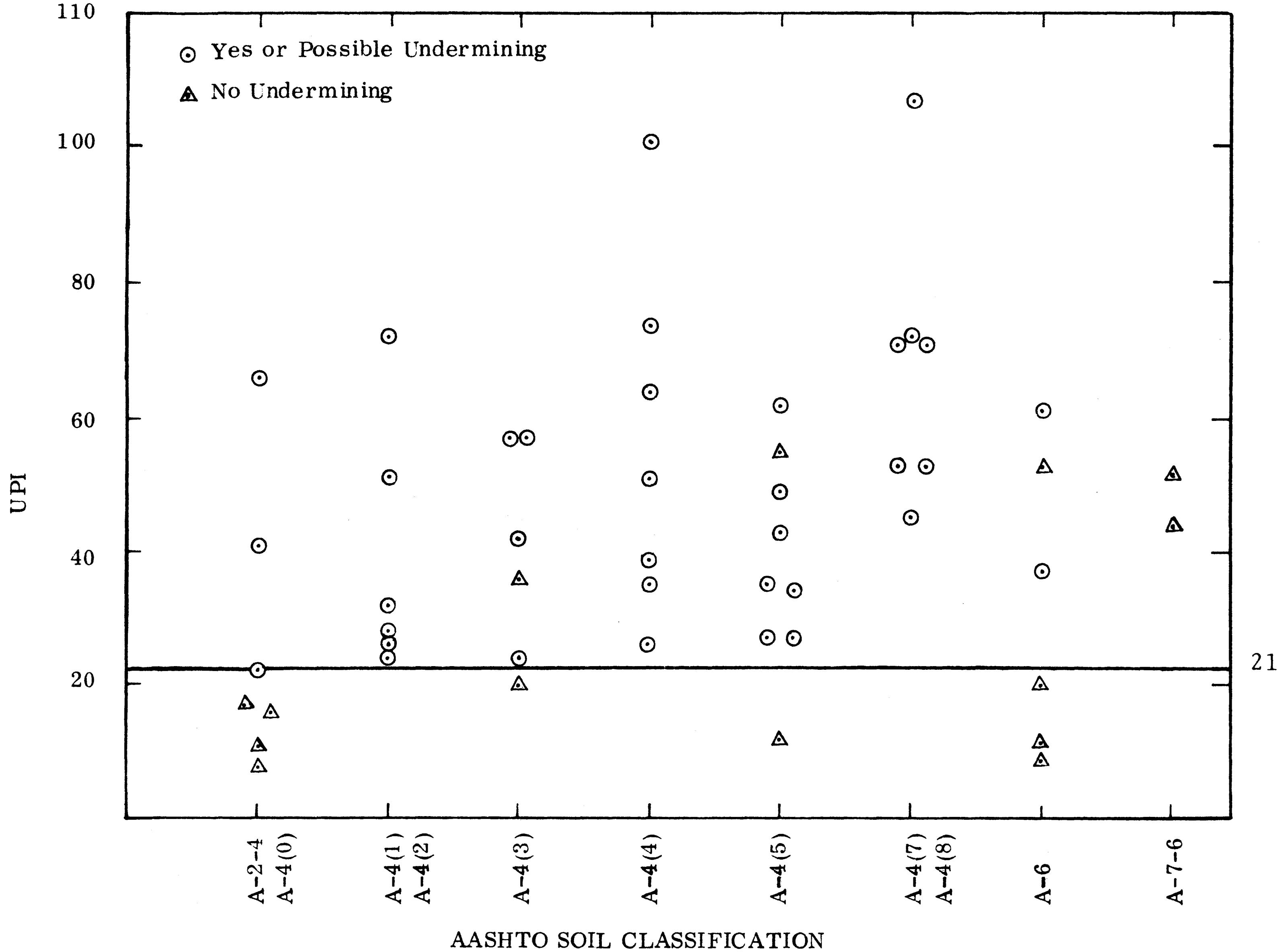

Figure 6. Undermining of sample sites plotted as UPI versus AASHTO soil classification.

There are numerous other variables which, if accounted for, would result in a more exact correlation between the degree of undermining and the magnitude of the UPI. In addition to the exact yard slope to the sidewalk, and the number, location, and size of trees, if any, which were already mentioned, included would be compaction of the subgrade at the time of construction, the time of year of construction, exact age of the site, depth of the drainage area, roof area of the houses, precise location of the downspouts, and the exact distance from the downspout to the sidewalk. Even though these variables were not accounted for in calculating the UPI, there was a very good correlation between the degree of undermining and the magnitude of the UPI. The relations indicative of the data are listed in Table 7.

Table 7

Relationship Between Degree of Undermining and UPI

UPI	Degree of Undermining
< 21	None
21 to 30	Minor
30 to 45	Minor to Moderate
45 to 60	Moderate to Severe
60 to 100	Severe
>100	Very Severe

Thus, the magnitude of the UPI established for each sample site resulted in not only an excellent correlation as to whether there was undermining or not, but also as to the degree of sidewalk undermining that prevailed.

ALTERNATE SYSTEM

Even though the UPI system seems very capable of predicting undermining, it is quite involved. Normally, for construction purposes, only the coarse and fine gradations, the Atterburg limits, the maximum density, the optimum moisture content, and a California Bearing Ratio (CBR) are determined, and the soil sample is given an AASHTO classification. To establish a UPI for a particular situation, a hydrometer analysis and a specific gravity test must be conducted, and the organic matter content, the structure index, and the permeability class of the soil must be determined. Additionally, the effects of the length and slope of the site must be accounted for. These requirements involve more testing and much more time than normal, and consequently mean added cost. An alternate system whereby the erodibility characteristic of the soil at a sidewalk site can be estimated from the soil tests currently performed and from a general topographical description was, therefore, established. The factors considered in this sytem are as follows:

1. A minimum longitudinal gradient of 3% (sample B-3 (Table 4) bears out this fact),

2. the potential for more than two houses to drain toward the street, and

3. the erodibility characteristic of the soil defined as 34% or more of the total soil sample passing the No. 200 sieve and a PI of 13 or less.

It must be emphasized that all of the above factors are present when undermining is active or imminent. The relationship of undermining to the soil's erodibility characteristics as defined in this alternate system is shown graphically in Figure 7. Of the eight samples falling within the soil limitations set and designated as not undermined, six are defined as not discrepant under the more exact UPI system and the other two are samples A-1 and A-5, whose variances have been previously discussed.

This alternate technique is not as precise as the previously discussed UPI system because it is so generalized. However, its greatest advantage is that it would save a great deal of time and money over the UPI system, even though its use may lead to special construction treatment in some situations where undermining would probably not materialize and where no special consideration would be indicated by the UPI method. The resulting economy and ease of application make the alternate system much more practical and desirable for use in establishing criteria whereby special sidewalk construction may be required because of the high potential for undermining.

AREA OF UNDERMINING POTENTIAL

Additional analysis of the soil survey report for Fairfax County indicated that approximately 44% of the county area may have the type of soil encompassed by the alternate system.[8] However, of this amount, some is already developed and some of the undeveloped portion will have longitudinal gradients less than the 3% minimum designated by the alternate system.

The sidewalk undermining problem is not confined exclusively to Fairfax County. The Manassas Residency (i.e. Prince William County) has been experiencing problems with sidewalk undermining for the past few years. Prince William County has generally the same types of soils as Fairfax County.

Examination of the available soil survey reports of other counties of the piedmont region showed strong similarities between the soil types found in these counties and the soil types found in Fairfax. Specifically, seven of the ten reports examined (viz. those

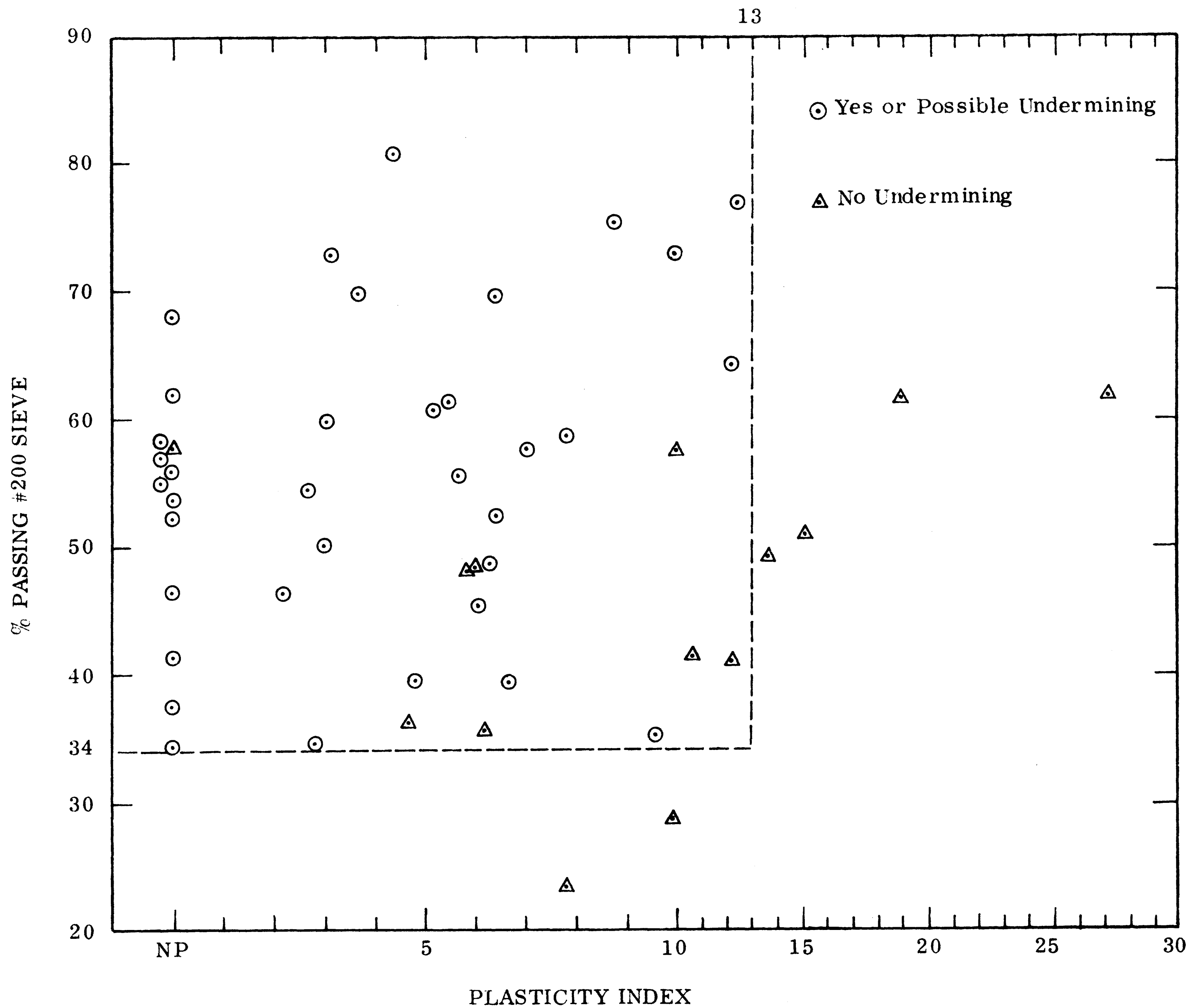

Figure 7. Undermining of sample sites plotted as percent passing #200 sieve versus plasticity index.

for the counties of Albemarle, Charlotte, Culpeper, Fauquier, Fluvanna, Loudoun, and Orange) displayed these strong similarities. The other three reports (those for the counties of Halifax, Mecklenburg, and Prince Edward) were much older, with seemingly much less detail and, therefore, no similarities could be deduced. Thus, it is felt that sidewalk undermining could become a problem throughout the piedmont region of Virginia if sidewalks meeting the geometric conditions given earlier are built.

CONCLUSIONS

Sidewalk undermining in Fairfax County can definitely be attributed to the combination of specific soil characteristics and site conditions. Generally, the factors that are necessary and sufficient to initiate sidewalk undermining are as follows:

1. A soil with 34% or more passing the No. 200 sieve and a PI of 13 or less,
2. a longitudinal gradient of 3% or more, and
3. a potential for more than two houses to drain toward the street.

The system whereby a UPI is established for each site is more exact but the more generalized alternative system is simpler and more economical. Further study will determine what special treatment would be necessary in new sidewalk construction to prevent undermining in areas as defined by either of the systems presented in this report.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the cooperation of Resident Engineer D. S. Roosevelt and his staff in the conduct of these studies. The efforts of R. W. Gunn, materials technician supervisor, in the conduct of the field work and of E. A. Wood, undergraduate student helper, in the conduct of the laboratory work are also very much appreciated.

Additionally, Culpeper District Materials Engineer C. H. Robson, Jr. and his staff must be commended for performing some of the laboratory work.

The study is under the general direction of J. H. Dillard, head of the Research Council, and is being financed from state research funds.

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