SIMULATING THE PERFORMANCE OF PAVEMENT SECTIONS CONTAINING TREATED AND UNTREATED PERMEABLE BASES USING THE MEPDG SOFTWARE

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Abstract

In an effort to provide subsurface drainage in rigid pavement structure, various types of bases ranging from unbound open-graded bases like the Michigan 4G to bound base types like Asphalt Treated Permeable Bases (ATPB) and Cement Treated Permeable Bases (CTPB) are available. The provision of subsurface drainage will increase the overall initial construction cost of the pavement and as such it is expected that the increased cost would be offset by improved pavement performance and reduction in the pavement's life cycle cost. A computer simulation of the performance of pavement sections containing different types of permeable bases/drainage layers under different loading and environmental conditions was carried out using the Mechanistic Empirical Design Guide (MEPDG) software. Results of the performance simulations show that the predicted pavement is not sensitive to the presence of a permeable basecourse within the pavement structure. This is in sharp contrast to field results of pavement sections containing permeable basecourses which have shown that the increase drainability as a result of the presence of a permeable basecourses have lead to a marked increase in the performance of these pavements.

Keywords: ATPB, CTPB, Pavement, MEPDG, base course, performance

Introduction

Permeable bases are made up of materials that have different properties i.e. aggregate type, maximum aggregate size, gradation and binder content. The underlying assumption is that pavement layers constructed with these materials have different hydraulic characteristics and as a result will have different drainage behavior. Field observations of pavement sections containing permeable bases have shown that pavement performance have been greatly improved and life cycle cost reduced as a result of their inclusion within the pavement structure (Schmitt R et al, 2010). Combine with other features like dowels, rigid pavement sections containing both permeable bases and dowels have shown increase performance over the years. However, since these two features i.e. permeable bases and dowels can often performed complimentary functions, it is also very prudent to determine the relative contribution of these features to the improved performance of the pavement.

According to the FHWA (2002) dowels represent the cheapest solution to the pumping problem affecting JPCP. As a result the FHWA is encouraging state highway agencies to incorporate dowels within their design and construction of concrete pavements. A field study conducted Schmitt et al. (2010) for the Wisconsin Department of Transportation (WisDOT), noted that there is very little difference in performance between pavements having both dowels and permeable bases to those having either a dowel or permeable base. As result therefore, the MEPDG simulations of pavement performance will be conducted with these two scenarios consisting of pavement sections outlined with and without dowels bars. This is aim at testing the predictive accuracy of the MEPDG software and how its results compare to field results.

In an effort to properly capture the various scenarios for which the use of permeable bases is deemed appropriate and desirable from a cost and performance perspective, a full factorial experimental design wherein several design inputs such as traffic volume, axle load spectra, climate and PCC thicknesses were varied. The mechanistic-empirical performance evaluation was designed in such a way that results of the computer simulation analysis are interpreted to mean the contribution of permeable bases to the performance of Jointed Plain Concrete Pavement (JCPC). This analysis is therefore intended as a means of quantifying the impact permeable bases have on pavement performance as predicted by the MEPDG.

Mepdg software

The MEPDG Software, a product of the Strategic Highway Research Project (SHRP), is the new pavement design software that incorporates mechanistic principles into the design and analysis of pavement structures. It was developed to overcome the limitations of the AASHTO 1993 Design Guide and its earlier versions which are based entirely on empirical methods. Details of why MEPDG stands out as pavement analysis tool as compared to AASHTO pavement design Guide are as shown in Coree 205.

However, one of the challenges of using the MEPDG is the large number of inputs needed to run the analysis unlike the AASHTO Design Guides that require very few inputs such as the number of Equivalent Standard Axles (ESALS), structural layer coefficient, drainage coefficient. The MEPDG on the other hand required a far greater number of inputs to run pavement performance models that can accurately reflect the complex interaction between pavement structure, material properties and environmental constraints **(**Rabab‟ah 2007**).** As a result of this, implementing the MEPDG for any given pavement design is a time consuming and costly exercise since it requires running a large amount of laboratory and field testing in order to determine these inputs. However, in an effort to provide pavement designer greater flexibility in the choice of design inputs, the MEPDG uses a hierarchical approach that is base on the significance of the project and the data that is available. The three levels of inputs MEPDG incorporates are as described in McCracken et al. 2008

MEPDG Performance Prediction Models for Portland Cement Concrete (PCC) Pavement

According to ARA Inc 2004, the three primary mechanistic performance models for JPCP MEPDG considers are: Faulting, Transverse/Longitudinal cracking, and International Roughness Index (IRI),

The MEPDG procedure uses faulting and cracking to predict the smoothness of a rigid pavement structure at any given point in the pavement‟s life. So once both faulting and cracking has been predicted, the MEPDG then uses empirical relationships to determine the IRI from these two performance criteria.

Procedure for Implementing MEPDG Sensitivity Analysis

The MEPDG Software was used to conduct computer simulations to predict the performance of pavement sections containing treated permeable bases and unbond granular bases.

The object of these computer simulations is to perform a sensitivity analysis on the effect of permeable bases on the predicted pavement performance and to determine the differences in performance between pavement sections containing these base types. The pavement performance simulation was conducted under comparative climate; subgrade soil and traffic conditions in order to determine appropriate conditions for which the use of stabilized permeable bases may provide reduced life cycle costs.

The pavement performance simulations were done for the following four base courses:

1. With unbound open-graded base courses(unbound permeable bases)
2. With Asphalt Treated Permeable Bases (ATPB)
3. With Cement Treated Permeable Bases (CTPB)
4. With bound dense-graded basecourse (ATB and CTB)

A full factorial experimental design containing different combinations of traffic, climate, pavement structure, design features was employed in the pavement simulation in order to correctly develop a sound basis of the relative merits of using stabilized permeable bases.

The following section discusses some of the variables used in the full factorial experimental design:

- Climate: The Long Term Pavement Performance (LTPP) program sponsored by the FHWA has identified four distinct climatic regions in the U.S. These regions are (ARA Inc, 2004):

Climate: The Long Term Pavement Performance (LTPP) program sponsored by the FHWA has identified four distinct climatic regions in the U.S. These regions are (ARA Inc, 2004):

i. Wet No-Freeze
ii. Wet Freeze
iii. Dry Freeze
iv. Dry No-Freeze

In order to run the MEPDG simulations, four states representing the four different climatic regions were selected:

- Wet No-Freeze (Florida)
- Wet Freeze (Michigan)
- Dry Freeze (Texas)
- Dry No-Freeze (California)

While it is understandable that the four States selected may have other climactic regions besides those designated above, only climate stations within the climatic regions outlined above were used in the MEPDG simulations. Each one of the four States has a different pavement design philosophy. However, since the objective of the pavement performance simulations was geared towards identifying a range of traffic and climatic conditions under which it is cost-effective to use permeable bases, a constant baseline material property was used for all the four climatic regions. In doing so therefore it was possible to capture the effect on the predicted pavement performance that can be directly attributed only to differences in permeable bases and not due to the differences in pavement design philosophies of the different states. As a result of this a summary of baseline values for pavement used in the MEPDG simulations of pavement performance is given in Table 5.4

Table 5.4: A summary of baseline values used in the MEPDG Performance simulations

Design life	30 yrs
Cement	660 lbs type1
Concrete flexural strength	650 psi
Curing	Curing compound
shoulder	Tied
JPCP dowel diameter	1.5 inches
Pavement opening	Spring
Base layers	4” ATPB/CTPB 6” granular base 6” chemically
Subgrade	5000 psi
Depth to ground water	12‟
28-day PCC compressive strength	4200 psi
Water/cement ratio	0.48

Traffic:

In the light of this current and projected national truck traffic, three truck traffic volumes representing low (AADTT=500), moderate (AADTT=5000) and heavy trafficked (AADTT=10000) pavement sections were used in the MEPDG performance simulations.

Table 5.5: NHS truck traffic classification (Alam et al, 2007)

Truck traffic classification	Truck traffic level (AADTT)
Very Low	0-480
Low	480-960
Medium	960-2880
Medium High	2880-5760
High	5760-11,520
Very High	>>11,520

Pavement Design Structures

The following pavement structures were used in the MEPDG simulation

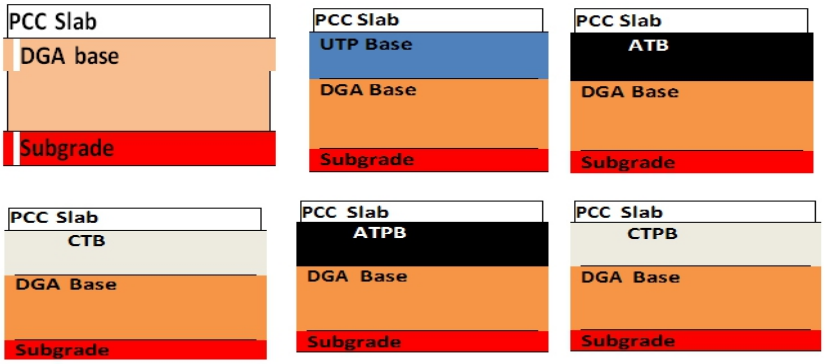

Figure 5.3: Pavement sections containing treated and untreated Permeable bases

Legend:
PCC - Portland cement Concrete Slab DGA- Dense Graded Aggregate Base
UTP - Untreated Permeable Base
ATB - Asphalt Treated Base
CTB - Cement Treated Base
ATPB - Asphalt Treated Permeable Base
CTPB - Cement Treated Permeable Base

PS1: pavement section 1 consists of a PCC slab, DGA and a subgrade. PS2: pavement section 2 consists of a PCC slab,UTB, DGA base and a subgrade.

PS3: pavement section 3 consists of a PCC slab, ATPB, DGA and a subgrade.

PS4: pavement section 4 consists of a PCC slab, CTPB, DGA and a subgrade.

PS5: pavement section 5 consists of a PCC slab,ATB, DGA and a subgrade.

PS6: pavement section 6 consists of a PCC slab,CTB, DGA and a subgrade

Full Factorial Experimental Design for the Sensitivity Analysis

The following three subsurface design features were utilized in the factorial design:

Open-Graded Aggregate (unbound) Base plus underdrain system

- 4-in open-graded, nonstabilized granular drainage layer.
- 6-in dense-graded, crushed aggregate base layer.

Cement-Treated Permeable Base (CTPB)
plus underdrain system

- 4-in CTPB layer.
- 6-in dense-graded, crushed aggregate base layer.

Asphalt-Treated Permeable Base (ATPB)
plus underdrain system

- 4-in ATPB layer.
- 6-in dense-graded, crushed aggregate base layer.

CTPB/ATPB
Directly on Subgrade
Cement-Treated Permeable Base

- Eliminate 6-in dense-graded aggregate base course.
- Add 6-in of CTPB.

Asphalt –Treated Permeable Base (ATPB)

- Eliminate 6-in dense-graded aggregate base course.
- Add 6-in of ATPB

In summary, the variables and factor levels in the full factorial design for the pavement prediction portion of the MEPDG simulations are as follows:

- Traffic levels: 3
- Axle load spectra: 1
- Base type: 6
- Climate regions: 4
- Dowels: 1, with dowels.
- Joint spacing: 1
- Subgrade: 1-high plasticity clay.
- PCC flexural strength at 28 days:700 psi
- Shoulder type: 1
- Portland Cement Concrete (PCC) thickness: 8, 10, and 12 in.(3)
- This factorial resulted in 216 runs.

Results and Analysis

The 216 combinations developed in the previous Section were run on the MEPDG software in batch mode. In running the simulations under the batch mode the cracking and faulting models need to be run separately. The sensitivity analysis was completed using a version 1.000 of the MEPDG Design Software. The default failure criteria established by the MEPDG was used in each analysis. These failure criteria were summarized in Table 5.4.

For this research project, the material properties for the entire pavement‟s layers used for the MEPDG simulations are the default values found in the software i.e Level 3 inputs (McCracker JK et al, 2008)..

The Analysis of Results of MEPDG Prediction of Pavement Performance for pavement containing Permeable Base layers.

Detailed results for this portion of the MEPDG simulations can be found in Appendix5A. Only graphical results of pavement performance in the Wet/Freeze and Dry/No - Freeze climatic regions under three traffic conditions and a 10” PCC slab will be displayed in this chapter in order to aid analysis of the results. Figs 5.6 through 5.11 showed the predicted pavement performance for these design conditions

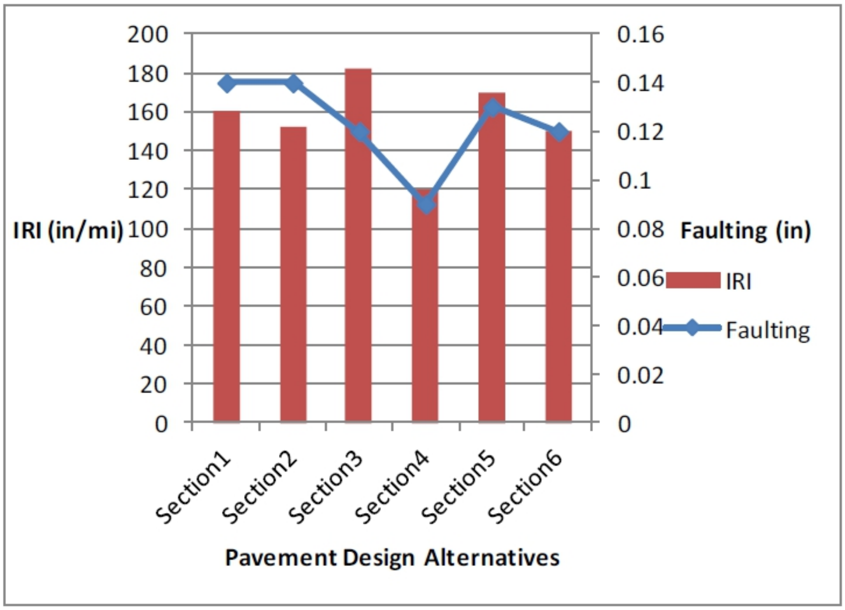

Figure 5.6: Predicted pavement performance for W/F Low traffic

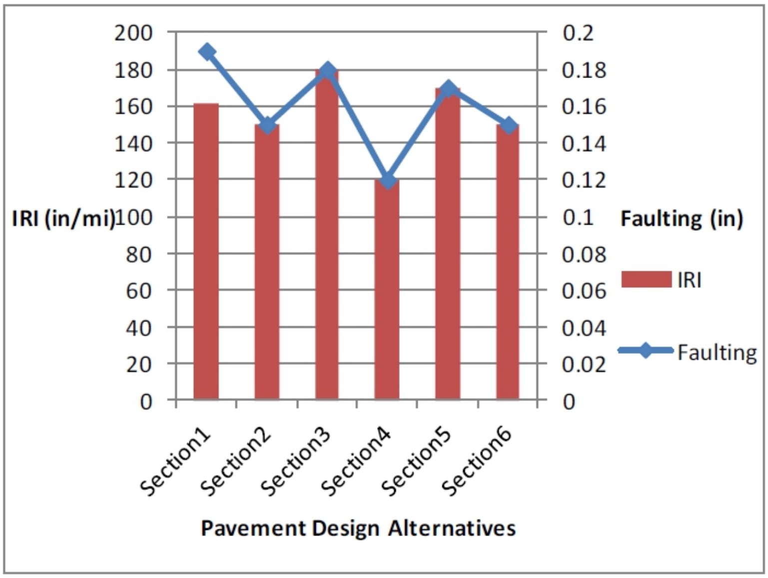

Figure 5.7: Predicted pavement performance for W/F Medium traffic

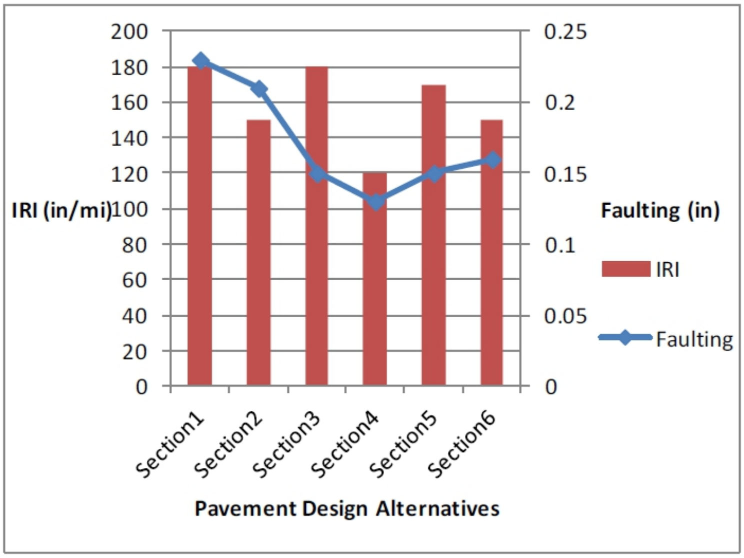

Figure 5.8: Predicted pavement performance for W/F High traffic

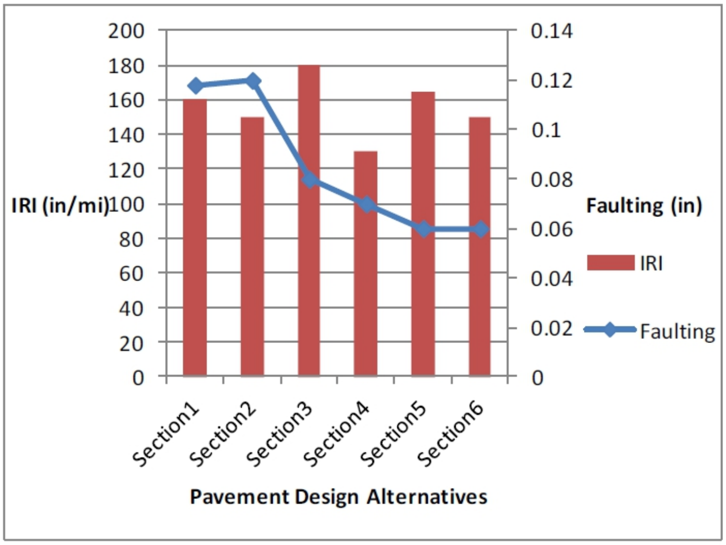

Figure 5.9: Predicted pavement performance for D /NF Low traffic

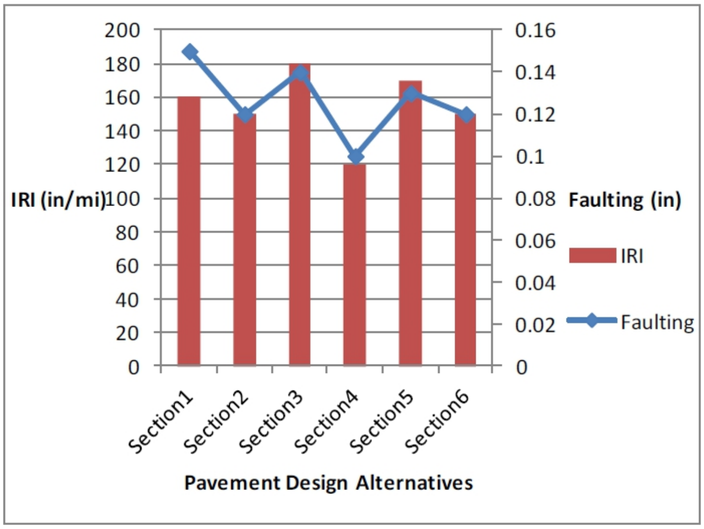

Figure 5.10: Predicted pavement performance for D/NF Medium traffic

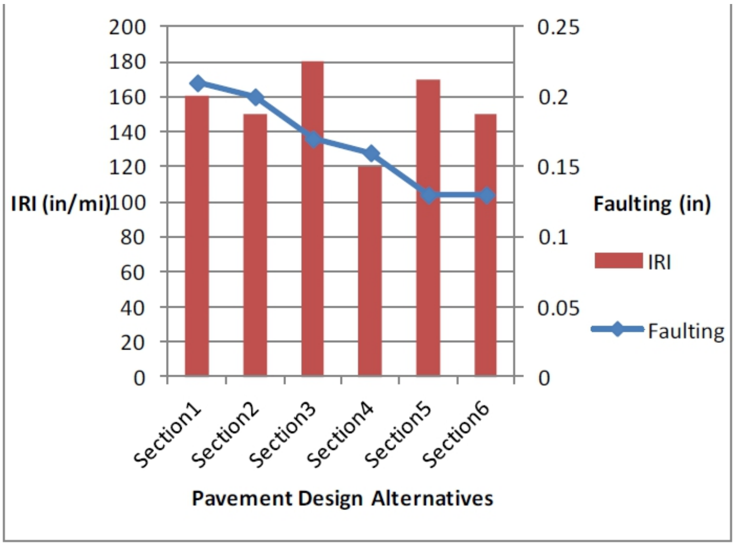

Figure 5.11: Predicted pavement performance for D/NF, High traffic

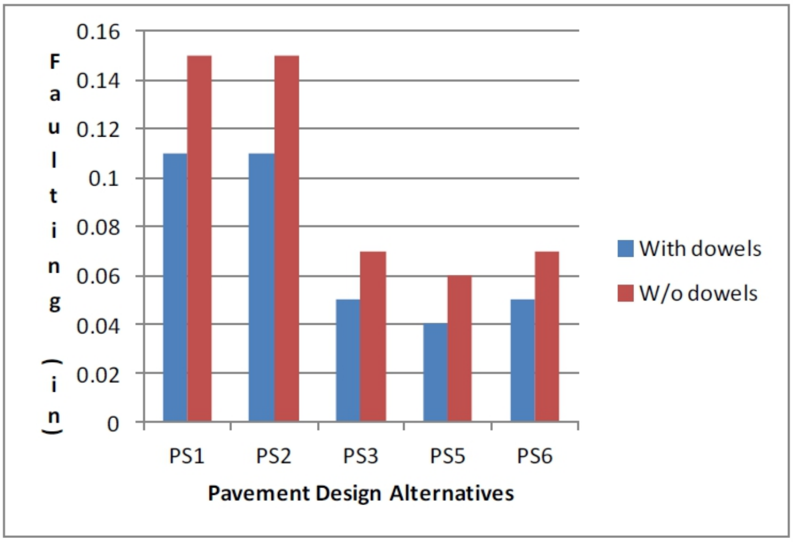

Figure 5.12: Differences in predicted faulting performance under Wet/Freeze and Low traffic

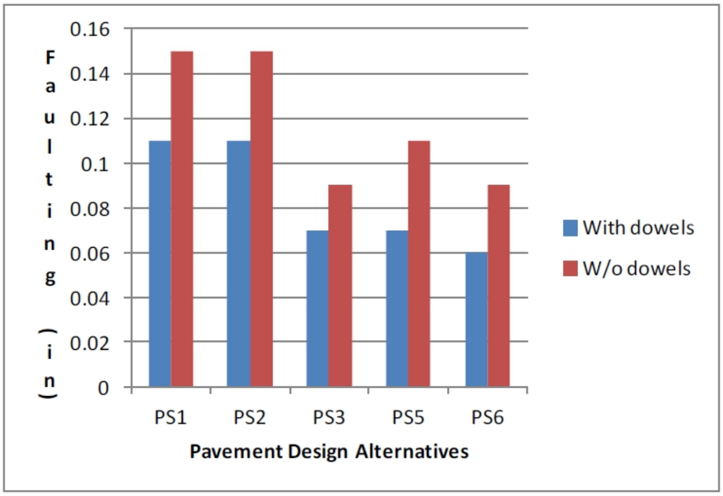

Figure 5.13: Differences in predicted faulting under Wet/Freeze and Medium traffic conditions

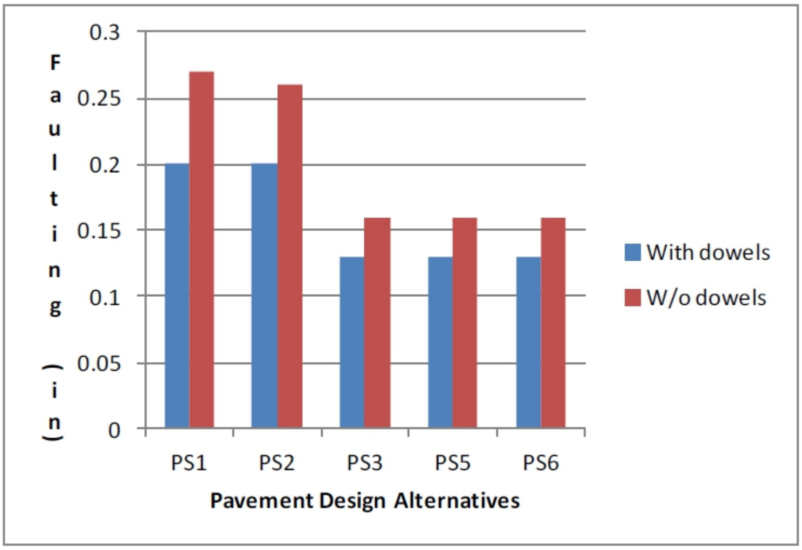

Figure 5.14: Differences in predicted faulting under Wet/Freeze and High traffic conditions

Conclusion

A summary of important findings pertaining to the effects of drainage layer on the predicted pavement performance is given below:

1. For PCC slab thickness above 8” thick, faulting is the critical distress that will dictate rehabilitations. Pavement section 1 containing the Dense-graded Aggregate base failed in both faulting and IRI for the medium and high traffic conditions. Even though subsurface drainage features are non-existent for this section, these failures cannot be entirely attributed to the absence of subsurface drainage features since the trend was repetitive for all the climatic regions under consideration.
2. The addition of a 4” untreated permeable base to PS1 i.e. PS2 does not provide any improvement whatsoever to the predicted faulting and IRI values. Pavement section 2 failed in the same manner as PS1 which means that the improved subsurface drainage that comes with introducing the 4” untreated permeable layer does not translate to an increase in pavement performance.
3. Pavement sections containing treated permeable bases did showed significant improvement in both the predicted faulting and IRI. The question now is whether this increase in pavement performance can be attributed to the positive effects of subsurface

drainage or some other factors.

4. Pavement sections containing highly stabilized bases ATB and CTB did show the greatest increase in pavement performance. Since these bases are highly dense in nature and do not have the same level of drainage capacity compare to that of treated permeable bases, it is safe to assume that the increase in pavement performance for these sections can be attributed to their high stiffness.
5. As is expected the Wet/Freeze region is the most critical climatic condition since the highest values of faulting and IRI are recorded there by all the pavement sections while results from the Dry/No- Freeze climatic region are the lowest. However one would expect that subsurface drainage to be critical in a Wet/Freeze climatic environment and less critical in a Dry/No-Freeze climatic region. But the performance trend for pavement sections with permeable bases is similar for both climatic regions which further make it difficult to quantify the degree of impact which improved subsurface drainage has on the predicted pavement performance.
6. That the predicted pavement is largely a function of stiffness rather than the hydraulic capacity of the underlying pavement layers. This explains why the 4” open-graded aggregate with a resilient modulus of 15000 psi did not make any significant improvement in the predicted faulting. It is also the underlying reason why PS5 and PS6 have the highest predicted pavement performance.
7. As was expected the predicted faulting increases as the volume of truck traffic increases for all the pavement sections under consideration. This is more noticeable for pavement sections with untreated aggregate bases.
8. As shown in Fig 5.12 through Fig 5.14, dowel sections showed a considerable increase in pavement performance compared to undowel sections. The average difference in faulting between a dowel and undowel pavement section was about 30%. Both permeable bases and dowels are design features that serve identical purpose which is to minimize pumping and its associated faulting distress. One objective of this simulation was to determine if the combined use of the two design features can produced greater pavement performance than when they are use separately. Schmitt et al. (2010) did a field study in which they discovered that there is very little difference in pavement performance between pavement sections containing both a

drainage layer and dowels to those containing either one of the two.

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