Crown on Soil-Aggregate Roads

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This paper summarizes a study of the relationship between road surface slopes and the severity of potholing on soil-aggregate roads. Although practice in crowning soil-aggregate roads often disregards the influence of longitudinal grade, the study suggests that the effect of grade on the potholing tendency is considerably more than a token effect; a resultant of transverse slope and longitudinal grade appears to be more strongly related to presence and severity of potholing than is crown slope alone. Because a tendency to tilt road crown downhill in sidehill locations can result in flatter crown (and often more severe potholing) on the uphill side of the road, caution in "by eye" shaping of soil-aggregate roads in such locations is suggested.

• POTHOLING is surely one of the primary maladies of soil-aggregate or gravel roads. Materials with good mechanical stability and hence immunity to rutting, and even materials protected against the dry weather problems of dusting and corrugation, may be far from immune to the development of potholes during the wet months. Although safety and convenience in vehicle operation do place some practical maximum on road crown, it has long been observed that soil-aggregate roads with flatter crown slopes are more likely to pothole than those with steeper crown slopes. It has also been observed that potholing is generally more severe on flat, or nearly flat, longitudinal grades. This study has explored the relationship between severity of potholing and crown slope and, perhaps more significantly, between potholing severity and a resultant of crown slope and longitudinal grade. The study has also explored an hypothesis that transverse terrain slope (or the misjudgment of vertical or horizontal which it creates) promotes a tipping or tilt of road crown in a downslope direction by grader operators. The tendency to flatter crown slope on the uphill side may be a primary explanation for an often observed greater frequency of potholes on the uphill side of soil-aggregate roads.

CROWN AND GRADE VS POTHOLING SEVERITY

In 1959, a comprehensive summary of current practice in the design, construction and maintenance of soil-aggregate roads, Huang (1) reported that the maximum rate of crown for soil-aggregate surfaces is usually between $\frac{1}{4}$ and $\frac{1}{2}$ in./ft (0.02 to 0.04 ft/ft). A 1949 publication of the U. S. Bureau of Public Roads (2) suggests this same range in crown slope; it is pointed out that needed crown slope is influenced by steepness of grade, but just how grade should influence needed crown is not defined.

In 1961, his study of circumstances associated with the occurrence of potholes on soil-aggregate roads in Illinois, Huang (3) noted a relationship between crown and pothole formation. Categories used were high crown ($\frac{1}{2}$ in./ft or more), low crown ($\frac{1}{4}$ in./ft), and no crown. Longitudinal grade was not indicated. In an earlier study of crown vs potholing of soil-aggregate roads in Indiana, Illinois, Missouri and Kansas, Burggraf (4) reported that the average of 29 determinations of crown slope where soil-aggregate roads had a good surface was 0.50 in./ft and that for 14 determinations where the road surface was

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potholed or rutted, the average crown slope was 0.24 in./ft. The longitudinal grades at the locations of these determinations were not reported. In recommending an A-shaped crown, Burggraf suggested that crown slope during construction should be ½ in./ft, and should never be less than ⅜ in./ft in the final compacted road. He recommended the use of the crown formula, $C = W(100 - 4L)/4{,}800$, in which L was the longitudinal grade in percent. This formula (very similar to the Rosewater formula (5, 6, 7) gives a crown of ½ in./ft on level sections and would reduce it only to 0.4 in./ft on a 5 percent grade. Burggraf suggested that "for ordinary purposes, the longitudinal gradient factor may be disregarded... ."

Still earlier recommendations or standards of practice concerning crown slope were perhaps as much the result of observation and experience as of specific investigation. Design suggestions are quite plentiful in the early literature but most suggestions are related to a curb and gutter cross-section. Green (5) reported in 1909 that the Chicago West Park Board used a crown height equal to 2 percent of the width of the roadway. Warren (6) suggested in 1909 that crown should be 1 in. for each 4 or 6 ft between curbs where longitudinal grade was 2 percent or less. The greater of these crown slopes was suggested for pavements "providing more secure foothold." Warren considered longitudinal grade in recommending that for 2 to 4 percent grades crown should be only one-half of that required where the grade was 2 percent or less; where longitudinal grade was above 4 percent, crown would be only one-third the basic value. It appears that Warren's corrections for longitudinal grade were as much related to foothold as to hydraulic or road performance considerations. In 1910, Zahniser (7) considered longitudinal grade in suggesting that for "rougher cartways," the crown (in ft) should be equal to the width of the roadway divided by 24 times the percent longitudinal grade. In 1916, an ASCE committee (8) recommended that the crown slope on gravel roads be from ½ to 1 in./ft. Longitudinal grade was not considered in the tabulation of recommended crown slope for various roadway surfacings. The words "the practice generally observed and to be recommended..." suggest that the committee recommendations were essentially a compilation of standard practice at that time.

The more recent studies have helpfully related soil-aggregate road performance to crown slope, but they have not seriously considered effects of longitudinal grade. Although some of the very early writings considered corrections for longitudinal grade, the recommendations are not related to the performance of soil-aggregate roads.

Method of Study

Roads Selected. —Twelve soil-aggregate roads on various town(ship) highway systems in Tompkins County, N. Y., were selected for this study. All roads were surfaced with local bank-run gravels of such gradation and containing enough soil binder that a consolidated but nonrutting surface was produced. Most roads had been treated with chlorides at the time of initial graveling (2 to 8 yr before this study); approximately half had follow-up chloride treatments. Roads selected had a minimum traveled-way width of 16 ft and were generally used full width; narrower roads were not selected to avoid tracking situations likely to leave a W cross-section. Traffic averaged 50 to 150 veh/day. Measurements and observations on these roads were made in early April, after thawing of the roadbed but before any spring maintenance.

Measurements and Observations. —At intervals of 250 ft along both sides of each of these roads, transverse slope and longitudinal grade were measured and severity of potholing was observed in the immediate area. The immediate area for pothole observations was about 20 ft long and included only that side of the road where slope measurements were then being taken. This predetermined spacing of points for measurement and observation minimized any bias in sampling. Measurements and observations were made at a total of 320 points. The size of sample was arbitrary but covered reasonably well the ranges in crown slope and longitudinal grade within which potholing is observed.

Measurements of transverse slope and longitudinal grade were made by liquid-level devices mounted on a pickup truck (Fig. 1). At a point located by use of an auxiliary odometer, the left wheels were placed (by eye) on the crest of the crown. The previously calibrated liquid-level devices gave longitudinal grade over the wheelbase of the

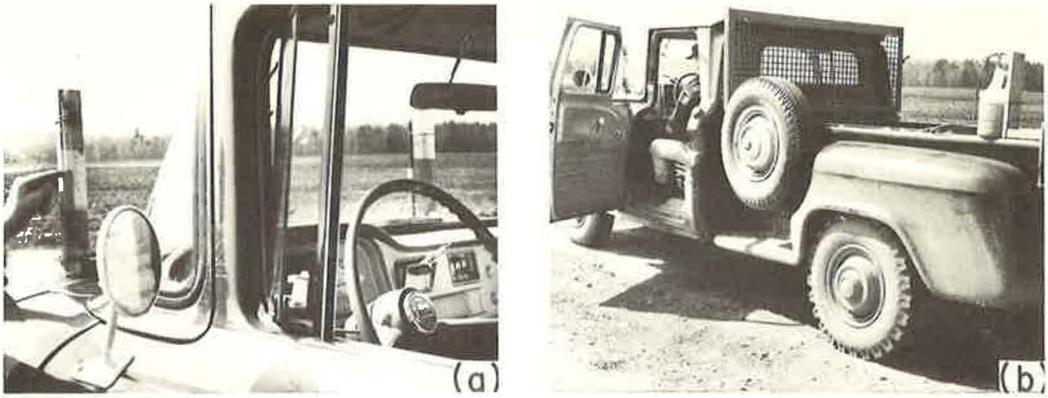


Figure 1. Devices for measuring (a) transverse slope, and (b) longitudinal grade.

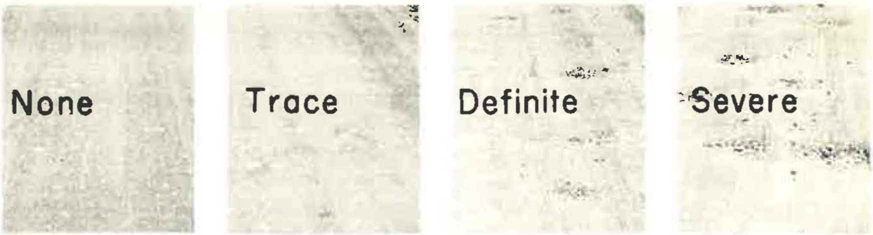


Figure 2. Visual definition of pothole severity.

vehicle and average transverse slope over the distance between left and right wheels. Transverse slopes were recorded to the nearest $^{1}/_{16}$ in./ft and longitudinal grade to the nearest 0.5 percent.

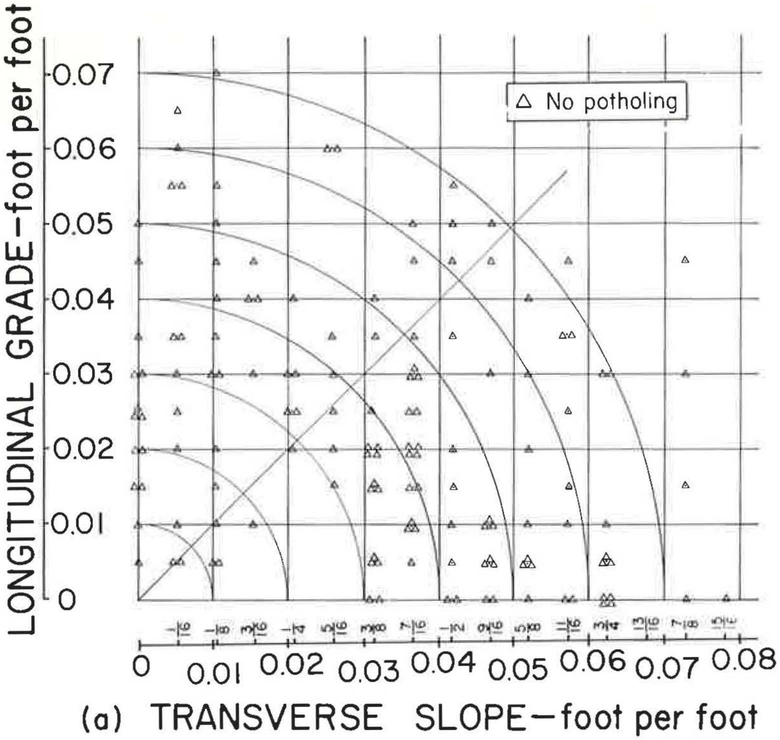
Pothole severity at the location of the measurements (on only that side of the road where slope measurements were then being taken) was observed and classified as none, trace, definite or severe. Visual definition of these degrees of potholing is provided in Figure 2.

Results

Results of this portion of the study are shown in Figure 3. To minimize clutter, Figure 3a defines only those situations where no potholing was observed. Figure 3b defines situations where potholing was observed and, by symbol, whether the potholing at that location was classified as trace, definite or severe. On both plots, each symbol represents one location of measurements and observation, with longitudinal grade plotted on the vertical axis and transverse slope on the horizontal axis. Where there were two or more observations at a particular combination of transverse slope and longitudinal grade, slope and grade are indicated by a point near the center of the symbol cluster. Maximum resultant slope, defined in Figure 4, at any of the points plotted in Figure 3 is indicated by its radial distance from the origin of coordinates.

Interpretation of Results

Crown Slope vs Potholing.—The relationship between crown slope only and the frequency and severity of potholing is summarized in Figure 5. Observations are grouped in crown slope ranges of 0 to 0.01 ft/ft (equal to or greater than 0 but less than 0.01), 0.01 to 0.02 ft/ft (equal to or greater than 0.01 but less than 0.02), etc.



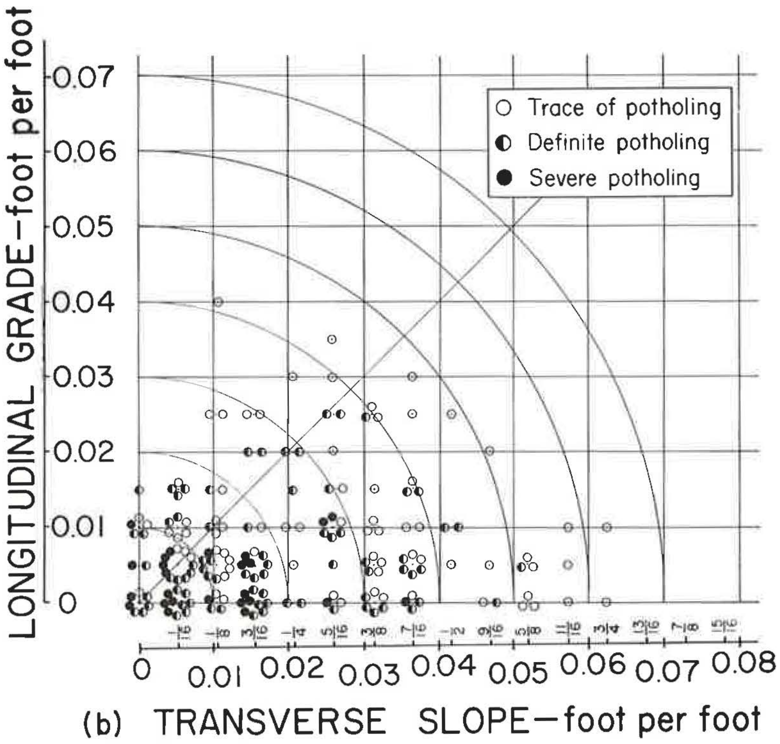


Figure 3. Relationship of potholing severity to transverse slope and longitudinal grade: (a) no potholing, and (b) potholing.

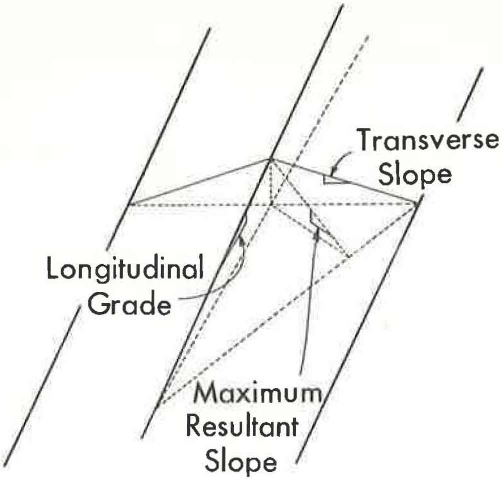


Figure 4. Definition of maximum resultant slope.

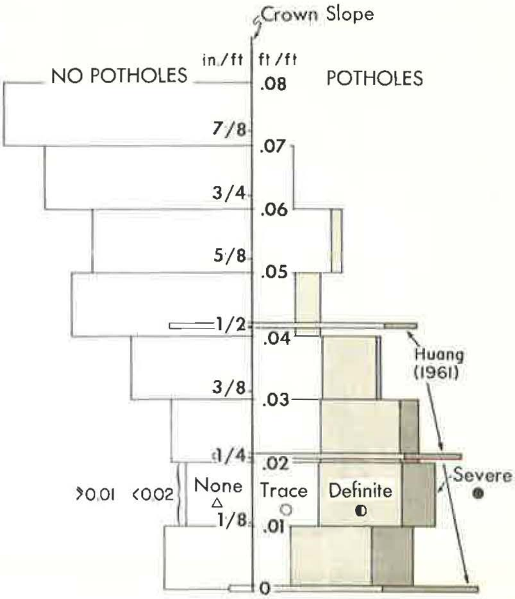


Figure 5. Relation of crown slope to frequency and severity of potholing.

With the total length of each bar made equal to 100 percent, the percent of observations of no potholes in each crown slope range is indicated by the portion of bar length extending to the left of the vertical line. Portions of bar length to the right of the vertical line indicate the percent of observations where potholing was in the trace, definite and severe categories There is a general trend of decrease in frequency of potholing with increase in crown slope. Where potholing was observed, there is a more definite trend of decrease in severity with increase in crown slope.

Trends in the data from this study are somewhat similar to those reported by Huang (3) from his work in Illinois. The frequencies he found of no potholing, slight potholing and severe potholing at no crown (¼ in./ft, and ½ in. or more per ft) are also plotted in Figure 5. Although the trends are similar, the Huang data indicate one-third to one-half the frequency of no potholing found in this study at the various crown slopes. At these same crown slopes, Huang's frequency of observation of severe potholing is considerably higher in each case. A partial explanation may be the probability of flatter topography and, hence, generally lesser longitudinal grades in Champaign County, Ill., than in Tompkins County, N. Y.

Maximum Resultant Slope vs Potholing. —A comparison of Figure 6 with Figure 5 suggests a more definite relationship when potholing frequency is plotted against maximum resultant slope than when it is plotted against crown slope alone. Frequency of pothole observations as well as severity of potholing decreases with increasing maximum resultant slope. This is as might be expected since where a road has some longitudinal gradient, runoff of surface water is not along the transverse crown slope but along some resultant of crown slope and the longitudinal grade.

Regression analysis of percent of no potholes observations in the various slope ranges on midpoint of each slope range (0.005, 0.015, ..., 0.075 ft/ft) for the data summarized in Figures 5 and 6 indicates regression coefficients of 10.2 for crown slope alone and 14.0 for maximum resultant slope. These coefficients, or slopes, are for regression lines not passing through the origin. Standard deviations from regression are 9.6 for crown slope alone and 6.7 for maximum resultant slope. Correlation coefficients are 0.94 for crown slope alone and 0.98 for maximum resultant slope.

It will be noted that the data from this study more closely approach Huang's frequency and severity pattern in Illinois (superimposed on Figure 5) if crown slope alone is replaced by maximum resultant slope.

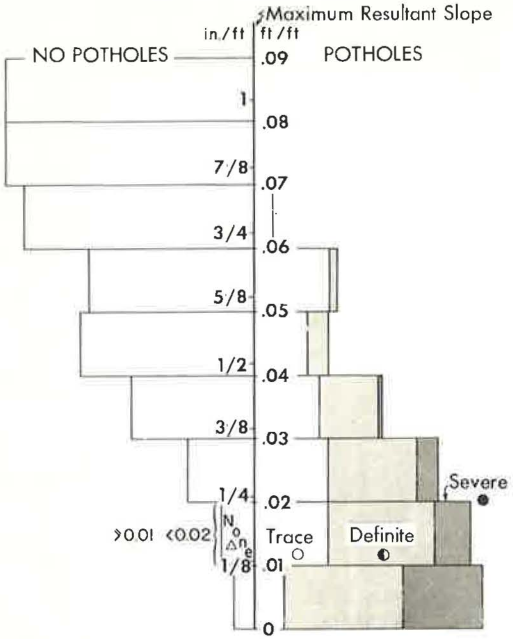


Figure 6. Relation of maximum resultant slope to frequency and severity of potholing.

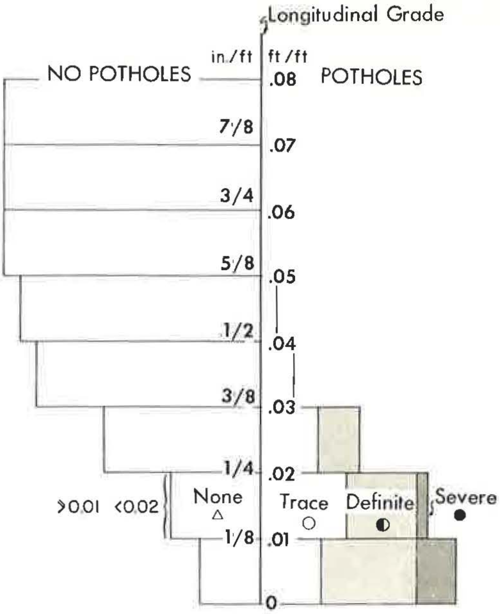


Figure 7. Relation of longitudinal grade to frequency and severity of potholing.

Longitudinal Grade vs Potholing. —Figure 7 indicates the relationship between longitudinal grade only and the frequency and severity of potholing. Although longitudinal grade is usually fixed by considerations other than potholing, its relation to potholing tendencies is at least of academic interest. Figure 3 indicates that, in this study, only traces of potholing were observed, irrespective of crown, where longitudinal grade exceeded 2½ percent. In contrast, there were more than traces of potholes where grades were flat or slight and crown slope exceeded 2½ percent. Figure 3 also indicates that there was lesser severity of potholing (for the several ranges in maximum resultant slope) where longitudinal grade exceeded transverse slope than where a predominant slope was in the transverse direction.

Why should more longitudinal than transverse orientations of maximum resultant slope be related to lesser frequency and severity of potholing? It might be reasoned that the greater length of catchment area for a particular slight depression and potential pothole results in higher velocity of runoff and a greater tendency to form rivulets which may drain or even obscure the slight depression. Another factor may be the longitudinal orientation of traffic which tends to pound down generally longitudinal spillways for slight depressions or birdbaths left from grading or shaping operations. High velocities of runoff are not an unmixed blessing, of course, since erosion also causes maintenance problems on soil-aggregate roads. The importance of transverse slope in heading surface water toward the side of the roadbed must not be neglected, but perhaps the influence of longitudinal grade when selecting minimum tolerable crown on soil-aggregate roads deserves more attention than it has received in research efforts as well as in standard practice.

Implications. —The selection of minimum tolerable crown on the basis of some value of resultant slope is less than an ideal approach, if only because frequency and severity of potholing appear to be related to orientation as well as amount of this maximum resultant slope. In addition to acknowledging variation in potholing tendency with variation in orientation of maximum resultant slope, it should be noted that runoff may, in reality, deviate from the maximum resultant slope. Such deviation would perhaps most frequently be caused by the longitudinal velocity component of runoff on grades

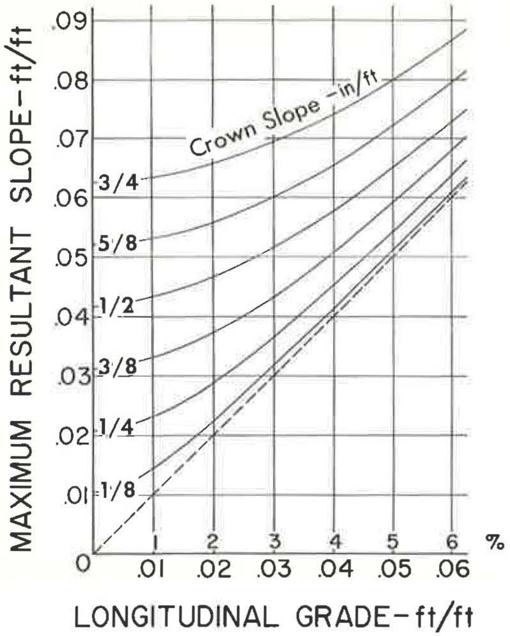


Figure 8. Maximum resultant slope for variations in longitudinal grade and crown slope.

where there is flattened crown at the road centerline. Until additional study suggests a more reliable design characteristic than maximum resultant slope, however, it may be more valid to base selection of minimum tolerable crown in a particular situation (for an acceptable frequency and severity of potholing) on this characteristic than to select minimum tolerable crown without any attention to longitudinal grade.

Figures 6 and 8 may be useful as guides for design. Assuming that about 9 to 1 odds against definite or severe potholing are acceptable, a minimum tolerable maximum resultant slope in the range of 0.04 to 0.05 ft/ft might be ½ in./ft (Fig. 6). Where longitudinal grade is absolutely flat, a minimum crown slope of ½ in./ft would, of course, be indicated. Where there is some longitudinal gradient, Figure 8 indicates the extent to which crown might be lessened and still maintain the desired resultant slope. For example, if longitudinal grade is about 2 percent, minimum crown slope could probably be between ⅜ and ½ in./ft, and if the grade is about 4 percent, the slope could be as low as ⅛ in./ft. Although zero crown is shown as a dotted line in Figure 8, some crown would be necessary to keep surface runoff heading for the edge of the roadbed.

Erosion considerations may well dictate a greater crown slope than that which would be needed for protection against potholing. Just as there may be minimum crowns for control of potholing and/or erosion, there may also be maximum crowns for safety and convenience in vehicle operation. In suggesting that minimum tolerable crown (from a potholing viewpoint) is related to longitudinal grade, it is not suggested that a crown slope should be changed with every minor change in gradient. Frequent changes in crown may be not only impractical from a maintenance operations viewpoint but undesirable from the viewpoint of road-user safety.

TRANSVERSE TERRAIN SLOPE VS TILT OF ROAD CROWN

Soil-aggregate roads on sidehill locations are more likely to be potholed on the uphill than downhill side of the road. Such situations usually reflect, as in Figure 9, a lesser crown slope on the uphill side. It was hypothesized that crown slope should tend to be flatter on the uphill side of the road because of a downhill tilt of the crown caused by a misjudgment of vertical (or horizontal) datum in sidehill terrain by a grader man shaping a road by eye.

Study Method

To explore whether there is, in fact, a higher frequency of downhill than uphill tilt of road crown and whether amount of tilt is related to transverse terrain slope, measurements of the traveled way cross-section and transverse terrain slope were made at some 66 locations. These locations, on eight town highways in Tompkins County, were taken semi-routinely at 0.1-mi intervals and at intermediate points where transverse terrain had dictated a cut-fill cross-section; data on curves were omitted because of the probability of intentional banking or warping of the cross-section.

Measurement of Crown.—Crown measurements were made with the liquid-level device shown in Figure 10. With the gallon jug placed approximately (by eye) at the center

Figure 9. Potholing on uphill side of soil-aggregate road.

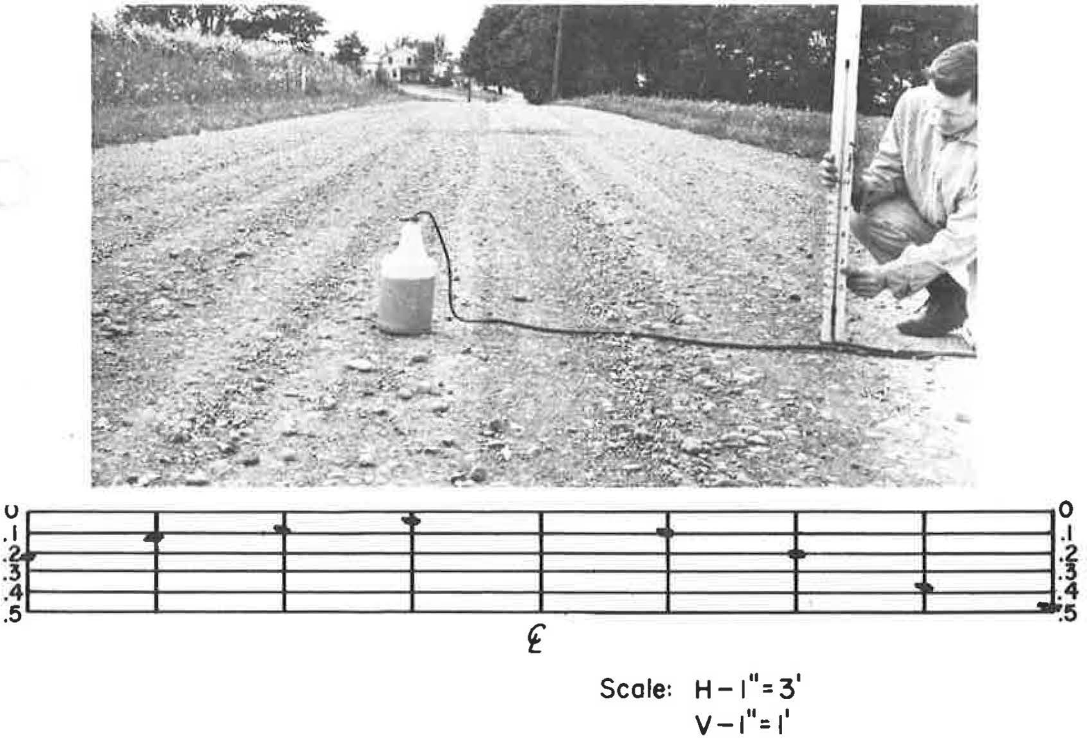


Figure 10. Measurement and recording of crown.

line of the road, readings of the drop in elevation were taken at intervals of 2 ft to the left and right of the center line. The readings were plotted on a record card, shown in Figure 10.

Computation of Crown Tilt. —Tilt of crown was computed as illustrated in Figure 11. A straight line of best fit was drawn through the plotted road surface elevations on each side of the road. At the intersection of these straight lines representing average crown

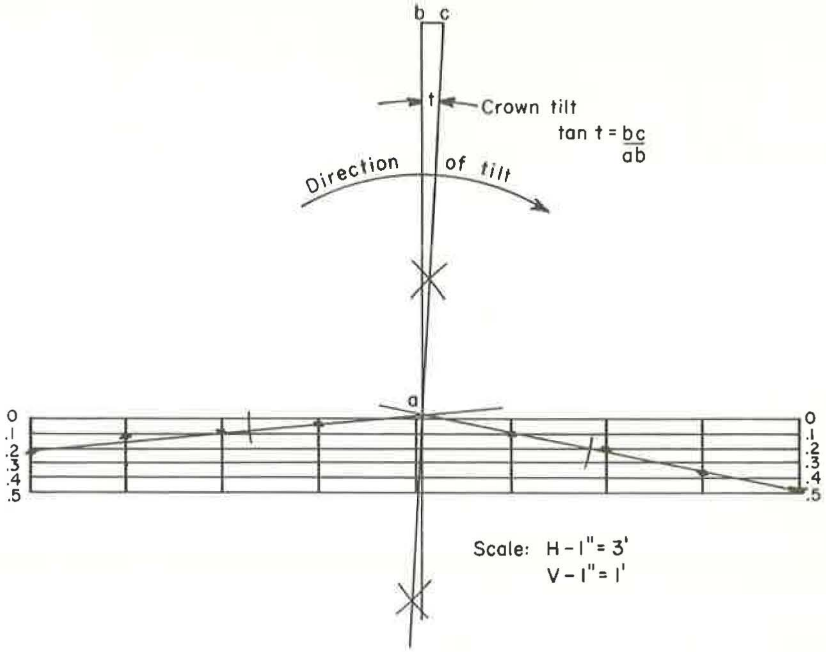


Figure 11. Determination of crown tilt.

Figure 12. Measuring transverse terrain slope.

slope were erected vertical lines (ab and ac) bisecting the angle formed by the lines of average crown slope. The angle (t) between lines ab and ac was computed from scaled distances bc and ab. It was necessary, of course, to adjust the ratio of these scaled distances to correct for the 3:1 ratio of vertical to horizontal scale on the plots of crown cross-section. Direction of crown tilt, whether uphill or downhill, was noted.

Measurement of Transverse Terrain Slope.—Average terrain slope was determined with a protractor as shown in Figure 12. The observer stationed himself so as to be able to align the flat edge of the protractor with average slope of terrain at the location

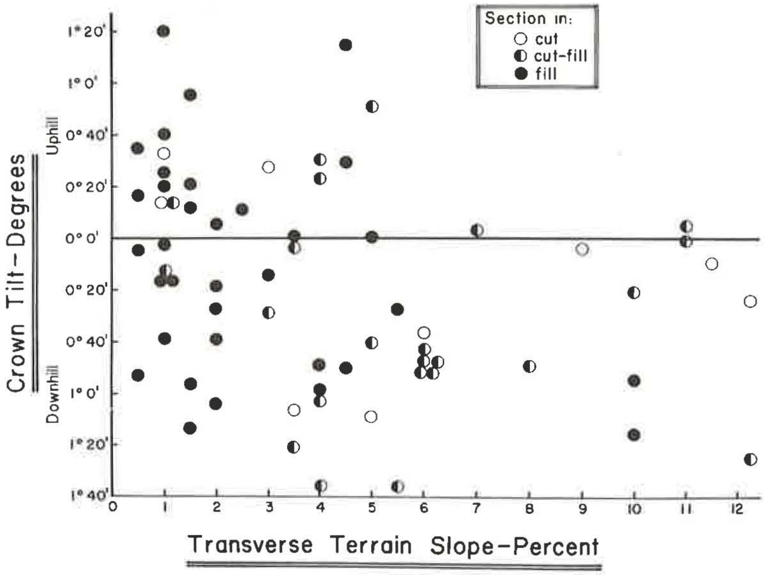


Figure 13. Crown tilt vs transverse terrain slope.

where crown measurements had been made; slope was recorded to the nearest ½ percent. Although for simplicity, this terrain slope was measured at the location of crown measurement, it is recognized that a grader operator's concept of vertical (or horizontal) was influenced by topography as he approached and even looked some distance beyond the points where measurements were made in this study.

Results

Crown tilt in relation to transverse terrain slope at the 66 points included in this study is summarized in Figure 13. Points on the chart are coded to indicate whether the road cross-section at that point was in cut (8 points), on fill (35 points), or on cut-fill (23 points).

Interpretation of Results

Considering all 66 points together (ignoring whether sections were in cut, fill or cut-fill), it is noted in Figure 13 that for transverse terrain slopes of 2 percent or less, there was equal frequency of uphill and downhill tilt (13:13). For transverse slopes of 2½ through 5½ percent, there were 14 downhill tilts in contrast to 7 uphill tilts and 2 sections without perceptible tilt. For transverse terrain slopes of 6 percent and over, there was considerably higher frequency of tilt in the downhill direction; in these situations, 15 cross-sections were tilted downhill in contrast to only 2 uphill. Although frequency of downhill tilt appears generally to be related to transverse terrain slope, the amount of tilt does not.

There are too few points in Figure 13 to make any conclusive statements concerning relative tendency to tilt road crown downhill on cut, fill, and cut-fill cross-sections. It is noted, however, that average tilt for the cut-fill cross-sections was 0° 30' for the fill sections and 0° 9' for the cut sections; average tilt in each case was in the downhill direction. Mention of average tilt should be qualified by average transverse terrain slope for each type of cross-section; these were 5.8, 2.7 and 5.9 percent for the cut-fill, fill and cut cross-sections, respectively.

The significance of such small angles of tilt may be questioned. It should perhaps be pointed out that a road with intended crown slopes of ½ in./ft on each side of the centerline would need to be tilted downhill less than 2° to reduce the crown slope on the uphill side to less than ¼ in./ft.

CONCLUSIONS

Potholing of soil-aggregate roads, though generally related to crown slope, appears to be more closely related to some resultant of crown slope and longitudinal grade. The maximum resultant slope, though less than an ideal design characteristic, may be useful as a guide in selecting minimum tolerable crown. Figures 6 and 8 provide a guide to selection of the lowest maximum resultant slope for an acceptable risk of potholing and, for a given longitudinal grade, determination of the minimum crown to produce this resultant slope. Although soil-aggregate roads on longitudinal grades steeper than about $2\frac{1}{2}$ percent were observed to have potholed very little, irrespective of crown slope, the benefits of crown in minimizing erosion problems cannot be disregarded.

There is evidence that grader operators shaping roads by eye in sidehill terrain tend to tilt the crown in the downhill direction. Probably due to a misconception of vertical, a practical implication is a less-than-desired crown slope on the uphill side and increased vulnerability to potholing. Sidehill locations should be an invitation to periodic checks on crown slope during grading or shaping operations.

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