

SIDEWALK UNDERMINING STUDIES

Phase I

Hydrology and Maintenance Studies

by

K. H. McGhee
Research Engineer

(The opinions, findings, and conclusions expressed in this report are those of the author 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

May 1975
VHTRC 75-R48

2376

SUMMARY

Studies of the maintenance and hydrology considerations involved in a sidewalk undermining problem in the Fairfax area are reported. Sidewalk undermining is attributed principally to a highly erodible soil found in much of the area and to the fact that current design standards and construction specifications are not adequate for sidewalk construction on such a soil.

Recommendations of the study include:

1. The use of a sidewalk replacement technique wherein the subgrade soil is protected by polyethylene sheeting and infiltrated water is carried away by a subsurface drainage system.
2. A nomograph suggested for the determination of infiltration water and subdrainage requirements.
3. A suggestion to construct several test sections where sidewalk would be replaced on a densely graded base with a polyethylene or asphalt covering.
4. A suggestion to consider a slab removal and reuse technique.

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INTRODUCTION

Since mid-1974 the Research Council has been working with the Fairfax Residency on a severe sidewalk maintenance problem stemming from the erodibility of certain soils found in much of Fairfax County. While there are other problems associated with sidewalk maintenance in the area, the most difficult to handle are the many cases where sidewalks have been undermined through erosion of the immediately underlying soil layer. Undermining removes the support from under the sidewalks and results in faulting of 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 repair. Due to the current policy of accepting sidewalks into the secondary system concurrent with acceptance of the adjacent subdivision pavements, the sidewalks become a maintenance responsibility of the Highway and Transportation Department. Maintenance costs of around \$200,000 to \$400,000 per year are associated with the sidewalk undermining problem. The situation is aggravated by the fact that undermining occurs at a faster rate than maintenance can be programmed. Thus, a recent estimate places the cost of presently needed repairs at some \$2,000,000.

The attention of the Research Council was first called to the problem through a memorandum dated March 22, 1974, from District Engineer D. B. Hope to Director of Program Management H. G. Blundon. Specifically requested in this memorandum was the Council's assistance in the development of solutions applicable at the time of initial construction to prevent the occurrence of undermining on future sidewalks. During preliminary studies and discussions with Residency personnel it became evident, however, that any assistance with maintenance procedures, especially assistance directed at reducing costs, would also be welcomed. Therefore, the present report describes two test sections on which maintenance replacement procedures differing from those used by Residency personnel were employed.

In connection with these test sections, certain hydrology considerations were necessary and are also described in this report.

It should be noted that other studies are under way to better define the problem soil areas and to develop construction specifications and design standards for sidewalks. Such standards are necessary as guidelines for local governmental agencies that control construction before the sidewalks are offered to the state for acceptance.

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 square blocks of subdivision development. Yards typically slope steeply 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.

Evidence of undermining is dislocation of joints and distortion (rotation) of slabs in either the transverse or longitudinal planes. Eroded material is usually deposited at the low point of vertical curves although it may break out intermittently at sidewalk joints or along the edges. After heavy rains these deposits are very evident although much of the material is carried away into the storm drain system. Voids under the walks range from negligible up to several feet, depending upon the severity of erosion. It is apparent that large volumes of water may flow under the sidewalks on occasion. Some evidence of the severity of undermining and the types of distortion encountered is indicated in Figures 1 and 2.

An approximate mechanism of erosion and undermining is as follows:

1. First stage erosion initiates a void at the interface between the sidewalk and the underlying soil. This condition may be aggravated by inadequate construction control, and peculiarities of the subgrade soil. No base material is used between the sidewalk and the subgrade.
2. Water goes beneath the sidewalk at the "yard" side, enters the void, and proceeds downgrade causing further erosion and transportation of the subgrade soil as water volume and velocity increase.



Figure 1. Severe sidewalk undermining.

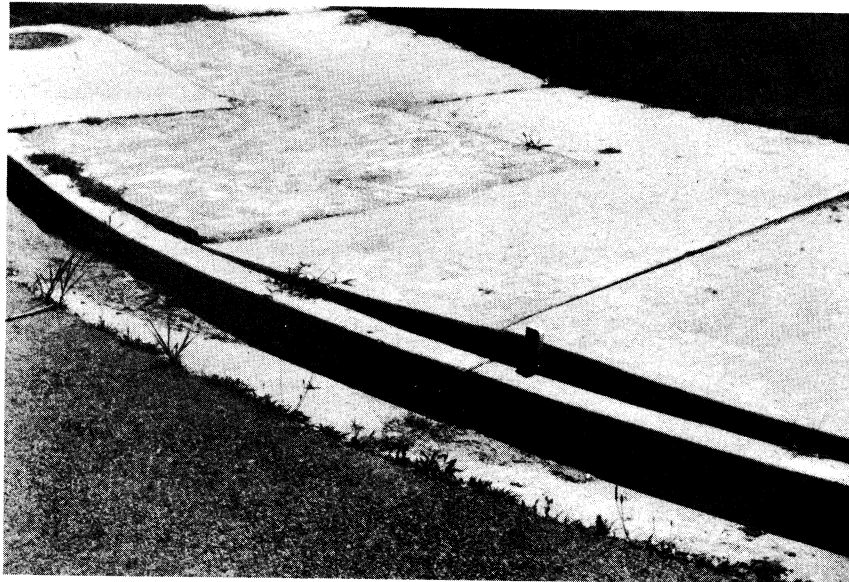


Figure 2. Sidewalk distortion due to undermining.

3. In most cases, 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 yards typically is higher in elevation than the sidewalk, and the sidewalks thus function as paved ditches to carry much of the drainage longitudinally. If voids are present under the walks, the water will flow under as well as over the concrete slabs. In an earlier study of the sidewalk maintenance problem, much of the undermining was attributed to excessive edge trimming of the walks by property owners.⁽¹⁾ Such trimming, sometimes to the depth of the 4-inch (100 mm) slabs, gives the water ready access to the subgrade soil.
4. The earlier observation that undermining is most often present where longitudinal grades are 3% or more is probably related to the fact that unless longitudinal grades are flat there will always be some longitudinal drainage, either on top of the sidewalks or beneath them. Although some of the problem sidewalks were constructed flat, many have cross-slopes of approximately 2%. When longitudinal grades exceed this 2% cross slope, the preponderance of drainage will be longitudinal.
5. One further complication to the undermining problem is provided by water flowing downgrade on the surface of walks which have been repaired or have never been undermined until it reaches an undermined section and enters the area beneath the walks. In such cases, the volume of water contributing to the undermining can greatly exceed the runoff attributable to the property directly adjoining the walk.

METHODS OF PREVENTING UNDERMINING

Upon even scant consideration it becomes apparent that at least four actions or combinations of actions can be taken to prevent undermining of sidewalks built on erodible soils. These are:

1. Stop the entry of water to the areas beneath the sidewalks.

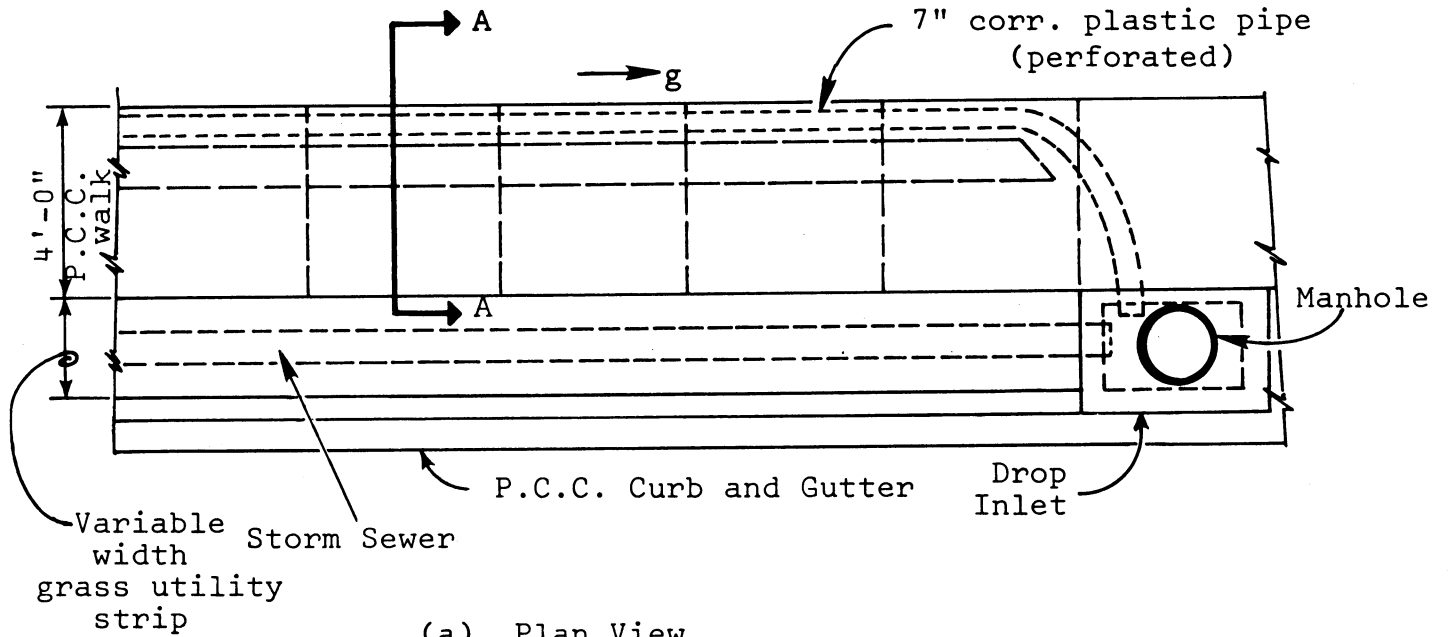
2. Protect the erodible soil through use of a cover material or through special handling of the subgrade.
3. Reduce the undermining potential of infiltrated water by reducing its velocity.
4. Provide an effective means of removing infiltrated water from beneath the walks without damage to the subgrade soils.

Detailed study by others of several severe undermining situations led to the conclusion that it would be very difficult to prevent the infiltration of surface water into the area beneath the sidewalks. (1,2) Thus, for maintenance purposes, both the County of Fairfax and Fairfax Residency personnel have decided that it would be better to protect the erodible soil by the use of aggregate base and longitudinal curtain walks 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. (1,2)

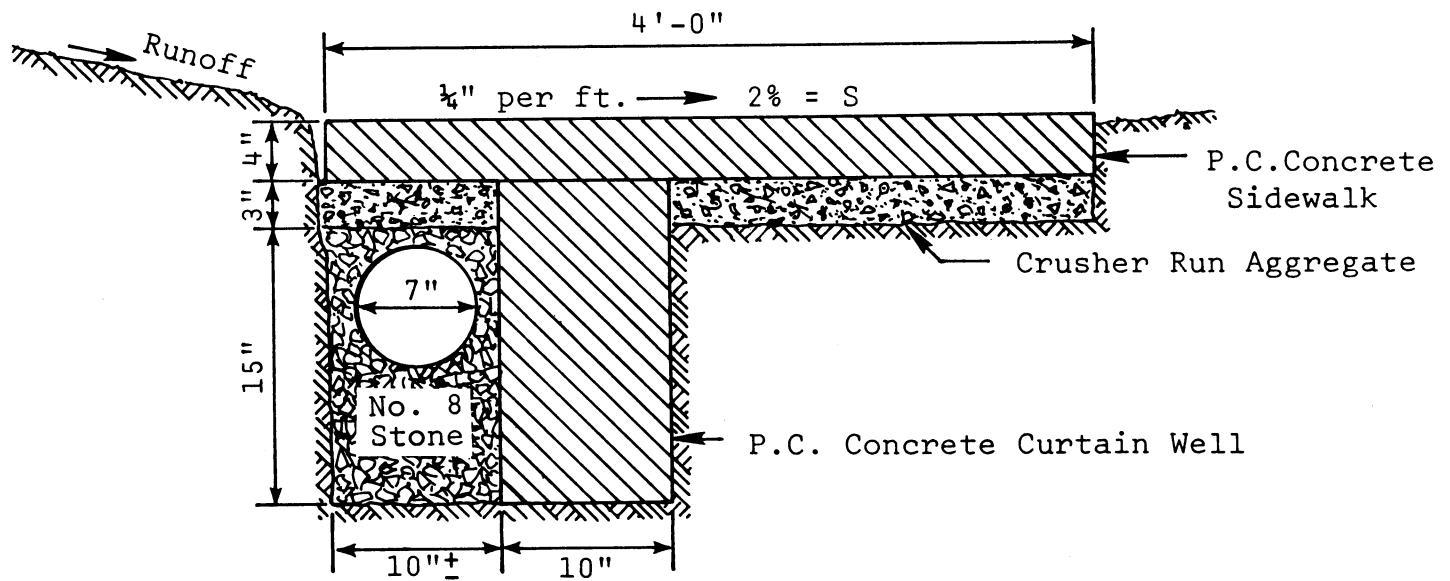
A typical installation of this type is shown under construction in Figure 3 and schematically in Figure 4. Note that the drainage system is installed on the high side of the walk to intercept lateral drainage from yards or longitudinal drainage along the sidewalk and direct it into the storm sewer system. The concrete curtain wall prevents the flow of infiltrated water laterally and directs it into the perforated plastic drain pipe. The subgrade soil to the right (Figure 4(b)) of the curtain walk is protected by a layer of densely graded crushed stone.



Figure 3. Sidewalk replacement utilizing curtain wall and subsurface drainage.



(a) Plan View
(Not to Scale)



(b) Section A-A
(Not to Scale)

Figure 4. Sidewalk reconstruction with curtain wall and drainage system. (Metric conversion 1 in. = 25.4 mm).

While this method of replacement has proven successful in that no subsequent undermining has been found, it is costly and questions have been raised concerning the determination of pipe sizes to be used on the various grades encountered in the maintenance program.⁽³⁾ Further discussion of these questions is presented below.

HYDRAULIC CONSIDERATIONS

The runoff of rainfall from drainage areas is traditionally calculated from the Rational Formula.⁽⁴⁾

$$Q = CIA$$

where:

$$Q = \text{Discharge (cfs)}$$

$$C = \text{Runoff coefficient}$$

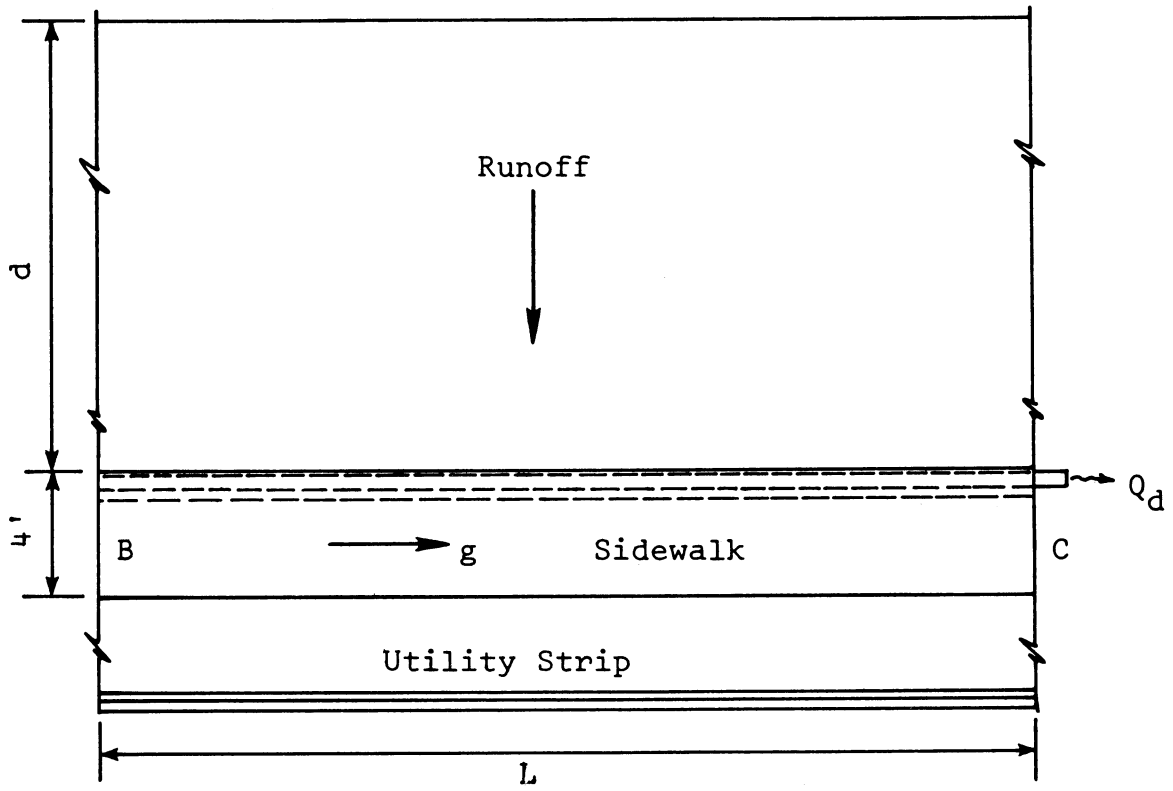
$$I = \text{Average rainfall intensity (in./hr.)}$$

$$A = \text{Drainage area}$$

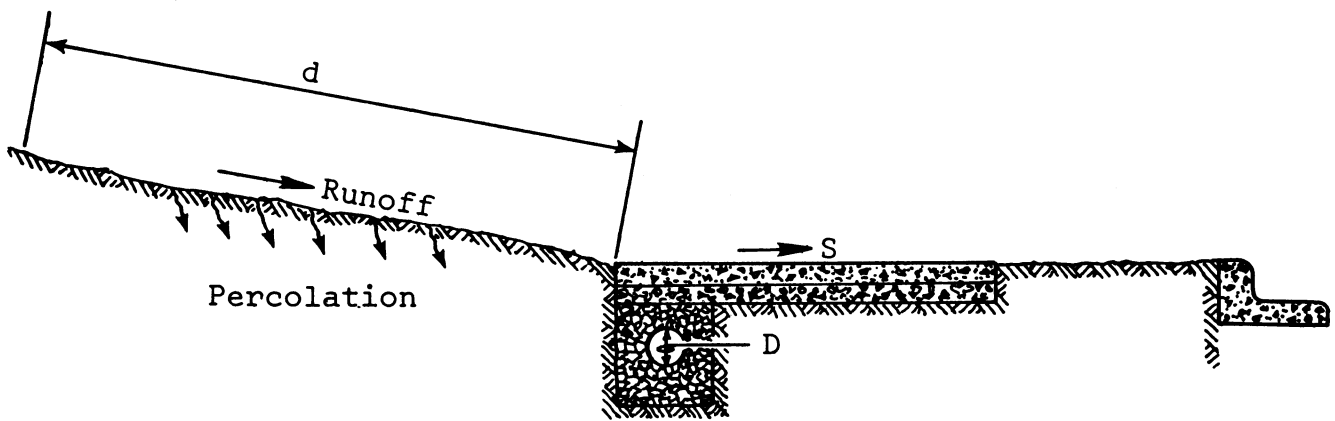
For the purpose of designing sidewalk underdrains the drainage area (A) may be considered as any of the surrounding area lying at a higher elevation than the sidewalk and draining to the sidewalk without relief at some intermediate point. A simplified case is illustrated in Figure 5, where, for a sidewalk of length L with an underdrain discharging at point C, the runoff area of depth (d) will be $A = dL$.

For the design of pavement subdrainage systems (highly analogous to the sidewalk drainage problem) Cedargren recommends using the 1 hour/1 year frequency precipitation rate as the design precipitation rate.⁽⁵⁾ This rate is the maximum rainfall in 1 hour that can be expected to occur one time each year. The rate given for Virginia and recommended for this discussion is $I = 1.5$ in./hr. (38 mm/hr).

The runoff coefficient is related to the slope and permeability of the drainage area and is subject to a great deal of variability. Although in most cases some water will percolate into grass covered drainage areas, it is suggested that a value of $C = 1.0$ be used in the present case even though a slightly excessive computed runoff may result.



(a) Plan View
(Not to Scale)



(b) Cross Section
(Not to Scale)

Figure 5. Runoff computations.
(Metric conversion 1 ft. = 0.3 m).

It must be recognized that not all the runoff reaching the upper edge of the sidewalks will infiltrate into the area beneath the walks. Cedargren recommends that a design infiltration rate (I_d) be determined by multiplying the design precipitation rate by a coefficient between 0.50 and 0.67 for portland cement concrete pavements.⁽⁵⁾ The 0.67 coefficient is suggested for the determination of sidewalk infiltration so that $I_d = 0.67 I = 0.67 \times 1.5 = 1.0$ in./hr. (25 mm/hr).

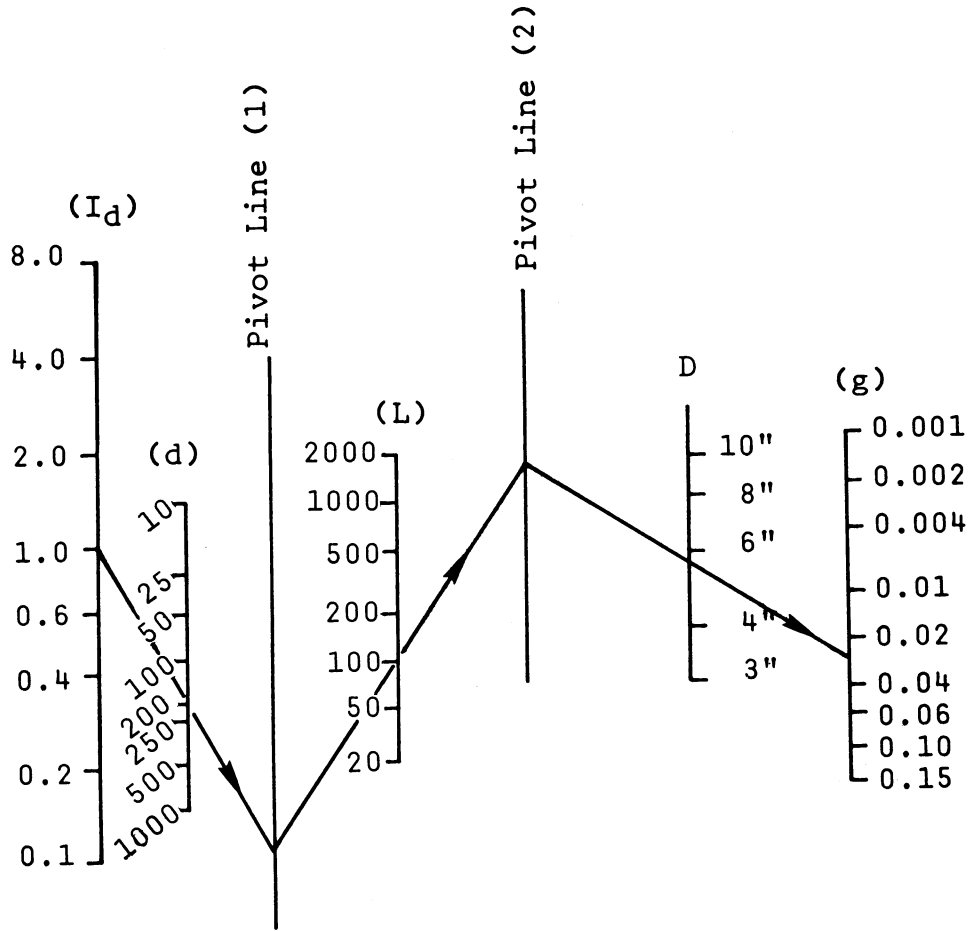
In view of the above discussion, the design discharge, Q_d , from the Rational Formula with the proper dimensional constant is

$$Q_d = \frac{CI_d A}{43200} = \frac{1.0 \times 1.0 \times dL}{43200} = \frac{dL \text{ (cfs)}}{43200} \text{ or } 650 \text{ dL } \frac{\text{mm}^3}{\text{s}}$$

The pipe size required to carry the design discharge with a hydraulic gradient equal to the grade of the sidewalk (g in Figure 5) can be computed from any of several pipe formulas such as those used in culvert design. Cedargren, however, has developed a nomograph for the determination of collector pipe diameter and spacing for use in the design of pavement subsurface drainage systems.⁽⁵⁾ A modification of this nomograph to accommodate the sidewalk under-drain factors is given in Figure 6.

In using the nomograph, assuming I_d is always 1.0, it is necessary only to estimate the depth of the drainage area adjoining the walk and the average grade of the walk. The nomograph then may be used directly to determine the required pipe diameter (D) and the outlet spacing (L). In most practical cases the outlet spacing will be dictated by the location of storm sewer drop inlets so that the pipe size will be the only factor to be determined.

Clearly, the judgment of the engineer will be required to make use of the suggested approach in special cases, such as for extremely long segments of walk or extremely deep drainage areas. On the other hand, if the normally specified pipe is of large enough diameter, most practical cases will be handled automatically. For example, the 7-inch (178 mm) diameter pipe currently used as illustrated in Figure 4 will be adequate for most cases, some of which are given in Table 1.



KEY: I_d = design rainfall rate (in/hr)

d = depth of yard (feet)

L = distance between outlets (feet)

D = perforated pipe (corrugated) diameter (inches)

g = pipe gradient (sidewalk grade) = $\frac{\text{fall}}{\text{length}}$

EXAMPLE: $I_d = 1.0 \text{ in/hr}$, $d = 200 \text{ ft.}$, $L = 100 \text{ ft.}$, $g = 0.03$

1. Extend line from $I_d = 1.0 \text{ in/hr}$ through $d = 200 \text{ ft.}$ to intercept pivot line (1).
2. Extend line from pivot line (1) through $L = 100 \text{ ft.}$ to intercept pivot line (2).
3. Extend line from pivot line (2) to $g = 0.03$.
4. Read, $D = 6''$ pipe required.

Figure 6. Nomograph for selection of perforated pipe diameters and outlet spacings. Adapted from Cedargren. (5)
(Metric conversion 1 ft. = 0.3 m).

Table 1

Typical 7-Inch Pipe Application (I_d - 1 inch)

<u>g</u>	<u>L</u> (ft.)	<u>d</u> (ft.)
3%	100	400
3%	200	200
4%	100	600
4%	200	300
6%	200	350
6%	300	200

(Metric Conversion, 1 ft. = 0.3 m)

Upon consideration of the above factors, it was concluded that a suitable sidewalk maintenance-replacement scheme wherein the longitudinal curtain wall was eliminated could be developed with the assumption that all runoff could be handled by the under-drain system. Test sidewalk sections using this concept are discussed below.

EXPERIMENTAL MAINTENANCE INSTALLATIONS

During discussions of the sidewalk maintenance-replacement problem with Resident Engineer D. S. Roosevelt, it was recommended that several test sections using polyethylene sheeting to protect the erodible subgrade soil and incorporating a suitable subsurface drainage system be constructed. After several modifications to accommodate construction problems, two test sections were constructed as indicated in Figure 7. The actual cross section is variable in shape, depending upon the nature of the erosion channel (Figures 8 and 9). After cleaning and shaping of the subgrade soil approximately 6 inches (152 mm) of crusher run aggregate were placed in the lower portion of the trench. Polyethylene sheeting was then placed to cover the entire excavated area. A 7-inch (178 mm) diameter corrugated, perforated plastic pipe was laid in the trench and covered to the elevation of the bottom of the sidewalk with no. 8 stone. The no. 8 stone is open-graded to permit entry of infiltrated water to the drain pipe. After the 4-ft. (1.2 m) wide sidewalk was placed and the forms removed, the 1-ft. (0.3 m) width on either side of the walk was filled with top soil and seeded. Several of these operations are indicated in Figure 10.

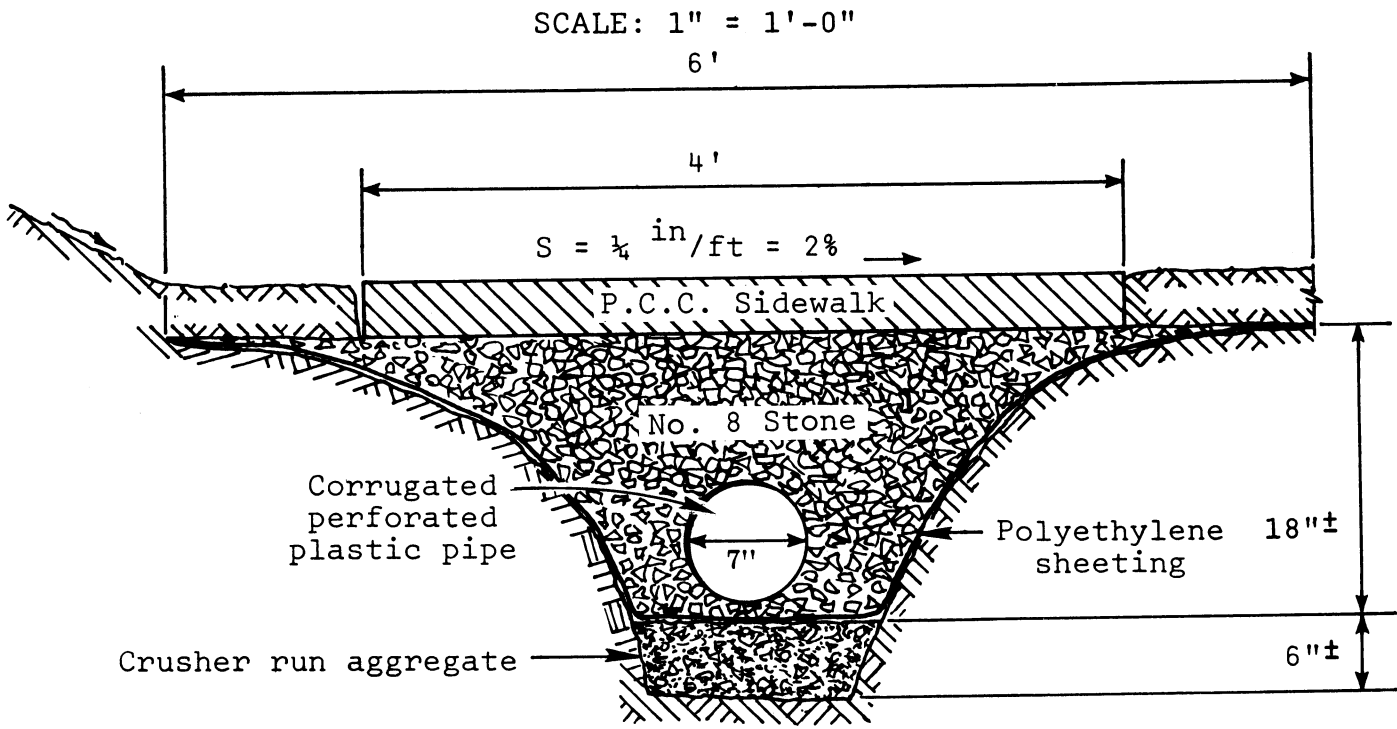


Figure 7. Cross section of experimental sidewalk installation. (Metric conversion 1 ft. = 0.3 m).



Figure 8. Test site showing erosion channel.



Figure 9. Test site showing erosion channel after shaping.

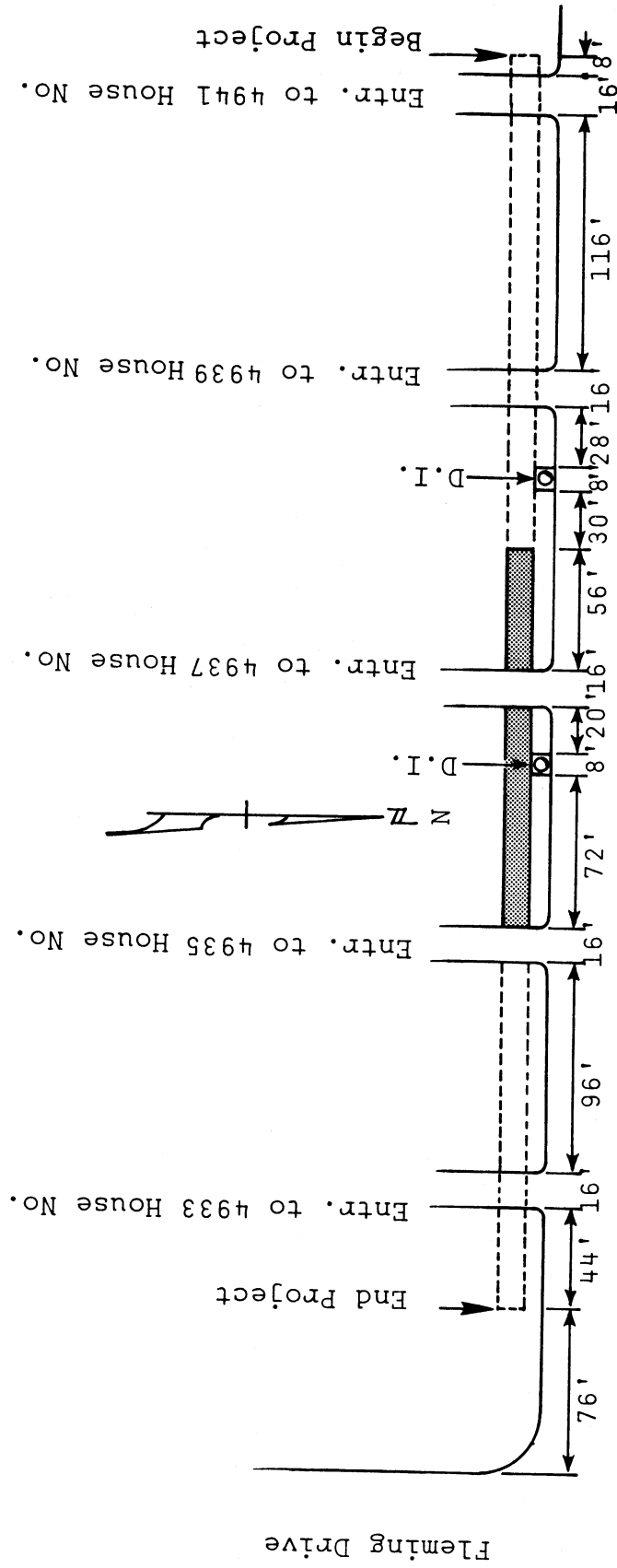


Figure 10. Test site showing installation of polyethylene, pipe, and No. 8 stone.

The experimental sidewalk sections are located, as shown in Figure 11, in the Redfox subdivision just north of Route 620 near the I-495 interchange in Fairfax County. The test sections are located on opposite sides of a vertical curve. The average grade for each section is approximately 6% and each is approximately 160 ft. (48 m) long. The section on the left is tied into a previously improved section, some 70 ft. (21 m) long, where the curtain wall method was used. Therefore, the total length of drainage systems is 230 ft. (69 m) and 160 ft. (48 m) for the left and right sections, respectively. The nomograph (Figure 6) discussed earlier indicates that an acceptable depth of drainage area would be 250 ft. (75 m) and 400 ft. (120 m) for the left and right sections, respectively. Based on the terrain surrounding the test sections, the longer (left) section is considered barely adequate while the shorter section (right) should be more than adequately designed.

The test sections were installed in August 1974 and have been inspected periodically since that time. There is ample evidence that water is entering the drainage systems along the edges of the walks, but there is no evidence of any damage to the structure. On January 9, 1975, after reviewing the test sections several times and with agreement that the drainage systems were functioning properly, D. S. Roosevelt and the author agreed that the new system would be used in most cases where undermined sidewalk replacement was necessary, especially where storm sewer systems are available. Much of the impetus for this change was in the fact that the revised system cost approximately \$26 per square yard as opposed to \$55 for the system containing the curtain wall. Thus, a \$29, or 53%, savings was realized from use of the revised method.(6)

Finally, on March 12, 1975, after three hours of moderate rainfall during an extremely wet period, R. W. Gunn of the Research Council staff observed that the drain from the long section of walk was running approximately one-eighth full of clear water while the drain from the short section showed only a very small flow of clear water.



Andrea Drive

LEGEND
 [Hatched Box] = Existing Sidewalk
 [Dashed Line] = New Test Sidewalk

Figure 11. Location of experimental sidewalk sections.
 (Metric conversion 1 ft. = 0.3 m).

SUGGESTED APPLICATIONS

The polyethylene sheeting — plastic pipe method of sidewalk maintenance, while considerably simpler and less expensive than the method utilizing the curtain wall, is not universally applicable and may not be universally desirable. For example, methods incorporating a subsurface drainage system are not practical where there are no storm drain systems. At the same time, subdrainage may not be necessary where the area draining into a segment of walk is very small. This can be seen by a detailed study of Figure 6, where it will be found that the required pipe size is negligible when the drainage area, dL , is less than about 4,000 sq. ft. (372 m²) or 0.1 acre (0.04 ha) and the grade is more than about 2%. On the other hand, it was pointed out earlier that undermining seldom occurs where grades are less than about 3%. It would, therefore, appear reasonable to eliminate the subdrainage system when the drainage area is less than 0.1 acre (0.04 ha). It is recognized that such a condition will occur only occasionally as in most cases some larger drainage area upgrade will determine the effective drainage area for the section of sidewalk to be repaired. Where the subdrainage system is to be omitted, consideration of the alternate repair procedure described below is suggested.

DESIGN WITHOUT UNDERDRAINS

In many cases, an effective underdrain system cannot be provided because storm drain systems or some other drainage outlets are not conveniently located. This condition will most often occur where grades are fairly gentle such that water velocities are low enough that any undermining that occurs is caused by an extremely erodible soil or very poor construction practices. In either case, it should be possible to prevent the recurrence of undermining by the provision of reasonable protection to the subgrade soil when undermined sidewalks are replaced. One way of providing this protection is through the use of a densely-graded crushed stone covered with polyethylene sheeting or an asphalt prime coat. A suggested design for this type of replacement scheme is illustrated in Figure 12.

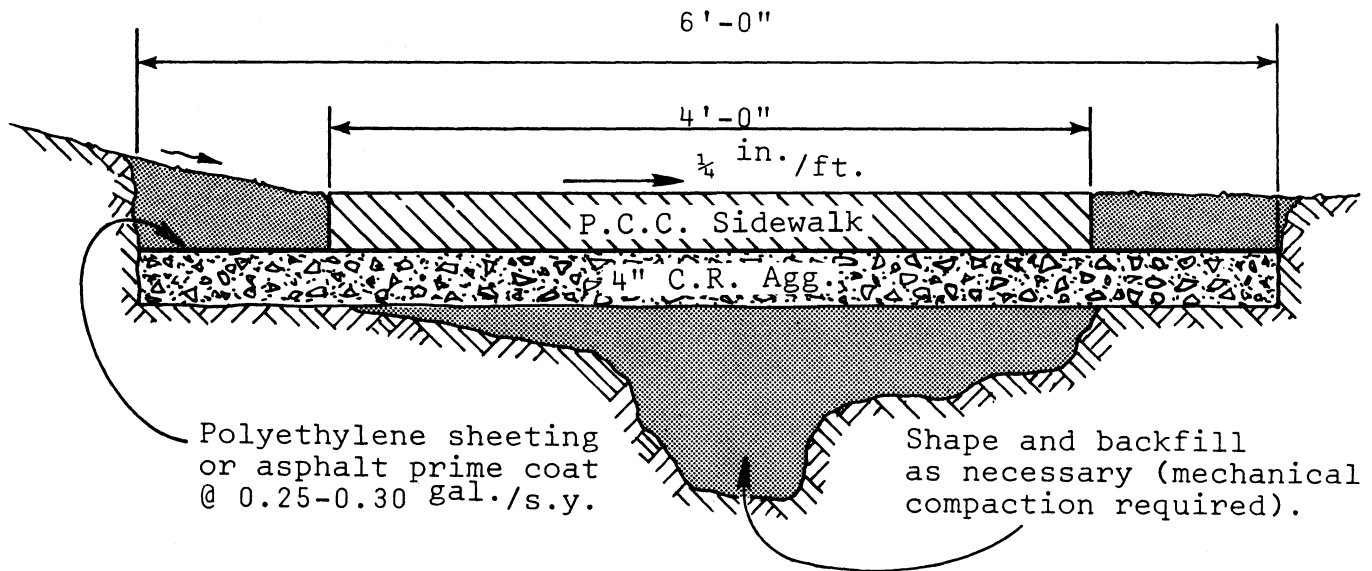


Figure 12. Proposed sidewalk replacement without underdrains. Metric conversion, 1 ft. = 0.3 m.

This proposal is based on two factors, either of which should prevent erosion of the underlying soil. First, if water cannot enter the interface between the sidewalk and its underlying layer, no change can be done. Secondly, even if a small amount of water does enter the interface, the underlying layer is so impervious that no damage will result. It should be noted that in order to minimize the possibility of settlements which may create voids under the walks, close attention to compaction on both the backfill material and the stone base is suggested. One of the several one-man compactors currently available should serve this purpose. In addition, personnel from the Research Council would be available to assist in the construction and evaluation of any test sections installed.

It may also be observed here that the foundation provided in this proposal would be ideally suited to the slab reuse concept wherein faulted or displaced blocks of sidewalk are sawed into manageable sizes, placed aside while the foundation is prepared, at which time the old slabs are reset.

RECOMMENDATIONS

In view of the fact that other studies are under way that are seeking to better define problem soil areas and to develop design standards and construction specifications for sidewalks, the several recommendations offered below should be considered only as interim solutions. Also it is noted that they apply only to sidewalk maintenance activities in areas where erodible soils are evidenced by the presence of undermining. When the problem soil areas and necessary construction controls are better understood, further recommendations for both construction and maintenance activities will be developed. For the time being, the following recommendations appear appropriate.

1. The undermined sidewalk replacement method utilizing polyethylene sheeting, an open-graded aggregate, and a subsurface drainage system should be used whenever practical.
2. The nomograph described earlier is suggested as a means of evaluating the ability of the subsurface drainage system to handle the water infiltrating from large drainage areas. Although the judgement of the maintenance engineer must be exercised when this nomograph is used, it is believed that the 7-inch (178 mm) diameter plastic pipe used in the earlier test sections will carry the drainage in most practical cases.
3. For very small drainage areas where a subsurface drainage system is impractical, a replacement method utilizing a densely-graded stone base with a polyethylene or asphalt covering is recommended.

The construction of several test sections employing this method for larger drainage areas is recommended. These could be located where storm drain systems are not conveniently located. Such test sections would provide an opportunity to assess this method of replacement and its performance. Satisfactory performance might suggest that subsurface drainage systems could be omitted from all future replacement activities.

4. Some consideration should be given to the slab removal and reuse methodology when an appropriate section of sidewalk is available.

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ACKNOWLEDGEMENTS

The author gratefully acknowledges the cooperation of Resident Engineer D. S. Roosevelt, and his staff in the conduct of these studies. The efforts and interest of R. W. Gunn, materials technician supervisor, in the conduct of the field work also are very much appreciated.

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

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