Development of Drainage Coefficients for the 1986 AASHTO Guide for Design of Pavement Structures

STEPHEN B. SEEDS AND R. GARY HICKS

A mechanistic-empirical methodology was applied to the procedure for considering the effects of drainage in the new AASHTO Guide pavement structural design process. The procedure considers the level of moisture exposure as well as the quality of drainage. Development of both rigid and flexible pavement models is covered. In addition, some of the general considerations associated with moisture effects and various drainage and subdrainage systems are discussed. Finally, recommendations are provided for future work to improve the methodology.

Generally speaking, most pavements fail because of a combination of three primary factors: traffic (cumulative wheel load applications), inadequate structural capacity (or loss of structural capacity), and poor support (or loss of support). Although some pavements have been known to fail because of various environmental effects, cumulative load applications are generally considered to be the number one cause of distress and deterioration. That is, if there were no traffic, there would be almost no distress. On the other hand, reduced capacity and inadequate support can also be important because, if the pavement is too thin or the support too weak, it would not take much traffic to result in failure.

Because engineers have little control over the ultimate traffic, their focus during the design stage is on the pavement structure and the support provided by the roadbed soil. If the support is strong, they tend to design relatively thin pavements. Conversely, if the support is weak, they must design relatively thick pavements. The strength of the support is dependent on the type of soil, its density, its permeability (or gradation), and its moisture content. Moisture content is perhaps the most critical factor related to support strength because it can make strong soils weak and weak soils weaker. In fact, it also weakens the strength of the layers that compose the pavement structure and, if present in sufficient quantities beneath a cut section of a sloping ground surface, can result in a severe slope failure. Recognition of the adverse effects of moisture on pavement performance led one famous pavement designer to observe that: "There are three important things to consider in the design of highway pavements, drainage, drainage, and drainage."

A considerable amount of work has been accomplished over the years in (a) identifying the sources of moisture that affect pavement performance, (b) developing design and construction procedures to drain or remove moisture, and (c) evaluating and predicting the effects of moisture. Following is a summary of several studies that are of pertinence to the subject. In 1974, Cedergren (*1*) prepared a textbook entitled *Drainage of Highway and Airfield Pavements* that describes the types of damage caused by poor drainage, provides techniques for estimating the influx of moisture, and reviews subsurface drainage design and construction methods that may be used to control moisture. With this work as a basis, Moulton (*2*) prepared a formal highway subdrainage design manual for the FHWA in 1980 that provided detailed procedures and guidance on the prediction of moisture inflow and on the design, construction, and maintenance of a variety of highway subdrainage systems. Ridgeway's report for NCHRP on pavement subsurface drainage systems (*3*) provided an excellent synthesis of design considerations and state practices through 1982. Carpenter et al. (*4*) completed a study for the FHWA in 1980 that provided a method for evaluating the potential for moisture accelerated (pavement) distress (MAD) to occur. It consists of a rating-indexing scheme both for the environment and for the characteristics of the pavement structure.

Recognition of the need to consider drainage in the pavement design process led the AASHTO Joint Task Force on Pavements to require the inclusion of drainage considerations in the new *AASHTO Guide for Design of Pavement Structures—1986* (*5*). Volume 1, Part I, of the Guide addresses the impacts of moisture, gives general design considerations, and references the work of Moulton (*2*) and Ridgeway (*3*). Volume 1, Part II, provides a subjective procedure for treating the moisture exposure level and the quality of drainage in the structural design process for both flexible and rigid pavements. Volume 2, Appendix AA, of the AASHTO Guide (*6*) contains an excerpt from a paper prepared originally by Benson (*7*) that, like Ridgeway (*3*), also provides guidelines for the design of highway internal drainage systems. This appendix is basically a summary documentation of the procedure that has been used extensively by the Illinois DOT in evaluating special moisture and drainage problems.

Overall, the AASHTO Guide provides procedures that can be used to evaluate the effects of drainage systems (and other important factors) on overall pavement performance and life cycle costs. In fact, the methodology has been incorporated into a user-friendly menu-driven computer program (*8*) that has made the process of evaluating alternative pavement designs much simpler.

S. B. Seeds, ARE Inc., 2600 Dellana Lane, Austin, Tex. 78746. R. G. Hicks, Department of Civil Engineering, Oregon State University, 106 Colvell Hall, Corvallis, Ore. 97331.

PURPOSES

One purpose is to discuss some of the key elements related to highway drainage as they are presented in the AASHTO Guide (*5*). The second (and more important) purpose is to describe the methodology that was used to treat the effects of moisture environment and quality of drainage in the pavement structural design process. Discussion of the first purpose is a recapitulation of Part I. Section 1.8, of the AASHTO Guide (*5*); the second purpose is essentially Volume 2, Appendix DD, of the Guide (*6*).

DRAINAGE DESIGN

Moisture Impacts

Drainage of water from pavements has always been an important consideration in road design; however, current methods of design that do not incorporate permeability into the design process have often resulted in base courses that do not drain well. This excess water combined with increased traffic volumes and loads often leads to early pavement distress in the pavement structure.

Water enters the pavement structure in many ways, such as through cracks, joints, or pavement infiltration, or as groundwater from an interrupted acquifer, high water table, or localized spring. Effects of this water (when trapped within the pavement structure) on pavements include

1. Reduced strength of unbound granular materials;
2. Reduced strength of roadbed soils;
3. Pumping of concrete pavements with subsequent faulting, cracking, and general shoulder deterioration; and
4. Pumping of fines in aggregate base under flexible pavements with resulting loss of support.

Less frequently noticed problems caused by entrapped water include (but are not limited to)

1. Stripping of asphaltic concrete,
2. Differential heaving over swelling soils, and
3. Frost heave.

The *AASHTO Interim Guide for Design of Pavement Structures* (*9*) did not treat the effects of drainage on pavement performance. In the new Guide, drainage effects were directly considered for the effect of moisture on roadbed soil and base strength (for flexible pavements) and for the effect of moisture on subgrade strength and base erodability (of concrete pavements). Although the effects of asphalt concrete stripping are not directly considered, those of swelling soils and frost heave are.

Moisture Treatment Methods

Methods for treating water in pavements have generally consisted of

1. Preventing water from entering the pavement,
2. Providing drainage to remove excess water quickly, and
3. Building the pavement strong enough to resist the combined effects of load and water.

When all possible sources of water are considered, protection of the pavement structural section from water entry requires interception of groundwater as well as sealing of the pavement surface. Considerable attention has generally been given to intercepting groundwater, whereas less attention has been given to sealing the surface to exclude infiltration from rain and snow melt. As a result, a considerable amount of water often enters the pavement substructure, resulting in a need for some type of drainage.

In order to obtain adequate pavement drainage, the designer should consider providing three types of drainage systems: (a) surface drainage, (b) groundwater drainage, and (c) structural drainage. Such systems, however, are only effective for free water. Water held by capillary forces in soils and in fine aggregate cannot be drained. The effects of this bound moisture must be considered in the design of pavement structures through its effect on the pavement material properties. Most existing pavements do not include drainage systems capable of quickly removing free water.

Most existing design methods have relied on the practice of building pavements strong enough to resist the combined effects of load and water. However, they do not always account for the potential destructive effects of water within the pavement structure. As a result, increased emphasis is needed to exclude water from the pavement and provide for rapid drainage. Although both approaches are extremely complex, the AASHTO Guide only emphasizes the treatment of drainage. However, maintenance policies should recognize the benefits and necessity of maintaining the joint and crack sealant and thus preventing water from leaking into the subbase layer.

Design Criteria for Pavement Subsurface Drainage

Two general types of pavement subsurface design criteria have been proposed for the use in pavements (*3*). These include

1. Criterion for the time of drainage of the base or subbase beginning with the flooded condition and continuing to an established acceptable level, and
2. An inflow-outflow criterion, by which drainage (outflow) occurs at a rate greater than or equal to the inflow rate, thus avoiding saturation.

Removal of the free water is often accomplished by draining the free water vertically into the subgrade, or laterally through a drainage layer into a system of pipe collectors. Generally, the actual purpose will be a combination of the two. Details of the design of subsurface drainage systems are important and are, therefore, addressed in Appendix AA, Volume 2, of the Guide (*6*).

Incorporation of Drainage Into the Guide

Drainage effects on pavement performance have been included in the new Guide by considering the effect of water on the properties of the pavement layers and the consequences to the structural capacity of the pavement. Additional work is needed to document the actual effect of drainage on pavement life.

For new design (Part II), the effect of drainage is considered by modifying the structural layer coefficient (for flexible pavements) and the load transfer coefficient (for rigid pavements) as a function of

1. Quality of drainage (e.g., the time required for the pavement to drain), and
2. Percent of time the pavement structure is exposed to moisture levels approaching saturation.

The development of this methodology is described in the following section.

DEVELOPMENT OF COEFFICIENTS FOR TREATMENT OF DRAINAGE

This development of drainage coefficients used in flexible and rigid pavement design procedures was presented in Part II of the Guide. For flexible pavement design, the *m* value is used to reduce or increase the layer coefficient of the base and subbase layers. For rigid pavement design, the C_d value is used to modify stress conditions in the portland concrete cement (PCC) slab.

Effects of Water on Pavement Behavior

The Interim Guide (*9*) did not recognize the effect of positive drainage within the pavement structure on the life of the pavement. The introduction of the *m* and C_d values is intended to account for this important factor. Moisture in the pavement structure has a direct effect on the following:

1. Asphalt Concrete Surface. Water can lead to moisture damage, modulus reduction, and a loss of tensile strength. The experience of the authors indicates that saturation alone can reduce the dry modulus by 30 percent or more.
2. PCC Surface. Moisture has only a slight effect on the modulus and strength of PCC, but it can have an effect on curling and warping stresses in the slab.
3. Aggregate Base and Subbase. Added moisture will result in a loss of stiffness for all unbound aggregate materials. Reductions in modulus values of more than 50 percent have been reported in the literature (*10,11*).
4. Treated Bases. For asphalt-treated base (ATB), modulus reductions of up to 30 percent can be expected. For cement-treated base (CTB) and lime-treated base (LTB), modulus reductions caused by moisture would be slight; however, these materials are more susceptible to freeze-thaw damage.
5. Roadbed Soil. Free-draining soils should experience little modulus reduction, whereas those with low to very low permeability could experience modulus reductions of 50 percent or more.

The effect of moisture on roadbed soil is considered in the development of an "Effective Roadbed Soil Modulus," Appendix HH, Volume 2, of the new AASHTO Guide (*6*).

Quality of Drainage

The first issue addressed was the establishment of what constitutes good, fair, and poor drainage conditions. The method used to establish the quality of drainage was to calculate the time required to drain the base layer to 50 percent saturation (T_{50}). The actual approach followed is described by Moulton (*2*); T_{50} is determined for different combinations of permeability (k), length of drainage path (L), thickness of drainage layer (H), effective porosity (n), and slope (S). Results of the calculations are presented in Table 1. Because the permeability of the AASHO Road Test materials was 0.1 ft/day (or less), and the length of the drainage path (lane width in this case) was 12 ft, the time required to drain the unbound layers would be on the order of 5 to 10 days (approximately 1 week). If the length of the drainage path had been 24 ft, it would have taken 18 to 36 days (approximately 1 month) to drain. Using information provided by Moulton (*2*), the quality levels presented in Table 2 were established for drainage.

These criteria are recommended for use in both flexible and rigid pavement design.

Development of Flexible Pavement *m* Values

The approach used to evaluate the effect of drainage for flexible pavement design was to include adjustment factors (*m* values) to the structural number equation that modify the layer coefficients according to the anticipated moisture (drainage) conditions:

$$\mathrm{SN} = a_1D_1 + a_2m_2D_2 + a_3m_3D_3 \tag{1}$$

where

SN = structural number,
a_1,a_2,a_3 = structural layer coefficients,
D_1,D_2,D_3 = layer thicknesses, and
m_2,m_3 = effect of water on the stiffness (strength) of each material.

In order to evaluate the effect of the *m* values on pavement thickness, three typical cross sections were evaluated (see Figure 1). It was assumed initially that the *m* values might vary from 0.5 to 1.4. This assumption resulted in new values of SN for each of the three cross sections shown in Figure 1. These values together with the incremental SN and D_1 values associated with each *m* value are given in Table 3. Note that an *m* value greater than 1.0 would result in a net decrease in required total SN or, if applied only to the surface layer, a decrease in surface thickness of about 1 to 2.5 in., depending on base thickness. Similarly, selection of an *m* value less than 1.0 would result in an increase in SN or in surface thickness. Because of its simplicity, this approach was selected for use in the Guide; however, additional evaluation was considered necessary to establish the *m* values for various qualities of drainage. Two approaches were considered in selecting *m* values:

1. Experience—based on field data, and
2. Theory—based on mechanistic analysis.

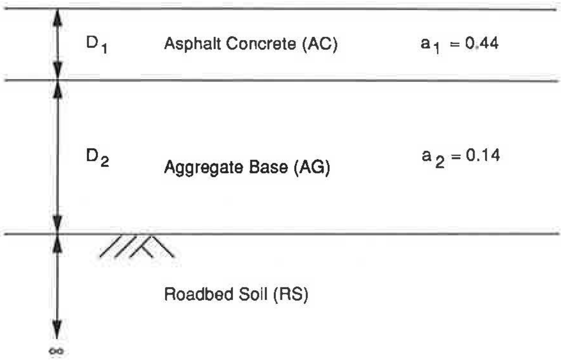
TABLE 1 TIME (DAYS) TO DRAIN BASE LAYER TO 50 PERCENT SATURATION (DAMP)

Permeability, k (ft/day)	Porosity, n	Slope, S	H = 1		H = 2	
			L=12	L=24	L=12	L=24
0.1	0.015	0.01	10	36	6	20
		0.02	9	29	5	18
1.0	0.027	0.01	2	6	5	18
		0.02	2	5	1	3
10.0	0.048	0.01	0.3	1	0.2	0.6
		0.02	0.3	1	0.2	0.6
100.	0.08	0.01	0.05	0.2	0.03	0.1
		0.02	0.05	0.2	0.03	0.1

Note: H refers to the thickness of the drainage layer (in feet) and L refers to the length of the drainage path (in feet).

TABLE 2 DRAINAGE QUALITY LEVELS

Quality of Drainage	Durations Required to Remove Water	
	Calculated	Recommended
Excellent	2–4 hr	2 hr
Good	½–1 day	1 day
Fair	3–6 days	7 days
Poor	18–36 days	1 month
Very poor	> 36 days	Does not drain



Case	Layer Thickness (inches)		SN
	D_1	D_2	
A	4	8	2.88
B	5	15	4.30
C	6	20	5.44

FIGURE 1 Pavement cross section (cases) evaluated in preliminary analysis.

TABLE 3 EFFECTS OF *m* VALUES ON SN AND SURFACE THICKNESS

m Value	m_2a_2	Cross Section (Case) A	B	C
Calculated SN values				
1.4	0.196	3.33	5.14	6.56
1.0	0.140	2.88	4.30	5.44
0.7	0.098	2.54	3.67	4.60
0.5	0.070	2.32	3.25	4.04
Incremental SN values				
1.4	–	−0.45[a]	−0.84	−1.12
1.0	–	0.00	0.00	0.00
0.7	–	+0.34	+0.63	+0.84
0.5	–	+0.56	+1.05	+1.40
Incremental surface thicknesses (in.)				
1.4	–	−1.02[a]	−1.91	−2.55
1.0	–	0.00	0.00	0.00
0.7	–	+0.77	+1.43	+1.91
0.5	–	+1.27	+2.39	+3.18

[a] A minus sign indicates a reduction in cross sections as a result of improved drainage. A plus sign indicates an increase in cross section as a result of the lack of drainage.

As there were few field data to evaluate the effect of drainage on pavement life or pavement thickness, the theoretical approach was selected.

For the factorial of cross sections shown in Figure 2, the surface deflections (between the dual tires) were calculated using the ELSYM5 computer program (*12*). The modulus value for the surface was selected to represent an average condition at the AASHO Road Test. The modulus values selected for the aggregate base from experience demonstrate the potential effect of moisture (e.g., 40,000 psi corresponds to good drainage, whereas 10,000 psi is equivalent to very poor drainage). Modulus values used for the roadbed soil are typical of those found throughout the United States. The

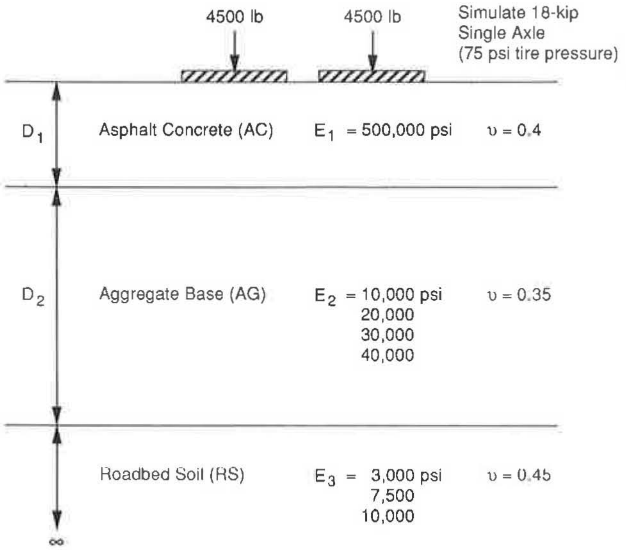


FIGURE 2 Pavement structural and material characteristics considered in ELSYM5 (elastic layer) analysis.

AASHO Road Test condition was assumed to have an aggregate base modulus of 30,000 psi and a roadbed soil modulus of 3,000 psi. Surface deflections for these conditions and for the three cases shown in Figure 2 are presented in Table 4. Surface deflections for the other modulus values are shown in Figure 3.

In order to quantify the effect of reducing base modulus on pavement thickness requirements, similar calculations were made, but with overlay thicknesses of 3, 5, and 6 in. over the sections shown in Figure 2. These results are presented in Table 5.

For E_2 equal to 10,000 psi (poor drainage), the surface deflections are plotted in Figure 4 versus overlay thickness. The added overlay thickness needed to maintain the surface deflection for the AASHO condition (E_2 = 30,000 psi) is also shown on the figure. Note that added surface thickness required increases with increasing base thickness. Figures 5 and 6 show similar results for E_2 to 20,000 and 40,000 psi, respectively.

In order to associate reduced modulus with *m* value, the incremental surface thicknesses summarized in Table 3 have been plotted in Figure 7. When these values are compared with the incremental thickness requirements on the basis of equal deflections, *m* values can be determined for the different base modulus values as presented in Table 6. This table indicates that a material having a base modulus of 10,000 psi would have an *m* value of about 0.4 whereas those with base moduli of 20,000 and 40,000 psi would have *m* values of about 0.7 and 1.2, respectively. Extrapolating these results yields an *m* value of 1.4 for an E_2 of 50,000 psi. On the basis of these results, the *m* values presented in Table 7 are recommended. However, it is recognized that these values would also vary with the percent of time the pavement structure is exposed to moisture levels approaching saturation. Figure 8 shows the approach for considering the variation in *m* value with percent of time the structure is in or near a saturated condition. This procedure was used for the development of the recommended *m* values presented in Table 8 [from Volume 1, Part II, Table 2.4 (*5*)].

TABLE 4 SURFACE DEFLECTIONS FOR THREE CASES SHOWN IN FIGURE 2

Case	SN	Deflection (10^{-3} in.)
A	2.88	48
B	4.30	34
C	5.44	28

These *m* values apply only to the effect of drainage on untreated base and subbase layers. Although improved drainage is certainly beneficial to stabilized or treated materials, the effects on performance of flexible pavements were not considered as profound as those indicated in Figure 8.

Development of Rigid Pavement C_d Values

The rigid pavement performance equation that has been modified to include a term C_d to account for the effects of drainage follows:

$$\log_{10}(W_{18}) = 7.35 * \log_{10}(D + 1) - 0.06 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.5 - 1.5}\right)}{\left[1 + \frac{1.624 * 10^7}{(D + 1)^{8.46}}\right]} + (4.22 - 0.32 * p_t) * \log_{10}\left\{\frac{S_c' * C_d * (D^{0.75} - 1.132)}{215.63 * J\left[D^{0.75} - \frac{18.42}{(E_c/k)^{0.25}}\right]}\right\} \quad (2)$$

where

W_{18} = predicted number of 18-kip ESAL applications that can be carried by the pavement structure after construction,
D = pavement slab thickness (in.),
P_t = design terminal serviceabiliy index,
ΔPSI = difference between the initial design serviceability index (p_0) and the terminal design serviceability index (p_t),
S_c = PCC modulus of rupture (psi),
J = load transfer coefficient,
C_d = drainage coefficient,
E_c = PCC modulus of elasticity (psi), and
k = modulus of subgrade reaction (pci).

Because drainage condition influences slab support and therefore the overall stress condition in the slab, C_d was introduced into the portion of the performance Equation 2 that considers the slab's strength, stress, and support condition. In fact, C_d has the same relative impact on rigid pavement performance as both the modulus of rupture (S_c) and the load transfer

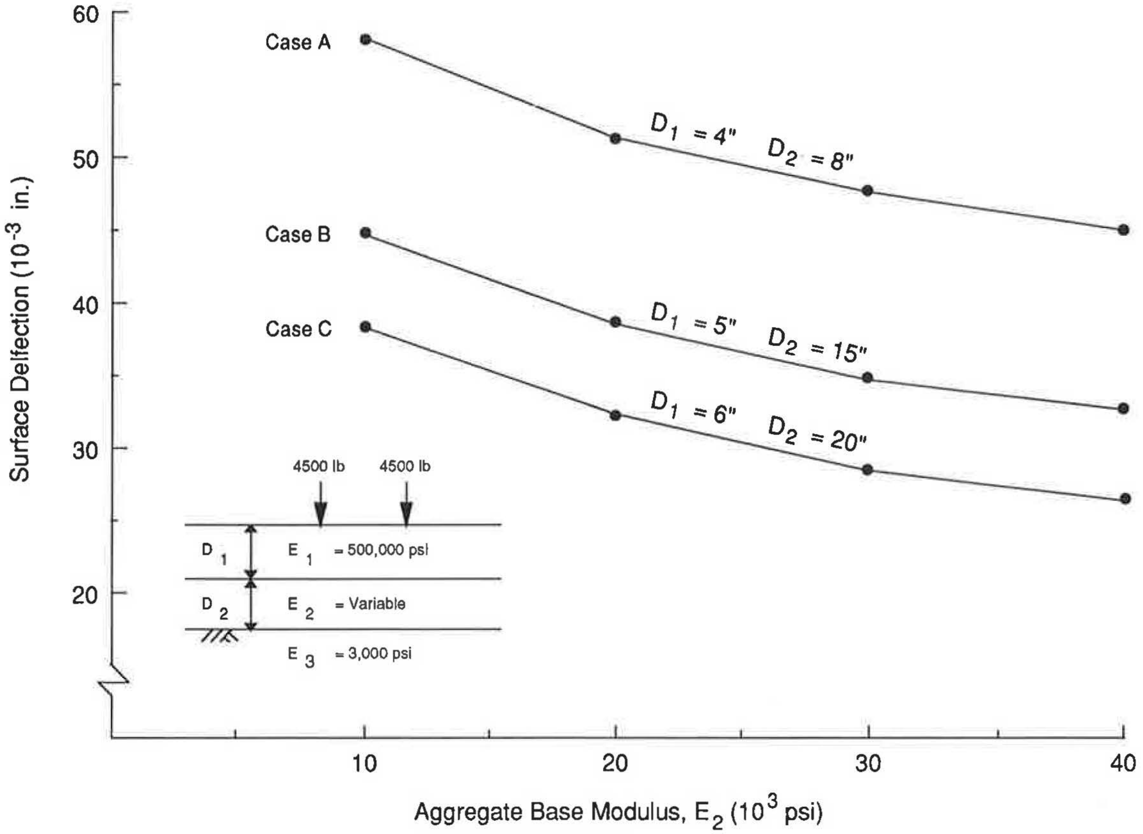


FIGURE 3 Variation in surface deflection with base modulus, AASHO road test conditions.

TABLE 5 VARIATION IN SURFACE DEFLECTION WITH OVERLAY THICKNESS (ROADBED SOIL MODULUS, E_3 = 3,000 psi)

Aggregate Base Modulus, E_2 (psi)	Case	Surface Deflection (10^{-3} in.) for Various Overlay Thicknesses, D_{ov} (in.) -2.0	0.0	3.0	5.0	6.0
10,000	A	81.3	57.6	39.4	32.9	30.6
	B	58.2	44.9	33.6	29.0	27.2
	C	47.3	38.1	29.8	26.1	24.6
20,000	A	68.0	51.5	37.2	31.7	29.5
	B	46.7	38.5	30.5	26.8	25.3
	C	37.9	32.2	26.4	23.5	22.3
30,000	A	60.9	47.7	35.7	30.7	28.7
	B	41.1	34.9	28.4	25.3	23.9
	C	33.2	28.9	24.2	21.8	20.7
40,000	A	56.2	45.0	34.5	29.9	28.0
	B	37.6	32.4	26.9	24.1	22.8
	C	30.3	26.6	22.6	20.5	19.5

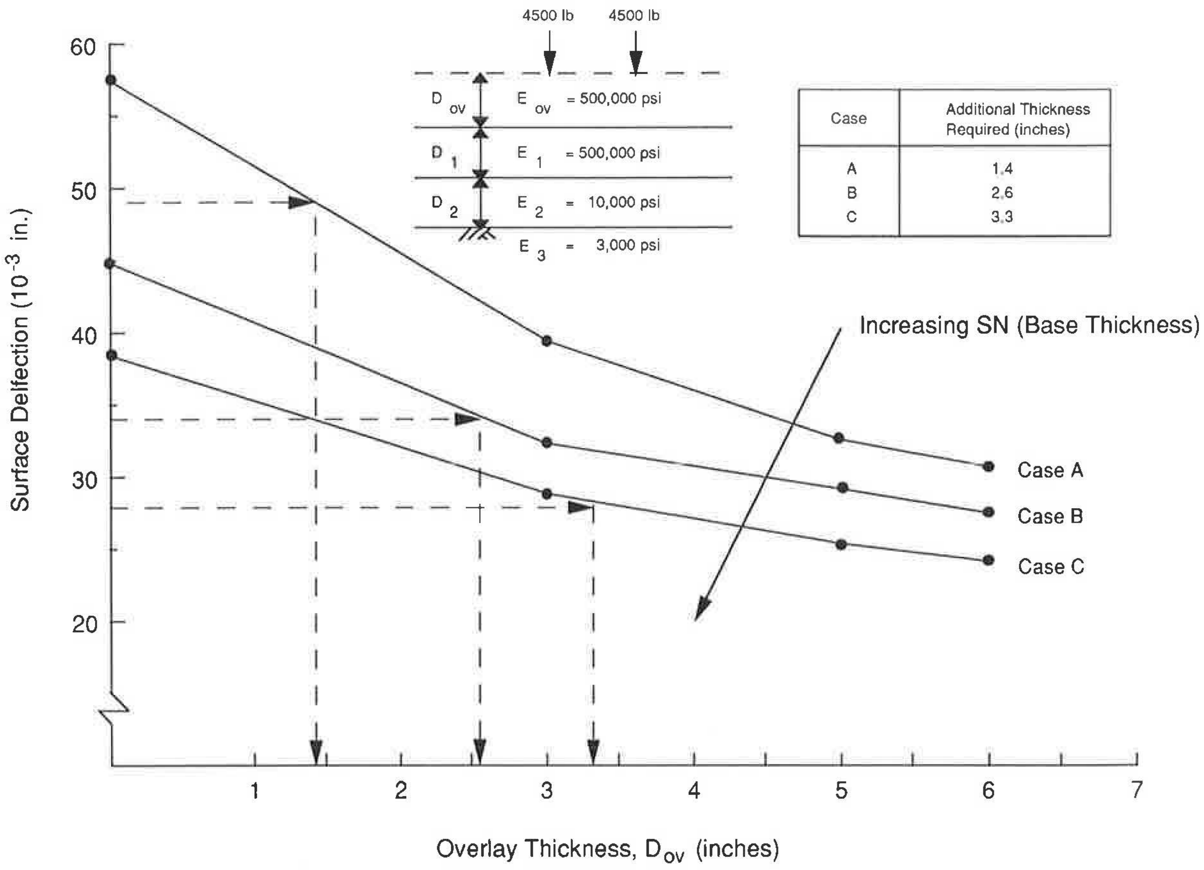


FIGURE 4 Variation in surface deflection with overlay thickness (E_3 = 3,000 psi, E_2 = 10,000 psi).

coefficient (J). For example, a 20 percent increase in C_d would have the same effect as a 20 percent increase in S_c or, because J is in the denominator, a 20 percent increase in $1/J$.

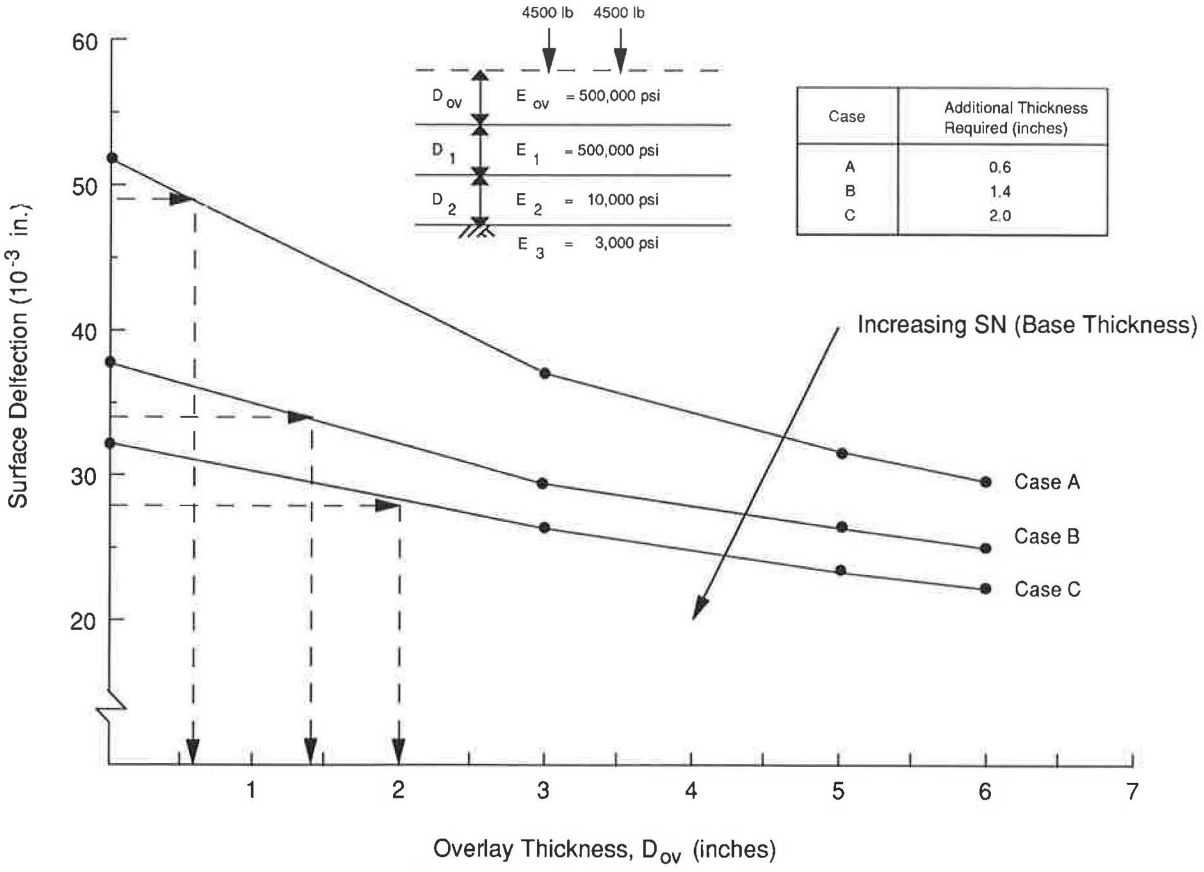
Unlike the approach used to develop m values for flexible pavement design, the consideration of drainage effects on base or subbase strength alone could not be used to derive C_d values that had a realistic impact on slab thickness; in other words, results of the approach did not pass the test for reasonableness. Consequently, an alternate approach was adopted whereby C_d values were backcalculated from Equation 2 using expected minimum effects of drainage condition on slab thickness. Figure 9 represents the results of these C_d calculations for a factorial of design combinations.

1. Original slab thicknesses (D) of 7, 10, and 13 in.;
2. Slab thickness variations (about the original thickness) of −1.5, −1.0, −0.5, +0.5, +1.0, and +1.5 in.;
3. PCC elastic moduli (E_c) of $3 * 10^6$, $5 * 10^6$, and $7 * 10^6$ psi; and
4. Modulus of subgrade reaction (k) values of 60, 100, 200, and 400 pci.

Variations in flexural strength (S_c) and load transfer coefficient (J) were not considered as they cancelled out of the equation. Other factors inherent in Figure 9 are (a) a fixed terminal serviceability (p_t) of 2.5, and (b) an average effect of PCC elastic modulus variation.

The curves shown in Figure 9 provide the basis for selection of the recommended ranges of C_d in Table 8 (from Volume 1, Part II, Table 2.5, of the Guide (*5*)). Basically, a 1-in. reduction in slab thickness was used to identify the maximum value of C_d (i.e., that corresponding to the excellent drainage class). Likewise, a 1.5-in. increase in slab thickness was used to identify the minimum value of C_d (i.e., that corresponding to the very poor drainage class). The other values in Table 9 were selected on the basis of an interpolation between these extreme values, considering (a) the percent of time the pavement structure is exposed to moisture levels approaching saturation, and (b) the intermediate levels of drainage quality or condition.

Figure 9 may also be helpful to some users who wish to apply their own experience in drainage effects on slab thickness to identify C_d values for their local conditions. In doing so, it should be recognized that the shaded regions for the three original slab thicknesses shown represent the effects of variation in slab support (i.e., modulus of subgrade reaction). For example, if the original slab thickness corresponding to conditions when drainage effects are not considered (i.e.,



Case	Additional Thickness Required (inches)
A	0.6
B	1.4
C	2.0

FIGURE 5 Variation in surface deflection with overlay thickness (E_3 = 3,000 psi, E_2 = 20,000 psi).

when C_d is equal to 1.0) is 7.0 in. and a C_d of 1.2 is used, the reduction in thickness would be about 0.75 in. for *k* to 60 pci and about 0.9 in. for *k* equal to 400 pci.

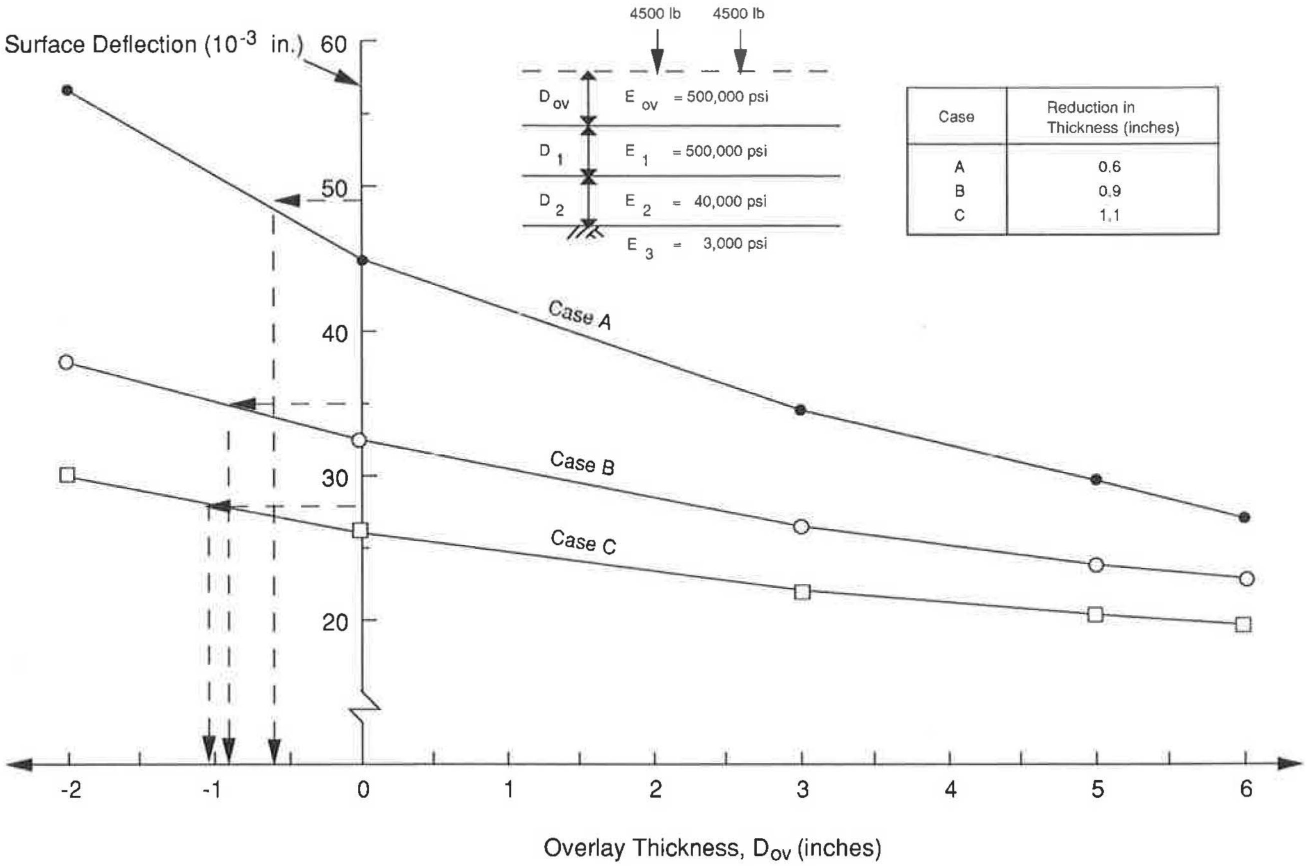
Table 10 presents the significance of the range of C_d values on how the slab support (*k* value) would vary to produce the same effect. It is based on a 10-in. PCC slab with an elastic modulus of $5 * 10^6$ psi. Because the range of *k* values is so wide compared to the associated range of C_d values, the obvious implication from this table is that the recommended C_d values account for more than just the effect of drainage condition on slab support. There may be some inherent recognition of the effect moisture environment has on curling and warping stresses in the slab. In any case, the recommended ranges of C_d do provide reasonable results for their effect on design slab thickness for different drainage conditions. However, data from field experiments and long-term pavement performance monitoring should be used to validate and improve these values.

FUTURE WORK

Some of the general considerations associated with the effects of moisture in pavements and how they have been treated have been addressed. More important, the methodology that was used to incorporate drainage considerations in the new *AASHTO Guide for Design of Pavement Structures—1986* has been described. In summary, a mechanistic approach combined with sound engineering judgment was applied to derive coefficients that could be used in the structural design process for both flexible and rigid pavements. The coefficients depend on the pavement's level of moisture exposure (environment) as well as the quality of drainage.

One of the problems with the methodology is that there are no well-defined procedures for translating the results of various drainage design procedures into the rather subjective inputs (coefficients) used in the Guide. In addition, there is no standard computer program that can be used by the highway pavement and subdrainage design engineers to assist them in evaluating moisture conditions and generating suitable drainage designs. Lastly, the process of determining appropriate drainage system unit costs for use in the Guide (and its related microcomputer program) is rather time-consuming and subject to error.

Therefore, improvements are needed to make the methodology less subjective and easier to use. It is anticipated that these improvements will be considered in a forthcoming FHWA project.



Case	Reduction in Thickness (inches)
A	0.6
B	0.9
C	1.1

FIGURE 6 Variation in surface deflection with overlay thickness (E_3 = 3,000 psi, E_2 = 40,000 psi).

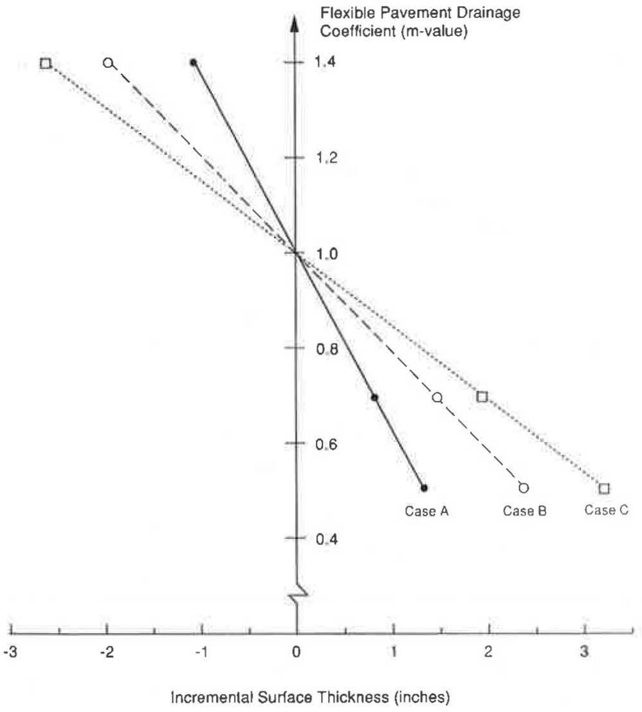


FIGURE 7 Variation in surface thickness requirements with *m* values from Table 3.

TABLE 6 ESTIMATED *m* VALUES FOR THREE CASES SHOWN IN FIGURE 7

Case	Aggregate Base Modulus (psi)	Incremental Thickness (in.)	Estimated *m* Value
A	10,000	+1.4	0.40
	20,000	+0.6	0.75
	40,000	−0.6	1.22
B	10,000	+2.6	0.40
	20,000	+1.4	0.72
	40,000	−0.9	1.20
C	10,000	+3.3	0.50
	20,000	+2.0	0.70
	40,000	−1.1	1.20

TABLE 7 RECOMMENDED *m* VALUES

Base Modulus E_2(psi)	Quality of Drainage	Recommended *m* Value
50,000	Excellent	1.4
40,000	Good	1.2
30,000	Fair	1.0
20,000	Poor	0.7
10,000	Very Poor	0.4

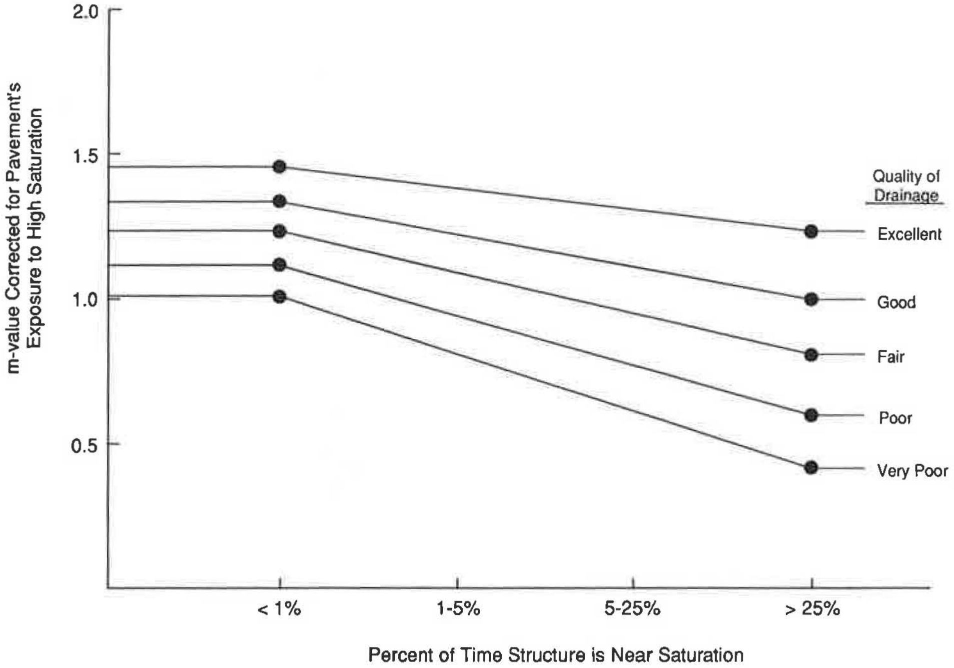


FIGURE 8 Recommended *m* values as a function of the quality of drainage and exposure to saturation.

TABLE 8 RECOMMENDED m_i VALUES FOR MODIFYING STRUCTURAL LAYER COEFFICIENTS OF UNTREATED BASE AND SUBBASE MATERIALS IN FLEXIBLE PAVEMENTS (*5*)

	Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation			
Quality of Drainage	Less Than 1%	1-5%	5-25%	Greater Than 25%
Excellent	1.40-1.35	1.35-1.30	1.30-1.20	1.20
Good	1.35-1.25	1.25-1.15	1.15-1.00	1.00
Fair	1.25-1.15	1.15-1.05	1.00-0.80	0.80
Poor	1.15-1.05	1.05-0.80	0.80-0.60	0.60
Very Poor	1.05-0.95	0.95-0.75	0.75-0.40	0.40

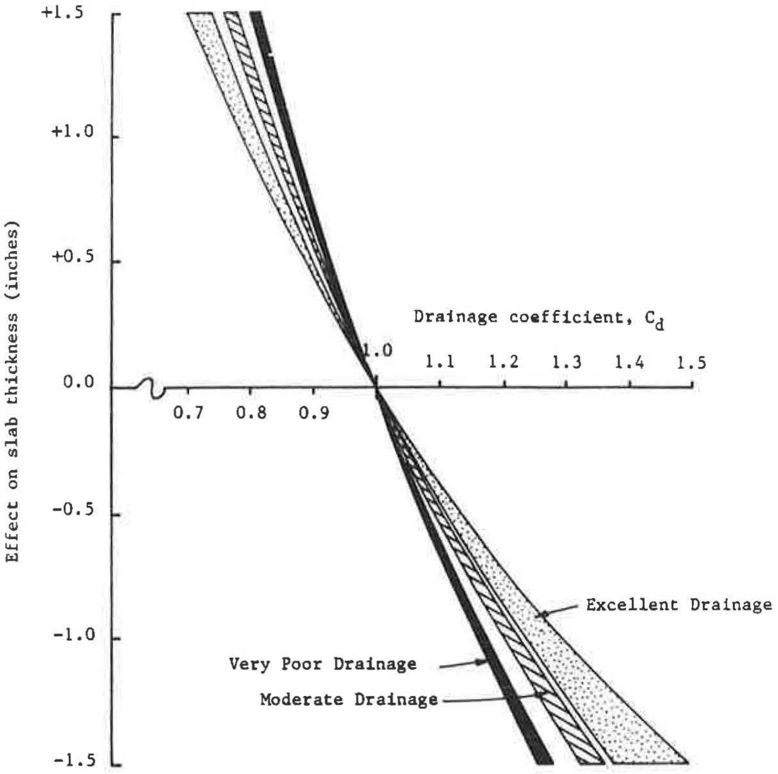


FIGURE 9 Effect of drainage coefficient on reducing or increasing original slab thickness.

TABLE 9 RECOMMENDED VALUES OF DRAINAGE COEFFICIENT C_d, FOR RIGID PAVEMENT DESIGN (*5*)

	Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation			
Quality of Drainage	Less Than 1%	1-5%	5-25%	Greater Than 25%
Excellent	1.25-1.20	1.20-1.15	1.15-1.10	1.10
Good	1.20-1.15	1.15-1.10	1.10-1.00	1.00
Fair	1.15-1.10	1.10-1.00	1.00-0.90	0.90
Poor	1.10-1.00	1.00-0.90	0.90-0.80	0.80
Very Poor	1.00-0.90	0.90-0.80	0.80-0.70	0.70

TABLE 10 VALUES OF *k* PRODUCING SAME EFFECT AS CORRESPONDING VALUES OF C_d

Quality of Drainage	Selected C_d Value	Corresponding *k*-value (pci)
Excellent	1.2	942
Good	1.1	501
Fair	1.0	200
Poor	0.9	44
Very Poor	0.8	1

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