CALBACK: ENHANCING CALTRANS MECHANISTIC-EMPIRICAL DESIGN PROCESS WITH NEW BACKCALCULATION SOFTWARE

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ABSTRACT

Until recently, California Department of Transportation (Caltrans) procedures for pavement design and rehabilitation have been largely based on empirical approaches developed from road test sections built in California in the 1940s. While Caltrans empirical procedures performed generally well over time, they are limited in their ability to benefit from the vast number of emerging products, construction practices, and design innovations. In 1996, California initiated an extensive project to develop Mechanistic-Empirical (ME) design and analysis tools in order to benefit from these new products, practices, and technologies. These tools will help state design engineers incorporate the impact of new products and technologies, increased traffic volumes and axle loading, various axle configurations, and variable climatic conditions. As part of the development of new ME design procedures, Caltrans is developing a suite of dedicated software. CalME is an ME design program for flexible pavements that parallels the NCHRP 1-37A (MEPDG) and is calibrated for California conditions. CalBack is a sophisticated backcalculation program that contains specific features pertinent to California and is designed to work as a standalone, or in concert with CalME. This paper describes the successful development and implementation of CalBack in three ways: (1) why and how Caltrans developed CalBack; (2) how CalBack functions; and (3) a representative study that shows how well the software works. Results from numerous projects, including the case study presented in this paper, show that CalBack is highly capable of delivering accurate and repeatable results for the practitioner and researcher.
INTRODUCTION

Until recent years, the California Department of Transportation (Caltrans) procedures for new pavement design and rehabilitation of existing pavements have been generally based on empirical approaches developed from road test sections built in California in the 1940s. While the Caltrans empirical procedures have performed generally well through the years, they are limited in their ability to benefit from the vast number of emerging new products, construction practices, and design innovations that optimize performance of the pavement system and minimize traffic interruptions and costly maintenance and rehabilitation activities.

In order to realize the benefits of continuously emerging innovations in the pavement field (industry and research), and with the help of improved computer speeds, California initiated in 1996 an extensive research project for developing Mechanistic-empirical (ME) design and analysis tools. These tools will help design engineers in the state to incorporate the impact of new products, new construction technologies, increased traffic volumes and axle loading, various axle configurations, and variable climatic conditions.

As part of the development of new ME design procedures, Caltrans is developing a suite of dedicated software. These programs will support engineers in the state in designing new and rehabilitating existing flexible and rigid pavements. They will also be general tools for pavement performance analysis. One major product of this suite is CalME, which is an ME design and analysis program for flexible pavements that parallels the NCHRP 1-37A product, MEPDG (1) for use with flexible pavements. New ME rigid designs have been cataloged in the 2006 edition of Caltrans Highway Design Manual (HDM) (2). CalBack, another product of this suite, is a sophisticated backcalculation program that contains specific features pertinent to California and is designed to work as a standalone or in concert with CalME.

This paper describes the successful development and implementation of the CalBack backcalculation program. The rationale for why and how the software was developed is presented. The functioning of CalBack and what makes it unique are described. A case study is presented that highlights the usefulness of the program to the practitioner and the researcher.

CALBACK DEVELOPMENT

CalBack (short for California Backcalculation) is a software tool developed under the ongoing ME research activities funded by Caltrans under contract with the University of California Pavement Research Center (UCPRC) (Davis and Berkeley), and the Dynatest Group. The CalBack software is currently under final evaluation and revision, prior to adoption by Caltrans as the official computer program for analysis of pavements. The Caltrans Mechanistic-Empirical Technical Working Group (CTMETWG), with members from a number of functional units in Caltrans, was formed in July 2006 and has been involved in evaluating and revising the program to enhance both its accuracy and user interface. CalBack will support other ME based programs currently being developed and evaluated by the CTMETWG. Caltrans plans to have an operational ME design and analysis system by early 2010. This hybrid design system will include both California-developed ME analysis programs (e.g., CalME and CalBack) and the ME analysis product of NCHRP 1-37A, currently called MEPDG (1).

CalBack, developed specifically for California and based on California testing practices, offers a number of significant features that makes it a unique and useful tool for state pavement engineers. Many of these key features are presented below and are described in greater detail later in this paper:
1. *CalBack* possesses a “library” of engineering properties for those materials that have been extensively characterized. This allows the design engineer to analyze the exact or very similar material under consideration with *CalBack*. The expandable nature of *CalBack* allows for further growth of the materials library via inputs from real projects.

2. Three search engines may be used to determine material moduli: a gradient search, a Kalman filter (3, 4), and a genetic algorithm (5).

3. Data may be directly input from both Jils and Dynatest Falling Weight Deflectometers (FWDs) since Caltrans and UCPRC own both types of machines.

4. Computed moduli values may be automatically adjusted for temperature if desired.

5. The program contains three response models for analysis of flexible pavements: Odemar-Boussinesq (6), WESLEA (7), and University of California’s layered elastic analysis program, LEAP (8), giving flexibility to the design engineer during analysis. All response models may include a nonlinear subgrade material.

6. The software can be used to analyze flexible, rigid, and composite pavements with the ability to automatically import and analyze data from FWD output files.

7. The software handles multiple deflection basins for long stretches of the pavement and allows division of the pavement into “statistically similar” subsections for design purposes.

8. The program may be run in either SI or customary US units.

9. *CalBack* can be run under either “normal” or “advanced” mode of analysis to suit the pavement engineer’s degree of experience and the amount of information sought.

Other important features are presented in the following section.

**GENERAL FEATURES OF CALBACK**

The main purpose of *CalBack* is to provide layer moduli for use for rehabilitation design with *CalME*. The layer moduli are backcalculated from surface deflections measured with an FWD. The first screen of the *CalBack* software that the user sees after clicking the *CalBack* icon is shown in Figure 1.

When starting a new project a *CalBack* database is created in Microsoft *Access* format and the FWD raw data are imported. Raw data may be imported from the Caltrans Jils FWD format or from a database created by the *ELMOD5* program (9). During import, the raw data may be checked for nondecreasing deflections, zero deflection, temperature range, and deflection ratios, and points that are flagged may be discarded. Figure 2 shows a screen shot of the main window of *CalBack*. Color codes (red, yellow, and green) similar to those used in the *MEPDG* are used in *CalBack*. 
FIGURE 1 Shot of first screen of CalBack.

FIGURE 2 Screen shot of the main window of CalBack.
For each layer in the pavement structure a standard material is imported from a CalME design database. This process assigns values to a large number of material parameters defining the asphalt concrete master curve, fatigue behavior, development of permanent deformations, etc., that will be needed for the flexible pavement rehabilitation design. The parameters can be edited from CalBack. A maximum of five layers may be defined, including the subgrade, as shown in the backcalculation window of CalBack (Figure 3). In this window, the thickness and modulus seed value of each layer are entered or edited by users. Deflection basin then can be fitted for each individual test point, with the fitted and measured deflection and deflection modulus shown in the two plots on the right side of the window. Deflections at multiple test points can also be fitted consecutively in a batch mode.

![FIGURE 3 Screen shot of the backcalculation window of CalBack.](image)

For the joints and corners of portland cement concrete (PCC) pavements, the degree of load transfer efficiency and the k-values at center slab, joint, and corner may be calculated with this program using Westergaard’s equations. For flexible pavements, the layer temperature may be calculated from the measured surface temperature using the Bells equation. The procedure for determining the Bells temperature is described in the ASTM standard D7228-06a. Based on the imported master curve parameters and Bells temperature, CalBack calculates the (adjusted) modulus of each pavement layer at a reference temperature, as well as the (unadjusted) moduli at
the actual temperature. For asphalt concrete, the adjustment in modulus with temperature is determined from a model of the format used in *MEPDG* (1):

\[ \log(E) = \delta + \frac{\alpha}{1 + \exp(\beta + \gamma \log(tr))} \]  

where \( E \) is the modulus in MPa (or ksi), \( tr \) is reduced time in seconds, \( \alpha, \beta, \gamma, \) and \( \delta \) are constants, and logarithms are to base 10. Reduced time is found from:

\[ tr = lt \times \left( \frac{\text{visc}_{\text{ref}}}{\text{visc}} \right)^{aT} \]  

where \( lt \) is the loading time in seconds, \( \text{visc}_{\text{ref}} \) is the binder viscosity at the reference temperature, \( \text{visc} \) is the binder viscosity at the present temperature (with both viscosities having same units), and \( aT \) is a constant.

The results of the backcalculation are stored in the project database. The results, as well as the raw data, may also be plotted in *CalBack* or exported to Microsoft *Excel*. The *CalBack* plots have facilities for calculation of mean values and standard deviations and for division into uniform subsections, as illustrated in Figure 4. The plots may also be saved to the clipboard or to a disk, or to be printed. *CalME* can import the results for rehabilitation design.

**FIGURE 4** Screen shot of the plot window of *CalBack*. 

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If several drop heights have been used on PCC joints and corners, potential gaps between the slab and the support may be estimated using a regression analysis, and plotted. Temperatures (surface and Bells), deflection ratios, and the “Area” parameter may also be plotted. For asphalt layers, the backcalculated moduli may be plotted versus temperature together with the master curve for the standard material, and the master curve parameters may be edited to fit the calculated moduli.

CalBack has facilities for editing the raw data, deleting a specific geophone, and calculating average values for several drops, for use in the backcalculation. Files may also be subdivided, combined, renamed, copied, or deleted. Several files may be used in a batch run.

A “calculator” is available for determining stresses, strains, or displacements at different positions and under different loads, using either of the three response models. The residual life, in terms of ESALs, may also be estimated using the backcalculated moduli and the material parameters imported from the CalME design database.

A context sensitive help function and a user’s manual are available in CalBack.

RESPONSE MODELS AND SEARCH ALGORITHMS

For flexible pavements, three response models are available for backcalculation: the Odemark-Boussinesq approach (6), the linear elastic program WESLEA developed by the U.S. Army Corps of Engineers Waterways Experiment Station (7), and a layered elastic program called LEAP (8) developed by Symplectic Engineering, Inc. for the University of California. All response models have been modified to enable a nonlinear elastic subgrade, an essential requirement on thin or weak pavement structures. Depth to bedrock may also be determined with Odemark-Boussinesq and LEAP, which also allows partial bonding of the layers. Both the WESLEA and LEAP elastic analysis programs give very similar responses.

The nonlinear subgrade modulus model used in CalBack is as follows:

\[ E = C \cdot \left( \frac{\sigma_1}{p_a} \right)^n \]  

(3)

where \( E \) is the subgrade modulus, \( \sigma_1 \) is the major principal stress, positive for compression; \( p_a \) is a reference stress (atmospheric pressure = 0.1 MPa), and \( C \) and \( n \) are constants (\( n \) being negative).

Odemark’s method is based on the assumption that the stresses and strains below a layer depend on the stiffness of that layer only. If the thickness, modulus, and Poisson’s ratio of a layer are changed, but the stiffness remains unchanged, the stresses and strains below the layer should also remain relatively unchanged. Figure 5 shows a transformed system of a semi-infinite halfspace on which Boussinesq’s equations may be used for stresses, strains, and displacements below the interface.
The following equality holds, and the equivalent thickness is calculated from the following equation:

$$\frac{h_1^3 E_1}{1 - \nu_1^2} = \frac{h_e^3 E_2}{1 - \nu_2^2} \quad \text{or} \quad h_e = h_1^3 \sqrt[3]{\frac{E_2}{E_1}} \frac{1 - \nu_2^2}{1 - \nu_1^2}$$

where $h_1$ is the original thickness, $h_e$ is the “equivalent” thickness, $E_1$ and $E_2$ are stiffness of each layer, $\nu_1$ and $\nu_2$ are Poisson’s ratio of each layer.

To compare the relative accuracy of backcalculated moduli using these three response models, a three-layer pavement structure consisting of a hot-mix asphalt layer over aggregate base and subgrade (AC/AB/SG) with various known moduli was assumed. Pavement surface deflections were calculated using the Odemark-Boussinesq method and the multilayer linear elastic program Elsym5 (10), and used as inputs in CalBack for backcalculation using the Odemark-Boussinesq’s approach and the LEAP approach, respectively. Results showed that the backcalculated moduli from the three models are all within 7 percent of the assumed values.

In CalBack, three search engines may be used: a gradient search, a Kalman filter, and a genetic algorithm. For the gradient search and the genetic algorithm, the minimization may be based on the Root Mean Square (RMS) values of either the absolute deflection differences or the relative differences. The closeness of fit may also be visualized from plots of measured and calculated deflections or surface (deflection) moduli.

The Kalman filter is a set of mathematical equations that provides an efficient recursive means to estimate the state of a dynamic system from a series of incomplete and noisy measurements (3). The application of Kalman filter in layer moduli backcalculation was proposed by Choi et al. (4). Sensitivity analysis showed that the filter can converge quickly to true layer moduli no matter what seed values are given. When applied to real FWD data, it can fit the deflections well, and in most cases changing seed values does not lead to different results at all, even when the subgrade is treated as nonlinear material. Backcalculation with the Kalman filter is fast, consistent, and robust (4). In rare cases, the backcalculated results from the Kalman filter may depend on seed values, although the difference is not significant.

The third type of search engine is the genetic algorithm (GA). GA is a heuristic global search technique that simulates the process of biological evolution (5). First, a “parent generation” is created. In CalBack, each parent has layer moduli randomly selected between three times the seed value and the seed value divided by three. For each member of the parent generation the deflections are calculated and the root-mean-square (RMS) value is stored. An "offspring" generation is produced from the parent generation by "mutating" the parents, by
randomly changing one or more moduli, by interchanging two layer moduli or by multiplying and dividing two moduli by the same factor. Again the deflections are calculated and the RMS is stored. The combined parent and offspring generation is sorted with respect to increasing RMS and the best members are used as a new parent generation, of the same size as the original parent generation. This process is continued until no reduction of the lowest RMS value has been accomplished within a number of tries specified by the user. If the algorithm has terminated due to a maximum number of generations, a satisfactory solution may or may not have been reached. This search routine is much slower than the other two methods, but it is less sensitive to the seed values and can often find a better solution than the other two methods.

VERIFICATION CASE STUDY
The development of CalBack was an iterative process where staff members from UCPRC and Caltrans used the program in several projects and suggested modifications to it. These modifications were implemented, further test cases were run, and additional changes made.

One verification case for CalBack was conducted on several flexible pavement test sections that were trafficked with the Caltrans Heavy Vehicle Simulator (HVS). An overview of the test sections used in the analysis is given below. Backcalculation of asphalt concrete moduli as well as modulus of aggregate base was carried out using CalBack, and will be given in a subsequent subsection. Finally, comparison between backcalculated and field and laboratory measurements is done and presented in the last subsection of the case study.

Overview of Test Sections
These test sections were constructed as part of a study aimed at evaluating the reflection cracking performance of asphalt mixes used in overlays for rehabilitating cracked asphalt concrete pavements in California. The accelerated pavement testing investigation was conducted by UCPRC at the Richmond Field Station of the University of California, Berkeley, from October 2001 to July 2007. The main objective of this investigation was to compare the performance of three overlays using modified binder (MB) mixes against two control overlay mixes (dense-graded asphalt concrete [DGAC] and gap-graded rubberized asphalt concrete [RAC-G]). These overlays represent typical pavement structures currently used throughout the California state highway system. The overlays were constructed over a uniform DGAC test pavement specifically prepared for the study, which was designed and constructed according to standard Caltrans procedures and specifications.

The accelerated pavement testing was divided into two phases. In the first phase, the uniform test pavement (90-mm DGAC over 350-mm aggregate base over subgrade), which consisted of six test sections, was trafficked with the HVS to induce fatigue cracking on the asphalt concrete layer. In the second phase, six reflection cracking test sections were constructed using various overlay mixes, as follows (11):

1. Half-thickness (45 mm) MB4 gap-graded overlay with minimum 15 percent recycled tire rubber (referred to as “MB15” in this paper): Section 586RF
2. Half-thickness rubberized asphalt concrete gap-graded (RAC-G) overlay: Section 587RF
3. Full-thickness (90 mm) DGAC overlay (CTM356): Section 588RF
4. Half-thickness MB4 gap-graded overlay: Section 589RF
5. Full-thickness MB4 gap-graded overlay: Section 590RF
6. Half-thickness MAC15TR gap-graded overlay with minimum 15 percent recycled tire rubber (referred to as “MAC15” in this paper): Section 591RF
FIGURE 6 Layout of MB road project (11).
The layout of the overlay test sections and the corresponding Phase I fatigue test sections is shown in Figure 6. There are also six rutting test sections (580RF through 585RF) shown in the figure, but they will not be discussed in this paper. The physical locations (and therefore the underlying aggregate base and subgrade) of Sections 567RF, 568RF, 569RF, 571RF, 572RF, and 573RF are the same as those of Sections 586RF, 587RF, 588RF, 589RF, 590RF, and 591RF, respectively. For simplicity, the suffix “RF” will be dropped from the section name in the remaining part of this paper.

**FWD Testing and Backcalculation**

FWD testing was performed on the six fatigue test sections (pre-overlay) and the six subsequent reflection cracking test sections (post-overlay). The purpose of the testing was to characterize the HVS sections with the FWD, detect aging and seasonal effects on mix stiffness, and compare the backcalculated modulus with that measured in the laboratory.

The FWD measurements were taken at both the centerline and offset 1 m parallel to the centerline of the trafficked area at various stages: (i) before and after testing the underlying fatigue sections (Phase I) and (ii) before and after testing the overlay sections (Phase II). The spacing between two consecutive test spots is 0.3 m and 0.9 m on the center (trafficked) line and the offside (untrafficked) line, respectively. Seven geophones were used in all tests to measure pavement surface deflections. The sensor spacing was fixed at 0, 200, 300, 460, 610, 910, and 1,520 mm (0, 8, 12, 8, 24, 36, and 60 inches) from the center of the loading plate. At each test spot, three drops with increasing loads were performed. In most cases, the FWD test was performed twice on the same section in one day, at different pavement temperatures.

CalBack (April 2007, version 0.93) was used to backcalculate the moduli of pavement layers. The Odemark-Boussinesq method was used for all backcalculation. Parameter estimation was based on the minimization of the relative difference (root mean squares) between the observed deflection and calculated deflection. The Kalman filter was used in all calculations, and in some cases, the genetic algorithm was used to search for the optimal values from a broader range of seed values.

Pavement temperatures were calculated at one third depth of the asphalt concrete layer, from Bells equation using the measured surface temperature and the average air temperature of the previous day as inputs. The surface temperature was measured by the FWD during the test, and the average air temperature was obtained from a nearby weather station. The average of thickness measurements from the dynamic cone penetrometer (DCP), coring, and trenching were used in the backcalculation.

In backcalculation normally it is not recommended to backcalculate the modulus of an asphalt layer if the thickness is less than half the radius of the loading plate (75 mm in this study). Because the thicknesses of overlays are generally smaller than the minimum allowable thickness for reliable backcalculation, both the overlay and existing DGAC layer were treated as one composite layer in the backcalculation. Therefore, only a three-layer pavement system was considered in the analysis.

**Comparison of Asphalt Concrete Stiffness Master Curves from Field and Laboratory**

Temperature affects the asphalt concrete modulus, which in turns affects the aggregate base modulus due to changes in confinement. To analyze the aging and seasonal effects or the stiffness recovery after HVS testing from the FWD data measured at different times and
temperatures, the temperature effect must first be removed. This operation requires knowledge of the stiffness master curve for each asphalt mix.

The FWD data measured at different temperatures in a short period were used to estimate the stiffness master curve for each asphalt mix based on the *MEPDG* master curve formula (Equation 1). During the HVS testing, a parallel laboratory study of the material properties was also conducted. The modulus of each asphalt mix was measured by the frequency sweep test using flexural beam specimens. The corresponding stiffness master curve was also developed based on the same *MEPDG* master curve formula. The master curve parameters were determined using a least squares method that minimizes the absolute difference or the relative difference. For field master curves, a minimum modulus of 100 MPa was imposed to make the curves realistic.

Figure 7 shows the stiffness master curves of DGAC, estimated from the laboratory frequency sweep test and the FWD data on the overlay section (Section 588). For overlay Section 588, the thickness of the combined DGAC is around 180 mm, which is thick enough for reliable backcalculation. The stiffness master curve estimated for this section closely matches the laboratory master curve, indicating good correlation between backcalculation and testing results.

![Figure 7 Stiffness master curves of DGAC estimated from laboratory and FWD data.](image_url)

For the other overlay sections, the composite asphalt concrete layer consists of two different mixes: the underlying DGAC and the overlaid modified binder mix. In the laboratory, the modulus of each mix was measured separately from flexural beam specimens. To compare the moduli backcalculated from field data to those measured in the laboratory, the laboratory moduli of individual mixes needed to be converted into composite moduli. The Odemark’s method was used for the conversion as follows. First, the overlay is converted into an equivalent layer with a different thickness \( h_e \) and the same modulus as the existing asphalt layer. This equivalent layer along with the existing layer is then converted into a composite layer with the thickness equal to the sum of the overlay thickness \( h_1 \) and the existing layer thickness \( h_2 \). The thickness and modulus of the composite layer are calculated from:

\[ h_e = \frac{h_1 m_1 + h_2 m_2}{m_1 + m_2} \]

\[ M_e = \frac{m_1 h_1 + m_2 h_2}{h_1 + h_2} \]
where $E_1$ is the overlay modulus obtained from the frequency sweep test; $E_2$ is the modulus of the existing layer obtained from the frequency sweep test; $E_c$ is the calculated composite modulus; $f_1$ and $f_2$ are correction factors, $f_1=0.9$ and $f_2=1.0$. These correction factors were chosen to achieve good agreement between the Odemark’s method and the theory of elasticity.

Figure 8 shows the stiffness master curves measured from the laboratory frequency sweep test, and the composite moduli backcalculated from FWD measurements, for different composite asphalt concrete layers. It can be seen that the backcalculated moduli using the FWD data are in good agreement with the corresponding laboratory master curves.

**Comparison of Stiffness of Aggregate Base from Field and Laboratory**

The aggregate base (AB) was 100 percent recycled, well-graded material (mainly crushed portland cement concrete, PCC) (11). It is classified as GW-GM according to USCS, with 34 percent passing 4.75-mm sieve. The optimum moisture content is 7.9 percent, and the maximum dry density is 2,097 kg/m$^3$. Samples were taken during construction of the test road and tested in the laboratory for the resilient modulus ($M_r$), following the LTPP test protocol P46, “Resilient Modulus of Unbound Granular Base/Subbase Materials and Subgrade Soils.” The test results are presented in Figure 9.

Figure 9 shows that the resilient modulus of aggregate base material changes with water content and confining pressure, but is less affected by the peak deviatorial stress. At water contents between 6.0 percent and 8.5 percent, the aggregate base resilient modulus ranges from approximately 200 MPa to 300 MPa with confining pressures between 21 kPa and 34 kPa, and will extrapolate to around 200 MPa with confining pressure around 10 kPa.

In the analysis of FWD data from this study, the effect of water content was not detected in the backcalculated modulus of aggregate base, primarily due to the limited number of data points and compounding effects of other factors such as aging and self-cementing.

Before Phase II HVS testing, the backcalculated moduli of AB were significantly higher than the values measured in the laboratory on most sections (except sections 589 and 590), with the highest value reaching 3,700 MPa, as shown in Figure 10. This is primarily due to the self-cementing of the PCC particles in the field after construction. Except for the two sections overlaid with the MB4 mix (sections 589 and 590), Phase II HVS loading started 3 to 4 years after the completion of Phase I HVS testing. Such long periods allowed the crushed PCC particles to develop a chemical bond among them. The stiffness of the aggregate base, therefore, increased correspondingly. In the laboratory, specimens were tested shortly after their fabrication, so self-cementing was not allowed sufficient time to develop.

After Phase II HVS testing, the aggregate base modulus in the trafficked area dropped to between 200 MPa and 300 MPa on all sections except Section 586 (Figure 10). This indicates that the self-cementing developed over time had been mostly destroyed due to HVS loading. On Section 586 the aggregate base still retained some cementing. Based on LEAP, the confining pressure at the mid-depth of the aggregate base was around 7 to 10 kPa for all sections. This matched the range of confining pressure in the laboratory test that gave a measured aggregate
base modulus of around 200 MPa. Therefore, the backcalculated AB moduli match well with laboratory measured values.

FIGURE 8 Comparison of asphalt concrete stiffnesses backcalculated from FWD tests and measured in the laboratory.
FIGURE 9 Resilient modulus of aggregate base measured in the laboratory (PD means peak deviatorial stress).

FIGURE 10 Backcalculated moduli of aggregate base before and after Phase II HVS testing.
In the backcalculation, it was found that the AB modulus changes with the pavement temperature. There is a positive correlation between the asphalt layer modulus and the AB modulus. This is the opposite of what would be expected because lower AC stiffness should lead to a higher bulk stress in the AB and to a higher AB modulus, according to the triaxial tests and to conventional wisdom. A possible reason for this result is that the stiffness of the upper AC layer affects the displacement of the underlying granular particles (12). Soft AC applies less confinement to the AB and thus may lead to lower AB stiffness. However, this hypothesis this needs further examination.

SUMMARY
This paper focused on the rationale for development, the technical capabilities, and the usefulness of a newly created backcalculation program for the state of California, called CalBack. This software tool will be an essential analysis component in Caltrans’ new ME design process. CalBack has significant versatility via three deflection-matching search engines; three response models for flexible pavements; Westergaard model for rigid pavements; and a large, self-contained, expandable material characterization library. Results from numerous projects, including one major case study presented in this paper, indicate that CalBack is capable of delivering accurate and repeatable material property estimations.

In producing dedicated and very specific design software, Caltrans now possesses a suite of engineering tools that will greatly enhance the new ME design process. Through Caltrans’ decision to develop in-house software tools that are directly relevant to California, it is expected that pavement design engineers’ capabilities to develop strongly performing pavements will be markedly increased.

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