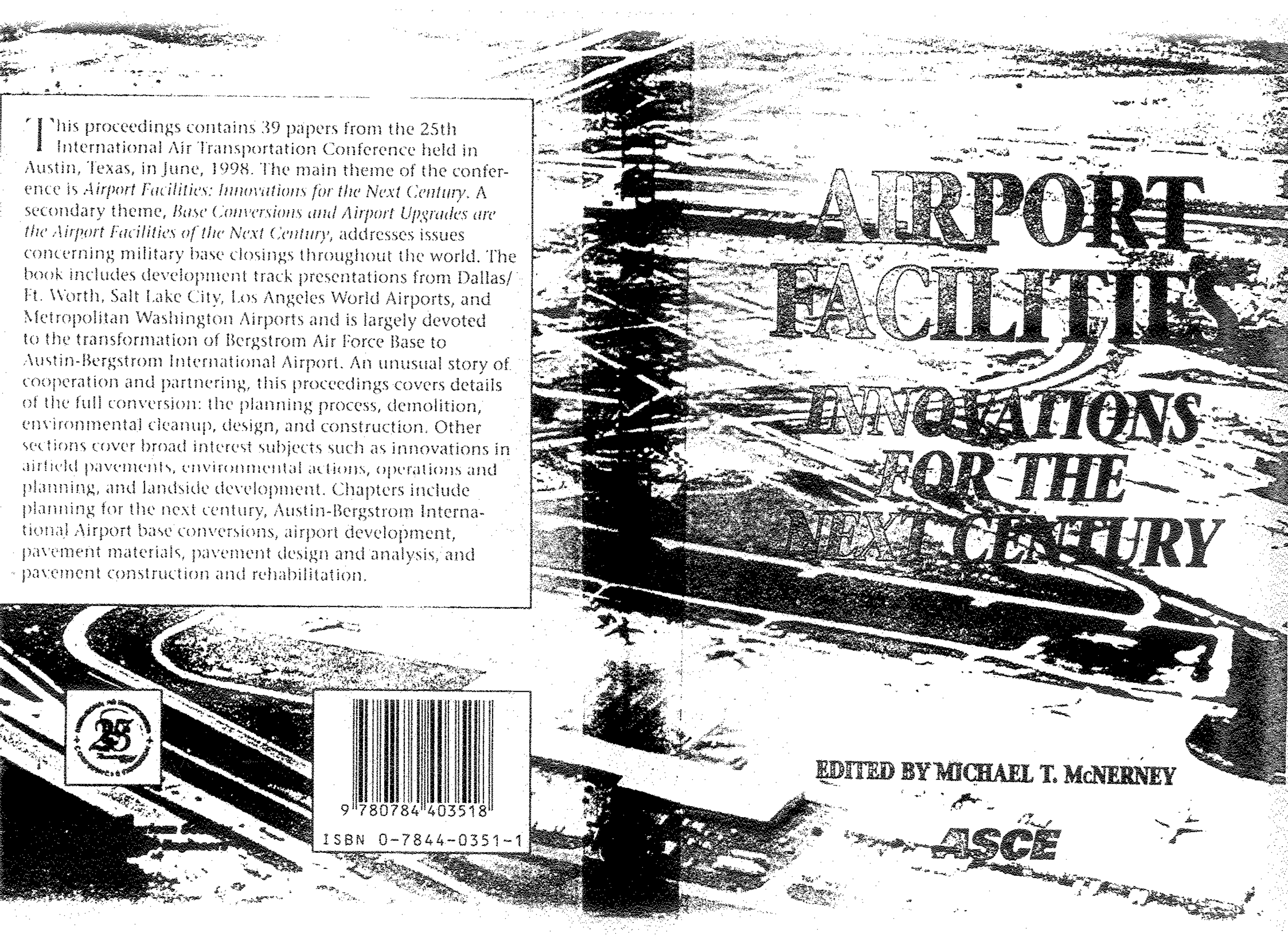

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INNOVATIONS FOR THE NEXT CENTURY

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PROCEEDINGS OF THE 25TH INTERNATIONAL AIR TRANSPORTATION CONFERENCE

June 14–17, 1998
Austin, Texas

EDITED BY
Michael T. McNerney

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MODIFIED DEFLECTION RATIO PROCEDURES FOR BACKCALCULATION OF CONCRETE PAVEMENTS

Ying-Haur Lee[1], Associate Member ASCE
Chao-Tsung Lee[2], and Jean-Hwa Bair[3]

ABSTRACT

The main objective of this study was to develop a general purpose rigid pavement backcalculation program for various nondestructive deflection testing (NDT) devices. This study strives to minimize the major limitations and deficiencies of traditional backcalculation procedures by modifying the most widely-used AREA deflection basin concept. A modified deflection ratio (w/w_0) backcalculation procedure is introduced using the ILLI-SLAB finite element (F.E) program and the principles of dimensional analysis. Prediction models were developed using the projection pursuit regression technique for the modified deflection ratio. Subsequently, the proposed backcalculation procedure was implemented in a user-friendly backcalculation program (TKUBAK) to expand its applicability for any different NDT loading radius, sensor locations, finite slab sizes, as well as locations of loading plate (interior, edge, and corner of the slab). The effects of random error in deflection measurements, a second layer, a temperature differential, and adjacent slabs on backcalculation should be further investigated to account for more practical pavement conditions.

INTRODUCTION

The use of nondestructive deflection testing (NDT) devices has been widely adopted to obtain surface deflection data in order to evaluate an existing pavement's conditions recently. Since the elastic moduli of pavement layers which represent the stiffness of a pavement structure cannot be calculated directly from surface deflection data, they are often obtained using backcalculation procedures. Traditional backcalculation procedures for rigid pavements may be grouped into three major classifications in general: iterative method, database method, and closed-form backcalculation procedures using plate theory [*Lee et al. 1997; Crovetti 1994; Hall 1991*]. To estimate the elastic modulus of each pavement layer, an iterative backcalculation procedure has to first assume an initial trial set of modulus values, and then repetitively calculate theoretical deflections in order to match the actual surface deflection measurements within the specified error tolerance ranges. The database approach finds a suitable set of modulus values by linearly interpreting the measured deflections with the theoretical deflections, which have already been built in a large database with pre-specified ranges of modulus values. Closed-form solutions for rigid pavement backcalculation, which greatly enhanced the effectiveness of in situ pavement evaluation, use a series of charts or prediction models to backcalculate modulus values more quickly than any other existing backcalculation procedures.

The main objective of this study was to develop a general purpose rigid pavement backcalculation program using closed-form solutions for various nondestructive deflection testing (NDT) devices frequently used in Taiwan, such as a Dynaflect, a Road Rater, and a Falling Weight Deflectometer [*Lee et al. 1997*]. This study strives to minimize the major limitations and deficiencies of traditional backcalculation procedures by modifying the most widely-used AREA deflection basin concept. A modified closed-form deflection ratio backcalculation procedure was introduced and implemented in a user-friendly computer program (TKUBAK) for the backcalculation of jointed concrete pavements.

CLOSED-FORM DEFLECTION SOLUTIONS

Losberg [*1960*] has provided closed-form equations for the deflection of a PCC slab resting on a dense liquid foundation (Winkler) and an elastic solid foundation under a uniformly distributed load:

$$w = \begin{cases} \dfrac{P}{\pi a}\displaystyle\int_0^\infty \dfrac{J_0(\alpha r)J_1(\alpha a)}{k + D\alpha^4}\,d\alpha & \text{for Winkler Foundation} \\ \dfrac{2P}{\pi a C}\displaystyle\int_0^\infty \dfrac{J_0(\alpha r)J_1(\alpha a)}{\alpha\left(1+\alpha^3\ell_e^3\right)}\,d\alpha & \text{for Elastic Foundation} \end{cases} \tag{E.1}$$

$$\ell = \sqrt[4]{\frac{Eh^3}{12(1-\mu^2)k}}\ , \quad \ell_e = \sqrt[3]{\frac{Eh^3(1-\mu_s^2)}{6(1-\mu^2)E_s}} = \sqrt[3]{\frac{2D}{C}} \tag{E.2}$$

$$C = \frac{E_s}{(1-\mu_s^2)}\ , \quad D = \frac{Eh^3}{12\left(1-\mu^2\right)} \tag{E.3}$$

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where:

w = surface deflection at any radial distance r, [L];
J_0, J_1 = Bessel function of zero order and first order, respectively;
P = applied load, [F];
a = radius of the applied circular load, [L];
h = thickness of PCC slab, [L];
C = modified modulus of elasticity of the subgrade, [FL^{-2}];
D = bending stiffness of the slab, [FL];
k = modulus of subgrade reaction, [FL^{-3}];
E, E$_s$ = modulus of elasticity of the PCC slab and subgrade, [FL^{-2}];
μ, μ_s = Poisson's ratio of the PCC slab and subgrade; and
ℓ, ℓ_e = radius of relative stiffness for Winkler foundation and elastic solid foundation, [L].

Where, [F] and [L] represent the dimensions of force and length, respectively.

Based on the assumptions of an infinite or semi-infinite slab over a Winkler foundation, Westergaard has also presented the following maximum deflection equations for three circular loading conditions, i.e., interior, edge, and corner for a Poisson's ratio of 0.15 [*Westergaard 1926; Ioannides 1985*]:

$$w_0 = \begin{cases} \dfrac{P}{8k\ell^2}\left\{1 + \dfrac{1}{2\pi}\left[\ln\left(\dfrac{a}{2\ell}\right) - 0.673\right]\left(\dfrac{a}{\ell}\right)^2\right\} & \textit{interior loading} \\ \dfrac{0.431P}{k\ell^2}\left[1 - 0.82\left(\dfrac{a}{\ell}\right)\right] & \textit{edge loading} \\ \dfrac{P}{k\ell^2}\left[1.1 - 0.88\left(\sqrt{2}\,\dfrac{a}{\ell}\right)\right] & \textit{corner loading} \end{cases} \tag{E.4}$$

where, w_0 is the Westergaard's maximum deflection at the interior, edge, and corner of the slab, respectively. Furthermore, according to Losberg, the maximum deflection at the center of an interior load for elastic solid foundation may also be expressed as follows:

$$w_0 = \frac{2P}{C\ell_e}\left[0.19245 - 0.0272\left(\frac{a}{\ell_e}\right)^2 + 0.0199\left(\frac{a}{\ell_e}\right)^2 \ln\left(\frac{a}{\ell_e}\right)\right] \tag{E.5}$$

TRADITIONAL BACKCALCULATION PROCEDURES USING AREA CONCEPT

Hoffman and Thompson [*1981*] proposed the following AREA concept to backcalculate the modulus values of a rigid pavement system. The area of the deflection basin using four deflection sensors was defined as follows:

$$AREA(in.) = 6 * \left[1 + 2\left(\frac{w_1}{w_0}\right) + 2\left(\frac{w_2}{w_0}\right) + \left(\frac{w_3}{w_0}\right)\right] \tag{E.6}$$

where:

AREA = normalized area of deflection basin, ranging from 11.1 to 36 inches;
w_0 = measured maximum deflection at the center of the load, [L]; and
w_1, w_2, w_3 = measured deflections at 12, 24, 36 in. distance from the loading center, [L].

Higher AREA values indicate stiffer slabs relative to the foundation; whereas lower values are indicative of some serious slab weakening problem.

In the ILLI-BACK closed-form backcalculation algorithm, Ioannides [*1990*] applied the concept of dimensional analysis and has indicated that there exists a unique relationship between AREA and the radius of relative stiffness (ℓ or ℓ_e) for a given load radius and pre-specified sensor locations. Hall [*1991*] further solved Losberg's deflection equation (E.1) through direct integration of Bessel functions for radial distances of 0, 30.5, 61.0, 91.4 cm (0, 12, 24, and 36 inches) and for ℓ or ℓ_e values from 38.1 to 203.2 cm (15 to 80 inches) using the IMSL library and developed the following nonlinear regression models:

$$\ell = \left[\frac{\ln\left(\dfrac{36 - AREA}{1812.279}\right)}{-2.559340}\right]^{4.387009} \quad \text{or} \quad \ell_e = \left[\frac{\ln\left(\dfrac{36 - AREA}{4521.676303}\right)}{-3.645555}\right]^{5.334281} \tag{E.7}$$

With AREA calculated from the four measured deflections, the radius of relative stiffness (ℓ or ℓ_e) in inches may be obtained from the above equation [*Hall 1991; Losberg 1960*]. The k-value or the elastic modulus (E$_s$) of subgrade may be obtained by rearrangement of Westergaard's or Losberg's maximum interior deflection equation given in equations (E.4) and (E.5). The elastic modulus of PCC slab can then be determined using the appropriate ℓ or ℓ_e equation as defined in equation (E.2). This approach was adopted by AASHTO [*1993*] for the evaluation of existing concrete pavements.

Crovetti [*1994*] further indicated that finite slab size, the locations of loading plate (interior, edge and corner of the slab), and the presence of adjacent slabs or a tied concrete shoulder, etc. may all affect pavement surface deflection measurements. Additional prediction equations were developed to account for the effects of finite slab size and three different loading locations. The deflection response of multiple slabs was also investigated. Consequently, revised procedures for the backcalculation of modulus values using equation (E.7) were also available [*Crovetti 1994*].

DEVELOPMENT OF A MODIFIED DEFLECTION RATIO BACKCALCULATION ALGORITHM

The use of the traditional closed-form backcalculation procedures using the AREA concept inherited assumptions such as: the radius of loading plate $a = 15$ cm (5.9 in.) and four deflections measured at radial distances of 0, 30.5, 61.0, 91.4 cm (0, 12, 24, 36 inches). Thus, surface deflections measured at other locations (e.g., 121.9, 152.4, 182.9 cm or 48, 60, and 72 inches) or by a Road Rater with a loading plate radius $a = 22.9$ cm (9.0 in.) may not be used for the analysis. This study strives to eliminate such limitations by modifying the AREA concept using the principles of dimensional analysis. A modified deflection ratio algorithm will be introduced for the backcalculation of rigid pavements using various NDT devices.

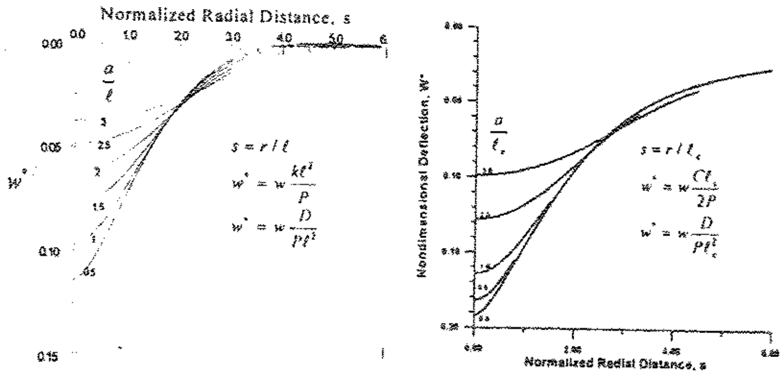
Identification of Dimensionless Variables

Based on the principles of dimensional analysis, Losberg's deflection equation (E.1) may be simplified as follows:

$$w^* = \begin{cases} \dfrac{wk\ell^2}{P} = \dfrac{wD}{P\ell^2} = f\left(\dfrac{a}{\ell}, \dfrac{r}{\ell}\right) & \text{for Winkler Foundation} \\ \dfrac{wC\ell_e}{2P} = \dfrac{wD}{P\ell_e^2} = f\left(\dfrac{a}{\ell_e}, \dfrac{r}{\ell_e}\right) & \text{for Elastic Foundation} \end{cases} \tag{E.8}$$

In which, nondimensional deflection (w^*) was introduced by Losberg to illustrate its relationship with normalized radial distance ($s = r/\ell$ or r/ℓ_e) and normalized load radius (a/ℓ or a/ℓ_e). This study first validated Losberg's closed-form deflection equation through the use of the IMSL library of Microsoft FORTRAN PowerStation 4.0 [*1994*] for the integration of Bessel functions as shown in Figure 1.

The analysis of finite slab size effect was not possible until the introduction of finite element models. The basic tool adopted for the analysis was the ILLI-SLAB F. E. program since it had extensive checking, revisions, and verifications by many researchers, could structurally model many key design factors of importance, and had less errors than any other available computer program for rigid pavements [*Huang 1993*]. Based on the principles of dimensional analysis, the structural response characteristics of a rigid pavement are dominated by the following four dimensionless variables: $(a/\ell, L/\ell, W/\ell, r/\ell)$ or $(a/\ell_e, L/\ell_e, W/\ell_e, W/\ell_e)$ for finite slab dimensions[*Ioannides 1984; Ioannides et al. 1989*]. Thus, the nondimensional deflection (w^*) can be expressed by:



(a) Dense Liquid Foundation (b) Elastic Solid Foundation

Figure 1 Nondimensional Deflection Relationship

$$w^* = \begin{cases} \dfrac{wk\ell^2}{P} = f(\dfrac{a}{\ell}, \dfrac{L}{\ell}, \dfrac{W}{\ell}, \dfrac{r}{\ell}) & \textit{Winkler Foundation} \\ \dfrac{wD}{P\ell_e^2} = f(\dfrac{a}{\ell_e}, \dfrac{L}{\ell_e}, \dfrac{W}{\ell_e}, \dfrac{r}{\ell_e}) & \textit{Elastic Foundation} \end{cases} \tag{E.9}$$

Note that a/ℓ or a/ℓ_e is the normalized load radius; L/ℓ or L/ℓ_e is the normalized slab length; W/ℓ or W/ℓ_e is the normalized slab width, and r/ℓ or r/ℓ_e is the normalized radial distance. While keeping the dominating mechanistic variables constant for any arbitrary combinations of other individual input variables, the resulting w^* values of ILLI-SLAB runs still remain constant. Thus, the above relationship was numerically validated in this study [*Lee et al. 1997*].

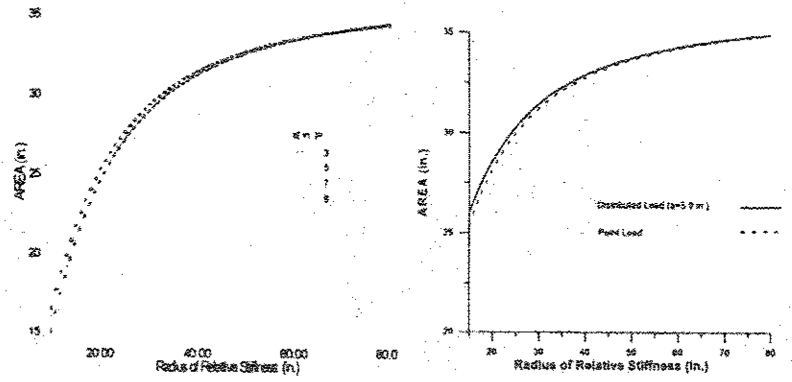
Modified Deflection Ratio Concept

In the ILLI-BACK backcalculation algorithm, Ioannides [*1990; 1989*] has applied the deflection ratio concept for the backcalculation of a concrete pavement resting on a Winkler or an elastic solid foundation under an interior circular load. For a given load radius a, if two deflections (w_0 and w) are measured, the following deflection ratio (w_i/w_0) equation was obtained:

$$\frac{w}{w_0} = \frac{f(\ell)}{f_0(\ell)} = f'(\ell) \quad \text{or} \quad \frac{w}{w_0} = \frac{f(\ell_e)}{f_0(\ell_e)} = f'(\ell_e) \tag{E.10}$$

Where w_0 is the maximum surface deflection under the center of the load and w is the surface deflection measured at any given radial distance r. In other words, the above relationship indicated that ℓ or ℓ_e may be determined by providing only two deflection measurements. Thus, the unknown pavement parameters may be subsequently determined using equations (E.4) or (E.5) and (E.2).

If four sensors are used, modulus values are often backcalculated using the normalized area of deflection basin (AREA) which may be treated as a weighted average of four deflection ratios as shown in equation (E.6), in which $1=w_0/w_0$. This relationship was further validated for a fixed load radius a = 15 cm (5.9 in.), and the deflection at four radial distances of 0, 30.5, 61.0, 91.4 cm (0, 12, 24, 36 in.) as shown in Figure 2 for a Winkler foundation and an elastic foundation.



(a) Dense Liquid Foundation (b) Elastic Solid Foundation

Figure 2 Relationship between Radius of Relative Stiffness and AREA

Consequently, a modified deflection ratio concept was adopted in this study to allow more general treatments of the closed-form backcalculation process using various NDT devices. Based on the concept of dimensional analysis, the modified deflection ratio w/w_0 can be uniquely determined by the four aforementioned dimensionless variables given as follows:

$$\frac{w}{w_0}=\begin{cases} f(\frac{a}{\ell},\frac{L}{\ell},\frac{W}{\ell},\frac{r}{\ell}) & \textit{Winkler Foundation} \\ f(\frac{a}{\ell_e},\frac{L}{\ell_e},\frac{W}{\ell_e},\frac{r}{\ell_e}) & \textit{Elastic Foundation} \end{cases} \qquad \text{(E.11)}$$

This modified deflection ratio is in fact a general form of the AREA expression, where any different NDT loading radius, sensor locations, finite slab sizes, as well as locations of loading plate (interior, edge, and corner of the slab) may be allowed for backcalculation. Since the above relationship is dimensionally correct, both English and metric (SI) unit systems can be used.

For a very large slab (L/ℓ and $W/\ell \geq 7.0$), the relationship of a/ℓ, r/ℓ, and w/w_0 for a Winkler foundation is shown in Figure 3. Figure 3 also shows that the results of ILLI-SLAB runs agree with Losberg's closed-form solutions very well. Figure 4 shows the relationship among a/ℓ_e, r/ℓ_e, and w/w_0 for an infinite slab (L/ℓ_e and $W/\ell_e \geq 7.0$) resting on an elastic solid foundation. Thus, if ℓ or ℓ_e can be determined by the modified deflection ratio, the unknown pavement parameters may be subsequently determined as usual.

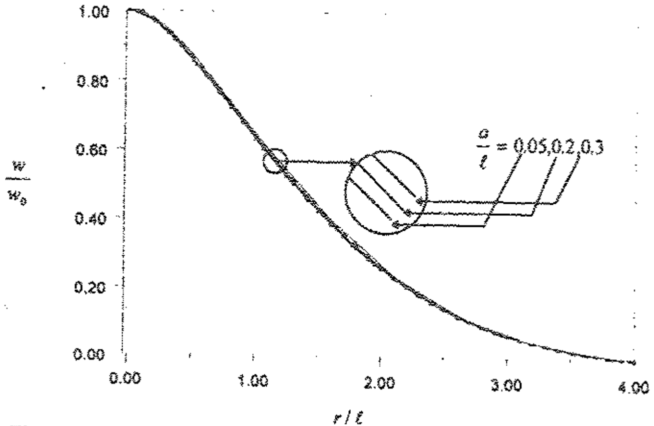


Figure 3 ILLI-SLAB and Losberg Solutions (Dense Liquid Foundation)

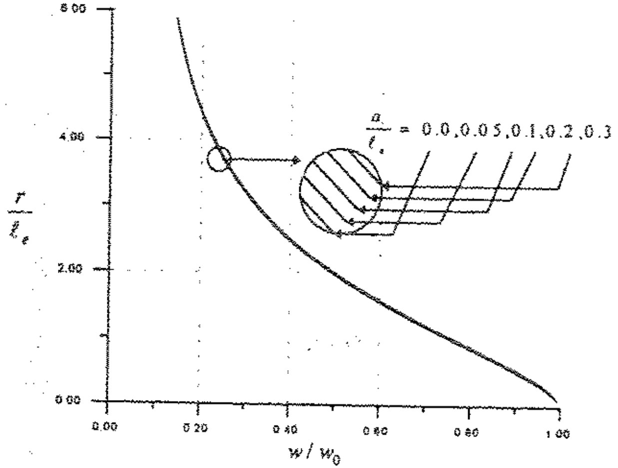


Figure 4 Relationship of $a/\ell_e, r/\ell_e$, *and* w/w_0 (Elastic Solid Foundation)

Ratio of Deflections Measured at Any Two Radial Distances

Theoretically, any two deflection measurements may be sufficient to backcalculate the two unknown pavement parameters, i.e., E and k or E and E_s. If N number of sensors are used, a total of N(N-1)/2 sets of solutions may be obtained in such case [*Fwa et al. 1997*]. Nevertheless, a special effort was also conducted in this study to investigate the relationship of any deflection ratio (w_2 / w_1) with a / ℓ_e and r / ℓ_e for elastic foundation, where w_1 and w_2 are measured at any radial distances of r_2 and r_1 and $r_2 = 2\,r_1$. As shown in Figure 5, there may exist no solution, a unique solution, or two solutions for ℓ_e under such conditions. This relationship may help to explain some of the difficulties in interpreting in-situ deflection measurements with random errors. Further investigation in this respect is recommended. Thus, the modified deflection ratio is currently defined as the ratio of a surface deflection measured at any radial distance to the maximum deflection as shown in equation (E.11). Therefore, a total of (N-1) sets of solutions may be obtained using the proposed modified deflection ratio concept.

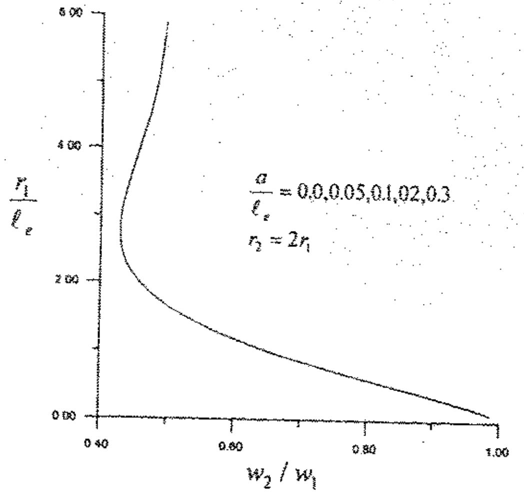


Figure 5 Relationship of $a / \ell_e, r_1 / \ell_e, w_2 / w_1$ (Elastic Solid Foundation)

Application of Projection Pursuit Regression Technique

Projection pursuit regression (PPR) techniques introduced by Friedman and Stuetzle [*1981*] strives to model the response surface (y's) as a sum of nonparametric functions of projections of the predictor variables (x's) using local smoothing techniques. Assuming there is a true model:

$$y = \bar{y} + \sum_{m=1}^{M_0} \beta_m \phi_m\left(a_m^t x\right) + \varepsilon \tag{E.12}$$

Where $x = (x_1, x_2, \cdots\cdots, x_p)^T$ denotes the vector of predictor variables, $\bar{y}$ is the expected (or mean) value of response variable, β_m is the regression coefficient, and ε is the residual or random error. The PPR algorithm strives to minimize the mean squared residuals over all possible combinations of β_m, ϕ_m, and a_m values. Conceptually, the explanatory variables x's are projected onto the direction vectors $a_1, a_2, \cdots, a_m$, to obtain the lengths of the projections $a_m^t x$, where $m = 1, \cdots\cdots, M_0$. An optimization technique is also used to find the best combinations of nonlinear transformations $\phi_1, \phi_2, \cdots, \phi_m$ for the multidimensional response surface. In the above equation, $\phi_m\left(a_m^t x\right)$ represents the unknown nonparametric transformation functions of the projected lengths $a_m^t x$ to be estimated.

As proposed by Lee and Darter [*1994*], the two-step modeling approach using the PPR technique was utilized for the development of backcalculation prediction models. Through the use of local smoothing techniques, the PPR attempts to model a multi-dimensional response surface as a sum of several nonparametric functions of projections of the explanatory variables. The projected terms are essentially two-dimensional curves which can be graphically represented, easily visualized, and properly formulated. Piece-wise linear regression technique was then used to obtain the parameter estimates for the specified functional forms of the predictive models. This algorithm is available in the S-PLUS statistical package [*Statistical Sciences, Inc. 1995*].

Development of Backcalculation Prediction Models

A series of finite element factorial runs was conducted based on the dominating dimensionless variables identified. Several QBASIC programs were written to automatically generate the finite element input files and the results of ILLI-SLAB finite element runs were automatically summarized in several databases to reduce the possibility of manual errors [*Lee et al. 1997*].

Prediction models of the modified deflection ratio ($R_L = w / w_0$) were developed using the aforementioned two-step modeling approach for three different loading conditions, i.e., interior, edge, and corner. Separate models based on the four dimensionless variables identified in equation (E.11) for both Winkler foundation and elastic foundation are available. Additional prediction models (R_d) defined as the ratio of the maximum deflections of an infinite slab and a finite slab were also developed for different loading conditions and foundation types. Note that R_d is a function of $(L / \ell,\ W / \ell,\ a / \ell)$ or $(L / \ell_e, W / \ell_e,\ a / \ell_e)$, respectively.

In addition, two additional prediction models were developed to estimate the maximum deflection solution of an infinite slab resting on an elastic solid foundation for edge and corner loading conditions, since there is no such closed-form solution.

Modified Deflection Ratio Backcalculation Procedures

The following modified deflection ratio procedures are proposed for the backcalculation of concrete pavements over a Winkler foundation or an elastic solid foundation:

1. Compute a modified deflection ratio (w / w_0).
2. Backcalculate an estimate of ℓ or ℓ_e using the prediction models (R_1) through a very quick iterative process.
3. Calculate R_d using the prediction model.
4. Calculate k or E_s using the relationship of R_d, w_0, and the maximum deflection of an infinite slab size determined by equations (E.4), (E.5), or prediction models.
5. Repeat steps (1) to (4) to obtain (N-1) sets of solutions for k or E_s.
6. Calculate E using equation (E.2) and the averaged k or E_s value obtained in step (5).

DEVELOPMENT OF A GENERIC BACKCALCULATION PROGRAM FOR CONCRETE PAVEMENTS

To facilitate practical trial applications of the proposed modified deflection ratio procedures for rigid pavement backcalculation using various NDT devices, a prototype window-based computer program (TKUBAK) was developed using the Microsoft Visual Basic 4.0 software package [*1995*]. The main features of the program include:

1. the traditional AREA deflection basin backcalculation procedure;
2. the ILLI-BACK closed-form deflection ratio backcalculation procedure; as well as
3. the proposed modification to the deflection ratio backcalculation procedure.

The TKUBAK program was designed to be highly user-friendly and thus came with many well-organized graphical interfaces, selection menus, and command buttons for easy use. Both English and Chinese versions of the program are available. Furthermore, since all the mechanistic variables used in the proposed models are dimensionally correct, both English and metric (SI) systems can be used by the program. Several example input screens of the TKUBAK program are shown in Figure 6.

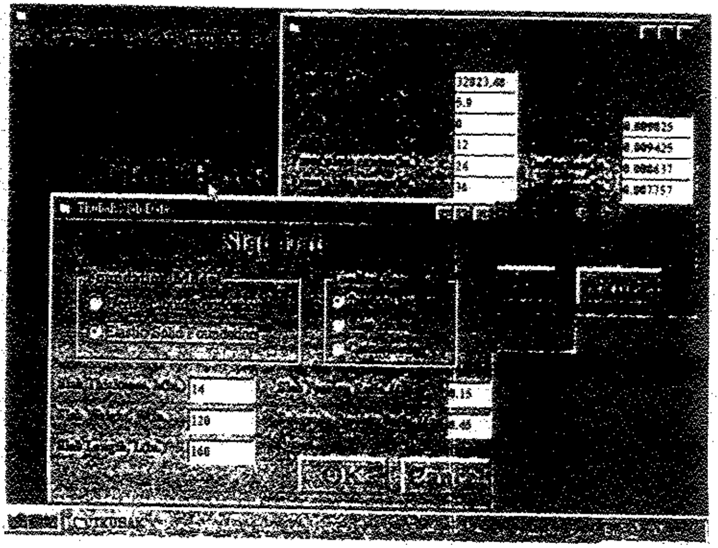


Figure 6 Sample Input Screens of the TKUBAK program

Validations of the Proposed Backcalculation Procedures

The proposed backcalculation procedures have been further validated through comparisons of equation (E.1), equation (E.7) and the TKUBAK program using the AREA concept. Fairly good agreement of such comparisons as shown in Figure 7 was identified. This also illustrated that this study has covered a much broader range of the case analyzed. In addition, the effects of finite slab dimensions are further illustrated in Figure 8, which also indicates that such effects should be considered and can be well accounted for by the TKUBAK program.

DISCUSSIONS AND RECOMMENDATIONS

The prototype generic backcalculation program developed under this study is currently valid for a single slab only. In most practical cases, the effect of adjacent slabs should play an important role for the backcalculation of edge and corner loading conditions. Preliminary analysis in this regard for a Winkler foundation was performed and will be incorporated into the program shortly. The effect of a random error in the sensor measurements on the backcalculated values will be further investigated and compared with those for the AREA method-based backcalculation. This will enable us to have a reasonable assessment of the reliability of the backcalculated pavement parameters. In addition, recommendations for future research are briefly listed as follows:

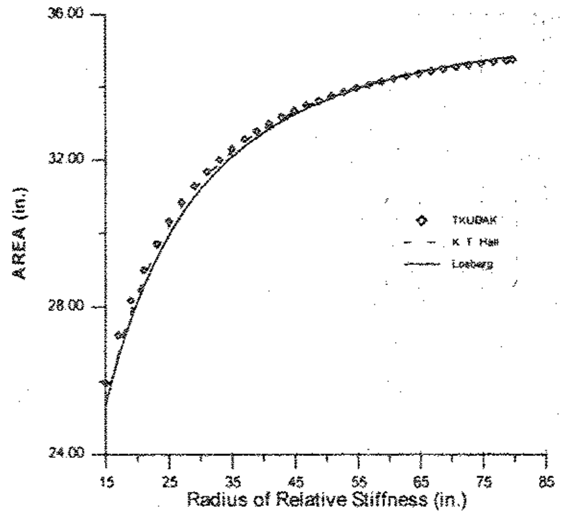


Figure 7 Validation of the TKUBAK Program Using the AREA Concept

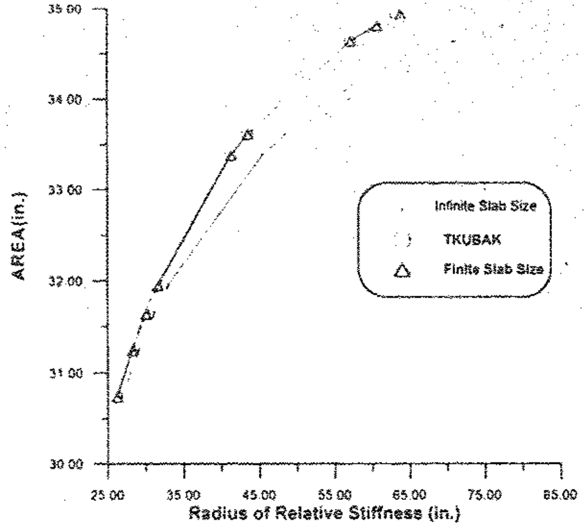


Figure 8 Validation of the TKUBAK Program for Finite Slab Size

1. The non-uniqueness issue raised in Figure 5 for the ratio of two deflections (w_2 / w_1) measured at any arbitrary radial distances should be further investigated. This relationship may help to explain some of the difficulties in interpreting in-situ deflection measurements with random errors.
2. There are differences between backcalculated modulus values and modulus values that are determined in the laboratory. A preliminary analysis of in-situ deflection basins showed fairly large discrepancies as already reported in the literature [*Lee et al. 1997; Crovetti 1994; Lin et al. 1995*]. The dynamic elastic modulus of subgrade (E_s) backcalculated by the traditional closed-form backcalculation procedures or by the proposed approach should be adjusted by a factor of no greater than 0.33 to be used for design as recommended by the AASHTO guide [*1993*].
3. The effects of a second layer (bonded or unbonded layer), a linear temperature differential, and adjacent slabs or load transfer efficiency should be further investigated to account for practical conditions more accurately.
4. Even though most of the proposed prediction models as currently implemented in the TKUBAK program showed very good prediction accuracy, i.e., the coefficient of determination R^2 is greater than 0.99, it is still desirable to simplify the models by neglecting some of the less significant parameters.
5. On-going special efforts to simplify the backcalculation process using database approach and a local regression algorithm [*Statistical Sciences Inc. 1995*] are underway.

CONCLUSIONS

This study strives to minimize the major limitations and deficiencies of traditional backcalculation procedures by modifying the most widely-used AREA deflection basin concept. A modified closed-form deflection ratio (w / w_0) backcalculation procedure was introduced and implemented in a prototype user-friendly computer program (TKUBAK) for the backcalculation of jointed concrete pavements. The following conclusions may be drawn from this study:

1. This study enhanced the applicability of the deflection ratio concept because any different NDT loading radius, sensor locations, and the effects of finite slab sizes can be analyzed by the proposed approach.
2. Modulus backcalculation during NDT testing may be possible using the proposed procedure.
3. For a given set of N deflection measurements, the proposed approach may produce as many as N-1 pairs of backcalculated modulus values. Thus, possible measurement errors from faulty sensors can be detected or promptly adjusted in the field and more consistent and accurate modulus values may be backcalculated.

4. Since all the mechanistic variables (e.g., normalized load radius, normalized radial distance, normalized slab sizes) used in the prediction models are dimensionless, both English and metric (SI) unit systems can be used by the program.
5. The main features of the program include: the traditional AREA deflection basin backcalculation procedure, the ILLI-BACK closed-form backcalculation procedure, as well as the proposed modification to the deflection ratio backcalculation procedure.

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