PAVEMENT CROSS SLOPE DESIGN

— A TECHNICAL REVIEW

OKTAY GÜVEN AND JOEL G. MELVILLE

AUBURN UNIVERSITY
HIGHWAY RESEARCH CENTER
238 HARBERT ENGINEERING CENTER
AUBURN, AL 36849-5337

APRIL 1999

ABSTRACT

This report presents a summary and discussion of available information from the literature related to the selection of a pavement cross slope value in the design of high-type highway pavements consisting of portland cement concrete or open graded asphalt concrete surface courses. Special attention is given to the climatic conditions and the current design practice in Alabama. In addition to the available information from the literature, a new implicit relation is derived giving the cross slope as a function of the relevant factors and a new set of curves is presented to aid in the selection of the design pavement cross slope value. The information presented in the report indicates that the cross slope values used in the current design practice in Alabama are more than adequate for the surface drainage of high-type pavements.

ACKNOWLEDGMENTS

This project was supported by the Highway Research Center and the Department of Civil Engineering of Auburn University. The authors thank Dr. Frazier Parker, Professor of Civil Engineering and Director of the Highway Research Center, for his support of the project and his technical assistance at various stages of the study.

The authors also want to thank Jane Ballard who typed the report, Thelma Allen who helped with the acquisition of some of the reference material and Wesley Dawsey who assisted with the preparation of the report's figures.

TABLE OF CONTENTS

PAGE

ABSTRACT i

ACKNOWLEDGMENTS ii

LIST OF FIGURES iv

I. INTRODUCTION 1

II. MECHANICS OF FLOW ON PAVEMENTS 3

III. HYDROPLANING CRITERIA 7

Hydroplaning on a Plane Surface 7

Hydroplaning on Ruts and Puddles 10

IV. DESIGN RAINFALL INTENSITY 12

V. CROSS SLOPE SELECTION FACTORS 14

VI. CONCLUDING REMARKS 23

REFERENCES 24

LIST OF FIGURES

PAGE

Figure 1 Definition Sketch 4

Figure 2 Variation of Spindown Water Depth with Vehicle Speed and Other Parameters 9

Figure 3 Variation of Water Depth with Pavement Width, Cross Slope and Rainfall Intensity for a Texture Depth of TXD = 0.04 inch and a Longitudinal Gradient of $S_g = 0$ 15

Figure 4 Variation of the Cross Slope Ratio S_x / S_{xo} as a Function of the Longitudinal Gradient Ratio S_g / S_{xo} 20

Figure 5 Variation of the Cross Slope S_{xo} as a Function of the Pavement Width (L_x) for Several Values of the allowable Water Depth (WD) and Rainfall Intensity (I) for a Texture Depth of TXD = 0.04 inch 21

Figure 6 Variation of the Cross Slope S_{xo} as a Function of the Pavement Width (L_x) for Several Values of the Rainfall Intensity (I) and the Texture Depth (TXD) for an allowable Water Depth of WD = 0.06 inch. 22

I. Introduction

Standard 1/4 inch or 5/16 inch per foot (2.08% or 2.60%) cross slopes are used on Alabama highway pavements, and, in general, a cross slope range of 1.5% to 4% is recommended for high-type pavement surfaces in the United States (FHWA, 1984; AASHTO, 1994). A sufficient amount of cross slope is necessary for effective removal (drainage) of stormwater from a pavement surface for traffic safety during periods of rainfall. The selection of a particular cross slope is often a compromise between the need for a reasonably steep cross slope for drainage and a relatively mild slope for driver comfort (FHWA, 1984). As it has been found that cross slopes of 2% or less have little effect on driver effort in steering, or on friction demand for vehicle stability, cross slopes of 2% or less are considered desirable (FHWA, 1979; FHWA, 1984).

Stormwater accumulation on a pavement surface occurs in the form of sheet flow over the surface or in the form of flowing or standing water in ruts and puddles. An extensive experimental investigation of the factors which influence the accumulation of stormwater on pavement surfaces and of the effects of stormwater accumulation on vehicle performance carried out at the Texas Transportation Institute at the Texas A & M University by Gallaway et al. (FHWA, 1979) forms the basis of the present understanding of pavement drainage and current design practice. A summary discussion of the factors which influence the accumulation and drainage of stormwater over pavement surfaces, based primarily on the findings of the aforementioned report by Gallaway et al. (FHWA, 1979), may also be found in AASHTO (1992).

Experience has shown that current design practices associated with cross slope selection and pavement drainage provide safe, acceptable drainage of pavements in most circumstances. However, because it is important to understand the role and relative significance of various factors which influence the accumulation and drainage of storm-water over pavement surfaces in the cross slope selection process, a discussion and new analysis are included in the present report based on the available information from previous studies. Attention is focused in this report on high-type pavement surfaces such as tined portland cement concrete (PCC), or open graded asphalt concrete (AC) friction courses. Special attention is given to the climate conditions of Alabama.

II. MECHANICS OF FLOW ON PAVEMENTS

When rain falls on a sloped pavement surface the path that the runoff takes to the pavement edge (see Figure 1) is called the resultant flow path and its length (L_f) and the resultant slope (S_f) can be determined from the following relationships (AASHTO, 1992):

$$S_f = (S_x^2 + S_g^2)^{0.5} = S_x\,(1 + (S_g/S_x)^2)^{0.5} \qquad (1)$$

$$L_f = L_x(S_f/S_x) = L_x\,(1 + (S_g/S_x)^2)^{0.5} \qquad (2)$$

where

S_x = cross slope in *ft/ft*
S_g = longitudinal gradient in *ft/ft*
S_f = resultant flow path slope in *ft/ft*
L_x = pavement width
L_f = length of flow path

A definition sketch for these variables is shown in Figure 1. It can be seen from Figure 1 and equation (2) that as the pavement width (L_x) is increased or as the longitudinal gradient (S_g) is steepened the resultant flow path length (L_f) is increased.

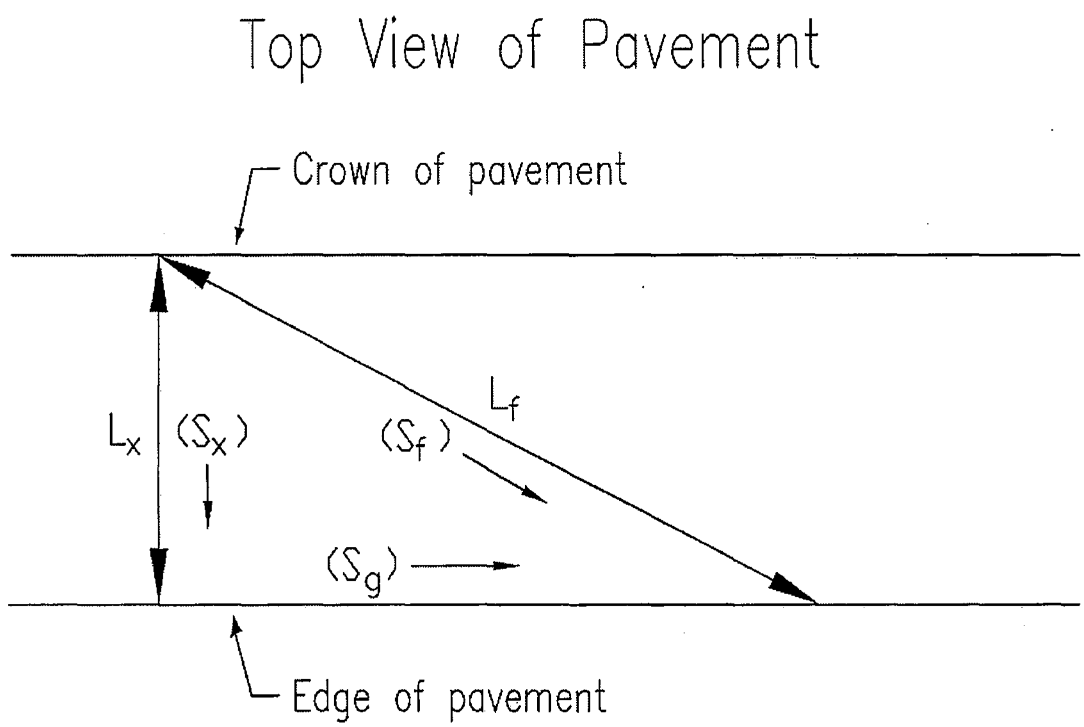

Figure 1. Definition Sketch

The depth of water (WD) which accumulates on the pavement depends on the rainfall intensity (I), the length of the resultant flow path (L_f), the slope of the resultant flow path (S_f), and the texture depth (TXD) of the pavement surface (FHWA, 1979; AASHTO, 1992). The texture depth (TXD) is a measure of the roughness, or the "macro-texture", of the pavement and may be determined using the silicone putty impression test (see, e.g., FHWA, 1979, page 45 of the original reference). Macrotexture consists of the asperities associated with the voids in the pavement surface between pieces of the aggregate. A high level of macrotexture may be achieved by tining new PCC pavements while still in the plastic state and by utilizing open graded AC surface courses for bituminous pavements (AASHTO, 1992). According to FHWA (1979) the median (50 percentile) value of the texture depth (TXD) is about 0.04 inch while the 7 percentile value is about 0.01 inch for highways in the United States.

An empirical equation for the water depth (WD), based on a regression analysis of experimental data on water film depths on pavements is presented in FHWA (1979). This equation may be written as:

$$WD = 0.00338\ TXD^{0.11}\ L_f^{\ 0.43}\ I^{0.59}\ S_f^{\ -0.42} - TXD \qquad (3)$$

where

WD	= water depth above the top of the surface asperities in inches
TXD	= texture depth in inches
L_f	= length of flow path in feet
I	= intensity of rainfall in inches per hour
S_f	= slope of flow path in *ft/ft*

Equation (3) may give a negative or zero value for the water depth (WD) for small values of the flow path length (L_f) and rainfall intensity (I) or large values of the slope (S_f) of the flow path. This is because the water depth (WD) is defined relative to the top of the surface asperities; a negative depth simply indicates that the surface of the water film is below the top of the asperities.

Using equations (1) and (2), equation (3) may be transformed as:

$$WD = (WD_o + TXD)\,(1 + (S_g / S_x)^2)^{0.5} - TXD \tag{4}$$

where

$$WD_o = 0.00338\ TXD^{0.11}\ L_x^{0.43}\ I^{0.59}\ S_x^{-0.42} - TXD \tag{5}$$

Equation (4) provides an expression of the water depth (WD) at the edge of the pavement in terms of the pavement width (L_x), the cross slope (S_x) and the longitudinal gradient (S_g). The quantity WD_o defined by equation (5) corresponds to the water depth which would occur at the pavement edge for a zero longitudinal gradient ($S_g = 0$).

Calculations with equation (4) with some typical values of S_x and S_g indicate that the longitudinal grade does not have a significant effect on the water depth although it does have an effect on the flow path length; for example, the water depth increases by less than 5% for S_x values of 2.08% and 2.60% as the longitudinal gradient is increased from 0 to 6%. It may be useful to note that as the longitudinal grade is steepened and the flow path lengthened, the flow velocity also increases because of the increase in the resultant slope, thereby offsetting the tendency for an increase in the water depth. The end result is that the longitudinal grade does not have an appreciable effect on the water depth at the edge of the pavement (AASHTO, 1992).

III. Hydroplaning Criteria

Hydroplaning on a Plane Surface:

Hydroplaning is a phenomenon which occurs on a wet pavement when the tires of a vehicle lose contact with the pavement and begin to ride on a thin film of water. At this point, any accelerating, braking or cornering forces may cause the driver to lose control. The potential for hydroplaning can be evaluated using an empirical equation based on experimental studies conducted at the Texas Transportation Institute (FHWA, 1979). An equation for estimating the vehicle speed at which a certain amount of wheel "spindown" occurs on a wet pavement is given in FHWA (1979) as follows:

$$V = SD^{0.04}\, P^{0.3}\, (TD + 1)^{0.06}\, A \tag{6}$$

where

V	= vehicle speed in miles per hour (mph)
SD	= spindown percent, defined as 100 $(W_d - W_w) / W_d$
W_d	= rotational velocity of a rolling wheel on a dry pavement
W_w	= rotational velocity of a rolling wheel after spinning down due to contact with a flooded pavement
P	= tire pressure in pounds per square inch (psi)
TD	= tire tread depth, in units of 1/32 inch
A	= the greater of $[(10.409 + WD^{0.06}) + 3.507]$ or $[(28.952 / WD^{0.06}) - 7.817]\ TXD^{0.14}$
WD	= water depth above the top of the surface asperities on a flooded pavement, in inches
TXD	= pavement texture depth, in inches

A spindown percent (SD) of 10 is considered to be an indicator of almost full hydroplaning (FHWA, 1979, page 8 of the original reference). Approximate 7 percentile and 50 percentile values of the other relevant parameters are given in FHWA (1979) as follows:

TD	= 2/32 in (7 percentile) and 7/32 in (50 percentile)
P	= 18 psi (7 percentile) and 27 psi (50 percentile)
TXD	= 0.01 in (7 percentile) and 0.038 in (50 percentile)

It is suggested in the "Model Drainage Manual" of AASHTO (1991, pages 13-22) that the following values may be used for "design" purposes:

TD = 2/32 in, P = 24 psi, TXD = 0.02 in.

Equation (6) may be rearranged to define an approximate "spindown" water depth (WD_s) at or above which hydroplaning occurs for a range of vehicle speeds, tire pressures, tire tread depths and pavement texture depths. Using a critical value of 10 for the spindown percent (SD), equation (6) gives:

$$WD_s = \text{the smaller of } [10.409 / (A_s - 3.507)]^{16.67} \text{ or } [28.952 / (A_s / TXD^{0.14} + 7.817)]^{16.67} \quad (7)$$

where

$$A_s = V / [10^{0.04} P^{0.3} (TD + 1)^{0.06}] \quad (8)$$

Figure 2 shows the variations of the spindown water depth (WD_s) given by equation (7) as a function of the vehicle speed (V) for two values of the texture depth (TXD = 0.02 in and 0.04 in), two values of the tire pressure (P = 24 psi and 18 psi) and a tire tread depth of 2/32 inch (TD = 2). It may be seen from Figure 2 that at high vehicle speeds (V greater than 50 mph) the spindown water depth (WD_s) is not affected appreciably by the texture depth (TXD) and depends mainly on the vehicle speed (V). It may also be seen that the spindown water depth required for hydroplaning decreases with decreasing tire pressure.

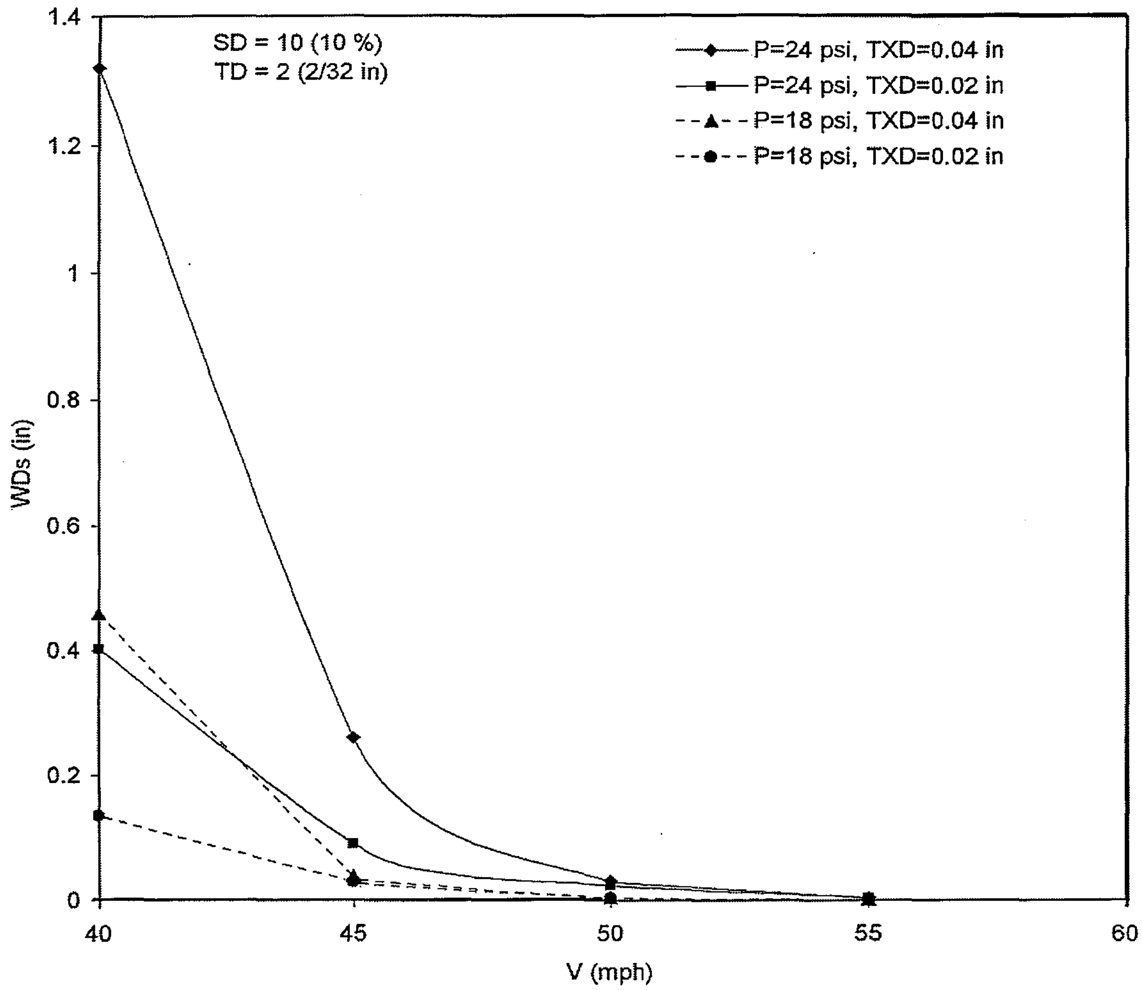

Figure 2. Variation of Spindown Water Depth with Vehicle Speed and Other Parameters

HYDROPLANING ON RUTS AND PUDDLES:

Normal wear will produce ruts in some pavements. These ruts and puddles tend to concentrate water in the wheel path and increase the potential for hydroplaning. A vehicle's wheels can lose pavement contact between 40 and 45 mph in puddles of about 1 inch depth and a length of 30 feet or more due to ruts in the pavement or ponding from other sources. In addition, drag forces have adverse affects on a moving vehicle at moderate speeds when water depth reaches approximately 3/8 inch. As the wheels on one side of a vehicle encounter ponding, the uneven lateral distribution of these drag forces could cause hazardous directional instability (FHWA, 1979; AASHTO, 1992).

In order to prevent or reduce the effects of pavement ruts, periodic resurfacing of the pavement is recommended (FHWA, 1979; AASHTO, 1991, 1992). As a guideline, a wheel path depression in excess of 0.2 inches (as measured from the normal cross slope of the pavement) should be used as a criterion for resurfacing when dense AC or PCC pavements are used (FHWA, 1979; AASHTO, 1991).

The foregoing criterion is based on a simplified geometric analysis presented in FHWA (1979; page 76, and Figure 37, page 75 of the original reference). According to this analysis, the allowable critical wheel path depression to provide natural drainage on a cross slope is a function of the cross slope value (S_x) and varies from 0.06 inch for a cross slope of $S_x = 1\%$ to 0.30 inch for a cross slope of $S_x = 3\%$. This means that for traffic lanes with cross slopes smaller than 2% it may be appropriate to use a critical wheel path depression value less than 0.2 inch (perhaps 0.06 inch or 0.10 inch) as a criterion for resurfacing.

It may be useful to note that the potential for hydroplaning is expected to be greater from wheel path depressions than from surface sheet flow depth over a pavement. Periodic maintenance of the pavement is therefore a crucial requirement for traffic safety (AASHTO, 1991).

IV. DESIGN RAINFALL INTENSITY

It is proposed in FHWA (1979) that a probabilistic approach should be adopted in selecting a rainfall intensity for design purposes, since rainfall intensity is a random environmental variable (see FHWA, 1979, Chapters IV and IX, included in Appendix 2). In this approach, the design rainfall intensity for a particular geographic location would be based on the choice of an acceptable level of the proportion of time (or, probability) throughout a year when a rainfall of specific or greater intensity may be expected at that location. An empirical equation, obtained from an analysis of recorded rainfall data from several states, including Illinois, Texas and Alabama, is presented in FHWA (1979). This equation, reproduced below, gives the probability (P_{ri}) of driving a rainfall of a specific intensity (I_i) or greater at a particular location, as a function of the intensity (I_i, in inches per hour) and the average annual rainfall rate (R_r, in inches per year) of that location:

$$P_{ri} = 0.0324\ [0.041 - (R_r - 60)^2 / 87{,}500] / I_i \qquad (9)$$

This equation is assumed to be valid where the annual rainfall (R_r) is less than 60 inches per year.

In FHWA (1979) example design rainfall intensities corresponding to different annual rainfall rates are given based on equation (9) for an assumed probability level of $P_{ri} = 0.002$ (see FHWA, 1979, Table 19, page 91 of the original reference). For example, at this probability level the design rainfall intensity corresponding to an average annual rainfall rate of $R_r = 50$ in/yr is $I_i = 0.65$ in/hr, and the design rainfall intensity corresponding to the average annual rainfall rate for Alabama, namely, $R_r = 57.3$ in/yr as given in FHWA (1979), is $I_i = 0.663$ in/hr.

Regarding the choice of a design rainfall intensity, it may be useful to note that there is an upper limit imposed by the poor visibility conditions which occur during heavy or severe rainfall periods. For example, visibility is reduced when rainfall intensity exceeds 2 in/hr, and becomes poor when intensity exceeds 3 in/hr (see FHWA, 1979, page 5 of the original reference). It is expected that vehicle operators would refrain from driving (or drive very slowly) during such heavy rainfall periods. Hence, a reasonable upper limit of rainfall intensity for cross slope design purposes appears to be 2 in/hr, or, at most, 3 in/hr.

V. Cross Slope Selection Factors

The information presented in the previous sections indicates that the factors which influence the water depth (WD) on the pavement are the surface texture depth (TXD), the length of the resultant flow path (L_f), the resultant surface slope (S_f), and the rainfall intensity (I). The resultant flow path length depends on the pavement width (L_x), the cross slope (S_x) and the longitudinal gradient (S_g). While the longitudinal grade may significantly influence the flow path length, it does not appreciably affect the water depth at the pavement edge, as also noted previously. Hence, the primary geometric factors which influence the water depth at the edge of the pavement are the width of the pavement (L_x) and the cross slope (S_x), while the longitudinal gradient (S_g) has a small influence.

The variation of the water depth (WD) as a function of the pavement width (L_x), the cross slope (S_x) and the rainfall intensity (I), obtained using equation (3), for a texture depth of TXD = 0.04 inch and a longitudinal gradient of $S_g = 0$ is shown in Figure 3. A similar graph is provided in AASHTO (1992, Figure 4 of the original reference), for a pavement with a longitudinal gradient of $S_g = 3\%$ and a texture depth of TXD = 0.038 inch. The specific values of the cross slope included in Figure 3 (namely, $S_x = 2.08\%$ and 2.60%) correspond to the ones currently used in the Alabama design practice, and the particular rainfall intensity of I = 0.663 in/hr corresponds to the value of the design rainfall intensity (I_i) obtained from equation (9) using the average annual rainfall rate for Alabama (namely, $R_r = 57.3$ in/yr) and a design probability value of $P_{ri} = 0.002$, as also noted previously in Section IV (Design Rainfall Intensity).

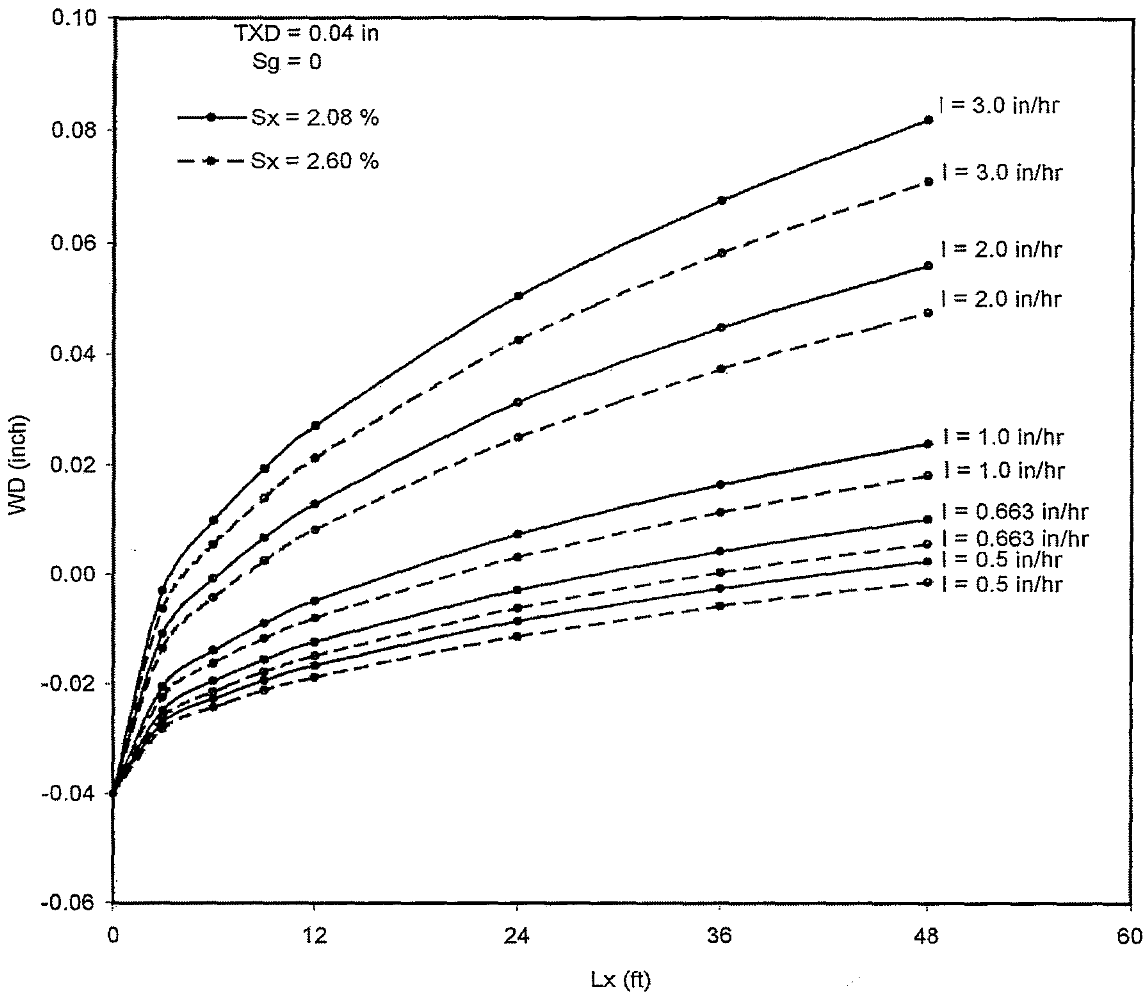

Figure 3. Variation of Water Depth with Pavement Width, Cross Slope and Rainfall Intensity for a Texture Depth of TXD = 0.04 inch and a Longitudinal Gradient of $S_g = 0$

Figure 3 shows that the pavement cross slope values currently used in Alabama (S_x = 2.08% and 2.60%) may be considered to be more than adequate for pavement widths of 24 ft or less and rainfall intensities of 3.0 in/hr or less, if the surface texture depth is 0.04 inch or larger and if the allowable water depth at the edge of the pavement is taken as 0.06 inch. This particular value of the allowable water depth, namely WD = 0.06 inch, is suggested as an acceptable upper limit for design purposes in FHWA (1979), and is also quoted in AASHTO (1992). Indeed, it may be seen from Figure 2 that the vehicle speed (V) corresponding to a spindown depth of 0.06 inch at which hydroplaning would occur is between 40 to 50 mph, and vehicle operators would be expected to refrain from exceeding such speeds, due to poor visibility conditions, during periods of heavy rainfall ($I \geq 2$ in/hr).

If, on the other hand, an allowable water depth of zero (WD = 0) were adopted as an ideal design objective, the cross slope values currently used in Alabama would not be adequate for design rainfall intensities of 1 in/hr or more for a pavement width of 24 ft. However, they would still be considered to be adequate if the design rainfall intensity is taken as I = 0.663 in/hr.

The foregoing discussion shows that the selection of the design cross slope would depend on the surface texture depth, the pavement width, the longitudinal gradient, the design rainfall intensity and the allowable water depth at the edge of the pavement. Curves are presented in FHWA (1979, Figures 42 through 44 of the original reference) which depict various combinations of the parameters which correspond to an allowable water depth of zero, based on equation (3). However, as noted in FHWA (1979) and

AASHTO (1992), a zero depth may not always be practicable as an design objective. As a reasonable upper limit for the allowable water depth, a value of 0.06 inch has been suggested in FHWA (1979), as also noted above. Hence, an allowable water depth between 0 and 0.06 inch appears to be an acceptable choice for design purposes.

Curves presented in FHWA (1979, Figures 42 through 44 of the original reference), based on equation (3), show that the pavement cross slope required for an allowable water depth of zero decreases with increasing texture depth for a given rainfall intensity and flow path length. FHWA (1979, Table 20 of the original reference) also gives acceptable combinations of the cross slope and the texture depth for various flow path lengths for a design rainfall intensity of I = 0.5 in/hr and an allowable water depth of zero (WD = 0). Based on these results, it is recommended in FHWA (1979) that the surface texture depth should not be allowed to fall below a level of 0.04 inch. Hence, the use of a texture depth of 0.04 inch would appear to be a reasonable choice when selecting a design cross slope.

As an aid in the selection of the pavement cross slope, an implicit expression can be derived from equations (1), (2) and (3), giving the cross slope as a function of the other factors. This implicit expression may be written as:

$$(S_x / S_{xo})^{86} - (S_x / S_{xo})^{2} = (S_g / S_{xo})^{2} \qquad (10)$$

where S_x is the cross slope value required for a water depth of WD at the edge of the pavement for a pavement with a longitudinal gradient of S_g, and S_{xo} is the cross slope value required for a water depth of WD at the edge of the pavement for a pavement with a longitudinal gradient of zero, given by the following expression:

$$S_{xo} = [0.00338\ (TXD^{0.11}\ L_x^{0.43}\ I^{0.59})\ /\ (WD + TXD)]^{1/0.42} \qquad (11)$$

Since equation (10) is not available in the previous literature and appears in this report for the first time, a derivation is presented below. In the derivation of equation (10), use is made of the equality

$$L_f^{0.43}\ S_f^{-0.42} = L_x^{0.43}\ S_{xo}^{-0.42} \qquad (12)$$

which results from equation (3) since the water depth (WD) at the pavement edge, the rainfall intensity (I), and the texture depth (TXD) are, respectively, assumed to be the same for both the pavement with a finite longitudinal gradient (S_g) and the pavement with a longitudinal gradient of zero.

Using equations (1) and (2), the flow path length (L_f) and the resultant slope (S_f) may be expressed as:

$$S_f = S_x\ (1 + (S_g/S_x)^2)^{0.5} \qquad (13)$$

$$L_f = L_x\ (1 + (S_g/S_x)^2)^{0.5} \qquad (14)$$

Substitution of equations (13) and (14) into equation (12) gives:

$$[(1 + (S_g/S_x)^2)^{0.5}]^{0.01} = (S_x/S_{xo})^{0.42} \qquad (15)$$

or

$$1 + (S_g/S_x)^2 = (S_x/S_{xo})^{84} \qquad (16)$$

Multiplication of equation (16) by $(S_x / S_{xo})^2$ gives:

$$(S_x / S_{xo})^2 + (S_g / S_{xo})^2 = (S_x / S_{xo})^{86} \qquad (17)$$

Finally, rearrangement of equation (17) gives equation (10).

The variation of the ratio S_x / S_{xo} as a function of the ratio S_g / S_{xo}, given by equation (10), is shown in Figure 4. This figure shows that the required cross slope value for a given allowable water depth increases with increasing longitudinal gradient. However, the effect of the longitudinal gradient on the required cross slope may be considered to be small.

The variation of the required cross slope S_{xo} for a pavement with a longitudinal gradient of zero as a function of the pavement width L_x, obtained from equation (12), is shown in Figures 5 and 6 for several values of the rainfall intensity (I), the allowable water depth (WD), and the surface texture depth (TXD). Figures 5 and 6, and similar figures which may be prepared with other values of the relevant parameters, together with Figure 4, should be useful in the selection of a pavement cross slope (S_x) which is appropriate for a given design rainfall intensity (I), allowable water depth (WD), texture depth (TXD) and longitudinal slope (S_g). As noted previously, a texture depth of 0.04 inch and an allowable water depth between zero and 0.06 inch appear to be reasonable for design purposes. If the allowable water depth is taken as 0.06 inch, the curves shown in Figures 5 and 6 suggest that cross slope values used currently in the Alabama design practice (namely, S_x = 2.08% and 2.60%) are more than adequate for a design rainfall intensity (I) up to 2 in/hr and any pavement width (L_x) up to 36 ft for a texture depth of TXD = 0.04 inch and even TXD = 0.02 inch (see Figure 6).

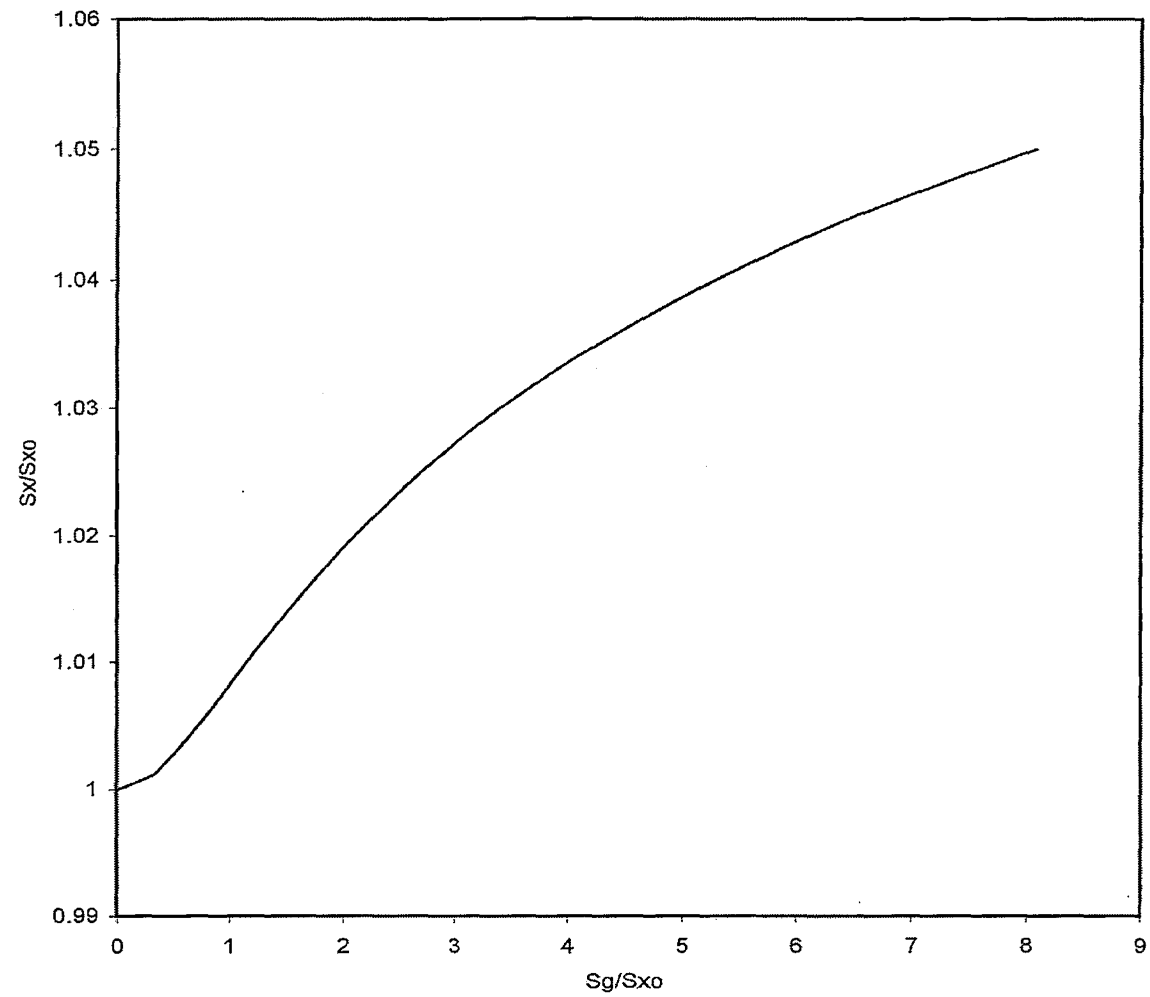

Figure 4. Variation of the Cross Slope Ratio S_x / S_{xo} as a Function of the Longitudinal Gradient Ratio S_g / S_{xo}

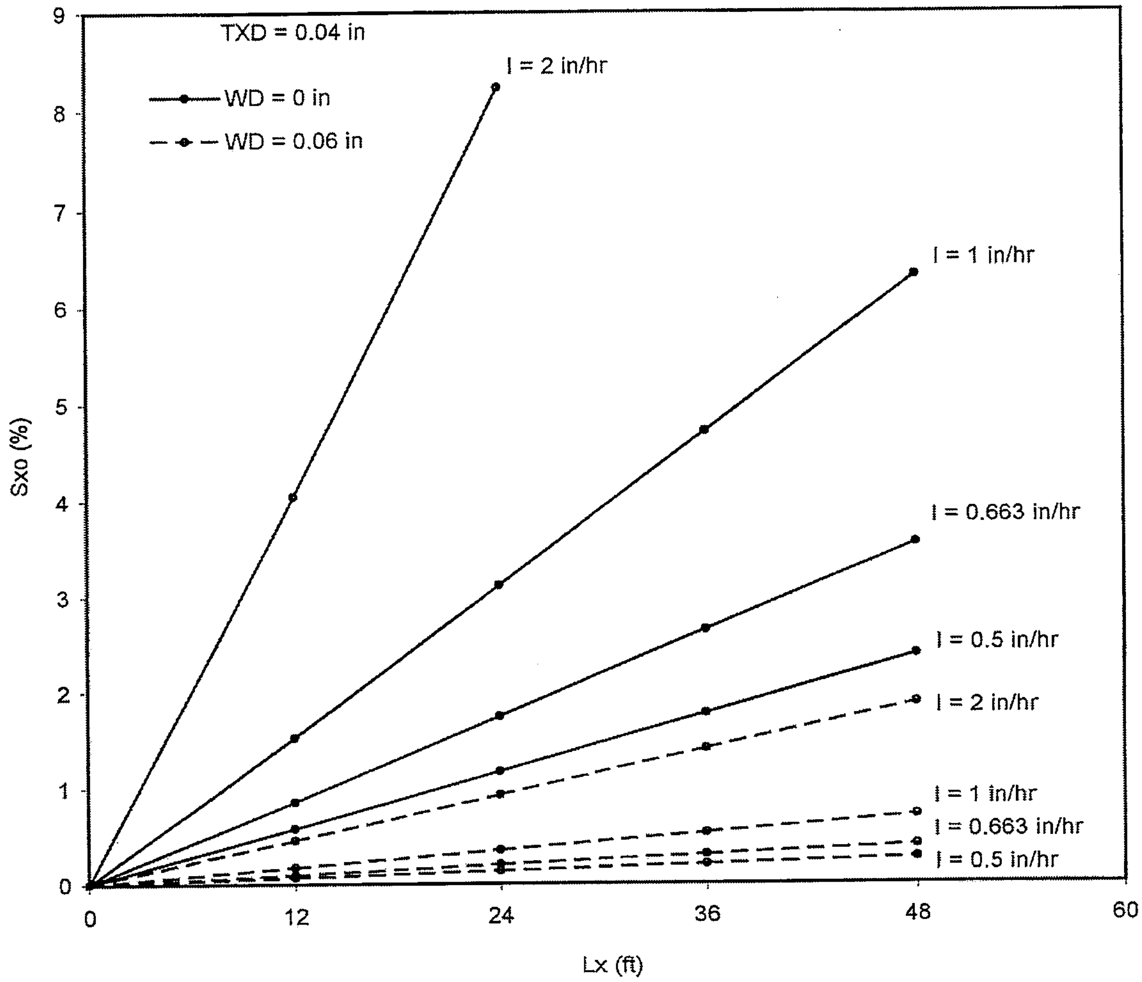

Figure 5. Variation of the Cross Slope S_{xo} as a Function of the Pavement Width (L_x) for Several Values of the Allowable Water Depth (WD) and Rainfall Intensity (I) for a Texture Depth of TXD = 0.04 inch

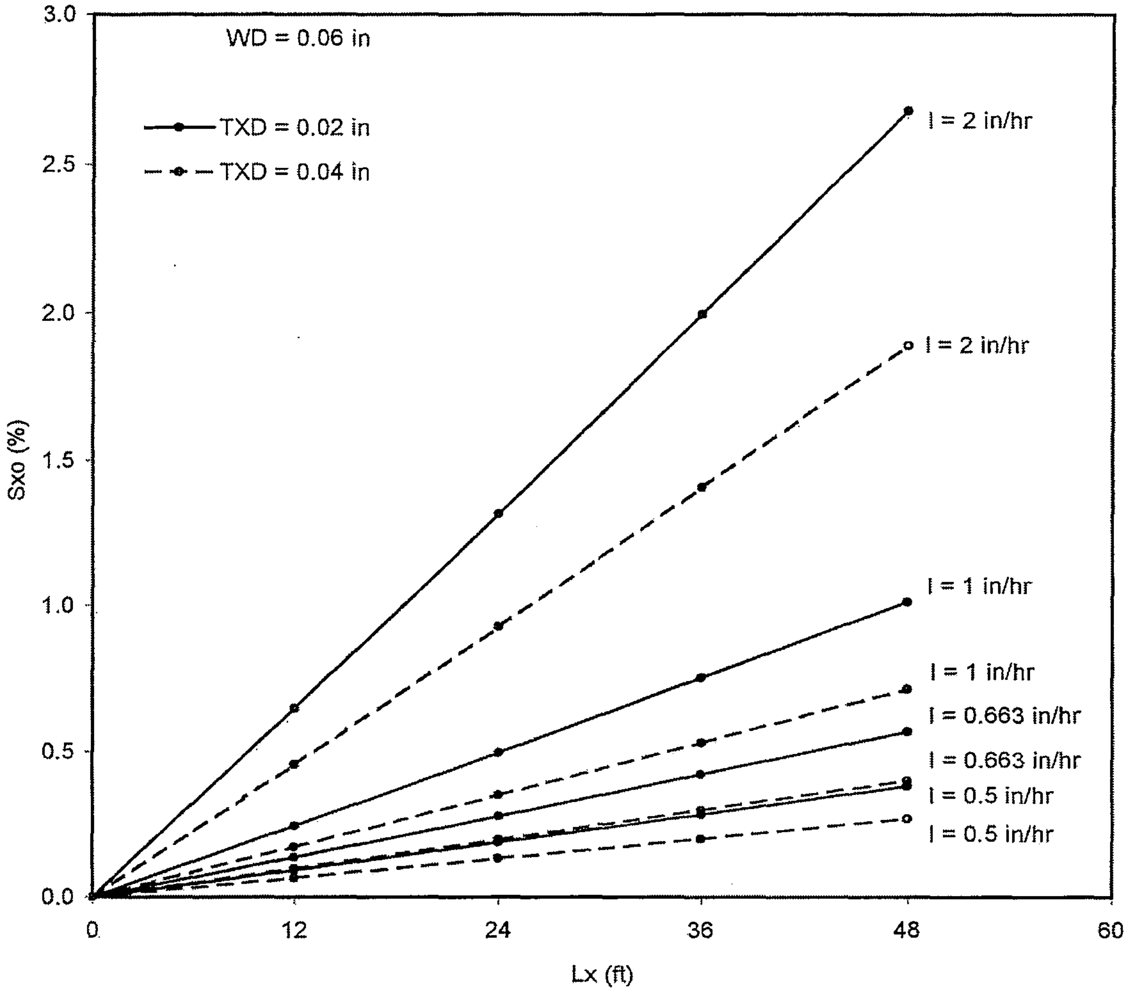

Figure 6. Variation of the Cross Slope S_{xo} as a Function of the Pavement Width (L_x) for Several Values of the Rainfall Intensity (I) and the Texture Depth (TXD) for an Allowable Water Depth of WD = 0.06 inch

VI. Concluding Remarks

Information presented in the previous sections indicates that a pavement cross slope value may be selected with the aid of parametric curves similar to those shown in Figures 5 and 6, based on equation (11), and Figure 4, based on equation (10). In addition to the factors which affect the choice of the cross slope on the basis of sheet flow (equation (3)) which have been discussed in detail in Section V (Cross Slope Selection Factors), other factors such as driver comfort and lateral vehicle stability would also be taken into account in the choice of the pavement cross slope value as previously discussed.

It has also been previously noted that water accumulating in ruts and puddles on the pavement presents a more severe threat to vehicle safety than water which occurs as surface sheet flow. Periodic resurfacing of the pavement is therefore necessary to prevent or reduce the effects of pavement ruts. Since the critical (maximum allowable) wheel path depression (as measured from the normal cross slope of the pavement) required for natural drainage increases with increasing cross slope (see Section III, Hydroplaning Criteria) a larger value for the cross slope, compared with the cross slope value based on sheet flow depth, may be preferable to reduce the probability of water accumulation in the pavement ruts.

References

AASHTO, 1991. Model Drainage Manual. American Association of State Highway and Transportation Officials, Washington, DC.

AASHTO, 1992. Highway Drainage Guidelines. American Association of State Highway and Transportation Officials, Washington, DC.

AASHTO, 1994. A Policy on Geometric Design of Highways and Streets. American Association of State Highway and Transportation Officials, Washington, DC.

FHWA, 1979. Pavement and Geometric Design Criteria for Minimizing Hydroplaning – A Technical Summary. December 1979, Final Report. B.M. Gallaway et al., Texas Transportation Institute. Report No. FHWA – RD – 79 – 30. Federal Highway Administration, Washington, DC.

FHWA, 1984. Drainage of Highway Pavements. Hydraulic Engineering Circular No. 12, FHWA – TS – 84 – 202. Federal Highway Administration, Washington, DC.