Sensitivity Analysis of 2002 Design Guide Distress Prediction Models for Jointed Plain Concrete Pavement

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The AASHTO 2002 design guide was calibrated with Long-Term Pavement Performance sections scattered throughout the United States but with very few sections from the state of California. To understand the reasonableness of the model predictions for California conditions, a detailed sensitivity study was undertaken. The reasonableness of the model predictions was checked with a full factorial considering traffic volume, axle load distribution, climate zones, thickness, design features, portland cement concrete (PCC) strength, and unbound layers. Satellite sensitivity studies were performed to study the effects of surface absorptivity and coefficient of thermal expansion, which were not included in the primary sensitivity analysis. The findings are summarized from about 10,000 cases run with the software as part of this study. The cracking model was found to be sensitive to the coefficient of thermal expansion, surface absorptivity, joint spacing, shoulder type, PCC thickness, climate zone, and traffic volume. The faulting values are sensitive to dowels, shoulder type, climate zone, PCC thickness, and traffic volume. Although on average both the cracking and faulting models show trends that agree with prevailing knowledge in pavement engineering and California experience, in some cases results were counterintuitive. These cases include thinner sections performing better than thicker sections and asphalt shoulders performing better than tied and widened lanes. It was also found that the models fail to capture the effect of soil type and erodibility index and that the cracking model is sensitive to surface absorption.

The limitations of the empirical procedures based on the AASHO Road Test led the AASHTO Joint Task Force on Pavements to take the initiative to develop a new pavement design tool based on mechanistic-empirical (ME) principles. The resulting pavement design procedure, called the 2002 Design Guide (2002DG in this paper), is intended to be user-friendly software for design of new and rehabilitated flexible, rigid, and composite pavements. The models in the design guide were calibrated with data from Long-Term Pavement Performance (LTPP) sections from across the United States. However, very few sections in California were used for the calibration, which led to the need to check the model's predictions for California conditions. Also, AASHTO recommends that each state validate and, if necessary, recalibrate the models with climate, traffic, and materials data more representative of that state. For California this process consists of three steps:

- Bench testing or sensitivity analysis,
- Validation with accelerated pavement testing data, and
- Validation with field data.

The first step of the validation process is reported on here, which is the sensitivity analysis of the jointed plain concrete pavement (JPCP) module of the software. Sensitivity analysis helps to check the reasonableness of the model predictions, identify key inputs for the design process, and identify any problems in the software. A positive outcome from the sensitivity analysis is a prerequisite to the expensive and time-consuming validation process with field data because the sensitivity analysis identifies important variables in the models and variables for which reasonable assumptions can be used without a significant change in the predicted performance.

The significance of the sensitivity analysis is acute for California because of the timetable for revision of highway design procedures in the state, which presents the opportunity to immediately incorporate findings from the sensitivity analysis. Some sensitivity analyses have already been made. Hall and Beam (*1*) looked at the sensitivity of the models to 29 different input variables. However, one major limitation of that study is that only one variable is changed at a time compared with the baseline case, resulting in very few cases and failure to capture the interactions among the variables. Mallela et al. (*2*) studied the sensitivity of the models to the coefficient of thermal expansion. Khazanovich et al. illustrated the sensitivity of the 2002DG faulting model to dowel diameter, slab width and edge support, built-in-temperature gradient, erodibility index of the base, and joint spacing (*3*). The 2002DG user's manual discusses sensitivity of the models to some variables but misses some key variables such as traffic volume, axle load distribution, and subgrade type (*4*). In the current study about 10,000 runs are analyzed, and this large number of runs enables the study to evaluate variable interactions as well as single effects for the full range of projects anticipated in California.

FULL FACTORIAL EXPERIMENTAL DESIGN

The variables and factor levels in the full factorial experimental design are as follows:

- Axle load spectra: rural and urban;
- Traffic volume: traffic indexes (TIs) of 12, 13, and 16;
- Climate regions: South Coast (Los Angeles), Valley (Sacramento), and Mountain and High Desert (Reno);
- Portland cement concrete (PCC) thickness: 7, 8, 9, 12, and 13 in. [since the software operates only with customary (English) units, customary units are also used to report the inputs and outputs of the software];

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- Base: asphalt concrete base and cement-treated base;
- Subgrade: high-plasticity clay and poorly graded sand;
- Dowels: dowels and no dowels;
- Shoulder type: asphalt shoulders, tied shoulders, and widened truck lane;
- Joint spacing: 15 and 19 ft; and
- PCC flexural strength at 28 days: 626 and 700 psi.

This factorial resulted in 8,640 cases. To the extent possible, the inputs for all the variables used in the sensitivity study were chosen to represent the practices and conditions in California. All cases were run with a reliability level of 50% and a design life of 30 years.

INPUTS

Traffic Inputs

California has a well-developed traffic database with input from about 100 weigh-in-motion (WIM) stations in the state. Most of the traffic inputs are derived from the WIM traffic database (*5*). WIM data from two types of locations, urban and rural, were used in the study. Urban locations are defined as freeway segments that have more Class-5 trucks than Class-9 trucks, and rural locations have more Class-9 trucks. Class-5 trucks are those with short trailers typically used for short-haul distribution, and Class-9 trucks have long trailers typically used for long hauls.

The three traffic volumes used are TI values equal to 12, 13, and 16, which correspond to approximately 11, 22, and 126 million equivalent single-axle loads (ESALs), respectively. Each TI for the factorial was calculated twice, once by using an example urban axle load spectrum from the WIM database and again by using the rural spectrum. The number of trucks was adjusted for each case to obtain the desired number of ESALS by using a 4.2 exponent per the practice at the California Department of Transportation (Caltrans) for each spectrum. Hourly truck distribution factors, vehicle class distribution factors, and monthly adjustment factors were obtained from the WIM database. Zero growth rate was assumed for simplicity. This assumption does not affect the results much because Miner's law is used for damage accumulation in the distress prediction models, which assumes a linear damage rate with traffic repetitions. The only sensitivity of the results would be due to PCC strength gain effects. The normalized axle load distributions used in this study were determined from the WIM data. Urban and rural locations have significantly different axle load distributions.

Climate Inputs

The three climate regions included in the sensitivity analysis are South Coast (Los Angeles), Valley (Sacramento), and Mountain and High Desert (Reno). The South Coast is characterized by mild temperatures, little temperature change from day to night, and low rainfall. The Valley Region has hot summers, cool winters, large day-to-night temperature changes, and moderate rainfall. The Mountain and High Desert Region is characterized by fairly hot summers, cold winters, and moderate rainfall (*6*).

Design Features

Different combinations of joint spacing, shoulder type, and load transfer efficiency are constructed from the factorial. For dowelled pavements, the diameter of the dowels is 1.5 in. and the dowel spacing is 12 in. The permanent curl-warp effective temperature difference is assumed to be −10°F, which was fixed in the LTPP calibration by the 2002DG team. It is assumed that there is no bonding between the base and the PCC slab. The erodibility index of the base is assumed to be 3, meaning that the base material is erosion resistant.

Surface and Drainage Properties

The default value used in the software for surface shortwave absorptivity is 0.85, and this value was fixed for calibrating the models in the software. However, in this study surface absorptivity is assumed to be 0.65, which was measured by the Lawrence Berkeley National Laboratory (*7*) for new rigid pavements. Default values are used for drainage parameters.

Pavement Structure

The pavement structure analyzed has a PCC slab of varying thicknesses (7, 8, 9, 10, or 12 in.), 6-in. cement-treated base (CTB) or asphalt concrete base (ACB), and 6 in. of aggregate subbase and high-plasticity clay (CH) or poorly graded sand (SP) subgrade. The lean concrete base used by Caltrans is characterized as CTB in this paper.

Material Properties

The values used for PCC material properties are typical values used by Caltrans. Values used for 28-day flexural strength are 626 psi and 700 psi. Flexural strength of 626 psi was obtained from a mix used for paving in Ludlow, California, and meets the Caltrans specification. The second strength was chosen to be about 12% more than 626 psi. The same mix design parameters were used for both flexural strength cases. Default values are used for CTB and the unbound layers.

RESULTS AND ANALYSIS

The software was run for all 8,640 combinations in batch mode, for which the cracking and the faulting models need to be run separately. After the faulting and cracking values were determined, empirical equations mentioned in the design guide's user's manual were used to estimate spalling and international roughness index (IRI). The sensitivity runs were made with a draft version, but later the results for some of the cases were compared with the current version. The comparison showed that there were no significant changes in the current version. The results from the cases run permitted identification of the effect of various variables on faulting, transverse cracking, and IRI. The effects of different variables are summarized in the form of box plots and discussed in the following sections. The four horizontal lines in a box plot represent minimum, 25th percentile, 50th percentile, 75th percentile, and maximum values present in the data.

Effect on Transverse Cracking

The results showed that joint spacing, PCC thickness, climate zone, traffic volume, and shoulder type have a significant impact on transverse cracking. Base type, subgrade type, and axle load spectrum for a fixed number of ESALs do not affect transverse cracking as much. The following effects were found:

- As the traffic volume increases, predicted cracking increases (Figure 1*a*).
- As the thickness of the PCC slab increases, the amount of cracking observed in the pavement decreases (Figure 1*b*).
- The models predict the least cracking for the South Coast climate followed by the Mountain climate. The Valley climate has the highest amount of cracking (Figure 1*c*).
- Joint spacing is the key variable that controls transverse cracking. The results from the sensitivity analysis show a dramatic difference in cracking between structures with joint spacing of 19 ft versus 15 ft. Joint spacing of 19 ft is very detrimental to the pavement. Figure 1*d* summarizes the effect of joint spacing. These findings match the experience in California, where repeated joint spacing of 12, 13, 18, and 19 ft has been used for many years.
- Pavement structures with a widened truck lane appear to perform better than those with tied shoulders or asphalt shoulders. Widened truck lanes reduce cracking considerably (Figure 1*e*). There are cases with widened truck lanes that show 100% cracking. This situation occurs because other inputs such as very high traffic loading in Valley or Mountain regions with joint spacing of 19 ft and 7-in. slab thickness dominate the expected performance.
- The results from the sensitivity analysis show that, on average, subgrade type has little effect on cracking (Figure 1*f*).
- Base type does not have much effect on cracking. Though on average CTB performs better than ACB, there are almost equal numbers of cases in which CTB performs better than ACB and ACB performs better than CTB.
- The flexural strength of PCC does not have much effect on transverse cracking, according to the model.
- Axle load spectrum has little effect on cracking. When the axle load distribution is changed, the other traffic characteristics associated with that location, such as vehicle class distribution, hourly

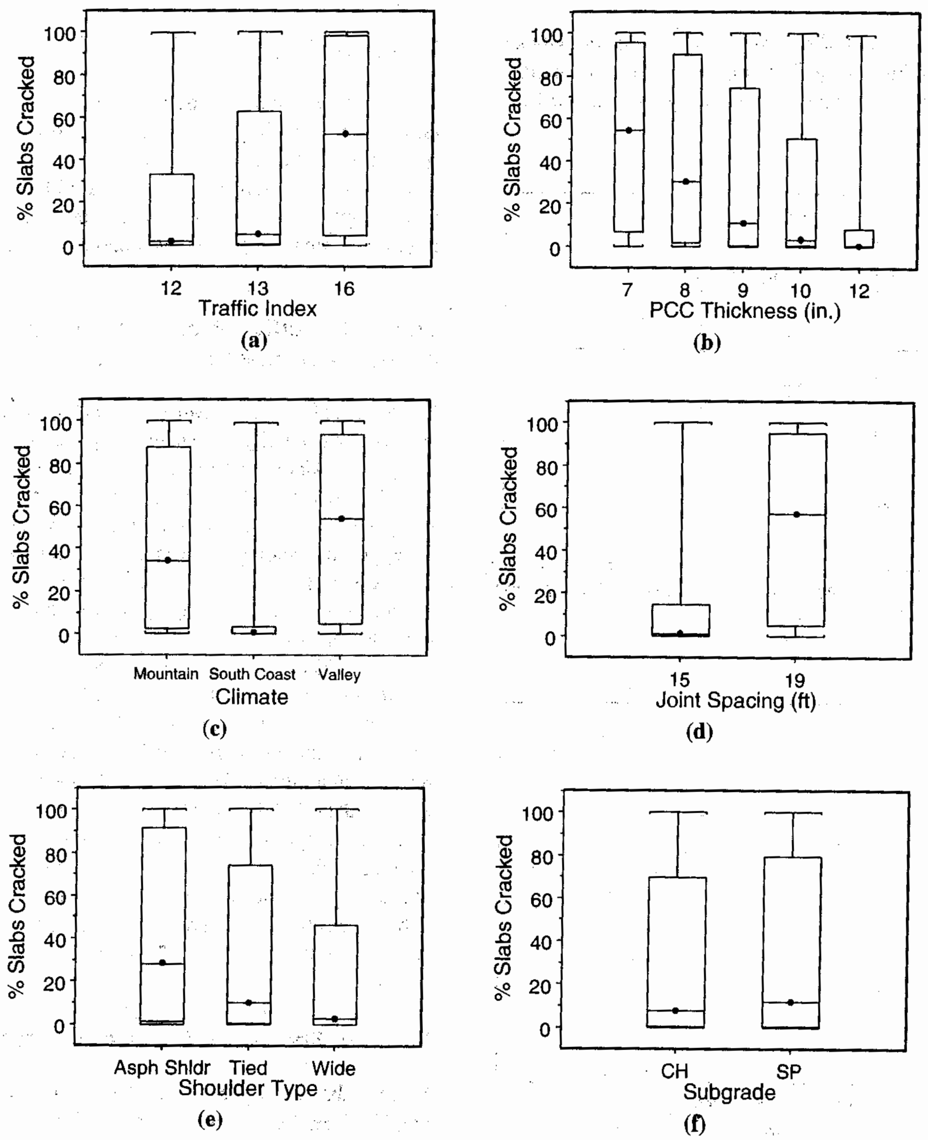

FIGURE 1 Effects of some key variables on transverse cracking.

traffic distribution, and annual average daily truck traffic, also change. Plausible reasons for the lack of significant effects are that

- The other traffic inputs are changed along with the spectrum, and
- TI, which is used to quantify the traffic volume, captures the effect of the spectrum fairly well.

Figure 2 summarizes the effects of all the variables on transverse cracking and their relative importance in controlling cracking. The plots show the average amount of cracking for each factor level of all the variables. Among the variables that a designer can control, joint spacing and shoulder type are significant and have already been dealt with in recent Caltrans practice. In general, model predictions for different factor levels of all the variables agree with prevailing knowledge in pavement engineering. However, there are some exceptions, which are presented later in the paper.

Effect on Faulting

Results showed the following effects on faulting:

- The most important factor that controls faulting is dowels, whose significant impact on faulting is shown in Figure 3*a*; there are hardly any structures with dowels that have fault heights greater than 0.1 in.
- Figure 3*b* shows that widened truck lanes reduce faulting.
- The effect of joint spacing is shown in Figure 3*c*, which shows less faulting with 15-ft joint spacing than with 19-ft joint spacing.
- As traffic volume increases, faulting increases (Figure 3*d*).
- As thickness of the PCC slab increases, faulting decreases (Figure 3*e*).
- Among the three climate zones, the South Coast zone shows the least faulting, with the Mountain and Valley zones having slightly greater faulting (Figure 3*f*).
- Base type, subgrade type, spectra, and strength of the PCC slab do not have much effect on faulting according to the models.

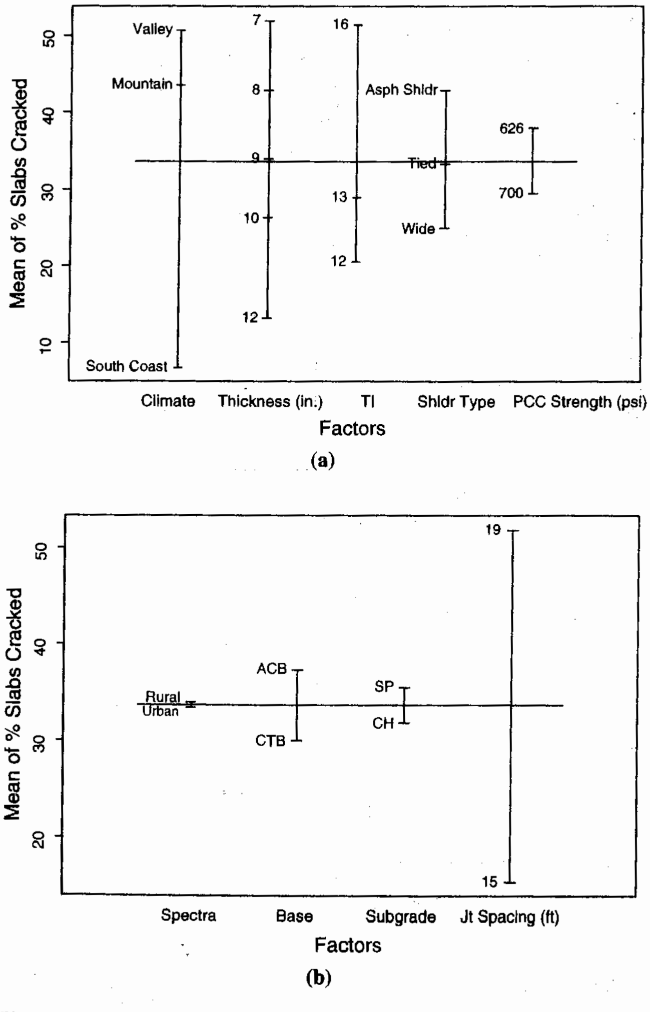

FIGURE 2 Effects of different variables on transverse cracking.

Figure 4 summarizes the effects of all the variables considered in the sensitivity study on faulting and their relative importance. The plots show the average amount of faulting for each factor level of all the variables. The results show that faulting is mainly controlled by dowels. Among the variables that can be controlled by the designer, dowels, shoulder type, and PCC thickness have significant effects on faulting. There are some anomalous cases with respect to faulting, which will be presented later.

Effect on IRI

The variables that affect the IRI most are the same ones that affect faulting and cracking significantly. So dowels, traffic volume, joint spacing, PCC thickness, climate zone, and shoulder type have a significant effect on IRI. However, treated base type, subgrade type, and strength of PCC have little effect on IRI according to the models. Figure 5 summarizes the relative importance of all the variables on IRI.

Effect of Coefficient of Thermal Expansion on Rigid Pavement Performance

Coefficient of thermal expansion (COTE) was not included in the sensitivity study initially. However, a separate sensitivity study was performed in order to check the sensitivity of cracking and faulting models to COTE. A subset of the full factorial used for the primary sensitivity study was run with two different COTE values (4×10^{-6}/°F and 7×10^{-6}/°F). The factorial consists of axle load spectra (urban and rural), thickness of PCC (9 and 12 in.), shoulder type (asphalt, tied, and widened truck lane), climate region (South Coast, Valley, and Mountain), dowelled and undowelled cases with TI of 16, SP subgrade, and CTB. COTE of 4×10^{-6}/°F corresponds to PCC with limestone or granite aggregate and COTE of 7×10^{-6}/°F corresponds to PCC with quartzite, cherts, and gravels. Granites, gravels, and quartzite are the most commonly used aggregate types in California. All the cases were run at a reliability level of 50% and 30-year design life. Figure 6 summarizes the effect of COTE on cracking and faulting. It can be seen that COTE significantly affects transverse cracking. The effect on faulting is minimal. The sensitivity of these results will be checked during subsequent field calibration of the models. If the results are found to be as sensitive as the model suggests, the specification of COTE or design for a site-specific COTE will need to be considered by Caltrans.

Effect of Shortwave Surface Absorptivity

Surface absorptivity (SA) is defined as the amount of solar radiation absorbed by the pavement surface. Though this variable was not included in the full factorial sensitivity study, it was found that the cracking model is highly sensitive to SA. A separate experimental design was run to understand the sensitivity of the 2002DG models

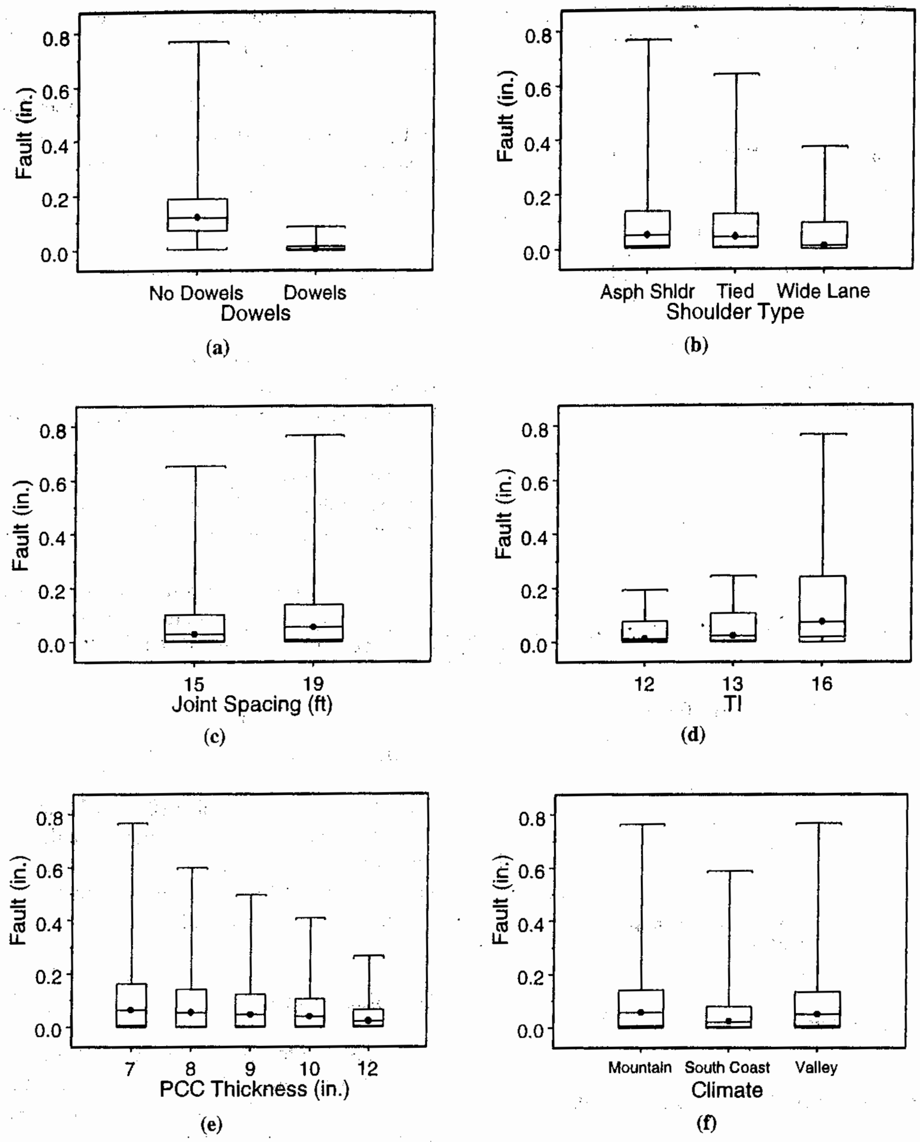

FIGURE 3 Effects of some key variables on faulting.

to this variable. The new experimental design was similar to the one used for the main sensitivity study but with fewer variables. The factorial consisted of axle load spectra (urban and rural), traffic volume (TI of 12 and 14), PCC thickness (8, 10, and 12 in.), base type (CTB and ACB), shoulder type (asphalt, tied, and widened truck lane), and joint spacing (15 and 19 ft). Two different values of SA, 0.65 and 0.85, were used. The models in the 2002DG software were calibrated with a fixed SA value of 0.85, and it was not measured on the calibration sections. In the main sensitivity analysis SA was assumed to be 0.65 (more reflective than 0.85), a typical value for new PCC pavements. The analysis included the desert climate, SP subgrade, and PCC strength of 626 psi. All the cases were run at a reliability level of 50% and for a 30-year design life.

In some cases there is a significant difference in cracking even when every other factor is the same except SA. In some cases cracking increased by as much as 17 times when the SA was changed from 0.65 to 0.85. Figure 7*a* shows a case in which there is a significant increase in cracking due to change in the SA value. The inputs corresponding to this case are urban spectra, 15-ft joint spacing, widened truck lane, CTB, and 8-in. PCC slab. A closer look at the results from this secondary sensitivity study revealed that thinner slabs were more affected by SA than thicker slabs. Figure 7*b* shows the effect of SA on cracking in comparison with the other key variables. It can be seen that according to the 2002DG models, SA is as important as traffic volume and shoulder type in its impact on transverse cracking. This result will also need to be verified to the extent possible during field calibration. Currently, any differences in SA are included in the error term of the models. SA does affect faulting, but the impact is not very significant. In the study by Hall and Beam, they found that SA was sensitive for cracking and insensitive for faulting (*1*).

ANOMALIES

Thickness of Slab

There are cases in which thinner pavement structures perform better than thicker pavement structures.

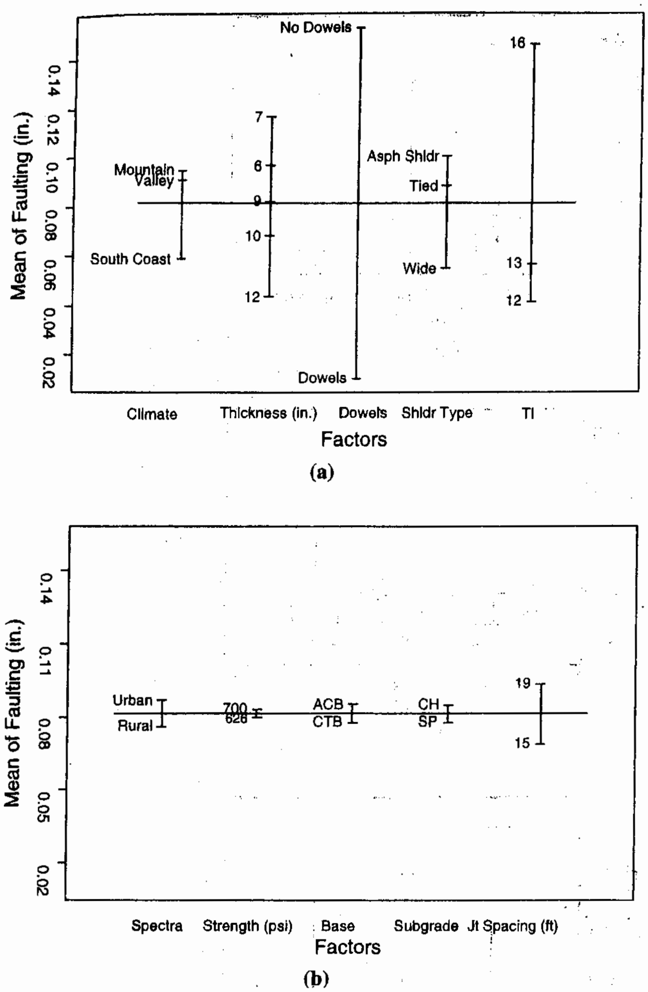

FIGURE 4 Effects of different variables on faulting.

Structures with 7-in. Slab Better Than Structures with 8-in. Slab

Out of all the sensitivity runs (8,640 cases), 126 cases showed that 7-in. slabs perform better than 8-in. slabs in terms of cracking and 136 cases showed the same result for faulting. In most of these anomalous cases the difference in distresses between 7- and 8-in. slabs is not great, with a maximum difference in proportion of slabs cracked being 12.5% and maximum difference in faulting being 0.27 in. followed by a difference of 0.058 in. Most of the anomalous cracking cases have an SP subgrade and 19-ft joint spacing in common. Most of the anomalous faulting cases have a CH subgrade in common.

Structures with 8-in. Slab Better Than Structures with 9-in. Slab

In terms of cracking and faulting, in about 12 cases 8-in. slabs have less cracking than 9-in. slabs, with the maximum difference in proportion of slabs cracked being 28.4%. The inputs that are common to these 12 cases are

- ACB,
- CH subgrade,
- Mountain climate zone,
- PCC flexural strength at 28 days of 626 psi, and
- Widened truck lane.

In about 155 cases 9-in. slabs have more faulting than 8-in. slabs, with a maximum difference in faulting of 0.0064 in. There are no inputs common to these 155 cases, but most of them have 19-ft joint spacing.

Structures with 9-in. Slab Better Than Structures with 10-in. Slab

There are 12 cases in which 9-in. slabs perform better than 10-in. slabs, with the maximum difference in proportion of slabs cracked being 18%. The inputs common to these 12 cases are

- CH subgrade,
- Mountain climate zone, and
- PCC flexural strength at 28 days of 626 psi.

There are 461 cases in which 10-in. slabs have more faulting than 9-in. slabs and the maximum difference in faulting is 0.008 in. The only input common to these 461 cases is that all of them have dowels.

Structures with 10-in. Slab Better Than Structures with 12-in. Slab

There are 419 cases in which 10-in. slabs have less faulting than 12-in. slabs, with a maximum difference in faulting of 0.014 in. The structures corresponding to all these cases have dowels. There are no cases in which 10-in. slabs perform better than 12-in. slabs in terms of percent of slabs cracked.

Shoulder Type

Most cases in the sensitivity study show that widened truck lanes perform better than tied shoulders, which in turn perform better than asphalt shoulders. This finding makes sense. However, some cases do not show this performance.

Asphalt Shoulders Better Than Tied Shoulders

In 18 cases in the study, structures with asphalt shoulders are better than those with tied shoulders. The maximum difference in proportion of slabs cracked is 24.4%. Inputs common to all these cases are

- CH subgrade,
- Mountain climate zone, and
- PCC flexural strength at 28 days of 626 psi.

There is only one case of structures with asphalt shoulders with less faulting than structures with tied shoulders, and the difference in faulting is 0.3282 in.

Asphalt Shoulders Better Than Widened Truck Lanes

In six cases structures with asphalt shoulders have less cracking than structures with widened truck lanes, with the maximum difference in the proportion of slabs cracked being 12.5%. All cases have CH

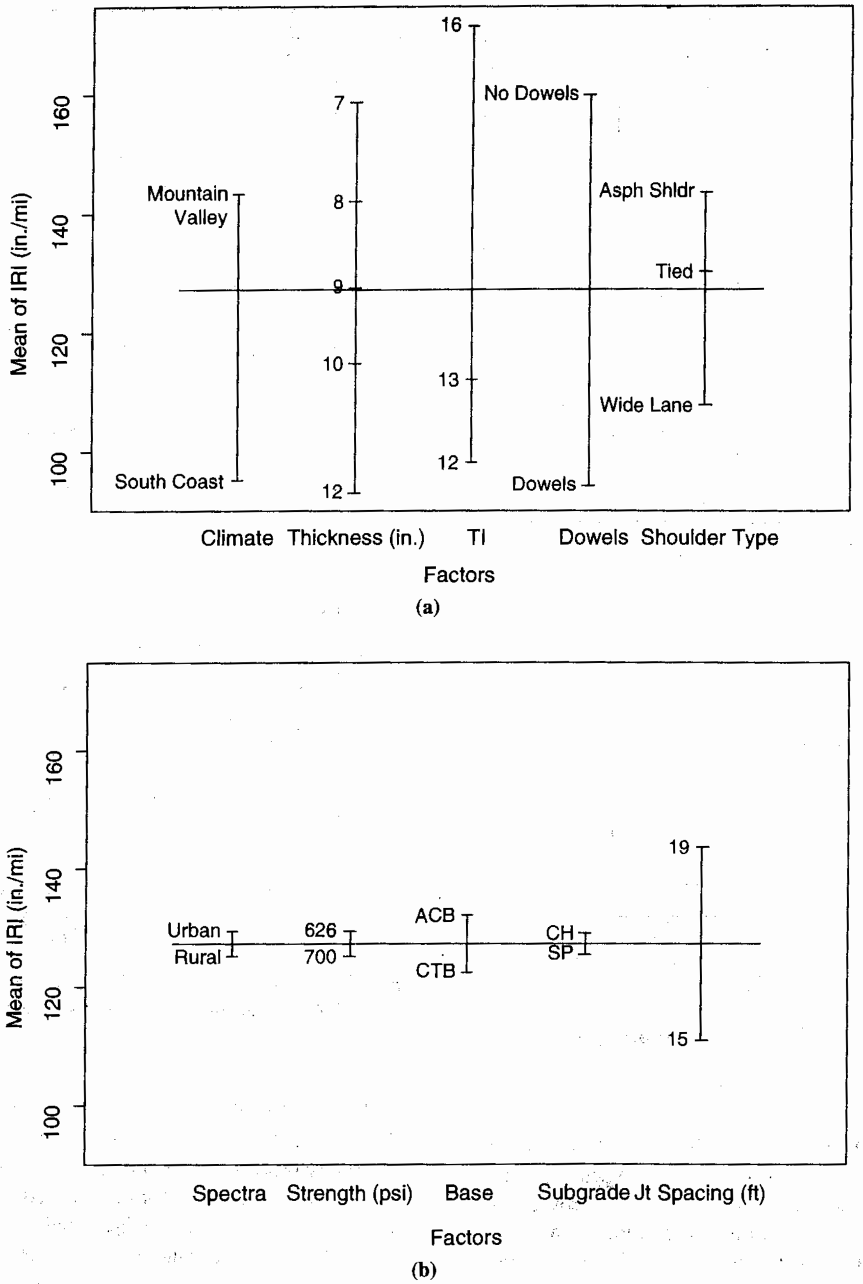

FIGURE 5 Effects of different variables on IRI.

subgrade, CTB, 28-day PCC flexural strength of 626 psi, 15-ft joint spacing, 9-in. slabs, and rural spectra and are located in the Mountain climate zone. There is only one case of structures with asphalt shoulders with less faulting than structures with tied shoulders; the difference in faulting is 0.1059 in.

Tied Shoulders Better Than Widened Truck Lanes

In eight cases structures with tied shoulders performed better than structures with widened truck lanes in terms of cracking. The maximum difference in proportion of slabs cracked is 32.1%. The inputs common to these eight cases are CH subgrade, 12-in. thick slabs, rural spectrum, and Mountain climate zone. There are no cases of tied shoulders performing better than widened truck lane in terms of faulting.

Subgrade Type

Poorly graded sand (SP) is stiffer and less erodible than high-plasticity clay (CH), so SP is naively supposed to be associated with better pavement performance than CH in terms of faulting and cracking. However, there are 2,644 cases in which structures with CH subgrade are predicted to have less cracking than structures with SP subgrade. There are no inputs common among these 2,644 cases, but most of them are in the Mountain climate zone. The difference in proportion of slabs cracked goes up as high as 80% in some cases,

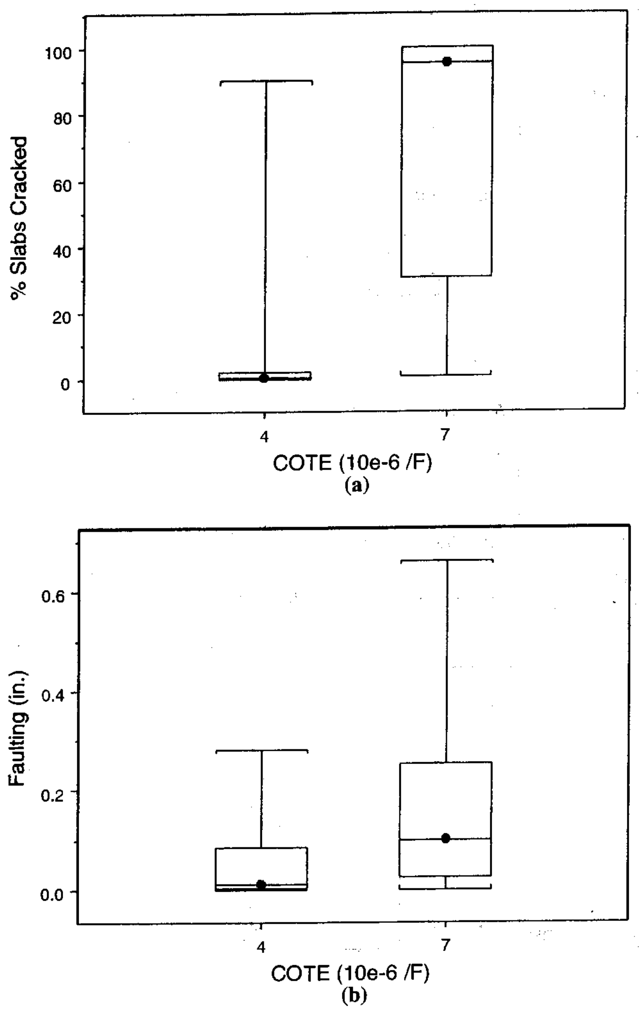

FIGURE 6 Effect of COTE on (*a*) transverse cracking and (*b*) faulting.

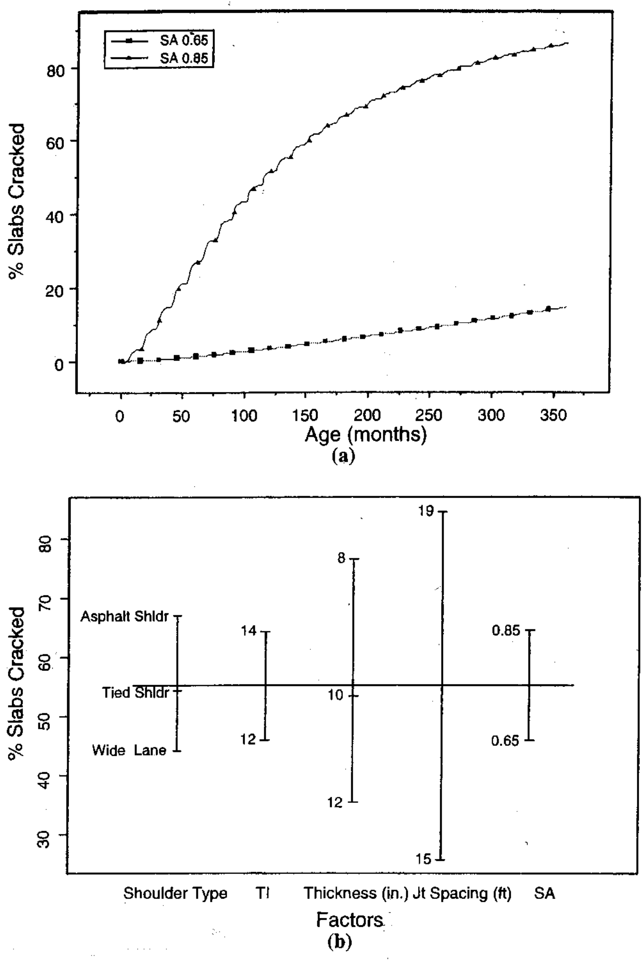

FIGURE 7 Effect of SA on transverse cracking: (*a*) example case and (*b*) in comparison with other variables.

but such cases are few. On average there is not much difference in cracking performance between the two subgrade types used in this study. Intuitively, the softer subgrade should potentially provide lower curling stresses under nighttime temperature gradients and moisture gradients because the layers underlying the slab accommodate more to the slab shape.

There are 735 cases of structures with SP subgrade that have more faulting than those with CH subgrade, with a maximum difference in faulting of 0.16 in. There are no inputs common to these 735 cases. There are no intuitive reasons why the more erodible CH subgrade should provide better performance than the SP subgrade.

To understand better the effect of subgrade type on rigid pavement performance, another small sensitivity analysis was performed. Four subgrade types having Unified Soil Classifications of GW, SP, CL, and CH were analyzed for two thickness of PCC slabs (9 in. and 12 in.) over 6 in. of CTB and 6 in. of aggregate subbase. The other key inputs used were rural spectrum, traffic of 225 million ESALs (TI = 17), Valley climate, COTE of 5.5×10^{-6}/°F, 15-ft joint spacing, and surface absorptivity of 0.65. The faulting, transverse cracking, and IRI values for different cases at the end of a 30-year design life and at 50% reliability are shown in Table 1. The assumed resilient modulus and the corresponding *k*-value estimated by the software for the four soil types are shown in the Table 1. The estimated *k*-values are much higher for sand and gravel subgrades than those encountered in the field.

Results show that a softer subgrade results in less faulting when dowels are not used. In all cases softer subgrade helps in reducing transverse cracking. This finding would lead a designer to be more concerned with faulting for undowelled pavements for well-graded gravel subgrades than for high-plasticity clay subgrades, which is not reasonable. To understand the reason behind this anomaly, the faulting model used in the design guide was examined (*3*). According to the model, faulting is directly proportional to the differential energy (DE), which in turn is a function of corner deflections. A three-dimensional finite-element analysis tool, EverFE, was used to calculate the deflections at the corner of a single slab, and the DE was estimated. According to EverFE, as the stiffness of the subgrade increases, the DE decreases and so faulting is supposed to decrease. However, in the 2002DG, DE increases as the stiffness of the subgrade increases. The reasons for this difference are not known.

Subbase

A few cases were run to see the effect of granular subbase under CTB. The results showed that the thickness of granular subbase had no effect on rigid pavement performance. When 6-in. granular subbase was used, the faulting, cracking, and IRI values obtained were 0.478 in., 96.7%, and 394 in./mil and when 2-in. subbase or no subbase was used, almost same results were obtained.

TABLE 1 Performance of Structures with Different Soil Types

Soil Type	M_r (psi)	k (psi/in.)*	Faulting (in.)	Cracking (% slabs)	IRI (in./mi)
No dowels					
GW	40,000	900	0.519	97.6	416.1
SP	28,000	775	0.478	96.7	394.1
CL	16,000	300	0.402	92.6	350.9
CH	8,000	180	0.372	89	332.3
Dowels					
GW	40,000	900	0.022	97.6	155.7
SP	28,000	775	0.022	96.7	155.5
CL	16,000	300	0.055	92.6	169.2
CH	8,000	180	0.061	89	169.7
CH	5,000	125	0.063	83.7	166.1
CH	1,000	41	0.084	61	158.5
CH	500	25	0.099	75.1	177.6

*Approximate dynamic k-value estimated by the software from the M_r value.

These results assumed SP subgrade and undowelled pavements. Similar results were obtained for CH subgrade and dowelled pavements. From these results it can be said that according to the models, the PCC slab and CTB layer can be constructed directly above high-plasticity clay without affecting the performance of the pavement, which is not reasonable. Current Caltrans practice of placing an aggregate subbase under the treated base on clay and silt subgrades and placing the treated base directly on sand and gravel subgrades will be recommended for use with other results from the 2002DG software.

SOFTWARE PROBLEMS

Inability to Produce Results

For some projects it was found that two input files containing the same data produced totally different outputs. There are few cases in which this problem was detected, and such cases showed unreasonable results such as 0% cracking for 7-in. slabs with 19-ft joint spacing under very high traffic volume. When such cases were rerun with the same input files, they gave different results, which were reasonable.

Aggregate Type

The type of aggregate is a redundant input since it does not affect the calculation of distresses. When aggregate type is changed, the COTE of PCC is not changed automatically and must be changed manually.

Climate Data

There are some major California weather stations that are not on the list of weather stations for which the software has climate data, and some stations on the software's list do not have more than 2 years' worth of data. If chosen, some weather stations on the software's list result in errors, and the program crashes.

CONCLUSIONS

The sensitivity analysis done as part of this study helped to identify the basic behavior of the models and to identify some flaws in the 2002DG models and the software. The following conclusions are drawn from the study:

- On average, both the cracking and faulting models show trends that agree with prevailing knowledge in pavement engineering, with a few notable exceptions.
- Anomalies occurred for a limited number of cases, applicable to both transverse cracking and faulting models:
  - –Thinner pavement structures performed better than thicker pavement structures,
  - –Structures with asphalt shoulders performed better than structures with tied shoulders and widened truck lanes, and
  - –Structures on softer subgrade performed better than structures on stiffer subgrades.
- Surface absorptivity (SA) is predicted to have an unreasonably large effect on cracking performance in some cases.
- Subgrade k-value in many cases is unusually high when a stiffer subgrade is used. This finding suggests there may be some flaws in the E-to-k conversion model used in the software.
- The sensitivity to subgrade type is counterintuitive and can lead to probably dangerous situations for inexperienced designers. It is recommended that local experience be used in the decision of whether to use aggregate subbases and that the model needs better calibration with regard to subgrade type.
- Inability to reproduce the results can confound the credibility of model predictions, which is a software bug.
- Some major weather stations in California are not included in the climate database built into the software. Some of the climate files are corrupt and cause the software to crash.
- PCC properties like COTE are not changed automatically when the user changes aggregate type, making it a redundant variable.

Overall, the JPCP module of the 2002DG produces reasonable predictions of pavement performance. However, the accuracy of the predictions needs to be validated by using field data in California. If

2002DG needs to be used for pavement design, it should be used with some caution, keeping in mind the anomalies mentioned here. The designer should be careful in selecting input values for SA and COTE and in using results for different subgrade types and should apply good judgment when selecting whether to use subbases because the models seem to fail to capture the effect of granular base and subgrade accurately.

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