Development of Weibull Reliability Factors and Analysis for Calibration of Pavement Design Models Using Field Data

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With the growing popularity of mechanistic-empirical design concepts, a need exists to address design in an unbiased manner that incorporates the natural capability of these concepts to provide designs for any region, soil type, or environmental condition on a comparative basis. With these possibilities within reach, the calibration of these designs consequently stands out as a key ingredient to the successful application of their results to actual performance standards. Design calibration can be determined such that reliability coefficients are not unduly biased. On the basis of this premise, design calibration applies to both design and reliability parameters and as a consequence is influenced by the intrinsic material and structural characteristics germane to different pavement types and climates. With this perspective of mechanistic design concepts, the age of subjective factors of safety in pavement design has long since passed. The full benefit of using rational, mechanistically based reliability and calibration factors may be realized only when these factors consider the "underlying" mechanisms relative to the development of pavement distress. The analysis of pavement performance data conducted on this basis provides insight and understanding that reflect the type of mechanisms noted earlier and leads to the greatest utility of design model calibration efforts.

The object of any pavement design procedure [and particularly mechanistic-empirical (M-E) designs], plainly stated, is to provide the lowest life cycle cost pavement to carry the expected traffic at or above a specific level of safety, riding quality, and durability at a specified level of reliability, regardless of surface material type. These expectations must be achieved by simultaneously considering the paving materials to be used and their behaviors under different load and environmental conditions with respect to the design factors and pavement type. These design factors normally will include design life, traffic loads, subgrade conditions, construction quality and timing, aggregate sources and characteristics, material strengths and properties, and construction weather, among others. To achieve the greatest amount of predictability, all pavement designs should be calibrated to the extent possible.

It is important that design calibration not be confused with design reliability. However, design reliability and design calibration must be given equal consideration. Calibration methodology should be mechanistically oriented based on using the same models and assumptions as those used in the design process, and focused on the adjustment of the predicted level of pavement performance and the parameters (reliability coefficients) that describe the distribution of pavement performance relative to the qualification of the various levels of design reliability. This approach to the characterization of pavement material behavior and pavement performance factors, from a practical point of view, is much more efficient than the empirically based alternative, which requires data collection on many costly, time-consuming, and inherently labor-intensive field test sections that will take years to produce any type of usable results. Calibrated reliability coefficients that are developed in an effective, cost-efficient manner on the basis of engineering mechanics and statistics, the knowledge about highway materials that experienced highway engineers already have, and currently available performance data for existing pavements will provide the most sound and theoretically correct approach to design.

Reliability is defined simply as the probability that something will not fail. To put it another way, reliability is 1.0 minus the risk of failure (*1–3*). The application of reliability to pavements makes it possible to erect objective standards of performance and to provide for the selection of pavements that will best serve their intended functions of carrying the traveling public in comfort and safety while providing this service with durable materials placed and maintained with the least life cycle costs. This pavement function, as expressed in public law, is desired by the ultimate owner and user, the taxpaying public. Reliability must be applied correctly to pavements to achieve this objective, hence its ultimate importance.

Highway pavements fail when different modes of distress reach a prescribed level. If stress relations can be used to represent some of these modes of distress as design models, then it may be possible to relate the level of stress to the number of load repetitions to the level of associated distress (cracking, rutting, etc.). Since several factors can influence the development of the distress, such as factors related to climate, probabilistic concepts allow the variabilities associated with these factors to be quantified in the calculation of reliability.

The purpose of the calibration process is then to adjust or finetune the reliability factors or coefficients associated with the distributions that characterize the variabilities (in cracking, rutting, etc.) referred to earlier. Taking this approach, the examination of the variability that is particular to each uniform pavement section should provide as many different "sets" of reliability coefficients as sections considered. Once these sets have been established, the engineering process should determine the "particularities" that are key to the correlation of the generated sets of reliability co-

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efficients. In this manner the calibration process can be achieved such that all sections are used to broaden the range of the calibrated coefficients, distributions, and design parameters. The emphasis of this paper is on the application and illustration of the Weibull distribution in a design model and reliability coefficient calibration process. Statistical calculations are included in an example to further elaborate and support the concepts and rationale presented in this paper.

APPLICATION OF RELIABILITY FACTORS IN DESIGN CALIBRATION

The methods discussed in the following pertain to any pavement distress for which deterministic engineering models are available to provide system responses. The examination presented will focus on pavement cracking (c) for purposes of illustrating the application of reliability concepts in design calibration.

Calibration Factors Based on Number of Load Applications To Reach Failure, N_f

The application of what pavement engineers know about pavements also applies to the form of the equation that defines the relation between cracking and the number of load applications. It is known that cracking does not occur at the same time over the entire length of the pavement. It is also known that it does not occur uniformly at all locations along a pavement section of uniform construction. Thus, it is known and has been represented in mechanics as the result of a stochastic process. Analysis of the cracking behavior of a pavement as a function of estimated traffic, if it is to respect what is known of its behavior, must make use of the forms of equations that are used in probability.

The question of which form of equation to use may be posed by asking which of the relations (a), (b), or (c) in Figure 1 should

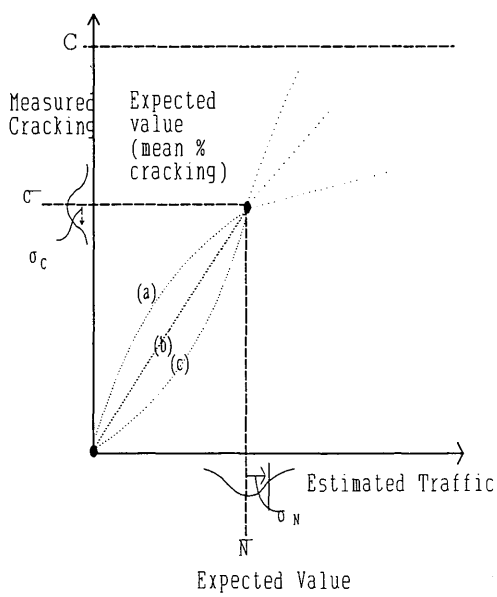

FIGURE 1 Possible relations between mean c and N for single pavement section.

be used to relate the expected value of cracking ($\bar{c}$) to the expected value of the traffic load application ($\bar{N}$).

With cracking data, one must analyze the relationship between two probabilistic quantities: traffic and cracking. The recorded traffic is an estimate of the actual traffic and has, as have all traffic estimates, an expected value ($\bar{N}$) as its most likely value and a likely range within which the actual value will fall. Thus, the estimate of N, the number of traffic load applications, has a probability density function (PDF) that can be characterized by its mean (μ), its standard deviation (σ), and its mathematical form. Commonly used mathematical forms used with traffic data are normal, lognormal, and Poisson.

The recorded cracking is also a mean value (c) measured over an entire pavement section that is of constant cross section and thickness and subjected to equal traffic along the section, although the occurrence of cracking in the section is by no stretch of the imagination uniformly distributed. Instead, c is arrived at by measuring all of the cracking along the pavement section and dividing by a theoretical maximum cracking level (e.g., the total area of pavement that could be cracked). Thus, the recorded value of cracking (c) is also an estimate of the expected value and represents a range of values that are likely to occur on the pavement from point to point. This indicates that cracking also has a PDF that is represented by a mean, a standard deviation, and its mathematical form. Commonly used forms of equations used to describe cracking frequency are normal, lognormal, and Weibull.

This leads to the question of how c and N are related. In the first place, it is recognized that this relation, whatever it is, is unique to the particular pavement on which it is measured. Second, it is recognized that the value of c has absolute limits of 0 and 1. Any mathematical form of the relation between c and N that allows c to go below 0 or above 1 is automatically invalid. Thus, the relations

$$\bar{c} = a\,\bar{N}^b$$

and

$$\bar{c} = a + b\,\bar{N} \tag{1}$$

which are illustrated in Figure 1 as Curves (c) and (b), respectively, are inappropriate mathematical forms to use in describing the relationship between c and N.

On the other hand, an appropriate mathematical relation is illustrated in Figure 1, Curve (a). The form of this equation is

$$\bar{c} = \text{prob [damage} > 1.0]$$

where

$$\text{damage} = \sum_{i=1}^{k} \frac{n_i}{N_{fi}},$$

n_i = number of load applications of load level i,
N_{fi} = number of load applications of load level i to cause failure, and
k = number of periods.

If a form of load equivalency is used to characterize the number of load applications for the traffic estimate, then the damage equation simplifies to

$$D = \text{damage} = \frac{N}{N_{fi}}$$

It is assumed for design proposes that when the damage ratio equals 1.0 at a given spot on the road surface, the crack, which has been working its way through the pavement, appears on the surface. The amount of mean cracking can be interpreted in probabilistic terms as the area under the damage distribution curve bounded by the damage values greater than or equal to 1.0. The relationship between the mean values of cracking and traffic load applications is governed by the probabilistic relationship that the mean value of cracking (c) is related to the mean value of traffic ($\bar{N}$) by the probability that the damage ratio (N/N_f) is equal to 1.0. That is

$$\bar{c} = \int_1^{\infty} p(x)\, dD$$

where x is defined in this paper for a Weibull distribution in terms of fatigue damage D. For a Weibull distribution,

$$p(x) = \gamma\lambda(\lambda x)^{\gamma-1} \exp\left[-(\lambda x)^{\gamma}\right]$$

where λ is the Weibull scale parameter and γ is the Weibull shape parameter. The cumulative PDF $P(x)$, which corresponds to the Weibull PDF, is the following exponential function:

$$\bar{c} = P(x) = \exp\left[-(\lambda x)^{\gamma}\right]$$

and

$$x = D_c \cong \frac{\bar{N}_c}{\bar{N}_{f\,|\bar{N}_c = \bar{N}_f}} = 1$$

where D_c is the critical level damage beyond which pavement cracking occurs. The form of this expression can be used to correlate the $\bar{c}-\bar{N}$ pairs of datum points.

Any of the aforementioned cumulative distribution functions (normal, lognormal, and Weibull) can be used to fit the $c-N$ pairs of data recorded for each pavement section one section at a time. Under most circumstances only two datum points are known for each pavement section:

1. The origin where $\bar{N}$ is equal to 1 and the cracking is an assumed small value, say, 0.001.
2. The actual measured point, c and N (x represents N in the equations $\bar{c} = \exp[-(\lambda x)^{\gamma}]$. A mathematical form (i.e., Equation 1) can be used to formulate either $c-N$ or $c-D$ relationships (discussed later).

Therefore, it is possible to find distribution parameters for each pavement section by using these two points on the curve by using the Weibull exponential functions (other forms such as normal or lognormal may also be considered).

To elaborate further, it is also possible, then, taking one pavement section at a time, to determine a relationship that can be used to find a value of $\bar{N}$ corresponding to some preset value of c and a corresponding value of $\bar{c}_{max}$ that the design engineer determines to be a maximum acceptable level of cracking. Also, the value of $\bar{c}_{max}$ leads to a value of $\bar{N}_f$ that is particular to the pavement in question and that can be used in the definition of damage. Consequently, the value of $\bar{N}_f$ is a design calibration parameter.

With a Weibull cumulative distribution, the scale and shape factors, λ and γ, respectively, can be determined by linear regression, one pavement section at a time, by the equation

$$y_i = a + b\, x_i \tag{2}$$

where

$y_i = \ln(-\ln \bar{c}_i)$,

$x_i = \ln \bar{N}_i$,

$b = -\gamma$,

$a = \gamma \ln \lambda$, and

$\lambda = \exp(-a/b)$.

Once these factors are known, the value of N_f can be found by using the following formula:

$$\bar{N}_f = \frac{1}{\lambda}\left[-\ln(\bar{c}_{max})\right]^{\frac{1}{\gamma}} \tag{3}$$

Values of N_f can be determined for each pavement section by this means. The value of N_f that is determined is a unique property of each individual pavement section and is a value by which each pavement section may be compared because it represents the number of load applications at which a standard condition of distress of each pavement section is reached. In a similar manner, the scale and shape parameters also represent design calibration terms. The value of N_f determined in this way can be used as the dependent variable in an expression that represents the number of load cycles required to reach failure.

Design Calibration Based on Reliability Factors Derived from Field Data

In light of the preceding discussion, the following is provided as an illustration of design calibration using field data obtained from 22 project sites in Minnesota listed in the Concrete Pavement Evaluation System (COPES) data base (*4*) to develop calibration constants that involve reliability factors derived from the COPES data. This illustration constitutes an approach to the consideration of the pavement distress of slab cracking that is unique in that it directly considers the performance data of each project individually rather than as a combination of the whole. In this manner this approach to calibration is constructed by using consistent statistical concepts as they would apply to a design philosophy that considers one pavement section at a time (as most of them do) in the quantification of pavement structure design parameters.

The data for the concrete pavement sections in the COPES data base for Minnesota were listed with respect to pavement design and construction data and pavement performance and environmental data. These data were also associated with the survey project identification number and the county where the project was located. Although the date of construction was listed in September of the year of construction for all of the listed projects, it was assumed that the actual paving occurred between May and August of the construction year. The percentage cracking for each project was calculated from the listed cracking data and was found by considering all reported transverse cracking, regardless of the level of severity, to account for all cracks that had occurred since construction (discounting controlled cracks). If all possible cracks, whether controlled or not, can be considered to include those cracks that may occur at intervals of 4.44ℓ (where ℓ is the radius of relative stiffness) and those that may occur midway between the cracks at intervals of 4.44ℓ, then the total possible number of cracks is 2 times the survey length (LEN) (in inches) divided by 4.44ℓ rounded to the nearest whole number. Subtracting from this the number of sawcut or controlled cracks results in the maximum number of cracks (nc_{max}) that may occur:

$$nc_{max} = \text{LEN}\left(\frac{24}{4.44\ell} - \frac{1}{\text{joint spacing}}\right)$$

Dividing the observed cracking (in terms of the number of 12-ft transverse cracks) by nc_{max} results in the percentage of cracking for each project in the data base. Heating degree-days (D-day) that are listed for the assumed paving period are based on a reference temperature of 65°F. It is noted that a D-day is 1°F difference between the reference temperature and the mean temperature over a 1-day period. D-day data were not available in the COPES data base.

An illustration of the project site performance data for all 22 projects is shown in Figure 2. Figure 2 tends to suggest that a broad scatter exists between pavement cracking in the field and applied wheel load applications [equivalent single-axle loads (ESALs)]. Because of this observed variability and the obvious difficulties in correlating these datum points, it is much more advantageous from a calibration standpoint to consider each of these sections on an individual basis. This can be achieved by considering the c–N relationship for each individual project shown in Figure 2 to follow one of the previously described distributions. A Weibull distribution is selected here for illustration purposes, but other previously mentioned distributions may be considered.

As pointed out previously, two known pairs of pavement performance data are assumed to be available for each project site if the data plotted in Figure 2 constitute one set of data and if the data representing the pavement performance at the time of pavement opening can represent the second set of data. The opening mean traffic level (N) is assumed to be 1 (however, some truck traffic during construction operations may have occurred before the opening of the pavement section). The initial cracking level may be considered to be close to 0 (0.0001 is suggested because of the mathematical nature of a Weibull distribution), but it has been noted that paving during warm temperatures can cause a certain amount of slab cracking before opening the pavement to traffic. Data obtained from test sites in Illinois (*5*) emphasize the effects that temperature conditions at the time of construction can have on the cracking performance of the pavement system. Experience has suggested that the initial cracking may range between 3 and 8 percent and is significantly affected by the pavement joint spacing. For reasons discussed subsequently, initial levels of cracking were assigned to each project, depending on the surveyed cracking level. These levels were subtracted from the observed cracking levels listed in the COPES data base to provide a more accurate accounting of wheel load–induced cracking. The initial cracking distribution is given in Table 1 with respect to four categories or groupings of cracking.

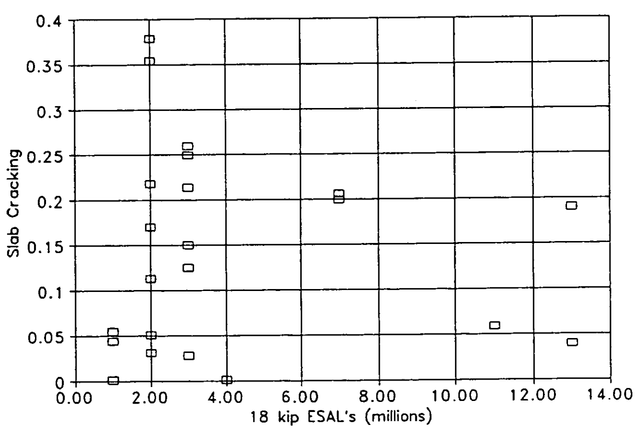

FIGURE 2 Field performance data for 22 sites in Minnesota.

Using linear regression techniques for the expressions shown in Equation 2, the terms a, $b(\gamma)$, and λ can be found for each project for the assigned values of x_i and y_i. The correlation between log (λ) and the mean slab cracking ($\bar{c}$) for the 22 project sites is shown in Figure 3. Significant trends for λ are noted within each cracking category. Similar correlations are noted for the coefficient γ but are not shown. On the basis of this observation it is of interest to correlate the λ and γ coefficients to pavement design parameters such that a comprehensive calibration process will result for all 22 project sites.

A characteristic parameter of jointed concrete pavements noted to be related to environmental factors (*6,7*) is L/ℓ, where L is the joint spacing. The radius of relative stiffness (ℓ) is

$$\ell = \left[\frac{Eh^3}{12(1 - \nu^2)k}\right]^{1/4}$$

where

E = concrete modulus of elasticity (FL^{-2}),
h = slab thickness (L),
ν = Poisson's ratio, and
k = foundation modulus (FL^{-2}/L)

The correlation trends between L/ℓ and the slab cracking data are shown in Figure 4. Other correlations to slab cracking shown in Figure 5 were found from the annual rainfall (for the year of construction) and D-day data for the assumed period. Since L/ℓ indicated signs of correlation to slab cracking and it is known that weather conditions at the time of construction can have a significant effect on slab cracking, it is not surprising that paving D-days correlate well to slab cracking. On the basis of these findings relationships between L/ℓ, rainfall $(r)/\ell$, D-day, λ, and γ were investigated. The usefulness of such relations is a key to the calibration process.

Preliminary correlations (measured in terms of the goodness of fit, r^2) of γ to the parameter D-day suggested that the D-day data should be partitioned according to the level of surveyed cracking. Even though the dates of construction were listed in September of the year of opening for each project, it was assumed that the actual construction took place sometime between May and August. Since the actual paving dates were unknown for each project, the D-day data were used to partition each project with respect to either an early or a late summer construction period. The early summer construction was assumed to be from May to June, and the late summer construction was assumed to be from June to August. Each project was partitioned with respect to the cracking

TABLE 1 Project Partitioning and Data Correlation Parameters

Survey Cracking Level (%)	Partitioning	Initial Crack Level (%)	Correlation Parameters	
			γ	λ
0 - 10	Early Summer	0	r/ℓ	r/ℓ
10 - 20	Late Summer	3	L/ℓ, D-Days	L/ℓ, D-Days
20 - 30	Late Summer	8	L/ℓ, D-Days	L/ℓ, D-Days
30 - 40	Late Summer	15	L/ℓ, D-Days	L/ℓ, D-Days

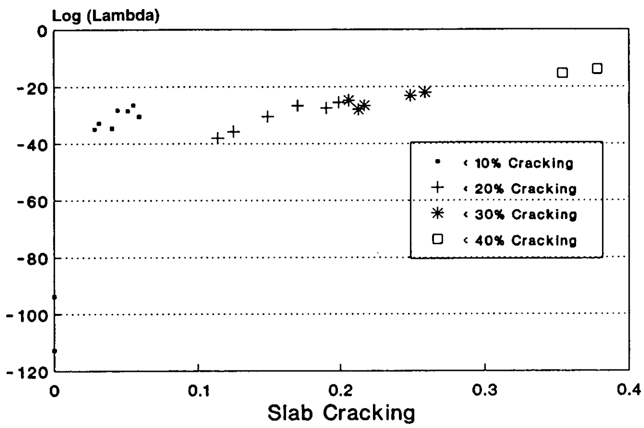

FIGURE 3 Correlation between mean slab cracking (c) and λ.

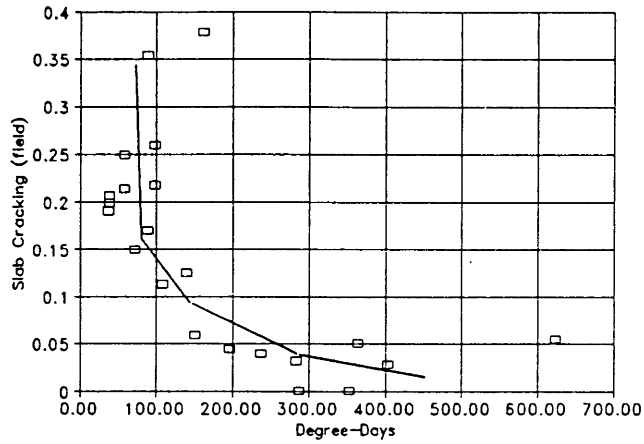

FIGURE 5 Correlation between slab cracking and heating degree-days.

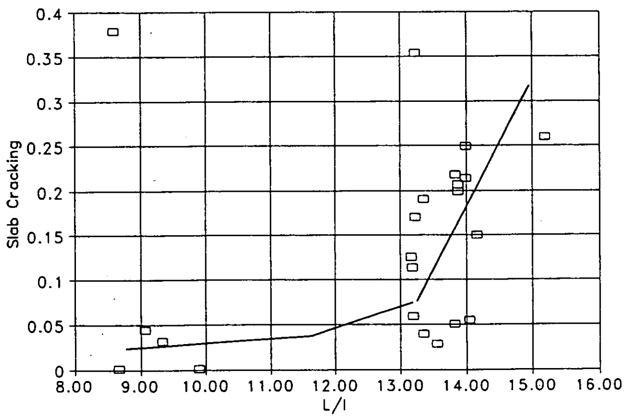

FIGURE 4 Correlation between slab cracking and L/ℓ.

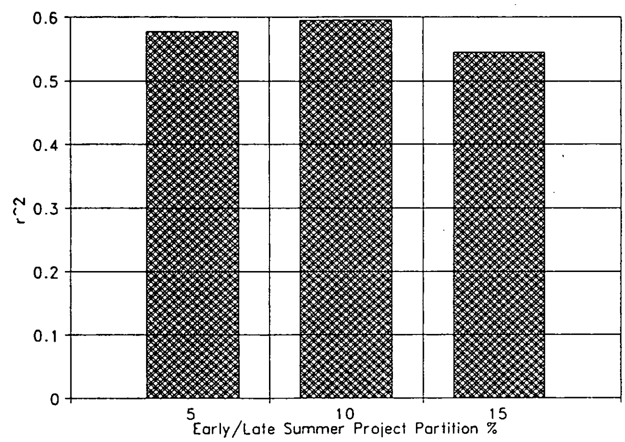

FIGURE 6 Partitioning of project sites by cracking level.

levels shown in Figure 6. Figure 6 also indicates the resulting r^2 for the correlation between γ and D-day on the basis of whether the surveyed cracking level was above or below the given level of cracking. As shown, the 10 percent cracking level resulted in the greatest correlation for γ; therefore, pavement sections showing 10 percent cracking or less were assigned to the early summer period. All remaining sections were assigned to the later summer period and, consequently, different levels of initial cracking, as shown in Table 1.

It should be noted that the adjustments and partitioning just described would not be necessary if sufficient construction data were available to properly assess the environmental conditions during paving. Since these modifications represent certain as-

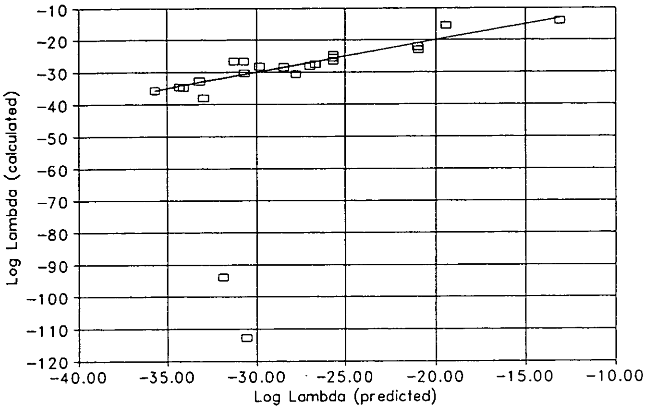

FIGURE 7 Comparison of predicted λ to calculated λ.

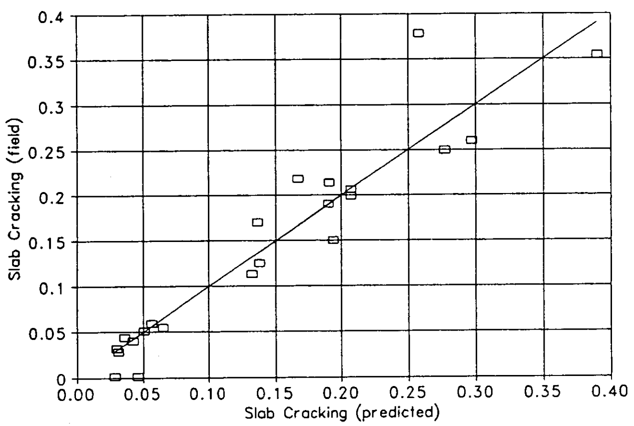

FIGURE 8 Comparison of predicted cracking to field cracking.

sumptions that can be used to improve the assessment of the performance data, some discontinuities in the data may have resulted (shown later in Figures 7 and 8). However, these discontinuities were not entirely apparent in the prediction equations for λ, even though these equations were delineated with respect to cracking category as a function of annual rainfall in the year of construction or D-day and the L/ℓ value. The correlation parameters for these expressions are presented in Table 1, and the regression statistics are given in Table 2. Note that rainfall was defined as a dimensionless parameter of rainfall/ℓ for the first category of slab cracking.

Figure 7 compares the predicted λ values with the calculated λ values in which two outliers represent datum points (of nearly zero cracking levels) that were not well accounted for by either of the correlation parameters shown in Table 1. Otherwise, the predicted value of λ is considered to be very good, as is the case with the predicted slab cracking (Figure 8). On the basis of Figures 7 and 8 it is apparent that the scatter in the data shown in Figure 2 can largely be accounted for through correlations of the Weibull distribution scale and shape functions (λ and γ, respectively) to factors that strongly influence early pavement behavior within the first week of construction.

With these correlations and the design engineer's maximum allowable cracking (c_{max}) level, the maximum allowable loads to failure (N_f) may be found for each project by using Equation 3. Therefore, N_f may be considered to be calibrated on the basis of the slab L/ℓ and the D-days to which a pavement may be subjected during construction.

It should be noted that N_f (which may be referred to as a calibrated value, N_{f_c}) will vary with the chosen level of maximum slab cracking. The term N_{f_c} is used to develop a universally applicable cracking damage curve as explained later and can be defined in terms of design for pavements meeting similar conditions according to the D-days, rainfall/ℓ, and L/ℓ ratios. It is apparent, however, that N_{f_c} is independent of r (the stress ratio) and that different strength (MR) and stress (σ_{WLS}) requirements different from those for the calibrated pavement may be desired design requirements, and therefore it is of interest with respect to these requirements to use a value of N_f that is also a function of the stress ratio (r).

The following discussion explains how this can be achieved. An expression for N_f based on laboratory fatigue data is often used in the determination of accumulated fatigue damage (D) (*8*).

$$\log N_{f_{LAB}} = k_1 + k_2 r$$

where

k_i = fatigue coefficients (k_1 = 17.61; k_2 = −17.61),
r = stress ratio (σ/MR for an existing pavement with known $c-N$ data),

TABLE 2 Regression Statistics ($y = a + bw + cx$)

Survey Cracking Level (%)	Parameter	a	b	c	r^2	SEE
0 - 10%	γ	3.58×10^{-2}	-1.4×10^{-1}	0	0.96	1.72×10^{-3}
	Ln (λ)	-76.38	59.53	0	0.94	0.89
10 - 20%	γ	-1.38×10^{-1}	1.72×10^{-4}	6.15×10^{-3}	0.52	5.79×10^{-3}
	Ln (λ)	-52.28	-0.084	2.16	0.58	3.52
20 - 40%	γ	-3.82×10^{-2}	-5.3×10^{-5}	9.34×10^{-5}	0.99	2.247×10^{-4}
	Ln (λ)	-9.38	2.68×10^{-2}	-0.94	0.65	4.71

* w = rainfall/ℓ or D-days (See Table 1)
x = L/ℓ

σ_{WLS} = wheel load stress,
MR = concrete modulus of rupture, and
$N_{f_{LAB}}$ = laboratory-based value of N_f.

The value of N_{f_c} may be adjusted in terms of the design r value (r_d), which can account for design configurations being different from calibrated design conditions. For design purposes this adjustment may be formulated in terms of a calibrated multiplying factor (MF_c) for stress ratios (r) other than the stress ratio for the calibrated projects, as shown here:

$$MF_c = \frac{N_{f_{LAB}}(r)}{N_{f_c}(L/\ell, \text{D-days})}$$

$$r_c = r - \frac{\ell n\, MF_c}{k_2 \ell n 10}$$

Note the consistency in the above expression with respect to the stress ratio (r). The term r_c accounts for environmental affects not considered in r. A design multiplying factor (MF_d) using r_d is computed as

$$MF_d = \exp\left[k_2(r_d - r_c)\,\ell n 10\right]$$

leading to a design N_{f_c} as

$$N_{f_d} = \frac{N_{f_{LAB}}(r_d)}{MF_d}$$

Therefore, the design loads to failure (NF_d) are a function of both design parameters and calibration parameters. By this process design features and material properties other than the ones used in the calibration for the design may be incorporated in the design calculations of new projects.

In addition to N_{f_d}, the damage scale and shape parameters (η, ζ), using the form of a Weibull distribution shown in Equation 2, should be determined to complete the calibration process. These parameters are calibrated as a function of N_{f_d} and the known values of $\bar{c}$ and $\bar{N}$ as:

$$y_i = a + b\,x$$

where

$$y_i = \ln(-\ln \bar{c}_i)$$

$$x_i = \ln \bar{D}_i$$

$$b = \zeta = \frac{y_2 - y_1}{x_2 - x_1}$$

$$a = -\zeta \ln \eta = y_1 - bx_1$$

$$\eta = \exp\left[-\frac{a}{b}\right]$$

The $\bar{c}$–$\bar{D}$ pairs are defined at the c_{max} level when $\bar{D}$ is 1 and at the known $\bar{c}$ where $\bar{D}$ is N/N_{f_d}. The following outlines the steps taken in the calibration process illustrated in this example:

1. Find the λ and γ scale and shape parameters by fitting $\bar{c}$–$\bar{N}$ pairs of data.
2. Set the value of c_{max}.
3. Determine N_{f_c} and N_{f_d}.
4. Find the η and ζ scale and shape parameters by fitting c–D pairs of data.

Use the following expression to predict cracking:

$$\bar{c} = \exp\left[-(\bar{D}/\eta)^{\zeta}\right]$$

where $D = n/N_{f_d}$.

5. If there are multiple points of c–N data, then follow the same procedure as outlined in Steps 1 through 4. Check that the assumed distribution, in this case the Weibull distribution, fits the actual data. If so,

$$\prod_{i=1}^{n} b = \left[\frac{y_2 - y_1}{x_2 - x_1}\right]^n$$

and

$$\prod_{i=1}^{n} a = [y_1 - b_1 x_1]^n$$

and then determine η and ζ. If not, return to Step 1 and try another distribution such as a lognormal or a normal distribution.

CONCLUSIONS

Several implications can be drawn from the correlations and analysis shown and discussed in this paper. It is apparent that the calibration portion of a pavement design procedure not only affects the overall utility of the procedure but encompasses the very core of how reliability can be or is considered in the design process. It should also be apparent that calibration not only applies to the design parameters (mean estimates of distress) but also to the reliability coefficients used to characterize the distress distribution. This also means that the distributions and assumptions used in the calibration process must be applied consistently to the design model to ensure accurate calibrated designs. Therefore, design calibration entails more than an aimless effort of overlaying scattered clouds of datum points with statistical distributions that result in unacceptable r^2 factors. On the basis of the evidence presented in this paper, dramatic improvements in representing field data in the design model calibration process are warranted.

The correlations presented in this paper suggest that paving conditions at the time of construction significantly affect the long-term performance of concrete pavements. It is also apparent that any correlation in fatigue performance that involves the ratio of L over ℓ will also involve other parameters that are directly related to the climatic conditions under which the pavement was constructed. These observations are evident because the correlations indicated here were developed for real field data under real conditions using real distributions.

It is evident from the results of the example presented that the use of reliability concepts combined with what engineers know about pavement behavior can serve as extremely powerful tools in the calibration of pavement performance with field data. By using a process of considering each pavement section, one at a time, the interpretation of what appeared to be very confusing patterns of performance data (Figure 4) was transformed into a form of order and understanding suitable for the application in design.

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