# Comparison of AASHTO and ROADHOG Flexible Pavement Overlay Design Procedures

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A comparison of the ROADHOG and AASHTO (1993) overlay design procedures for conventional flexible pavements is presented. Both procedures use a structural deficiency approach to overlay design yet differ in the methods used to estimate the effective structural number of an existing pavement and to estimate the in situ subgrade resilient modulus. Both methods use pavement surface deflections to backcalculate or estimate required design parameters. Specific comparisons include backcalculated subgrade resilient modulus, effective structural number, and recommended overlay thickness for a number of conventional flexible pavement configurations. Pavement surface deflections are generated using the ILLI-PAVE finite-element pavement model and the ELSYM5 elastic layer model. Pavement parameters varied to establish the deflection data base, including asphalt concrete surface thickness and resilient modulus, base course thickness and resilient modulus, and subgrade resilient modulus. The comparisons show that the AASHTO overlay design procedure recommends thicker overlays than does the ROADHOG procedure for pavements overlying relatively stiff subgrade soils. The difference in recommended overlay thickness is linked to differences in the estimates of both $SN_f$, the structural number required to carry future traffic, and $SN_{eff}$, the effective structural number of the existing pavement. The two design procedures recommend similar overlay thicknesses for pavements overlying soils with relatively low resilient modulus values. The analyses also show that the backcalculated value of subgrade resilient modulus plays a larger role in determining the overlay thickness for the AASHTO procedure than for the ROADHOG procedure.

The 1986 *AASHTO Guide for Design of Pavement Structures* (*1*) contains a framework for developing a structural overlay design procedure for flexible pavements but does not contain a complete design procedure. Subsequent development of AASHTO overlay design principles (*2*) resulted in the inclusion of a complete flexible pavement overlay design procedure in the 1993 AASHTO guide (*3*). The procedure contained in the 1993 guide is based somewhat on pavement surface deflections measured by a nondestructive testing device, such as the falling weight deflectometer (FWD) and elastic layer theory.

ROADHOG is a deflection-based structural overlay design procedure for flexible pavements developed in 1989 at the University of Arkansas for the Arkansas Highway and Transportation Department (AHTD) (*4*). AHTD designs new pavements using AASHTO procedures. ROADHOG was developed to be compatible with AHTD new-pavement design practices; thus, the structural pavement design concepts in ROADHOG are compatible with AASHTO flexible pavement design. ROADHOG was developed around the framework contained in the 1986 AASHTO guide but differs in its approach to determining the structural number of the existing pavement and the in situ subgrade resilient modulus.

This paper presents some results of a comparison between the flexible pavement overlay design procedures contained in the 1993 AASHTO guide and in ROADHOG. The overlay design parameters compared include the effective structural number of the existing flexible pavement ($SN_{eff}$), the resilient modulus of the roadbed soil ($M_R$), and their respective effects on resulting overlay thickness. Surface deflection basins are generated using the ILLI-PAVE finite-element structural model (*5*) and the ELSYM5 elastic layer model (*6*). Deflection basins are generated for conventional flexible pavements [asphalt concrete (AC) surface, granular base, subgrade] with varying AC and granular base layer thicknesses and resilient moduli, and varying subgrade moduli.

## FLEXIBLE OVERLAY DESIGN: STRUCTURAL DEFICIENCY APPROACH

Both the AASHTO and ROADHOG procedures use a structural deficiency approach to flexible pavement overlay design. Before looking at comparisons of the two procedures, it is useful to briefly review the structural deficiency concept.

AASHTO pavement design procedures use a structural number (SN) to express the structural capacity of a flexible pavement. The structural number of a pavement layer is determined by multiplying the thickness of the layer ($d_i$) by a layer coefficient ($a_i$), which is usually based on some measure of the layer material's strength or stiffness. The structural number of the pavement is determined by summing the individual SNs of the pavement layers, as shown in Equation 1.

$$SN = a_1 d_1 + a_2 d_2 + \ldots + a_n d_n \quad (1)$$

where

SN = structural number of the pavement,
$a_n$ = layer coefficient of layer $n$, and
$d_n$ = thickness of layer $n$.

Within the structural deficiency approach, the structural capacity required of the overlay is equal to the difference between the total structural capacity required to carry future traffic and the structural capacity of the existing pavement. For flexible pavements, this concept is expressed in Equation 2.

$$SN_{ol} = SN_f - SN_{eff} \quad (2)$$

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where

$SN_{ol}$ = structural number required for the overlay,
$SN_f$ = structural number required to carry future traffic, and
$SN_{eff}$ = effective structural number of the existing pavement.

The thickness of the overlay is determined by rearranging the structural number equation (Equation 1) for a single layer.

$$d_{ol} = \frac{SN_{ol}}{a_{ol}} \tag{3}$$

where

$d_{ol}$ = thickness of overlay,
$SN_{ol}$ = structural number of overlay, and
$a_{ol}$ = layer coefficient of overlay material.

The major differences in design procedures fully using the structural deficiency approach can be related to the specific methods used to estimate the effective structural number of the existing pavement ($SN_{eff}$) and the specific methods used to determine the structural number required to carry future traffic ($SN_f$). Both the ROADHOG and AASHTO procedures use the AASHTO new-pavement design method to determine $SN_f$, differing only by the method used to estimate the resilient modulus of the roadbed soil. A comparison of the two procedures, then, focuses on the respective methods of estimating $SN_{eff}$ and $M_R$.

## FLEXIBLE OVERLAY DESIGN: ROADHOG DESIGN PROCEDURE

A complete description of the ROADHOG overlay design procedure is given elsewhere (*7*). The methods used by ROADHOG to estimate $SN_{eff}$ and $M_R$ are briefly described here.

### Determination of $SN_{eff}$

The methodology used in ROADHOG for estimating the effective structural number of a flexible pavement was developed (*8*). The methodology uses two pavement surface deflections: (a) the deflection directly beneath the load, where it is assumed that the surface deflection is due to deflections within all paving layers and the subgrade, and (b) a deflection at some radial distance from the load (in the case of ROADHOG, a distance equal to the pavement thickness), where it is assumed that the surface deflection is due entirely to deflection within the subgrade. It was suggested that the difference between these two deflections, termed "delta-D," could be used as a measure of pavement stiffness (*8*). AASHTO methodology assumes $SN_{eff}$ to be a function of the pavement stiffness; using this assumption, $SN_{eff}$ can be expressed in terms of delta-D.

The $SN_{eff}$ of a number of conventional flexible pavement configurations to the deflection difference delta-D is given elsewhere (*8*). Deflection basins were generated using the ELSYM5 elastic layer model (*8*). $SN_{eff}$ was estimated using component analysis, in which each paving layer was assigned a typical layer coefficient based on its input elastic modulus, and the structural number calculated according to Equation 1. Figure 1 shows the relationship between $SN_{eff}$ and delta-D for various pavement thicknesses. Note the relationship shown in Figure 1 is primarily a function of total pavement thickness; subgrade resilient modulus is not explicitly considered.

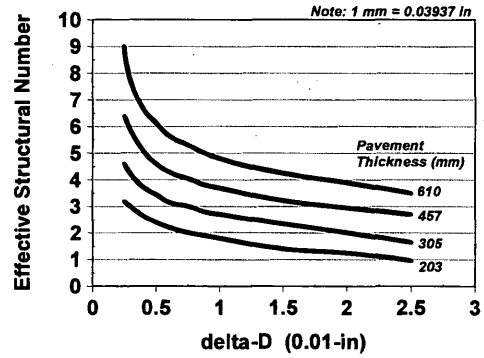


**FIGURE 1 Delta-D/$SN_{eff}$ relationship used in ROADHOG (*8*).**

### Determination of $M_R$

To calculate the SN required to carry future traffic (using AASHTO new pavement design procedures), an estimate must be provided of the roadbed soil (subgrade) resilient modulus. ROADHOG estimates $M_R$ using a single pavement surface deflection, measured at 914 mm (36 in.) from the load. $M_R$ is calculated by regression equations developed in a work by Elliott and Thompson from data generated by the ILLI-PAVE finite-element model (*9*). For illustrative purposes, the regression equation used for conventional flexible pavements with more than a 76-mm (3-in.) AC surface is shown as Equation 4.

$$E_{Ri} = 25.0 - 5.25 * D_{36} + 0.29 * D_{36}^2 \tag{4}$$

where

$E_{Ri}$ is the breakpoint resilient modulus of the subgrade soil (ksi), and $D_{36}$ is the pavement surface deflection at 36 in. (914 mm) from the load (mils).

## FLEXIBLE OVERLAY DESIGN: AASHTO PROCEDURE

A complete description of the AASHTO flexible pavement overlay design procedure is found in the 1993 AASHTO guide (*3*). Additional information concerning the development of specific methodologies used in the AASHTO procedure can be found elsewhere (*2*). The AASHTO methodologies used for estimating $SN_{eff}$ and $M_R$ are briefly described here. Because $M_R$ is used in the $SN_{eff}$ determination, the procedure for estimating $M_R$ is discussed first.

### Determination of $M_R$

The procedure recommended by AASHTO for backcalculating the resilient modulus of the subgrade soil is based on a method proposed in a work by Ullidtz (*10*). The concept includes two basic assumptions: (a) at some radial distance from the load, the pavement deflection measured at the surface is equal to the deflection at the top of the subgrade, and (b) as radial distance from a load increases, the approximation of a distributed load by a point load

improves. These two assumptions allow a deflection to be estimated by the Boussinesq equation for a one-layer system. After rearranging the Boussinesq equation to solve for the elastic modulus and assuming a Poisson's ratio of 0.5 for the subgrade soil, the equation recommended in the 1993 AASHTO guide for estimating $M_R$ is obtained.

$$M_R = \frac{0.24 * P}{d_r r} \tag{5}$$

where

$M_R$ = resilient modulus of subgrade soil,
$P$ = applied load,
$d_r$ = deflection at radial distance $r$ from load, and
$r$ = radial distance from load.

Equation 5 is recommended only for deflections measured at radial distances greater than 0.7 times the effective radius of the stress bulb at the subgrade-pavement interface ($a_e$).

### Determination of $SN_{eff}$s

The AASHTO approach to determining the effective structural number of an existing pavement is based on the premise that the structural capacity of a pavement is implicitly related to the pavement's stiffness. The 1986 AASHTO guide (Appendix NN) uses this premise in developing an equal stiffness approach to determining $SN_{eff}$ (*11*). The 1993 AASHTO guide follows a simplified version of this general approach. In the 1993 guide, $SN_{eff}$ is related to the total pavement thickness and the effective modulus of the total pavement structure.

$$SN_{eff} = 0.0045 * D * \sqrt[3]{E_p} \tag{6}$$

where

$SN_{eff}$ = effective structural number of pavement,
$D$ = total pavement thickness (surface, base, subbase) (in.), and
$E_p$ = effective modulus of pavement (psi).

Equation 7 is used to estimate the pavement's effective modulus ($E_p$). The method for estimating $E_p$ is based on the Boussinesq deflection equation, with subsequent development by Odemark and Barber. A complete description of the development of Equation 7 is given elsewhere (*2*).

$$d_0 = 1.5pa \left\{ \frac{1}{M_R \sqrt{1 + \left(\frac{D}{a} \sqrt[3]{\frac{E_p}{M_R}}\right)^2}} + \left[ 1 - \frac{1}{\sqrt{1 + \left(\frac{D}{a}\right)^2}} \right] \frac{}{E_p} \right\} \tag{7}$$

where

$d_0$ = maximum pavement surface deflection,
$p$ = load plate pressure,
$a$ = load plate radius,
$M_R$ = resilient modulus of subgrade soil,
$D$ = total pavement thickness, and
$E_p$ = effective pavement modulus.

In the AASHTO method, the stiffness of the pavement ($E_p$) is a function of the stiffness of the subgrade ($M_R$), the loading characteristics (plate radius and pressure), the thickness of the pavement ($D$), and the maximum surface deflection. With a known surface deflection, an iterative process is performed to find the pavement modulus.

## DATA ANALYSIS

Comparisons of the ROADHOG and AASHTO deflection-based overlay design procedures are performed using conventional flexible pavement configurations. Table 1 shows the parameters varied to establish the deflection data base. Pavement surface deflection basins are generated using the ILLI-PAVE finite-element model and the ELSYM5 elastic layer model. In the ELSYM5 model, all materials (AC, base, subgrade) are considered to be linear elastic, using the resilient modulus values shown in Table 1. The granular base and subgrade soil were modeled in ILLI-PAVE as stress dependent materials, using parameters taken from studies by Elliott and Thompson (*9*).

Overlay design factors directly compared include $M_R$ and $SN_{eff}$. A brief presentation of the comparison results for each of the factors follows. The comparison of $M_R$ backcalculation procedures is demonstrated using the results from only one pavement configuration [102-mm (4-in.) AC, 203-mm (8-in.) granular base]; the results presented are typical of the results obtained from the other conventional flexible pavement sections tested. The comparison of $SN_{eff}$ algorithms is performed using a variety of conventional flexible pavement configurations.

Figure 2 shows backcalculated values of subgrade resilient modulus plotted versus input $M_R$ values. Equation 4 is used to estimate $M_R$ for the ROADHOG procedure, and Equation 5 is used for the AASHTO procedure. The points shown represent $M_R$ values backcalculated from deflection basins generated by the ILLI-PAVE and ELSYM5 models.

The trends shown in Figure 2 are not surprising. Each backcalculation method provides relatively accurate estimates of $M_R$ for deflection basins generated by the model on which the method is based. The ROADHOG procedure accurately estimates $M_R$ for ILLI-PAVE-based deflections; Equation 4 (used in ROADHOG) is a regression equation developed from ILLI-PAVE-generated deflection data. The AASHTO procedure accurately estimates $M_R$ for ELSYM5-based (elastic layer) deflections; Equation 5 is developed using elastic layer theory. Conversely, neither procedure estimates $M_R$ accurately using deflections generated by the nonbasis model.

The points shown in Figure 2 raise the question of the accuracy with which each of the pavement models represents real-life pavements. Although it is beyond the scope of this paper to discuss the relative merits of the pavement models, it is worth noting that many researchers have recommended the use of stress-dependent models to represent unbound granular materials and subgrade soils (*12*). As used in this study, ILLI-PAVE models the nonlinear, stress-dependent behavior of paving materials and subgrade soils. ELSYM5 uses only linear elastic assumptions. Data generated from ILLI-PAVE are used for the comparisons that follow.

Based on the results obtained using the ILLI-PAVE-generated deflection basins, the AASHTO backcalculation method overestimates the subgrade resilient modulus, compared to the method used

**TABLE 1 Parameters Varied To Establish Deflection Data Base**

| Material | Layer Coeff. | Thickness (in) | Thickness (mm) | Resilient Modulus (ksi) | Resilient Modulus (MPa) | AC Temp (deg C) |
|---|---|---|---|---|---|---|
| Asphalt Conc (surface) | 0.44 | 2 | 51 | 1400 | 9660 | 5 |
| | | 4 | 102 | 500 | 3450 | 20 |
| | | 6 | 152 | 100 | 690 | 40 |
| | | 8 | 203 | | | |
| Crushed Stone (base #1) | 0.14 | 6 | 152 | 30 | 207 | |
| | | 8 | 203 | | | |
| | | 10 | 254 | | | |
| | | 12 | 305 | | | |
| Gravel (base #2) | 0.12 | 6 | 152 | 20 | 138 | |
| | | 8 | 203 | | | |
| | | 10 | 254 | | | |
| | | 12 | 305 | | | |
| Subgrade Soil | | | | 12 | 82.8 | |
| | | | | 7.5 | 51.8 | |
| | | | | 3 | 20.7 | |
| | | | | 1 | 6.9 | |

in ROADHOG. Because $M_R$ is used in the AASHTO effective structural number estimation procedure, an error in $M_R$ may result in an error in $SN_{eff}$, directly affecting the resulting overlay thickness. Additional discussion of this point is provided in the comparison of $SN_{eff}$ values.

Subgrade resilient modulus is also used to determine $SN_f$, the total structural number required to carry future traffic. $SN_f$ is determined in the AASHTO and ROADHOG procedures using AASHTO new-pavement design concepts. For new-pavement design, a design value of $M_R$ is needed. This design value should be obtained in a manner consistent with the assumptions underlying the development of the AASHTO flexible pavement design equation (*3*). The method of backcalculating $M_R$ used in the ROADHOG method was developed to be consistent with the original AASHO Road Test soil (*7*). However, $M_R$ values obtained using Equation 5 must be adjusted to make the values consistent with the laboratory measured value used for the AASHO Road Test soil (*2,3*). For conventional AC-surfaced pavements, the 1993 AASHTO guide recommends the $M_R$ value obtained using Equation 5 be multiplied by a correction factor of 0.33 for use in design (*3*).

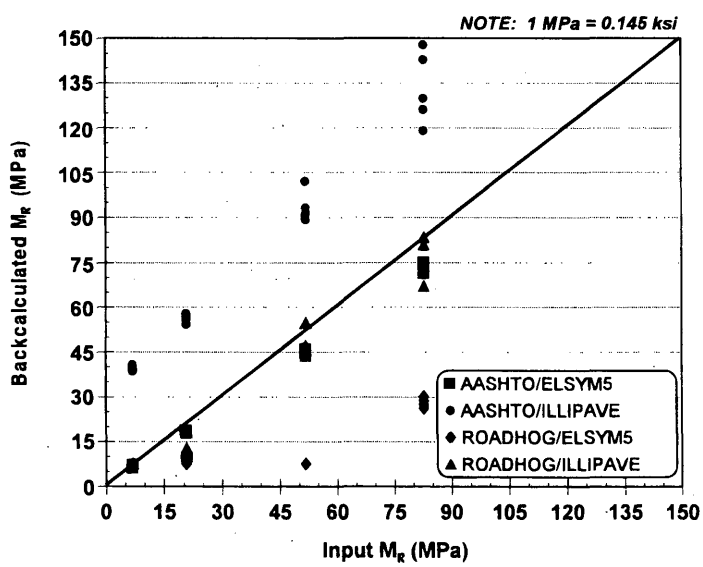


**FIGURE 2 Comparison of backcalculated $M_R$ with $M_R$ values used in pavement models.**

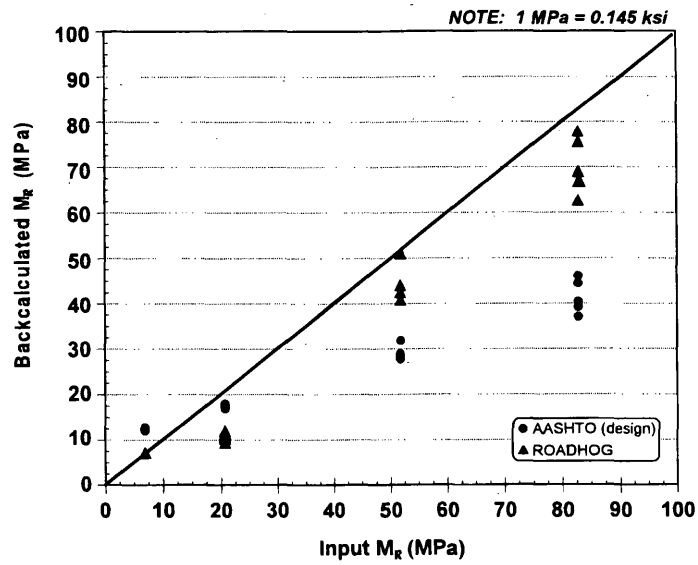


**FIGURE 3 Comparison of AASHTO design $M_R$ with $M_R$ used in ILLI-PAVE model.**

Figure 3 shows corrected design $M_R$ values (using a correction factor of 0.33) for the AASHTO procedure and $M_R$ values for the ROADHOG procedure plotted versus the input $M_R$ values for the ILLI-PAVE-generated deflection basins. At lower stiffness levels, the design AASHTO $M_R$ values reasonably reflect input values; however, the AASHTO method (using $C = 0.33$) underestimates $M_R$ at higher stiffness levels.

The AASHTO flexible pavement design equation is sensitive to $M_R$, particularly for low $M_R$ values. Underestimating the design subgrade resilient modulus has the general effect of increasing $SN_f$, while overestimating $M_R$ generally decreases $SN_f$. This is illustrated in Figure 4, which shows $SN_f$ values determined in the AASHTO and ROADHOG procedures plotted against $SN_f$ values calculated using the input $M_R$ values for ILLI-PAVE.

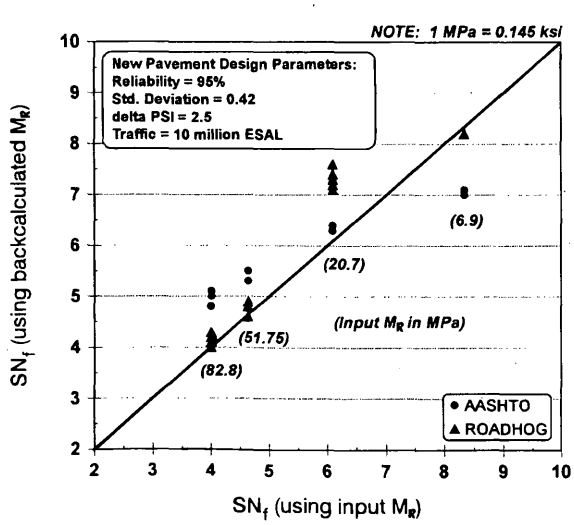


**FIGURE 4 Comparison of $SN_f$ from backcalculated $M_R$ with $SN_f$ from input $M_R$.**

## Effective Structural Number

To compare $SN_{eff}$ values obtained from the AASHTO and ROADHOG procedures, some standard must be established to serve as a basis for comparison. For this research, the standard of comparison is the $SN_{eff}$ value determined using component analysis (Equation 1). For each generated deflection basin, all paving layer thicknesses and modulus values are known. Layer coefficients are assigned to each material based on the material's modulus value and the relationships given in the 1993 AASHTO guide; layer coefficients used in this research are shown in Table 1. Two items regarding layer coefficients should be noted. The first is that layer coefficients used to determine the SN of the pavement section are selected with no consideration of material degradation—in other words, no reduced layer coefficients are used. The second item is that a single-layer coefficient is used for the asphalt concrete surface. The variation in AC modulus shown in Table 1 is related to temperature. Both the AASHTO and ROADHOG procedures adjust deflection data to a single reference temperature [approximately 20°C (68°F)]. The AC layer coefficient used (0.44) is typical for asphalt concrete at the reference temperature.

Figure 5 shows deflection-based $SN_{eff}$ values (AASHTO and ROADHOG) plotted versus component analysis–based values for an input subgrade modulus equal to 51.75 MPa (7500 psi). Because of the large number of data points, individual values are not plotted. Instead, $SN_{eff}$ data are plotted as trends determined by linear regression. The degree of fit as determined by the regression coefficient $r^2$ is shown for each regression line. For pavement configurations with lower $SN_{eff}$ values both the AASHTO and ROADHOG methods adequately reflect component-based $SN_{eff}$ values. At higher levels of $SN_{eff}$, the AASHTO method underestimates the pavement's effective structural number relative to component-based values. Underestimating $SN_{eff}$ has the general effect of increasing overlay thickness.

One item to consider in the comparison shown in Figure 5 is the role of the subgrade resilient modulus on $SN_{eff}$ values, particularly for

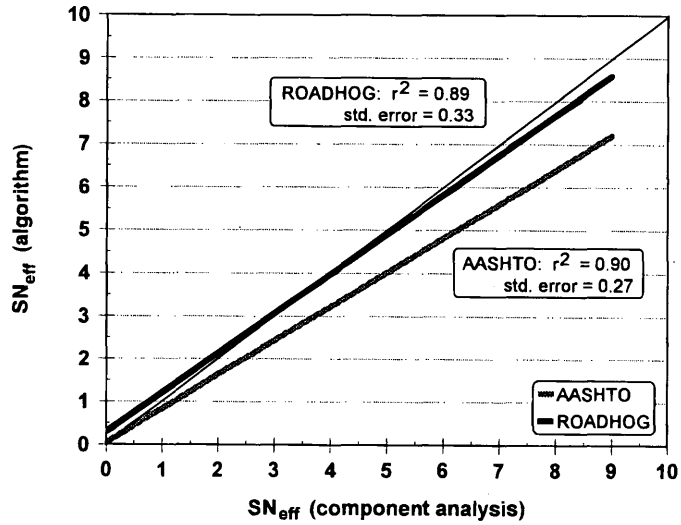


**FIGURE 5 Comparison of ROADHOG and AASHTO $SN_{eff}$ with $SN_{eff}$ from component analysis.**

AASHTO-based values. The ROADHOG $SN_{eff}$ algorithm is relatively independent of $M_R$. In the AASHTO procedure, $SN_{eff}$ and $M_R$ are interdependent (see Equation 7). To adequately compare $SN_{eff}$ procedures, it is necessary to distinguish the effect of $M_R$ on the $SN_{eff}$ estimate.

Figure 6 shows AASHTO-based $SN_{eff}$ trends for four input levels of subgrade modulus. The $SN_{eff}$ trends clearly reflect the effect of $M_R$, particularly for higher component analysis–based values of $SN_{eff}$. For any given component analysis–based $SN_{eff}$ value (which denotes a single conventional flexible pavement configuration in this research), the AASHTO procedure estimates a range of $SN_{eff}$ values, depending on the subgrade modulus used. It is apparent that the AASHTO $SN_{eff}$ determination procedure provides an estimate that reflects the structural capacity of the total pavement system (paving layers plus subgrade soil), not of the pavement layers alone. This violates the basic definition of the AASHTO structural number in which SN is a function of the layer thicknesses and material properties (see Equation 1). For overlay design purposes, $SN_{eff}$ should reflect only the structural capacity of the pavement layers. The effects of the subgrade will be reflected in the total SN required for the overlaid pavement.

Another complication in the AASHTO system and its use of $M_R$ in determining $SN_{eff}$ is that (for ILLI-PAVE-based deflections) the AASHTO procedure overestimates the subgrade modulus (Figures 2 and 3). This may help provide an explanation for why AASHTO underestimates $SN_{eff}$. For a given value of $d_0$ (refer to Equation 7), extremely high values of $M_R$ (as seen in Figure 2) result in relatively low $SN_{eff}$ values. An oversimplified explanation suggests that the AASHTO procedure gives too much credit to the subgrade soil and therefore discounts the structural capacity of the pavement structure, resulting in lower $SN_{eff}$ values.

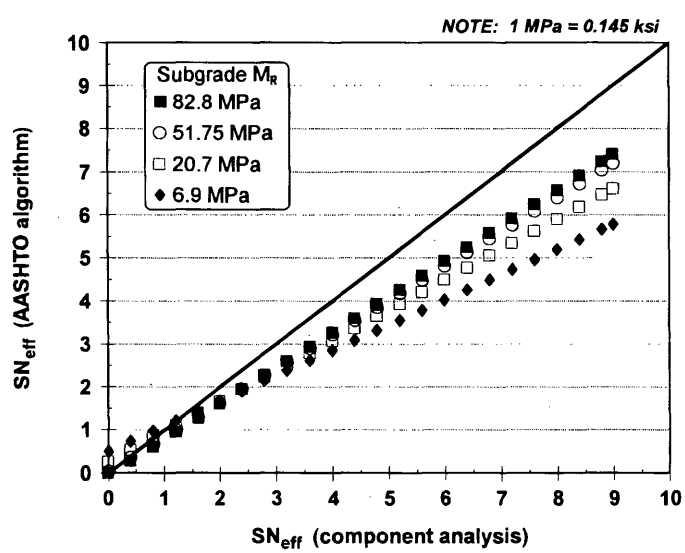


**FIGURE 6 Comparison of AASHTO $SN_{eff}$ at various $M_R$ values with $SN_{eff}$ from component analysis.**

## SUMMARY

The ultimate comparison between the two overlay design procedures is the recommended overlay thickness for a given pavement configuration and its associated deflection basin. Figure 7 shows a comparison of overlay thickness as determined by the AASHTO and ROADHOG methods for various conventional flexible pavement configurations. The AASHTO procedure generally recommends thicker overlays than does the ROADHOG procedure for pavements over stiffer subgrade soils; for pavements over soils with lower $M_R$ values, the two procedures recommend similar overlay thicknesses. Overlay thickness is a direct function of $SN_{o1}$. The factors affecting $SN_{o1}$(and therefore overlay thickness) are $SN_f$ and $SN_{eff}$ (Equation 2).

It was established earlier that corrected design $M_R$ values used in the AASHTO method generally underestimate the subgrade resilient modulus compared with the backcalculated modulus values used in ROADHOG. With all other new-pavement design factors constant, the $SN_f$ values determined by AASHTO are higher than those determined by ROADHOG (Figure 4). Higher $SN_f$ values will result in thicker overlays. It was also established that the AASHTO procedure generally underestimates $SN_{eff}$ relative to the ROADHOG procedure, particularly for those pavement configurations having higher component analysis–based $SN_{eff}$ values (Figure 5). Lower $SN_{eff}$ values result in thicker overlays. The observed differences in recommended overlay thicknesses between AASHTO and ROADHOG can be traced, then, to both the $SN_f$ and $SN_{eff}$ estimates.

Because differences in the recommended overlay thickness exist, the question to be answered becomes, Which of the two overlay design procedures produces a more correct or realistic overlay thickness? The two quantities identified as affecting the overlay thickness are $M_R$ and $SN_{eff}$. An independent basis of comparison is offered for each of these quantities: (a) the subgrade modulus value input into the pavement models, used for comparing $M_R$ values backcalculated by each method, and (b) the component analysis–based structural number for each pavement configuration, used for comparing $SN_{eff}$ values estimated by each method. In each case, the algorithms contained in the ROADHOG procedure produce values that compare more favorably with the standards used.

It becomes apparent through the analyses presented that the subgrade resilient modulus plays a crucial role in determining the overlay thickness, particularly in the AASHTO procedure. If stress-dependent, nonlinear material models, such as those used in ILLI-PAVE, produce more realistic pavement responses (e.g., surface deflections) than do linear elastic models, the apparent difficulty shown by the AASHTO procedure in estimating the subgrade modulus (particularly for stiffer subgrade soils) gives rise to concern about recommended overlay thicknesses.

## CONCLUSIONS

Based on the analyses presented in this paper, the following conclusions are offered:

- For conventional flexible pavements overlying relatively stiff subgrades, the AASHTO overlay design procedure generally recommends thicker AC overlays than does the ROADHOG procedure. For pavements over subgrade soils with lower resilient modulus values, the two procedures recommend similar overlay thicknesses.
- For pavement sections having higher component analysis–based effective structural numbers, the AASHTO procedure underestimates $SN_{eff}$ compared with the ROADHOG procedure.
- For higher values of subgrade resilient modulus, the AASHTO procedure generally overestimates $SN_f$ compared with the ROADHOG procedure.
- The interdependence of $SN_{eff}$ and $M_R$ in the AASHTO procedure makes the subgrade modulus the primary factor in determining the required overlay thickness.

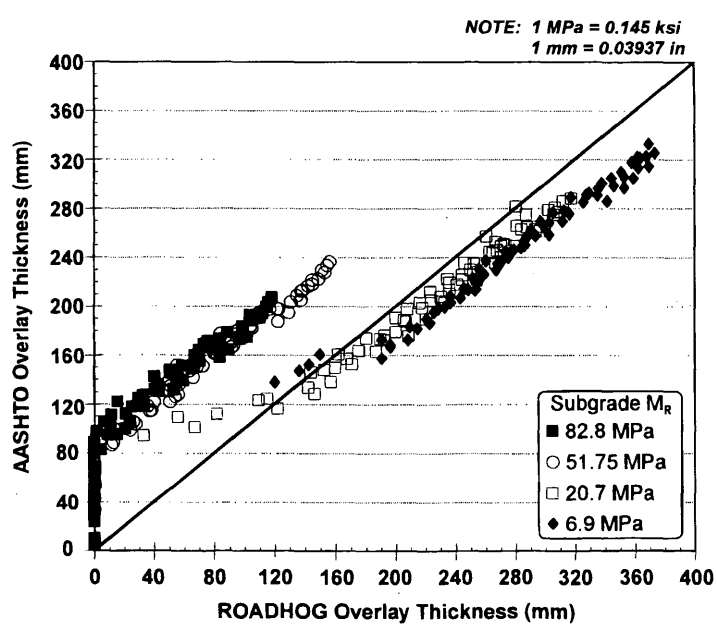


**FIGURE 7 Comparison of AASHTO and ROADHOG recommended overlay analysis.**

## ACKNOWLEDGMENTS

This paper is based on Project TRC-9403, Reliability and Design Procedure Revisions to ROADHOG, conducted by the Department of Civil Engineering at the University of Arkansas. The project is sponsored by AHTD, the U.S. Department of Transportation, FHWA, and the Mack-Blackwell National Rural Transportation Study Center.

The authors gratefully acknowledge the assistance of Robert P. Elliott, Professor and Head of the Department of Civil Engineering at the University of Arkansas, during the preparation of this paper.

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*Publication of this paper sponsored by Committee on Flexible Pavement Design.*