An Examination of the AASHTO Remaining Life Factor

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The 1986 AASHTO Pavement Design Guide introduced a remaining life factor that is applied in the design of pavement overlays. An examination of the remaining life concept was made to determine its practicality. The examination revealed inconsistencies in overlay designs determined using the AASHTO remaining life factor. Further investigation revealed that the remaining life factor should have a value of 1.0 for all overlay situations. As a result, it is recommended that the AASHTO overlay design approach be revised to exclude remaining life considerations.

The 1986 AASHTO Pavement Design Guide (*1*) introduced a remaining life concept that is applied in the design of overlays. The concept is based on the rationale that the structural capacity of a pavement decreases with load applications. For a pavement that has been overlaid, the structural capacity of the original pavement is a function of the loads applied before overlay as well as those applied after overlay. As presented by AASHTO, the remaining life concept requires that overlay thicknesses be selected considering both the "remaining" life of the pavement at the time of overlay and the expected "remaining" life when the next overlay will be applied.

For flexible pavement overlay design, the remaining life concept is applied using the equation:

$$SNol = SNn - Frl * SNeff \quad (1)$$

where

- $SNol$ = required structural number for the overlay;
- SNn = total structural number required, based on traffic soils, etc.;
- Frl = remaining life factor, a function of pavement condition prior to overlay and the condition predicted at the end of the design traffic; and
- $SNeff$ = the effective structural number of the existing pavement at the time of overlay.

The remaining life factor (Frl) is determined using the graph shown as Figure 1. In using the graph, RLx is the remaining life factor of the existing pavement at the time of overlay, and RLy is the anticipated future remaining life of the overlaid pavement when it will be overlaid. Concern has been expressed regarding the Frl concept. Of particular concern is the fact that at low values of RLx and RLy, the general slope of the Frl curve reverses. This investigation was initiated to study the concept and to establish a rationale for this slope reversal.

The investigation demonstrated inconsistencies in overlay designs using the AASHTO remaining life concept and suggests that for consistent designs Frl should be 1.0 for all values of remaining life.

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CONCEPT OF REMAINING LIFE

The AASHTO remaining life concept is discussed in detail elsewhere (*2*). The following abbreviated discussion is presented for those not familiar with that document.

The remaining life concept was developed to be used in a structural deficiency approach to overlay design. In the structural deficiency approach, the structural requirement for the overlay ($SNol$) is determined as the difference between the structure needed to support future (design) traffic (SNn) and the structural capacity of the existing pavement ($SNeff$). Frl was added to the basic structural deficiency equation to account for future structural damage to the existing pavement.

The fundamentals of remaining life are illustrated in Figure 2 using the flexible pavement structural number as the measure of structural capacity. The serviceability of a pavement decreases with time and traffic from an initial value, Po. Without rehabilitation, the serviceability would eventually reach a "failure" level, Pf. The total number of traffic applications to "failure" is shown as Nf.

At some point prior to failure, however, an overlay is placed. The traffic applications to that point are x. The remaining life (RLx) is defined as the additional applications that could have been applied to "failure" expressed as a fraction of the total possible applications. That is:

$$RLx = (Nf - x)/Nf \quad (2)$$

The structural capacity of the pavement decreases similarly from SNo to SNf. At the time of overlay, the pavement structural capacity is SNx. A pavement condition factor (Cx) can be defined as:

$$Cx = SNx/SNo \quad (3)$$

Since SNx is also the effective structural capacity ($SNeff$) of the pavement at the time of overlay, $SNeff$ can be expressed as a function of Cx and SNo.

$$SNeff = Cx * SNo \quad (4)$$

For the AASHTO Guide, a relationship between Cx and RLx was developed using the AASHTO flexible pavement design equation. Cx and RLx values were computed for various designs based on present serviceable indices at "failure" (Pf) of 1.5 to 2.5. These produced a "best-fit" relationship:

$$Cx = RLx^{0.165} \quad (5)$$

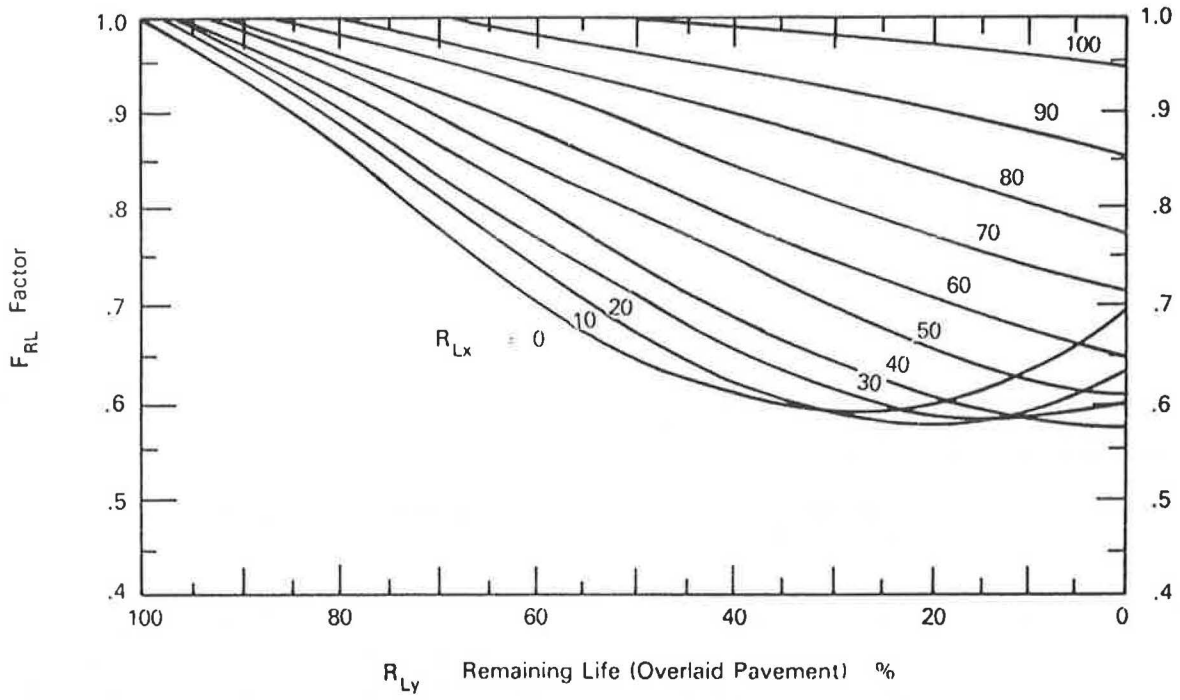

FIGURE 1 AASHTO remaining life factor curves (*1*).

A first step in this investigation was to attempt to reproduce this relationship. *Cx* and *RLx* values were computed for structural numbers ranging from 6.0 to 2.5, with *Pf* equal to 1.5 and 1.0. As shown in Figure 3, these values fit the AASHTO relationship reasonably well.

The AASHTO remaining life concept, however, does not use the "best-fit" relationship. Although the *Cx* values produced by the relationship were viewed as being realistic to *RLx* values as low as 0.005, the relationship was abandoned because *Cx* goes to zero at "failure" (*RLx* = zero). A modified relationship was used by AASHTO. The modified relationship (*2*) is:

$$Cx = 1 - 0.7 * e^{-(RLx + 0.85)^2} \quad (6)$$

The best-fit and modified relationships are compared in Figure 4. In addition to *Cx* not going to zero at "failure," the modified relationship provides a *Cx* value for a negative remaining life. Although the meaning of a negative remaining life is not clear, this feature of the modified relationship is a necessary (although perhaps erroneous) part of the AASHTO application of remaining life.

APPLICATION OF REMAINING LIFE TO OVERLAYS

The reduction in structural capacity of the overlaid pavement is similar to that shown in Figure 2. Thus, if *SNn* and *y* were used in place of the *SNo* and *x* used previously, the structural capacity of the overlaid pavement after *y* load applications would be:

$$SNy = Cy * SNn \quad (7)$$

Without the remaining life factor (*Frl*), *SNn* is *SNol* + *SNeff*. Thus, Equation 7 can be written:

$$SNy = Cy * SNol + Cy * SNeff \quad (8)$$

AASHTO (*2*) argued that this equation is incorrect since the existing pavement (*SNeff*) would lose structural capacity at a greater rate than would the overlay (*SNol*). To "correct" the equation, AASHTO stated that *Cy* * *SNeff* should be replaced by a similar function that includes the original (new) structural number of the existing pavement (*SNo*) and a condition factor (*Cyx*) that is a function of the traffic applications (or remaining life) both before and after the overlay. That is:

$$Cyx = f(RLx, RLy) \quad (9)$$

and

$$SNy = Cy * SNol + Cyx * SNo \quad (10)$$

From these, AASHTO developed a relationship for *Frl* in terms of *Cyx*, *Cx*, and *Cy*:

$$Frl = Cyx/(Cx * Cy) \quad (11)$$

At this point, it should be noted that Equation 8 already included *SNo* and a function of the traffic before and after overlay (*Cx* * *Cy*). Using Equation 4, *SNeff* in Equation 8 may be replaced by *Cx* * *SNo*, resulting in:

$$SNy = Cy * SNol + Cx * Cy * SNo \quad (12)$$

Nevertheless, the introduction of *Cyx* might be viewed as an advance since *Cx* * *Cy* specifies the structural loss relationship for the existing pavement, while *Cyx* does not. Yet,

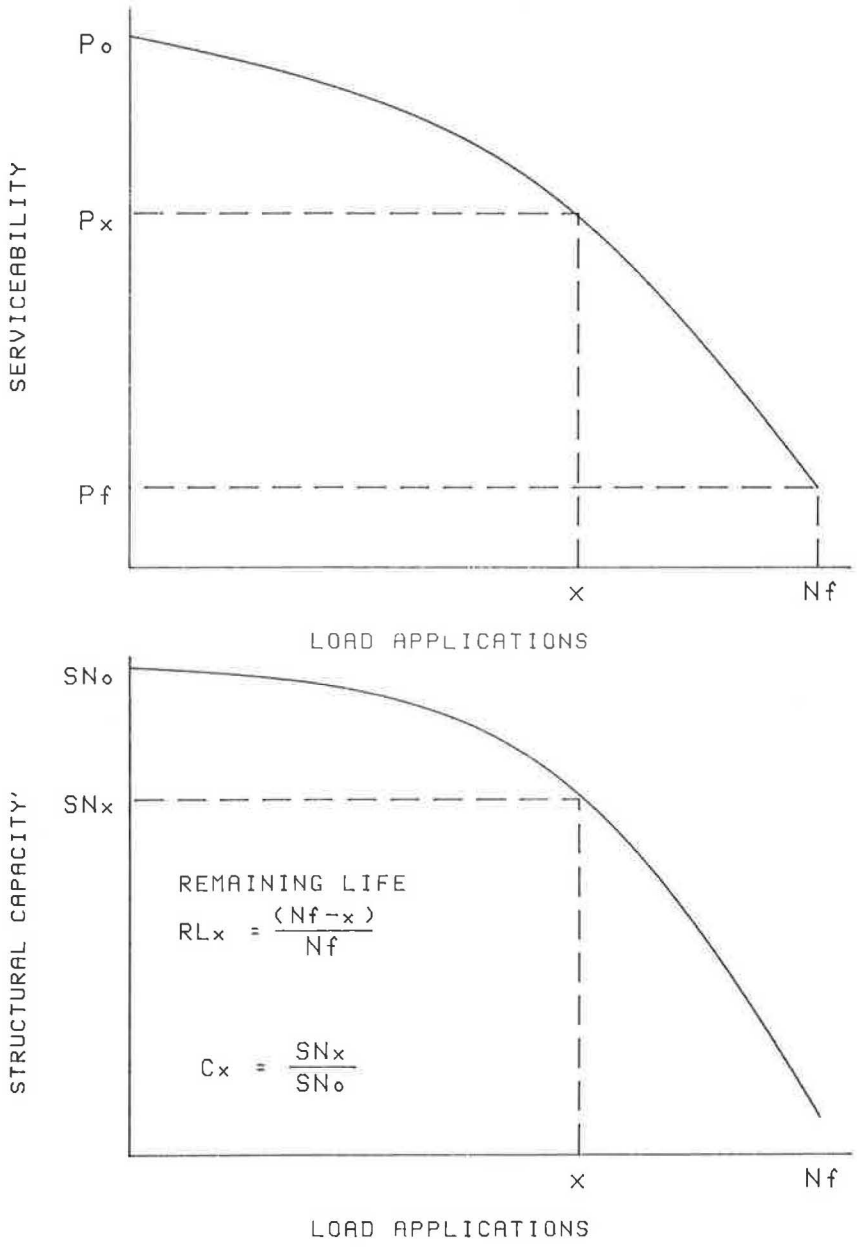

FIGURE 2 Illustration of the remaining life concept.

in order to apply *Frl*, it was necessary to assume an arbitrary relationship (Equation 13, below).

REMAINING LIFE FACTOR CURVES

The second step in the current investigation was to verify the remaining life factor curves (Figure 1). These curves were developed using Equations 6 and 11. However, because *Cxy* is a function of *RLx* and *RLy*, AASHTO has to assume a relationship between the two in order to apply Equation 6. It was assumed that the combined remaining life (*RLxy*) would be equal to the remaining life at the time of overlay (*RLx*) minus the damage done (*dy*) during the period of overlay. That is:

$$RLxy = RLx - dy \tag{13}$$

Since *dy* is $1 - RLy$, this equation may be written:

$$RLxy = RLx + RLy - 1 \tag{14}$$

Initially, this assumption seems reasonable. However, it produces an uneasiness that grows with further reflection. By subtracting the full damage done after overlay, there seems to be no accounting for the reduction in the rate of damage that results from the lower load stresses due to the overlay. Also, because both *RLx* and *RLy* generally will be less than 0.5, the combined remaining life will be negative. A negative remaining life has no meaning. Finally, because the condition

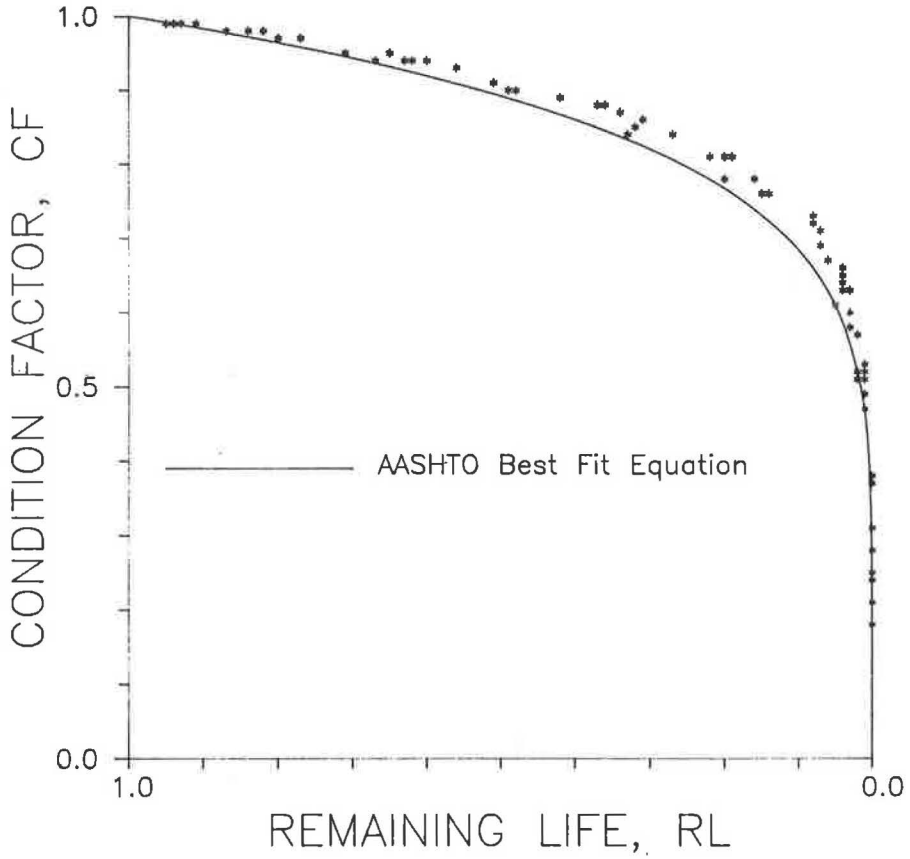

FIGURE 3 Comparison of values from this investigations with the AASHTO "best-fit" equation.

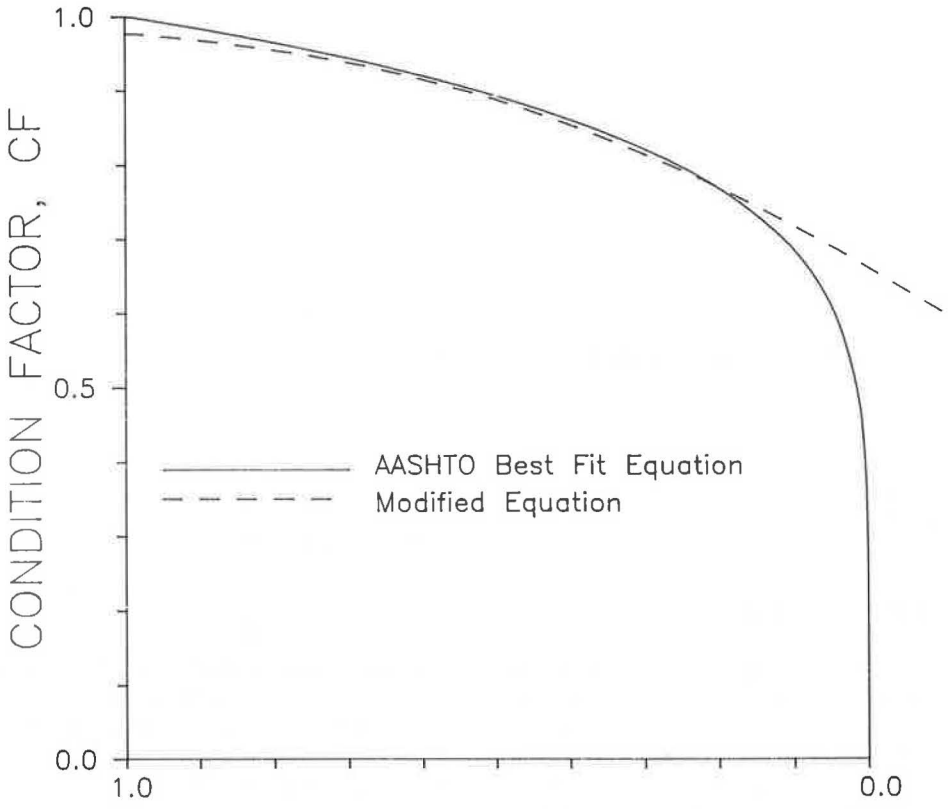

FIGURE 4 Comparison of the AASHTO "best-fit" and modified equations.

TABLE 1 OVERLAY COMPUTATIONS USING REMAINING LIFE FACTORS

Design ESAL = 5,000,000 SNeff = 4.5

Terminal PSI	Required SNn	RLy	RLx = 0.0 Frl	RLx = 0.0 SNol	RLx = 0.2 Frl	RLx = 0.2 SNol	RLx = 0.4 Frl	RLx = 0.4 SNol
3.5	6.65	.904	.988	2.20	.999	2.15	1.00	2.15
3.25	6.02	.904	.945	1.77	.967	1.67	.987	1.58
3.00	5.59	.827	.881	1.63	.919	1.45	.955	1.29
2.50	5.03	.603	.711	1.83	.773	1.55	.848	1.21
2.25	4.84	.465	.633	1.99	.689	1.74	.776	1.35
2.00	4.69	.317	.589	2.04	.616	1.92	.703	1.53
1.75	4.57	.167	.605	1.85	.576	1.98	.642	1.68
1.60	4.50	.062	.665	1.51	.578	1.90	.615	1.73
1.55	4.48	.029	.694	1.36	.586	1.84	.610	1.74

factor relationship itself (Equation 6) is assumed, this assumption (Equation 13) results in a compounding of assumptions.

Nevertheless, application of this assumption together with Equations 6 and 11 verified the mathematical accuracy of Figure 1, including the slope reversals at the lower values of *RLx* and *RLy*.

INCONSISTENCIES IN APPLICATION

The third step in the current investigation involved application of the *Frl* factors to a hypothetical design situation to see if reasonable values and trends were produced. The design situation selected involved a design traffic ESAL of 5 million and an effective structural number for the existing pavement (*SNeff*) of 4.5. The required overlay structural numbers (*SNols*) were determined for terminal Present Serviceability Indices (PSIs) ranging from 3.5 to 1.55. The remaining life of the existing pavement (*RLx*) was also varied, using the values 0.0, 0.2, and 0.4.

The total structural number required (*SNn*) and remaining life of the overlay (*RLy*) were computed using the AASHTO design equation (*1*) with a "failure" PSI of 1.5. A reliability to 50 percent and subgrade resilient modulus of 3,000 psi were used to reduce the equation to the original AASHO Road Test equation and eliminate any potential effects resulting from assumptions involved in adding reliability and subgrade modulus to the equation. To assure accuracy in application, the *Frl* values were calculated in lieu of being taken from Figure 1.

The results of the analyses are listed in Table 1 and displayed graphically in Figure 5. The slope reversals seen in Figure 5 clearly illustrate an inconsistency. The major inconsistency, however, is the general negative slope of the curves between terminal PSIs of 2.0 to 3.0. For a given design situation, design to a lower terminal PSI should result in a lower required structural number. This is correctly illustrated by the trend of the *SNn* values in Table 1. However, after *Frl* is applied to establish the overlay requirement, the general trend for *SNol* is reversed.

Quite obviously, something is wrong with the AASHTO remaining life approach.

MODIFICATION OF THE REMAINING LIFE APPROACH

The final step in the investigation was to identify the problem with the concept and to develop a recommended correction. The apparent source of the problem is in the compounding of assumptions: first, with the modification of the *Cx-RLx* relationship (Equations 5 and 6) and, second, with the combined remaining life relationship (Equation 14).

As an alternative to Equation 14, the following development is suggested. The curve in Figure 6 represents some as yet undefined relationship between *C* and *RL*. At some point (*x*), the pavement is overlaid and the existing pavement values are *Cx* and *RLx*. After the overlay, *C* of the existing pavement will continue to decline from *Cx*, but *RL* will now be 100. This is represented on Figure 6 by the revised *RL* scale.

At the time of the second resurfacing (*y*), the respective values are *Cyx* and *RLy*. A simple scale transformation of *RLy* from the revised scale to the original scale shows that:

$$RLxy = RLx * RLy \quad (15)$$

This equation for *RLxy* eliminates the need for a negative remaining life. The philosophy behind it is similar to the concept of the man who each day walks halfway to his destination. He never arrives. As long as the pavement is overlaid prior to "failure," "failure" is not reached in any component. The existing damage condition remains in the existing materials and progresses. However, the overlay is designed to slow the rate of additional damage, so that the "failure" condition is reached for the entire pavement.

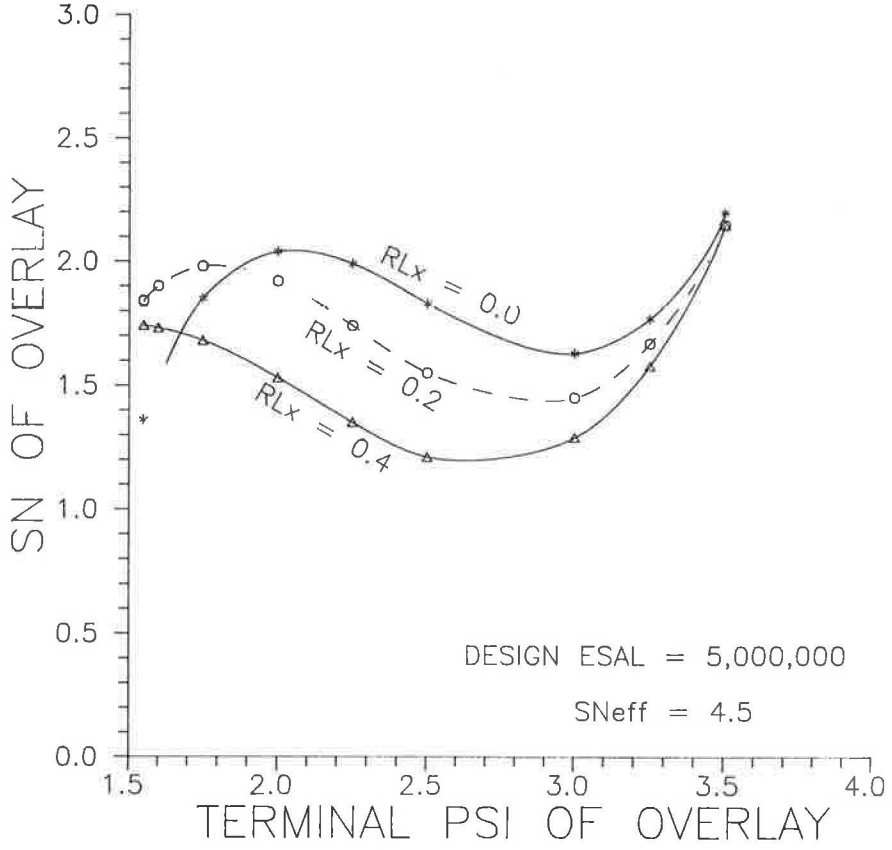

FIGURE 5 Results of overlay analyses using the AASHTO remaining life factor.

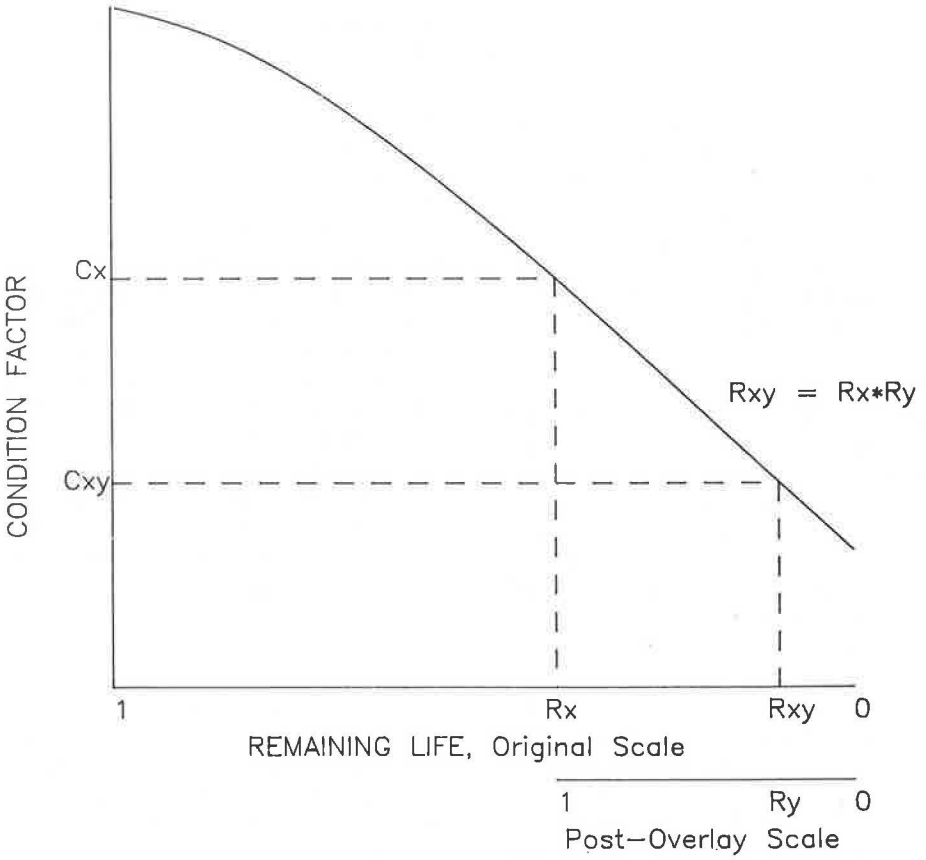

FIGURE 6 Modified approach for determining *Cxy*.

Equations 15 and 11 were used to determine *Frl* values with both the original *C-RL* relationship (Equation 5) and the modified version (Equation 6). With the original relationship, *Frl* is always 1.0:

$$Frl = (RLxy)^{.165}/(RLx^{.165} * RLy^{.165}$$

$$= (RLx * RLy)^{.165}/(RLX * RLY)^{.165} = 1.0 \qquad (16)$$

With the modified AASHTO relationship (Equation 6), the equation is more complicated. However, except for very low values of both *RLx* and *RLy*, *Frl* is generally about 1.0. At very low *RL* values, *Frl* becomes greater than 1.0. (At *RLx* and *RLy* equal to 0.0, *Frl* is 1.5.)

OTHER DIFFICULTIES

Inconsistency in application is not the only difficulty with the AASHTO remaining life concept. Other difficulties need to be recognized and researched. The first of these is the application of the AASHTO Road Test performance equation to establish a remaining life-condition relationship.

The Road Test equation is an empirical relationship selected to provide a means of predicting the performance of the research pavements at the Road Test. It is not a theoretical or fundamental performance relationship and may, in fact, not even be the "best-fit" prediction relationship. It is simply the best relationship found by the researchers involved in the Road Test using the analytic tools that were available at that time. To apply the equation in the fashion used relative to remaining life represents a very significant extrapolation beyond the data and original intent of the equation.

Second, as it is being applied, the remaining life concept assumes that all materials will experience damage and structural loss at the same rate. It is conceivable that at "failure" a stabilized layer will be reduced to the equivalency of a granular layer while a granular layer may experience little loss.

The third difficulty is with the reliance on structural number. Many pavement engineers and researchers have expressed concern with the structural number approach to pavement design since it was first introduced. The structural number approach assumes that each incremental thickness of a material provides an equal contribution to the structural capacity of the pavement regardless of the total thickness or total pavement configuration. Several studies have shown that this assumption is erroneous (*3–6*).

These difficulties are mentioned not to suggest abandonment of the AASHTO overlay approach but to remind the pavement design community of their existence, so that the procedures do not become "etched in stone." Additional thought and research in these areas are needed.

CONCLUSION AND RECOMMENDATION

This investigation has demonstrated that the AASHTO remaining life concept produced inconsistent overlay design thicknesses. The cause of the inconsistencies appears to be due to a compounding of assumptions used to produce the remaining life factor (*Frl*) curves (Figure 1). An alternative approach developed as a part of this investigation found that the appropriate value for *Frl* is 1.0. As a result, it is recommended that the AASHTO overlay design approach be revised to exclude remaining life considerations.

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REFERENCES

1. *AASHTO Guide for Design of Pavement Structures*. American Association of State Highway and Transportation Officials, Washington, D.C., 1986.
2. *Remaining Life Considerations in Overlay Design*. Appendix CC, Vol. 2, AASHTO Guide for Design of Pavement Structures. American Association of State Highway and Transportation Officials, Washington, D.C., 1986.
3. M. Gomez and M. Thompson. *Structural Coefficients and Thickness Equivalency Ratios*. Transportation Engineering Series 38. University of Illinois, Urbana-Champaign, 1983.
4. H. D. Dunn, Jr. *A Study of Four Stabilized Base Courses*. Ph.D. dissertation. Department of Civil Engineering, Pennsylvania State University, University Park, 1974.
5. R. P. Elliott. *Rehabilitated AASH(T)O Road Test—Analysis of Performance Data Reported in Illinois Physical Research Report 76*. QIP-101. National Asphalt Pavement Association, Riverdale, Md., 1981.
6. M. C. Wang and T. D. Larson. Performance Evaluation of Bituminous Concrete Pavements at the Pennsylvania State Test Track. In *Transportation Research Record 632*, TRB, National Research Council, Washington, D.C., 1977, pp. 21–27.

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