May 2008

Superpave In Situ Stress/Strain Investigation – Phase II
(SISSI II)

Draft Report:

Evaluating the Sensitivity of MEPDG to SISSI Data

Introduction

The objective of the sensitivity study was to evaluate the input parameters related to AC material properties, traffic, and climate that significantly or insignificantly influence the predicted performance for two specific SISSI flexible pavements: Warren and Blair. To achieve this objective, the sensitivity analysis of five MEPDG performance measures (longitudinal cracking, alligator cracking, AC rutting, subgrade rutting, and smoothness) was conducted by either varying the magnitudes or the distribution of a single input parameter. Although reflection cracking is arguably the most important distress in rehabilitated flexible and composite pavements, it is not included in the present study because the reflection cracking model in the current MEPDG is intended only as a very rough placeholder until a more accurate, reliable reflection cracking model can be developed; this work is currently under way in NCHRP Project 1-41.

Analysis Parameters

A thorough literature review suggests that over 50 MEPDG input parameters exhibit considerable sensitivity on various performance measures of flexible pavements, typically using Level 3 input with national calibrations. Noteworthy recent publications related to this topic include: Masad and Little 2004, Galal and Chehab 2005, Freeman et al. 2005, Kim et al. 2005, El-Basyouny and Witczak 2005, El-Basyouny et al. 2005a and 2005b, Yin et al. 2006, Sadasivam and Morian 2006, Carvalho and Schwartz 2006, Timm 2006, and Yin et al. 2006. With the research approach of this study, uncertainties associated with site-specific parameters will be only incorporated into the empirical part of performance predictions. In other words, only parameters required by transfer functions will be considered. Therefore, a total of 14 site-specific input parameters were selected as varied parameters for the sensitivity study. As shown in Tables 1 and 2, selected parameters can be categorized as the follows:

- Climate: ground water table depth (*GWT*).
- Structure: layer thickness (*h*).
- Material: effective binder content (V_b) and air voids (V_a) of bound materials and resilient modulus (E_r) of unbound materials.

The correlations among input parameters were not within the scope of this analysis. To investigate the effect of a particular pavement input parameter, the other input parameters are held constant. While one design parameter was being examined at multiple variation levels (such as 10 percent, 20 percent, and 30 percent), an "as constructed" value was assigned for the other input parameters.

Analysis Results

For the purpose of having comparable results, the sensitivity degree of each varied parameter was computed in terms of a ratio between percent changes of the parameter itself and percent changes of performance predictions (e.g., rut depth) at the end of analysis time period. For example, a sensitivity ratio (*SR*) of 1.0 means that the amount of variation in the varied parameter will result in, at most, the same amount of variation in the performance measure. Sensitivity analysis results are summarized in Tables 1 and 2 for Warren and Blair, respectively. Average *SRs* at all variation levels are also reported. Since SR values vary between two SISSI sites, selected analysis parameters were further classified for individual performance measures in accordance to their averaged *SRs* at all variation levels (Table 3) such that general conclusions can be made:

- Insensitive (*IS*): $SR < 0.5$
- Sensitive (*S*): $0.5 \leq SR < 1.0$
- Very Sensitive (*VS*): $SR \geq 1.0$

The following sections provide discussions for each performance measure.

Table 1. Sensitivity ratios at different variation levels for Warren.

Category	Analysis Parameter		Longitudinal Cracking				Alligator Cracking				AC Rutting				Subgrade Rutting				Smoothness			
			10%	20%	30%	Ave	10%	20%	30%	Ave	10%	20%	30%	Ave	10%	20%	30%	Ave	10%	20%	30%	Ave
Climate	GWT	Subgrade	0.09	0.11	0.10	0.10	0.33	0.27	0.41	0.30	0.00	0.00	0.00	0.00	1.05	1.43	1.58	1.35	0.20	0.35	0.43	0.33
Structure	*h*	Wearing	0.62	0.75	0.85	0.74	0.69	0.77	0.79	0.75	1.07	1.31	1.36	1.24	0.00	0.00	0.00	0.00	0.61	0.64	0.69	0.64
		Binder	0.61	0.62	0.89	0.70	0.77	0.95	0.96	0.89	1.08	1.26	1.36	1.23	0.00	0.00	0.00	0.00	0.73	0.84	0.85	0.80
		BCBC	0.21	0.45	0.49	0.38	0.55	0.87	0.92	0.78	1.00	1.15	1.42	1.19	0.00	0.00	0.00	0.00	0.58	0.65	0.77	0.66
		Leveling	0.06	0.11	0.13	0.10	0.53	0.57	0.94	0.68	1.22	1.39	1.43	1.34	0.00	0.00	0.00	0.00	0.69	0.82	0.84	0.78
Material	*Vb*	Wearing	1.76	1.79	1.89	1.81	0.66	0.74	0.77	0.72	1.47	1.58	1.59	1.54	0.00	0.00	0.00	0.00	0.80	0.84	0.96	0.87
		Binder	1.15	1.18	1.65	1.33	0.61	0.61	0.73	0.65	1.09	1.78	1.81	1.56	0.00	0.00	0.00	0.00	0.51	0.60	0.74	0.62
		BCBC	0.06	0.08	0.10	0.08	0.22	0.36	0.43	0.34	0.52	0.58	0.81	0.64	0.00	0.00	0.00	0.00	0.80	0.92	0.93	0.89
		Leveling	0.07	0.13	0.14	0.11	0.08	0.13	0.14	0.12	0.23	0.27	0.34	0.28	0.00	0.00	0.00	0.00	0.55	0.88	0.95	0.79
	Va	Wearing	0.30	0.41	0.46	0.39	0.07	0.08	0.13	0.09	2.15	2.19	2.95	2.43	0.00	0.00	0.00	0.00	0.58	0.61	0.90	0.70
		Binder	0.40	0.41	0.42	0.41	0.10	0.11	0.15	0.12	2.66	2.73	2.78	2.72	0.00	0.00	0.00	0.00	0.84	0.92	0.98	0.91
		BCBC	0.22	0.26	0.26	0.25	0.02	0.06	0.08	0.05	1.27	1.30	1.37	1.31	0.00	0.00	0.00	0.00	0.62	0.65	0.94	0.74
		Leveling	0.06	0.07	0.14	0.09	0.12	0.13	0.15	0.13	1.10	1.12	1.23	1.15	0.00	0.00	0.00	0.00	0.84	0.90	0.97	0.90
	Er	Granular	0.08	0.10	0.12	0.10	0.07	0.08	0.14	0.10	0.00	0.00	0.00	0.00	1.08	1.26	1.41	1.25	0.40	0.43	0.44	0.42

Table 2. Sensitivity ratios at different variation levels for Blair.

Category	Analysis Parameter		Longitudinal Cracking				Alligator Cracking				AC Rutting				Subgrade Rutting				Smoothness			
			10%	20%	30%	Ave	10%	20%	30%	Ave	10%	20%	30%	Ave	10%	20%	30%	Ave	10%	20%	30%	Ave
Climate	*GWT*	Subgrade	0.12	0.22	0.22	0.19	0.14	0.38	0.47	0.26	0.00	0.00	0.00	0.00	1.47	1.63	1.80	1.64	0.14	0.25	0.27	0.22
Structure	*h*	Wearing	0.53	0.70	0.76	0.67	0.56	0.95	0.96	0.83	1.17	1.27	1.28	1.24	0.00	0.00	0.00	0.00	0.62	0.65	0.78	0.68
		Binder	0.51	0.55	0.74	0.60	0.77	0.79	0.93	0.83	1.38	1.44	1.45	1.42	0.00	0.00	0.00	0.00	0.78	0.81	0.95	0.85
		BCBC	0.16	0.21	0.34	0.24	0.79	0.96	0.97	0.91	1.08	1.20	1.47	1.25	0.00	0.00	0.00	0.00	0.67	0.70	0.97	0.78
Material	*Vb*	Wearing	1.06	1.56	1.83	1.48	0.74	0.98	0.99	0.90	1.51	1.71	1.78	1.67	0.00	0.00	0.00	0.00	0.75	0.76	0.82	0.78
		Binder	1.14	1.34	1.74	1.41	0.75	0.89	0.96	0.87	1.06	1.49	1.79	1.45	0.00	0.00	0.00	0.00	0.65	0.66	0.84	0.72
		BCBC	0.17	0.19	0.28	0.21	0.14	0.29	0.37	0.27	0.53	0.69	0.74	0.65	0.00	0.00	0.00	0.00	0.58	0.71	0.82	0.71
	Va	Wearing	0.34	0.34	0.47	0.38	0.13	0.19	0.22	0.18	2.04	2.26	2.35	2.22	0.00	0.00	0.00	0.00	0.51	0.53	0.74	0.59
		Binder	0.27	0.32	0.40	0.33	0.16	0.17	0.25	0.19	2.45	2.91	2.98	2.78	0.00	0.00	0.00	0.00	0.58	0.72	0.90	0.73
		BCBC	0.16	0.17	0.46	0.26	0.17	0.18	0.20	0.18	1.32	1.37	1.42	1.37	0.00	0.00	0.00	0.00	0.56	0.70	0.76	0.68
	Er	Granular	0.11	0.18	0.27	0.19	0.14	0.17	0.18	0.16	0.00	0.00	0.00	0.00	1.05	1.07	1.19	1.10	0.59	0.61	0.80	0.67

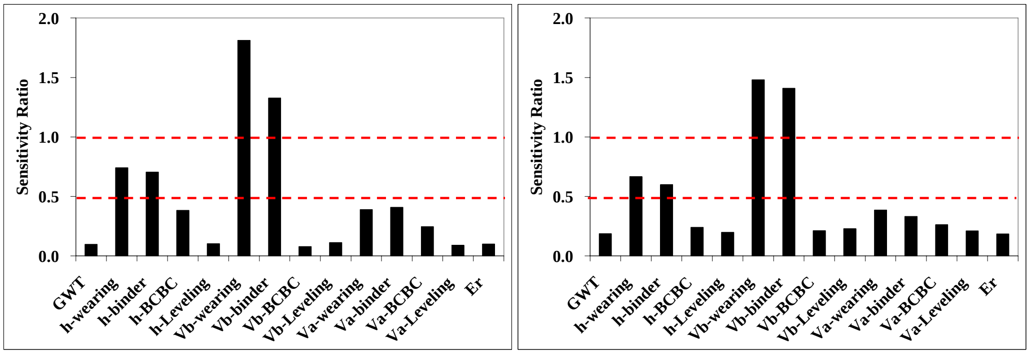
Table 3. Sensitivity classification of analysis parameters.

Category	Analysis Parameter		Sensitivity Classification				
			Longitudinal Cracking	Alligator Cracking	AC Rutting	Subgrade Rutting	Smoothness
Climate	*GWT*	Subgrade	*IS/IS*[a]	*IS/IS*	*IS/IS*	*VS/VS*	*IS/IS*
Structure	*h*	Wearing	*S/S*	*S/S*	*VS/VS*	*IS/IS*	*S/S*
		Binder	*S/S*	*S/S*	*VS/VS*	*IS/IS*	*S/S*
		BCBC	*IS/IS*	*S/S*	*VS/VS*	*IS/IS*	*S/S*
		Leveling[b]	*IS*	*S*	*VS*	*IS*	*S*
Material	*Vb*	Wearing	*VS/VS*	*S/S*	*VS/VS*	*IS/IS*	*S/S*
		Binder	*VS/VS*	*S/S*	*VS/VS*	*IS/IS*	*S/S*
		BCBC	*IS/IS*	*IS/IS*	*S/S*	*IS/IS*	*S/S*
		Leveling[b]	*IS*	*IS*	*IS*	*IS*	*S*
	Va	Wearing	*IS/IS*	*IS/IS*	*VS/VS*	*IS/IS*	*S/S*
		Binder	*IS/IS*	*IS/IS*	*VS/VS*	*IS/IS*	*S/S*
		BCBC	*IS/IS*	*IS/IS*	*VS/VS*	*IS/IS*	*S/S*
		Leveling[b]	*IS*	*IS*	*VS*	*IS*	*S*
	Er	Granular	*IS/IS*	*IS/IS*	*IS/IS*	*VS/VS*	*IS/S*

[a] Warren/Blair, [b] Warren

Longitudinal Cracking

As demonstrated in Figure 1, the MEPDG predictions for longitudinal cracking are very sensitive to the effective binder content of upper AC layers. This observation is reasonable because the effective binder content is an important source of variability in construction and among the most influential parameters determining the mixture stiffness and, hence, performance measures. Longitudinal cracks may be also caused by high tensile strains at the top of the surface AC layer due to load-related effects and the effects of age-hardening of AC materials. However, the binder layer thickness for both Warren and Blair exhibits some sensitivity on longitudinal cracking predictions. Part of this observation could be due to the immature nature of the MEPDG model; an enhanced top-down cracking model is the expected product from NCHRP Project 1-42A, which is currently under way.

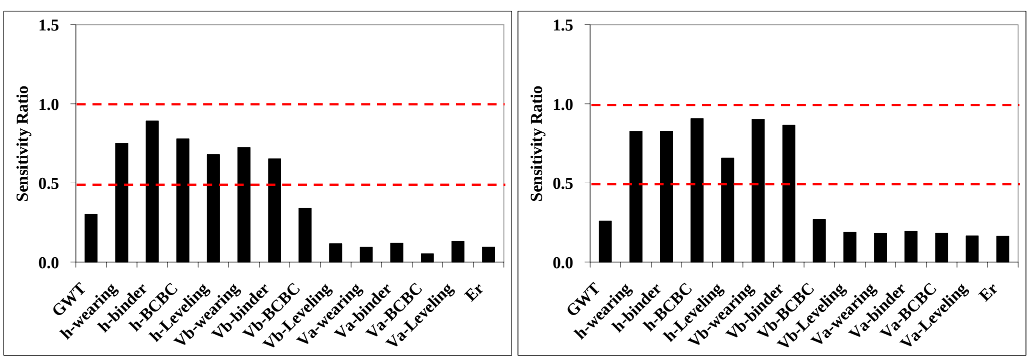


(a) Warren (b) Blair

Figure 1. Sensitivity of longitudinal cracking to analysis parameters

Alligator Cracking

It can be concluded from Figure 2 that the MEPDG predictions for alligator cracking are very sensitive to the layer thickness and effective binder content, particularly for upper AC layers. The total AC layer thickness not only influences strain and stress magnitude but is directly linked to the location where fatigue cracks initiate as well as under the specific mode of loading (constant stress or strain) under which fracture occurs. Increasing the AC thickness reduces the tensile strains at the bottom of the AC layer and consequently mitigates alligator (bottom-up) cracking. This feature is evident for both the Warren and Blair sites. Effective binder content also has a pronounced impact on top-down cracking. Mixtures rich in binder generally have better tensile strength and better cracking resistance.

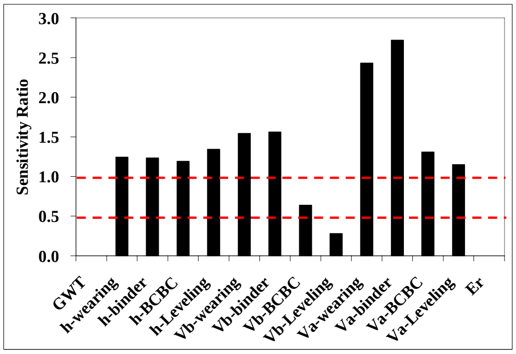


(a) Warren (b) Blair

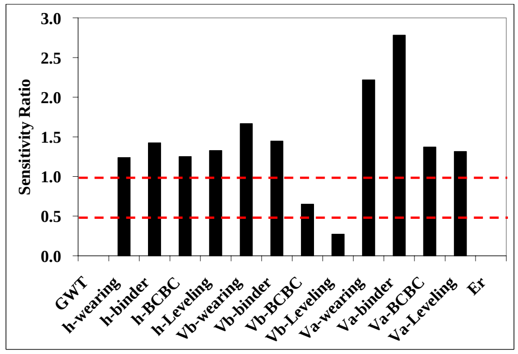
Figure 2. Sensitivity of alligator cracking to analysis parameters.

AC Rutting

Rutting was found to be sensitive or very sensitive to most of the analysis parameters. Figure 3 suggests that air voids have a more significant impact on rut depth than other parameters. Lack of adequate field compaction results in high air voids, which generates premature permanent deformations as the mixture becomes more dense under traffic. The MEPDG computes the total AC rutting depth from the permanent deformation of individual AC layers; therefore, it is expected that the layer thickness would play an important role in rutting predictions. Nevertheless, this feature is not very clear in the two pavement structures considered in this study.



(a) Warren

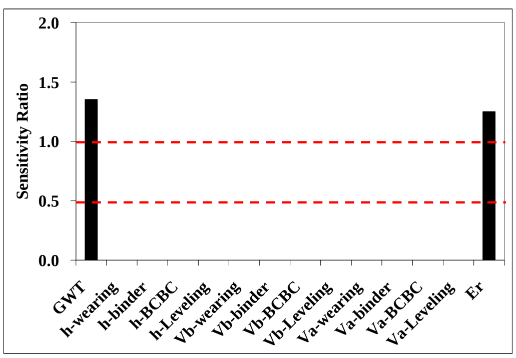


(b) Blair

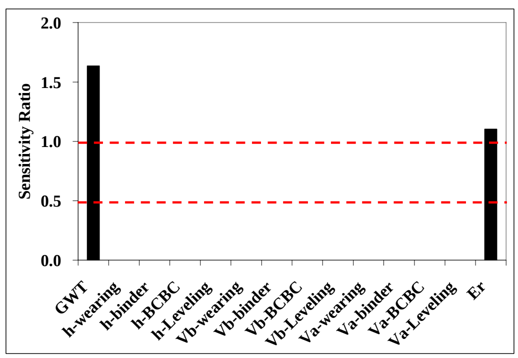
Figure 3. Sensitivity of AC rutting to analysis parameters.

Subgrade Rutting

Figure 4 reveals the sensitivity of subgrade rutting to unbound material-related analysis parameters, ground water table depth, and resilient modulus, which is what was expected. Compared to low resilient modulus, ground water table depth seems to weaken the subgrade more and, accordingly, causes a poorer subgrade rutting performance.



(a) Warren

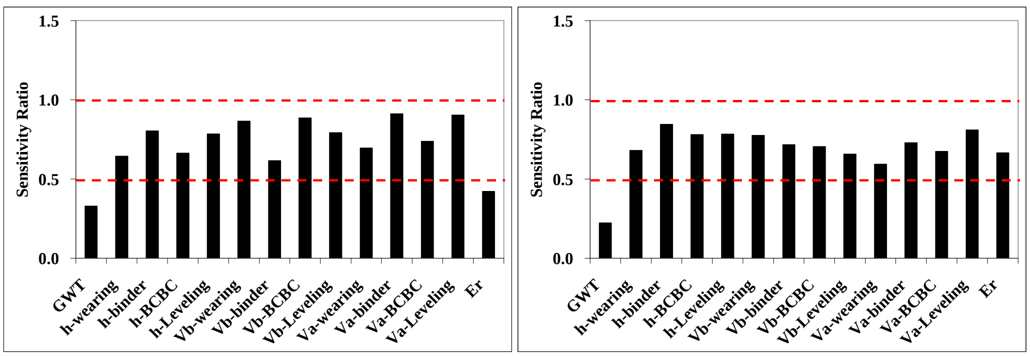


(b) Blair

Figure 4. Sensitivity of subgrade rutting to analysis parameters.

Smoothness

Interestingly, there is no input parameter that has an *SR* above 1.0 for either Warren or Blair. This examination indicates that a pavement designer using the MEPDG for flexible pavement design should recognize the interactive effects among input parameters to obtain the predicted functional performance for satisfying the design criteria. Among all analysis parameters selected for the sensitivity study, only resilient modulus of unbound materials shows a discrepancy in terms of sensitivity classifications in the projected smoothness (Figure 5) for Warren and Blair. This discrepancy might be attributed to the variations in traffic, climate, and the material components in the structures of the two investigated flexible pavements.



(a) Warren (b) Blair

Figure 5. Sensitivity of smoothness to analysis parameters.

Summary

The sensitivity study detailed in this report provides a better understanding of how the design parameters affect flexible pavement performance. Similar conclusions can be drawn for both Warren and Blair:

- Longitudinal cracking predictions are sensitive to the layer thickness and effective binder content of AC layers.
- Alligator cracking predictions are sensitive to the layer thickness and effective binder content of AC layers.
- AC rutting predictions are sensitive to most of the analysis parameters, especially air voids.
- Subgrade rutting predictions are sensitive to ground water table depth and resilient modulus of unbound materials.
- No parameter has a significant impact on smoothness.

From the sensitivity study, it may be concluded that a small amount of change in some design parameters will result in a large difference in the predicted pavement performance. Consequently, if the predicted performance results are used in a design procedure, some quite different budget planning and rehabilitation activities would be needed. This means that uncertainties in estimating these parameters as design input variables introduce a dilemma for a pavement designer in deciding which prediction is accurate and which preservation actions should be taken in a given year. Therefore, accurate prediction of pavement performance is one of the most important tasks in having a reasonable road network system for pavement maintenance/rehabilitation alternative strategies. In other words, the efficiency of the budget plan and the expected pavement service life depend mainly on the accuracy of the pavement performance prediction. Therefore, each of the sensitive and very sensitive parameters, such as AC layer thickness, should be considered as a random variable following a certain probability distribution. In turn, it is appropriate to develop a probabilistic-based approach for pavement performance predictions.

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