
PREVENTION OF JOINT FAULTING BASED ON FIELD PERFORMANCE MODELING

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ABSTRACT

Joint faulting has a very significant effect on ride quality. Thus, faulting should be directly considered in design to minimize and control its occurrence. This was accomplished through development of faulting prediction models for doweled and nondoweled joints based on mechanistic concepts and a comprehensive database. Site conditions (traffic, climatic, subgrade) and several design features (dowel diameter, subdrainage, joint spacing, base type, widened slab) were found to have a significant effect on joint faulting. Guidelines and procedures for design are provided.

INTRODUCTION

Faulting of transverse joints has a very significant effect on ride quality of jointed concrete pavements (JCP). Transverse joint faulting is the difference in elevation between abutting slab faces and is primarily the result of a combination of heavy axle loads, poor load transfer across the joint, excess free moisture beneath the pavement, and a supporting base or subbase material that is erodible. Pumping occurs when excess moisture is violently ejected from beneath the rapidly deflecting leave slab corner as a heavy axle crosses the joint. The excess moisture that is ejected carries base and subbase fines (and sometimes subgrade material) with it, thereby creating a void or cavity beneath the joint at the leave slab corner while building up material under the approach slab corner. Through this process, faulting and corner cracking—and even diagonal or transverse cracking—can develop. Many JCPs have been rehabilitated prematurely due to excessive faulting and associated cracking. Faulting is not directly considered in any design procedure, so direct design checks are needed to eliminate this serious problem.

The objective of this paper is to discuss the development and the results of the latest joint faulting models for both doweled JCP and nondoweled JCP. Based on the results of the models, developed from the largest and most comprehensive field data base ever compiled, practical recommendations and guidelines to prevent faulting are presented (1). The guidelines can be used to determine when dowels are required to control joint faulting.

Several previous models of joint faulting are available (2–7). The major limitation of previous models is the limited data base used in terms of the total number of sections, lack of time-sequence data, limited climatic coverage, lower traffic levels, and lack of sections with modern pavement design features (permeable bases, lean concrete bases, thick slabs, widened slabs, and dowels in dry climates). The models presented in this paper are based on two extensive concrete pavement performance studies sponsored by Federal Highway Administration (FHWA) that include over 300 in-service concrete pavement sections located throughout North America (1, 2).

JOINT FAULTING MODELS FOR JOINTED CONCRETE PAVEMENTS

Data Base Development

The concrete pavement sections evaluated under this study represent a wide variety of designs. Both jointed plain (JPCP) and jointed reinforced concrete pavements (JRCP) are included. The sections are located in the Eastern and Western United States, with the majority located in the upper Midwest. Time-series data were collected on about one-third of the sections.

A variety of design features (slab thickness, joint spacing, load transfer, widened lane, shoulder type, drainage, base type, etc.) are present on these pavement sections. The range of design features encountered in these projects is summarized in table 1. This table shows that a significant range of variables exists, although often these ranges occur over different projects located in different climates.

These projects also vary considerably in age and in cumulative traffic loadings (expressed in terms of equivalent single-axle load [ESAL] applications) that they have sustained. Most sections are between 15 and 25 years old, with about 20 sections greater than 25 years old. Most sections have sustained less than 10 million ESAL applications, although 3 sections have carried more than 20 million.

Joint Faulting Modeling for Doweled JCP

A formal mechanistic-empirical statistical model building approach was utilized. This approach included extensive data review and preliminary data analysis, identification of potential mechanistic variables, selecting variables and a plausible model form, multiple linear regression analysis (stepwise and all subset regression), evaluation of the regression summary and parameter estimates, goodness-of-fit diagnostics, functional transformation, and sensitivity analysis to evaluate the reasonableness of the model. The model building is an iterative process that results in a final mechanistic-empirical statistical model.

The dependent variable in the doweled joint faulting model is the mean transverse joint faulting (FaultD, in) measured about 0.3 m (1 ft) from the slab edge on each section. Based on the previous studies of joint faulting modeling, a large set of explanatory variables was selected from the data base representing traffic, time, key design features, subgrade support, and climatic conditions.

The modified Friberg analysis was used to calculate the maximum bearing stress exerted by the dowels on the surrounding concrete (Bstress, lb/in²) (8, 9). This factor is believed to contribute significantly to the development of transverse joint faulting and is given by the formula:

$$\sigma_{\max} = K * \delta_o$$

where:

- K = Modulus of dowel support, fixed at 1.5*10⁶ lb/in²/in (4.07*10⁸ kN/m²/m).
- δ_o = Deflection of the dowel at the face of the joint, in
- = $P_t (2 + \beta z) / 4\beta^3 E_s I$

in which

- P_t = Shear force acting on dowel, fixed at 9,000 lb (40-kN).
- z = Width of joint opening, in.
- E_s = Modulus of elasticity of dowel bar, fixed at 2.9*10⁷ lb/in² (2.0*10⁵ MPa).
- I = Moment of inertia of dowel bar cross-section, in⁴.
- = $0.25 * \pi * (d/2)^4$ for dowel diameter d in inches.
- β = Relative stiffness of the dowel concrete system, 1/in.
- = $[(Kd) / (4E_s I)]^{0.25}$.

The analysis assumes a 40-kN (9,000-lb) wheel load placed at the corner, which will produce the maximum stress in the outermost dowel bar. Only dowel bars within a distance of 1.0* ℓ from the center of the load are considered to be active, where ℓ is the radius of relative stiffness, defined as:

$$\ell = \left[\frac{Eh^3}{12k(1 - \mu^2)} \right]^{0.25}$$

where:

- E = Concrete modulus of elasticity, lb/in².
 h = Slab thickness, in.
 k = Effective modulus of subgrade reaction, lb/in²/in.
 μ = Poisson's ratio, fixed at 0.15.

The modified Friberg analysis is based on the assumption that 45 percent of the *load* (not the stress) is transferred across the joint.

The drainage coefficient, C_d , is based on the AASHTO drainage coefficient introduced in the AASHTO rigid pavement design procedure in 1986 (10). This factor is a reflection of the pavement's ability to drain excessive moisture from within the structure, as well as the pavement's potential for being exposed to near saturated conditions. Although the drainage coefficient represents a major input of the AASHTO design procedure, little guidance is presented for its selection. A rational procedure is presented in reference 11, which was also used in this study to develop drainage coefficients. Using that information, a simplified matrix was developed for the selection of drainage coefficients based on key climatic and pavement design information. This matrix is presented in table 2.

All the explanatory variables were tested for significance in the overall model using S-Plus™'s step-wise and all-subset linear regression procedures. Two-dimensional plots were also examined to determine the best functional form between the dependent variable and the independent variable. The Alternating Condition Expectation (ACE) algorithm introduced by Breiman and Friedman was used to help identify the proper functional forms for each variable (12, 13). Through all of this process, engineering judgement and expertise were applied in terms of known mechanics involved.

The final model developed for transverse joint faulting for the jointed concrete pavements (both JPCP and JRCP) with dowel bars is as follows:

$$\begin{aligned}
 \text{FaultD} = & \text{CESAL}^{0.25} * [0.0628 - 0.0628 * C_d + 0.3673 * 10^{-8} * B_{\text{stress}}^2 \\
 & + 0.4116 * 10^{-5} * J_{\text{space}}^2 + 0.7466 * 10^{-9} * FI^2 * \text{Precip}^{0.5} \\
 & - 0.009503 * \text{Basetype} - 0.01917 * \text{Widenslab} + 0.0009217 * \text{Age}]
 \end{aligned}$$

where: N = 146 data points (doweled JPCP and JRCP).
 R^2 = 0.60.
 RSE = 0.56 mm (0.022 in).

where:

CESAL	=	Cumulative 18-kip (80-kN) equivalent single axle loads, millions.
Bstress	=	Maximum dowel/concrete bearing stress, lb/in ² .
Jspace	=	Mean transverse joint spacing, ft.
Basetype	=	Base type (0 = nonstabilized base; 1 = stabilized base).
Widenslab	=	Widened slab (0 = not widened, 1 = widened).
C_d	=	Modified AASHTO drainage coefficient, calculated from data base information.
FI	=	Mean annual freezing index, degree (F)-days below freezing.
Precip	=	Mean annual precipitation, in.
Age	=	Pavement age, years.

R^2 represents the multiple R-squared value, which is defined as the fraction of the total variation in the response accounted for the variation in the fitted values. The residual standard error (RSE) is the square root of the sum of squared residuals divided by the number of degrees of freedom for residuals (usually the number of observations less the number of coefficients). The predicted versus actual faulting plot (goodness of fit) is given in figure 1.

Jointed Faulting Modeling for Nondoweled JCP

In nondoweled transverse joints, load transfer is accomplished through aggregate interlock of the abutting joint faces. However, under heavy traffic loadings and under certain environmental conditions, aggregate interlock can become ineffective, leading to pumping and faulting. This section describes the development of the model for faulting of nondoweled pavements.

As in the development of the transverse joint faulting model for doweled pavements, the independent variable for nondoweled pavements is the average faulting in inches (FaultND), and a large set of independent variables were selected in the model development based on the previous studies (2–7,14). In addition, The magnitude of the corner deflection was also considered in the development of the nondoweled faulting model.

The same modeling development procedure used for doweled pavements was followed in the development of the nondoweled faulting model. The model selected for transverse nondoweled joint faulting is as follows:

$$\begin{aligned} \text{FaultND} = & \text{CESAL}^{0.25} * [0.2347 - 0.1516 * C_d - 0.000250 * \text{Slabthick}^2 / \text{Jtspace}^{0.25} \\ & - 0.0115 * \text{Basetype} + 0.7784 * 10^{-7} * \text{FI}^{1.5} * \text{Precip}^{0.25} \\ & - 0.002478 * \text{Days90}^{0.5} - 0.0415 * \text{Widenslab}] \end{aligned}$$

$$\begin{aligned} N &= 131 \text{ data points (non-doweled JPCP).} \\ R^2 &= 0.45. \\ \text{RSE} &= 0.86 \text{ mm (0.034 in).} \end{aligned}$$

where:

CESAL	=	Cumulative 18-kip (80-kN) equivalent single axle loads, millions.
Jtspace	=	Mean transverse joint spacing, ft.
Slabthick	=	PCC slab thickness, in.
Basetype	=	Base type (0 = nonstabilized base; 1 = stabilized base).
Widenslab	=	Widened slab (0 = not widened, 1 = widened).
C_d	=	Modified AASHTO drainage coefficient, calculated from data base information.
FI	=	Mean annual freezing index, degree-days.
Precip	=	Mean annual precipitation, in.
Days90	=	Mean annual number of days over 30 °C (90 °F).

The plot of the predicted versus actual faulting is given in figure 2.

SENSITIVITY ANALYSIS

Sensitivity analyses were conducted to verify the engineering soundness of the model and to evaluate the effects of the changes of the key variables on faulting. First, to give an example of the validity of the models, figure 3 and figure 4 show comparison of the actual joint faulting values from the two sections with the predicted values from the faulting models developed in this study.

The sensitivity analysis of the key variables in the doweled model is provided in figures 5 through 8. As shown in the graphs, they all take a similar shape regarding CESAL, starting quite steep and then leveling off with increasing CESAL. Figure 5 shows the effect of the dowel bar diameter on joint faulting. By increasing dowel diameter, faulting can be greatly reduced. Figure 6 indicates that if joint spacing increases, faulting increases. As shown clearly in figure 7, the use of widened slab can decrease faulting over time. A three-dimensional sensitivity plot of the doweled joint faulting with CESAL and bearing stress is given in figure 8. It is clearly shown that as bearing stress increases, faulting increases. Bearing stress can be decrease rapidly by increasing the dowel diameter. For example, going from a diameter of 25 mm (1 in) to 38 mm (1.5 in) decreases bearing stress more than a factor of 2.5 times.

The sensitivity plots of the key variables in the nondoweled model are provided in figures 9 through 12. The sensitivity plots illustrate that, similar to the doweled joint faulting model, nondoweled joint faulting increases rapidly at first and then levels off with CESAL. Figure 9 gives the sensitivity plot of the nondoweled joint faulting with CESAL and slab thickness, and it shows that as slab thickness increases, faulting decreases only a small amount. As shown in figure 10, faulting increases with increasing joint spacing. Figures 11 represents the effect of the climatic factors on faulting. As shown, with same pavement design features and traffic, pavements in a wet-freeze zone are likely to have the greatest faulting, followed by pavements in wet-no freeze areas, dry-freeze areas, and dry-no freeze zones. It is clear from figure 12 that pavements with stabilized base (cement stabilized, lean concrete, asphalt stabilized) are likely to have less faulting compared to similar pavements with aggregate base.

DESIGN GUIDELINES

Joint faulting is a very serious distress that greatly affects ride quality. No conventional design procedure considers faulting directly; thus, it is only considered through joint design standards adopted by agencies. These standards do not consider the many site conditions and features that affect faulting. The joint faulting models included provide the opportunity to check the joint design for excessive faulting. The procedure to check the adequacy of the proposed joint load transfer design consists of the following steps:

- **Step 1. Develop the pavement design (including joint load transfer design) per agency procedures and standards.**
- **Step 2. Predict the mean joint faulting using the appropriate model for doweled or nondoweled pavements (Equation 3 or 4).** Tables 3, 4, and 5 provide some computed values for given conditions for illustration. Equation 3 or 4 should be used for varying site conditions or design features.
- **Step 3. Compare the predicted mean faulting to the recommended critical mean faulting level (2.5 mm for JPCP and 5.0 mm for JRCP) to prevent faulting from contributing significantly to ride quality and serviceability loss.** If the predicted mean faulting exceeds the critical level, the joint load transfer design should be modified. While these level of critical faulting appear to be quite low, it must be realized that these are mean values and are purposely set low for checking the pavement design. Potential design adjustments include the following but these should be evaluated for cost-effectiveness. Note that it is not recommended that slab thickness be increased to reduce faulting, because slab thickness has only a minimal effect.
 - If nondoweled, specify dowels of sufficient diameter and spacing.
 - If dowels are specified, select a larger diameter.
 - Specify a widened slab (i.e., 0.6 m) pavement.
 - If a granular base exists, specify a stabilized base resistant to erosion.
 - Specify a permeable base with an appropriate separation layer of granular material and edge drainage system.
 - Specify a shorter joint spacing.

Based on analysis of field data, critical mean joint faulting value of 2.5 mm (0.10 in) is recommended for the pavements with less than 7.6 m (25 ft) joint spacing, and 5.0 mm (0.20 in) for the pavements with greater than 7.6 m (25 ft) joint spacing. These values are based on results from the database that shows a mean faulting for pavements with a serviceability of 3.0 or less. Based on data from many short-jointed JPCP sections, a mean joint faulting of 3 mm (0.12 in) corresponded to a serviceability index of 3.0 or less. For long-jointed JRCP, the mean faulting level was 6.6 mm (0.26 in). The recommended critical levels for design were selected slightly lower than these values in order to eliminate faulting as a significant contributor to ride quality.

Example check for joint faulting

The pavement has a 4.9-m (16-ft) joint spacing, treated base, subdrains, and no dowel bars. A Freezing Index of 260°C (500°F)-days, an annual temperature range of 47.2°C (85°F), and an annual precipitation of 762 mm (30 in) are also assumed for the location. A slab thickness of 273 mm (10.75 in) was obtained using a design procedure for a design traffic of 20 million ESALs and 95 percent reliability. The mean predicted joint faulting of 3.3 mm (0.13 in) exceeds the recommended limit of 2.5 mm (0.10 in), so the joint design is inadequate. One possible design modification would be to specify 32-mm diameter (1.25-in diameter) dowels. The mean predicted joint faulting would then be 1.27 mm (0.05 in), which would be acceptable.

SUMMARY AND RECOMMENDATIONS

These faulting models have been implemented into the HDM4 software (15) after an extensive review of the existing models, and have been used as joint design checks for the 1997 AASHTO supplemental rigid pavement design procedure (16). The models are developed for the range of pavement designs included in the data base, as shown in table 1. Therefore, these models should only be used in the range of each of the variables used in the model.

Based on the results of the sensitivity analysis, both site conditions (truck traffic, climate, and subgrade type) and many design features have been found to have a significant influence on the development of joint faulting. The following design features were found to reduce faulting in doweled JCP:

- Use of dowels of proper diameter and spacing for heavier traffic loadings (reduces steel/concrete bearing stress).
- Improved drainability of the cross section (e.g., edge drains, permeable base, granular subbase and subgrade).
- Widened slab (0.61 m [2 ft]).
- Stabilized base with asphalt, cement, or lean concrete.
- Shorter transverse joint spacing.

For nondoweled JCP, based on the results of the sensitivity analysis of the models, the following design features were found to reduce faulting:

- Improved drainability of the cross section (e.g., use of edge drain, permeable base, granular subbase and subgrade).
- Use of stabilized base (designed for low erodability).
- Use of widened outside lane/slab.
- Shorter joint spacing.
- Thicker concrete slab.
- Skewing of joints (although not included in the model, skewing of joints was found to reduce faulting by 50 percent in two direct comparisons in the database, however, skewed joints are not recommended for doweled joints since dowels properly designed can eliminate faulting).

These models not only show general effects of site conditions and design features, but also allow engineers to check a joint design for faulting, make modifications to the design if needed, and recheck the design until the predicted faulting level is acceptable. Many design alternatives can be considered directly. Using these faulting models, the engineer can determine, for example, if dowel bars are needed or if aggregate interlock and specific design requirements (such as good subdrainage) are adequate to control faulting.

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TABLE 1 Range of Design Features Included in Study.

Design Feature	Range of Design Feature	Distribution of Design Feature	
		Categories	Number in Category
Slab Thickness	178 to 381 mm	< 203 mm 203 to 253 mm 254 to 304 mm _____ ≥ 305 mm	3 209 40 18
Joint Spacing— JPCP	1.5 to 9.2 m	< 4.4 m 4.5 to 5.9 m _____ ≥ 6 m	9 100 50
Joint Spacing— JRCP	6.4 to 24 m	< 7.6 m 7.6 to 12.1 m 12.2 to 18.2 m _____ ≥ 18.3 m	3 29 61 23
Joint Orientation		Nonskewed Joints Skewed Joints	130 148
Joint Load Transfer		Doweled Joints Nondoweled Joints	154 124
Base Type		None AGG Treated Base Permeable Base	8 97 129 36
Drainage		None Daylighted Edge Drains Only Edge/Trans. Drains	162 22 48 2
Shoulder Type		AC or other PCC WidenSlab	214 56 11
JRCP Reinforcement	0.04 to 0.25%	< 0.1 percent 0.1 to 0.14 percent 0.15 to 0.19 percent ≥ 0.20 percent	35 41 9 9
Climate		Wet-Freeze Wet-NoFreeze Dry-Freeze Dry-NoFreeze	144 50 38 45
Pavement Type		JPCP JRCP	161 117

Note: 1 mm = 0.04 in; 1 m = 3.3 ft

TABLE 2 Simplified Design Matrix for the Selection of the Drainage Coefficient, C_d .

Edge Drains	Precip. Level	Fine-Grained Subgrade		Coarse-Grained Subgrade	
		Nonpermeable Base	Permeable Base	Nonpermeable Base	Permeable Base
No	Wet	0.70–0.90	0.85–0.95	0.75–0.95	0.90–1.00
	Dry	0.90–1.10	0.95–1.05	0.90–1.15	1.00–1.10
Yes	Wet	0.75–0.95	1.00–1.10	0.90–1.10	1.05–1.15
	Dry	0.95–1.15	1.10–1.20	1.10–1.20	1.15–1.20

Notes:

1. Fine subgrade = A-1 through A-3 classes,
Coarse subgrade = A-4 through A-7 classes.
2. Permeable Base = $k = 1000 \text{ ft/day (305 m/day)}$ or $C_u \leq 6$.
3. Wet climate = Precipitation $>635 \text{ mm/year (25 in/year)}$;
Dry climate = Precipitation $\leq 635 \text{ mm/year (25 in/year)}$.
4. Select mid-point of range and use other drainage features (adequacy of cross slopes, depth of ditches, presence of daylighting, relative drainability of base course, bathtub design, etc.) to adjust upward or downward.

**TABLE 3 Example Mean Joint Faulting Predictions for Doweled JPCP Using Equation 3
(Shaded Areas Are Unacceptable Designs Due to Excessive Faulting).**

ESALs, millions	Granular Base			Treated Base		
	Dowel Diameter 25.4 mm	Dowel Diameter 32 mm	Dowel Diameter 38 mm	Dowel Diameter 25.4 mm	Dowel Diameter 32 mm	Dowel Diameter 38 mm
1	0.8	0.3	0.3	0.5	0.0	0.0
2.5	1.0	0.5	0.3	0.8	0.3	0.0
5	1.3	0.8	0.5	1.0	0.3	0.0
10	1.8	1.0	0.8	1.3	0.5	0.3
20	2.5	1.8	1.5	2.0	1.3	1.0
30	3.3	2.5	2.0	2.8	1.8	1.5
40	4.1	3.3	2.8	3.6	2.5	2.3
50	5.1	4.1	3.6	4.3	3.3	3.0
75	7.4	6.1	5.8	6.6	5.6	5.1
100	9.7	8.4	8.1	8.9	7.6	7.4

Notes: Values shown in table are mean predicted joint faulting, mm [1 mm = 0.04 in]

Joint spacing = 4.6 m (15 ft)

Slab thickness = 229 mm (9 in)

Aggregate base with edge drain

Modified $C_d = 0.95$

k-value = 27 MPa/m (100 psi/in)

Precipitation = 762 mm/yr (30 in/year)

FI = 93.3 C(200 F)-days

Annual temperature range = 42 C (75 F)

Age = ESAL * 0.5

Lane slab is not widened

**TABLE 4 Example Mean Joint Faulting Predictions for Doweled JRCP Using Equation 3
(Shaded Areas Are Unacceptable Designs Due to Excessive Faulting).**

ESALs, millions	Granular Base			Treated Base		
	Dowel Diameter 25.4 mm	Dowel Diameter 32 mm	Dowel Diameter 38 mm	Dowel Diameter 25.4 mm	Dowel Diameter 32 mm	Dowel Diameter 38 mm
1	1.0	0.5	0.5	0.8	0.3	0.3
2.5	1.3	0.8	0.5	1.0	0.5	0.3
5	1.5	1.0	0.8	1.3	0.5	0.5
10	2.0	1.3	1.0	1.8	1.0	0.8
20	3.0	2.0	1.8	2.5	1.5	1.3
30	3.8	3.0	2.5	3.3	2.3	2.0
40	4.8	3.8	3.3	4.1	3.0	2.8
50	5.6	4.6	4.1	5.1	3.8	3.6
75	7.9	6.9	6.4	7.1	6.1	5.6
100	10.4	9.1	8.6	9.7	8.4	7.9

Notes: Values shown in table are mean predicted joint faulting, mm [1 mm = 0.04 in]

Joint spacing = 13.7 m (45 ft)
 Slab thickness = 229 mm (9 in)
 Aggregate base with edge drain
 Modified Cd = 0.95
 k-value = 27 MPa/m (100 psi/in)
 Precipitation = 762 mm/yr (30 in/year)
 FI = 93.3 C(200 C)-days
 Annual temperature range = 42 C (75 F)
 Age = ESAL * 0.5
 Lane slab is not widened

TABLE 5 Example Mean Joint Faulting Predictions for Nondoweled JPCP Using Equation 4 (Shaded Areas Are Unacceptable Designs Due to Excessive Faulting).

ESAL, millions	Modified $C_d = 0.9$		Modified $C_d = 1.0$	
	Joint Spacing 4.6 m	Joint Spacing 6 m	Joint Spacing 4.6 m	Joint Spacing 6 m
1	1.8	1.9	1.5	1.5
2.5	2.3	2.3	1.8	1.9
5	2.8	2.8	2.2	2.2
10	3.3	3.3	2.6	2.6
20	3.9	3.9	3.1	3.1
30	4.3	4.4	3.4	3.5
40	4.7	4.7	3.7	3.7
50	4.9	5.0	3.9	3.9
75	5.4	5.5	4.3	4.4
100	5.8	5.9	4.6	4.7

Notes: Values shown in table are mean predicted joint faulting, mm [1 mm = 0.04 in]

Joint spacing = 4.6 or 6.1 m (15 or 20 ft)

Slab thickness = 229 mm (9 in)

Aggregate base with edge drain

Precipitation = 762 mm/year (30 in/year)

FI = 93.3 C (200 F) -days

Days₉₀ = 40 days

Lane not widened

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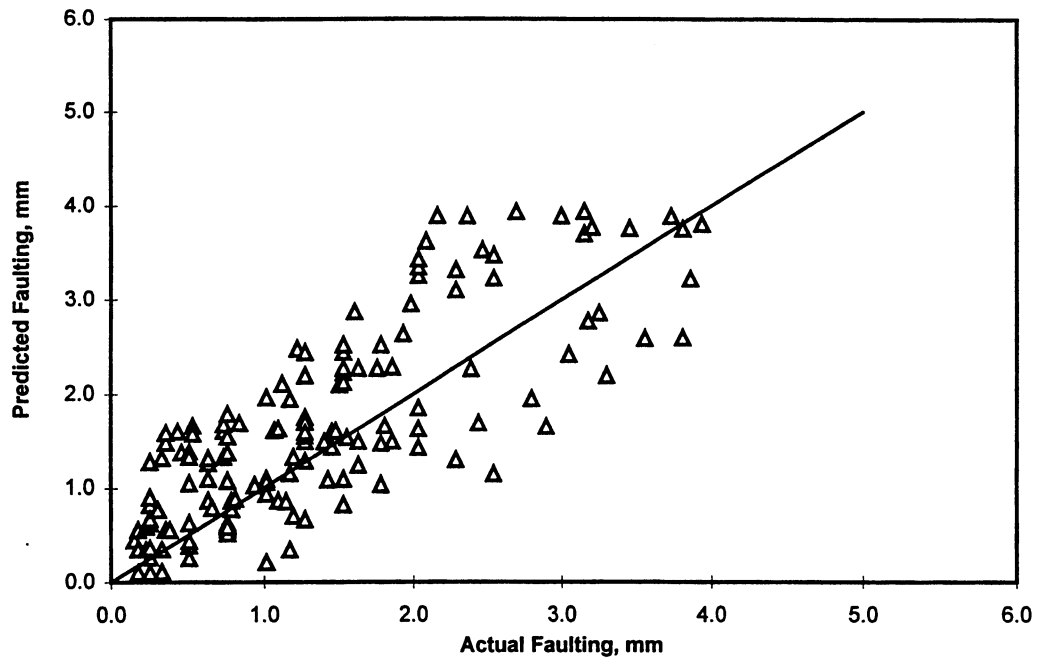


Figure 1. Actual versus predicted faulting for the doweled faulting model.

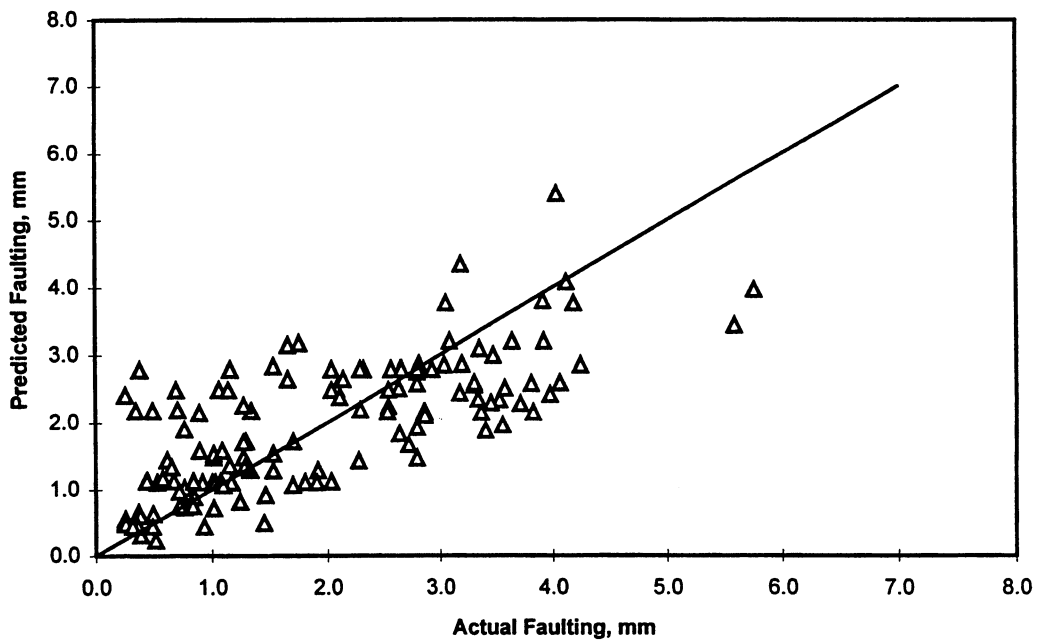


Figure 2. Actual versus predicted faulting for the nondoweled faulting model.

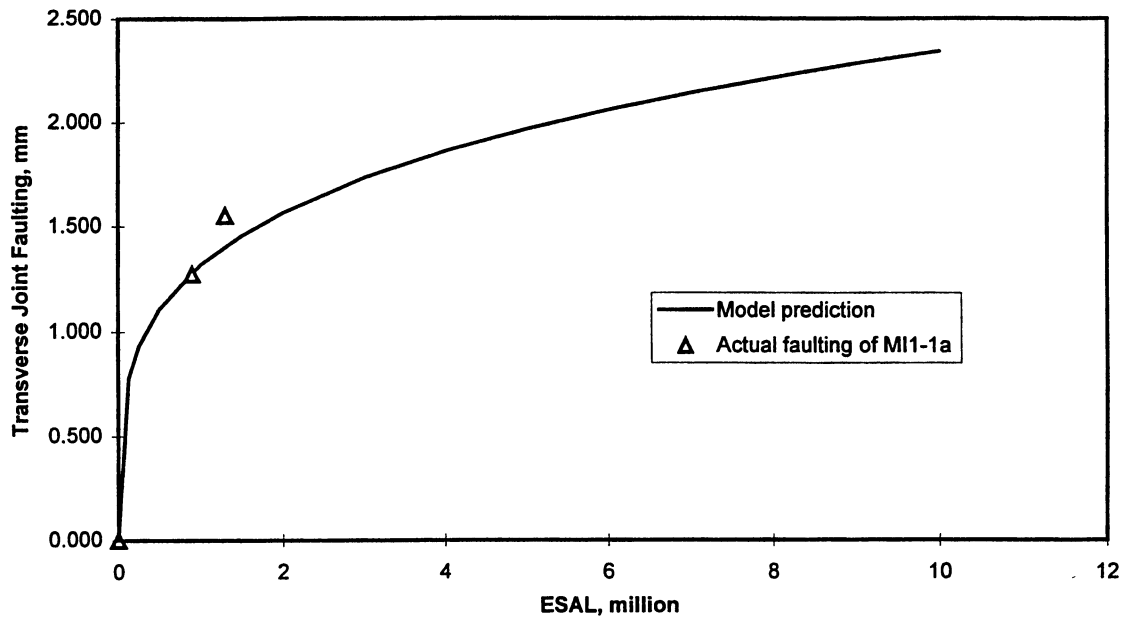


Figure 3. Comparison of actual joint faulting with the doweled joint faulting model for a JRCP section in Michigan.

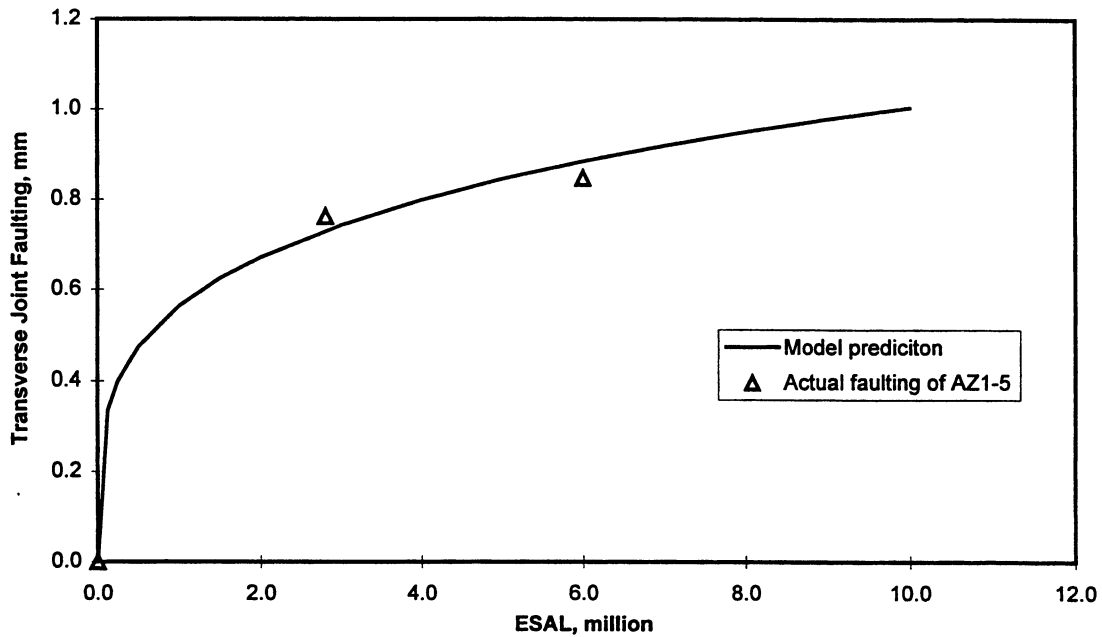


Figure 4. Comparison of actual joint faulting with the nondoweled joint faulting model for a JPCP section in Arizona.

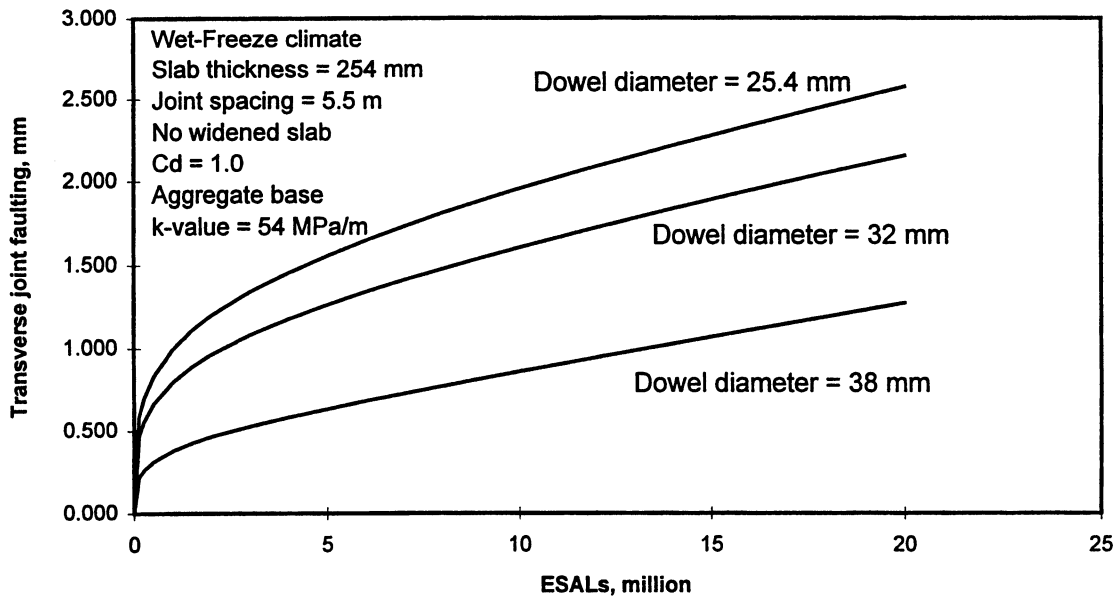


Figure 5. Sensitivity of doweled JCP faulting model (Equation 3) to dowel bar diameter (dowel spacing is 300 mm).

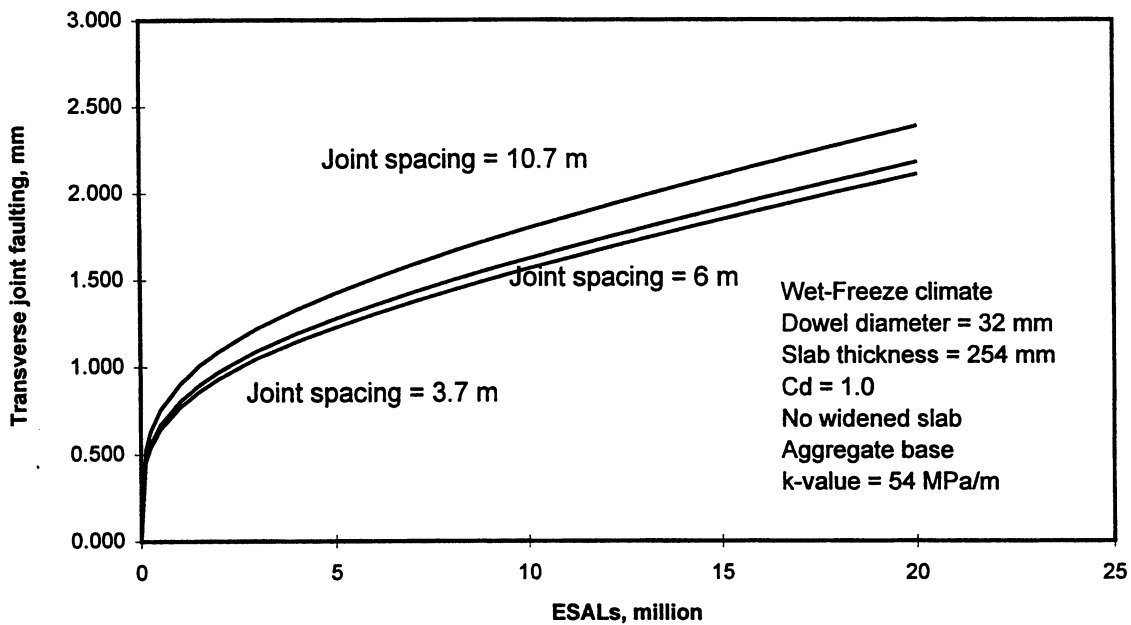


Figure 6. Sensitivity of doweled JCP faulting model (Equation 3) to joint spacing.

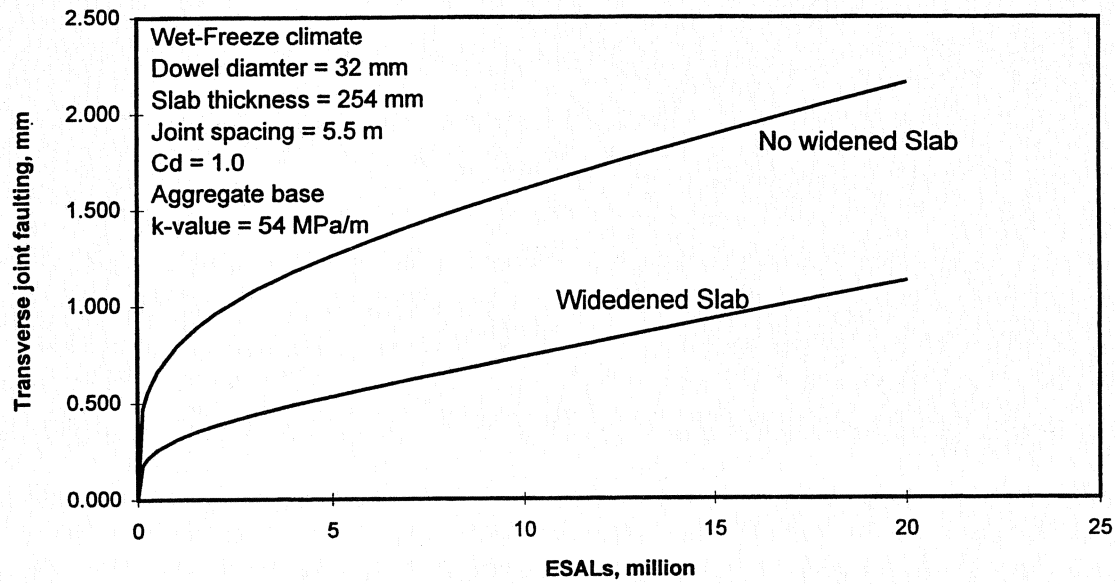


Figure 7. Sensitivity of doweled JCP faulting model (Equation 3) to widened lane.

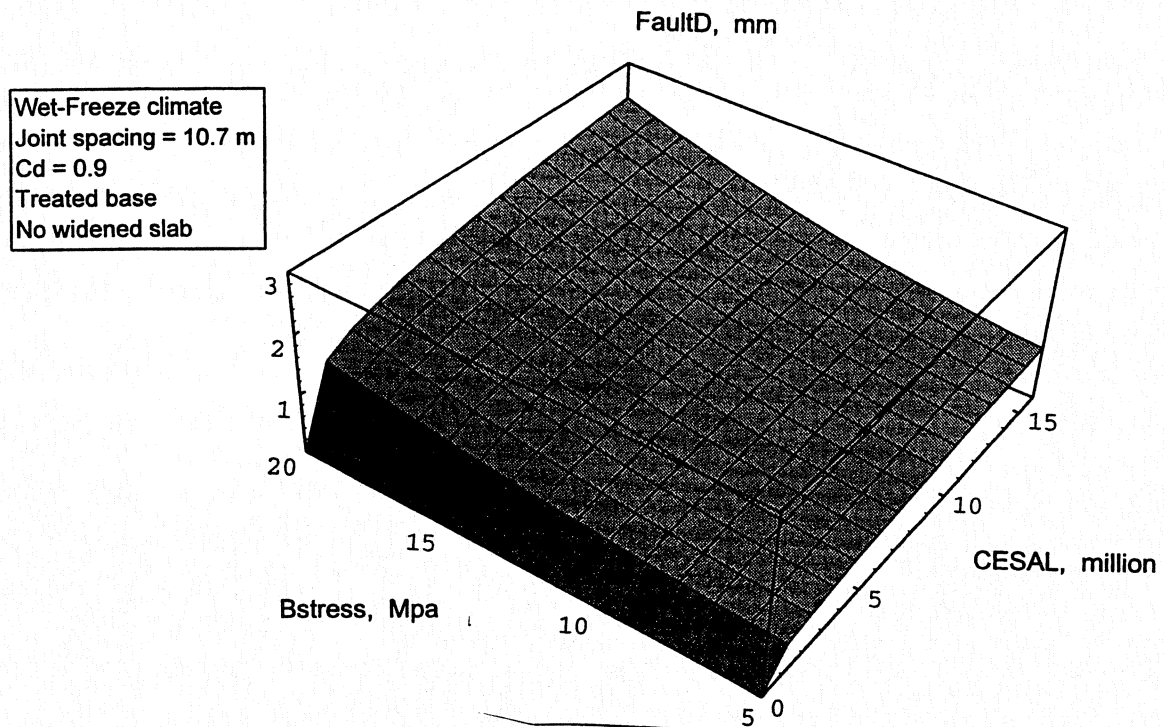


Figure 8. Three dimensional sensitivity plot of the doweled JCP faulting model (Equation 3) with cumulative ESALs and bearing stress.

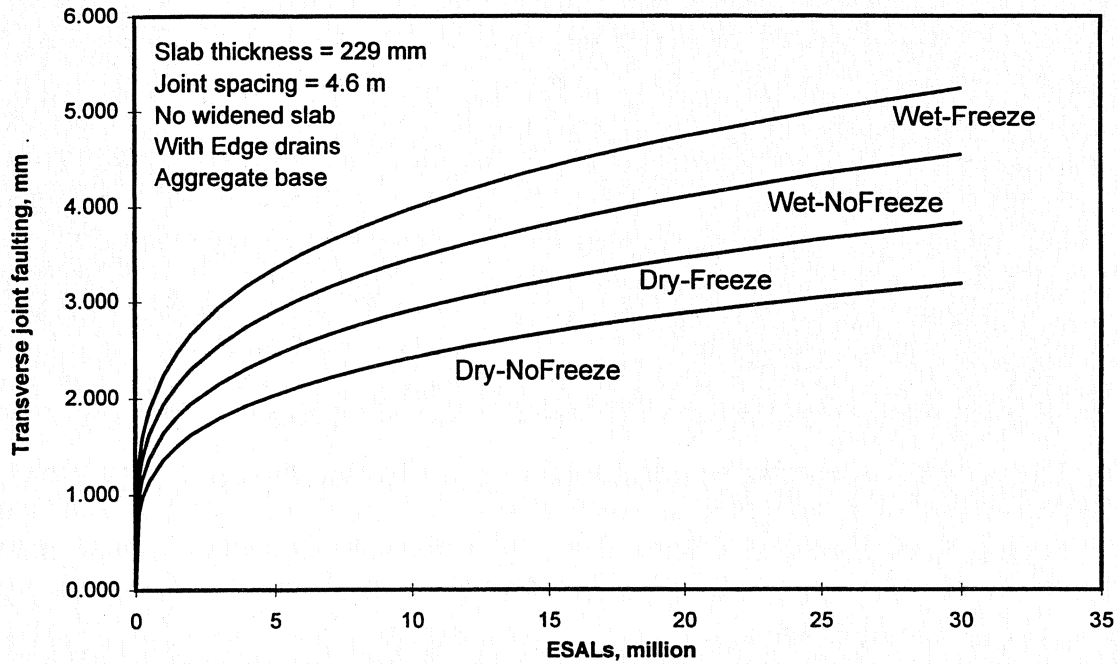


Figure 9. Sensitivity of nondoweled JCP faulting model (Equation 4) to climatic zones.

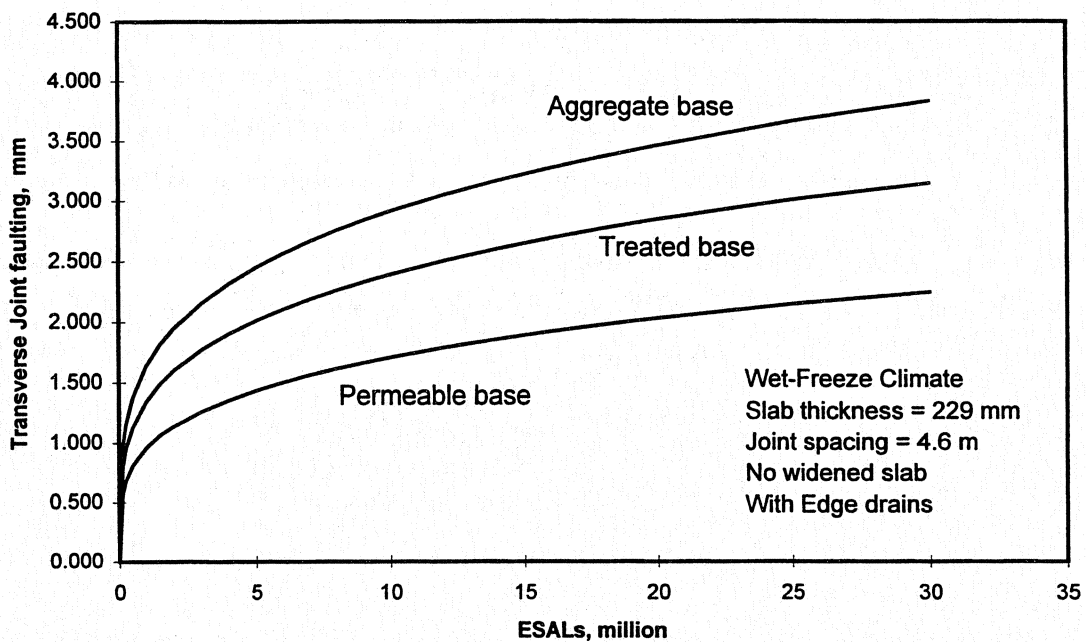


Figure 10. Sensitivity of nondoweled JCP faulting model (Equation 4) to base types.

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Wet-Freeze climate
 Joint spacing = 5.2 m
 $C_d = 1.0$
 Treated base
 No widened slab

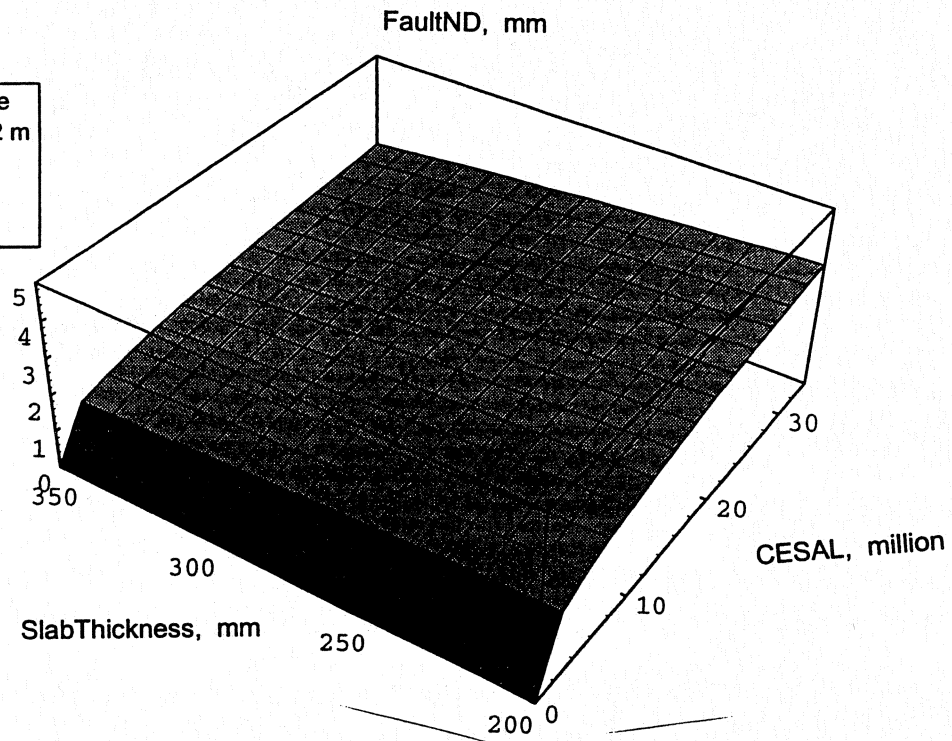


Figure 11. Three dimensional sensitivity plot of the nondoweled JCP faulting model (Equation 4) with cumulative ESALs and slab thickness.

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ACKNOWLEDGMENTS

This study was conducted by ERES Consultants, Inc., sponsored by the Federal Highway Administration (FHWA) as part of a study entitled "Performance of Concrete Pavements." The authors would like to acknowledge the contributions and comments of Mr. Kurt Smith and Mr. Roger Larson. The contents of this paper reflect the views of the authors and do not necessarily reflect the views or policy of the FHWA.