

## **CHAPTER 4**

### **CONCLUSIONS AND SUGGESTED RESEARCH**

Condition assessment of pavement layers using deflection data has been investigated. Information obtained from the literature provided a background to begin construction and analysis of synthetic data generated from a FEM structural model. ANN feed-forward deflection value based analysis took place following the construction of structures indicative of standard neural network modeling procedures. The conclusions that follow are a digestion of the information presented in the findings from the research. When applied to field testing, using the FWD deflection measuring device, pavement layer condition can be estimated.

During research activities, several issues that were either beyond the scope of this research or could be used to enhance the findings of this research were discovered. Suggestions for the extension or improvement of this research are documented. This additional information is expected to improve the performance and precision of the outlined prediction techniques.

#### **CONCLUSIONS**

The investigation of techniques to predict the condition of pavement layers using FWD deflection data produced several results pertinent to layer condition prediction. These results are enumerated as follows:

- Synthetic data generated by dynamic FEM forward models reasonably estimates actual field conditions for the ranges of pavements under consideration.
- The dynamic effect is important in simulating pavement responses under FWD loading. The nonlinearity of unbound aggregate base and subgrade is important to estimate responses of

aggregate base and full depth pavements, but not so for cement treated and AC/PCC pavements.

- For full depth and aggregate base pavements, a reasonable AC modulus-temperature relationship was observed when applying the dynamic, nonlinear analysis in the forward modeling. Also, the results from the proposed procedures, based on the dynamic, nonlinear analysis, in detecting base and subgrade condition agreed well with the DCP test results.
- For full depth and aggregate base pavements,  $E_{ac}$  can be used as an indicator to detect cracking and stripping in AC layer.  $BDI$  and  $\varepsilon_{abc}$  were found to be good indicators for base layer condition, while  $BCI$ ,  $\varepsilon_{sg}$ ,  $SSR$ , and  $E_{sg}$  appeared to be good condition indicators for subgrade. For intact pavements, the pavement overall fatigue cracking and rutting potentials are mainly controlled by  $\varepsilon_{ac}$ ,  $\varepsilon_{abc}$ , and  $\varepsilon_{sg}$ .
- Temperature adjustment is an important procedure in assessing condition of asphalt-surfaced pavements. Based on the synthetic database developed from nonlinear finite element analysis, temperature correction factors were developed for various condition indicators. These adjusted indicators were found to be able to predict fatigue cracking and rutting potentials of full depth and aggregate base pavements fairly well.
- The predicted  $E_{ac}$  values from the dynamic analysis based procedure were found to be larger than those from the static analysis based procedure. This trend could be more significant in the  $E_{sg}$  predictions.
- The minimum surface modulus,  $E_{smin}$ , was found highly related to subgrade modulus in full depth and aggregate base pavements. Based on the dynamic, linear elastic analysis, the relationship between  $E_{smin}$  and  $E_{sg}$  was established. The  $E_{sg}$  predictions from this relationship agreed well with the DCP test results.

- For full depth and aggregate base pavements, the analyses from both synthetic data and field data showed that *SCI* can be used to predict the AC modulus. Also, high correlation was found between *BDI* and  $\epsilon_{ac}$ .
- The DBP *BDI* can be used to assess upper layer condition in CTB pavements.
- Deflection values from the sensor four feet from the FWD load center ( $D_{48}$ ), can be used to estimate subgrade condition in CTB pavements.
- Stiff layer depth in CTB pavements can be determined using the  $F_3$  shape factor.
- A k-based approach can be used to detect voids under PCC slabs in AC/PCC pavements. This approach takes into consideration variations in void detection due to testing location (center, edge, or corner loading).
- Subgrade condition in AC/PCC pavements can be estimated using either an ANN with inputs  $D_{24}$ ,  $D_{36}$ ,  $D_{48}$ ,  $H_{ac}$ , and  $H_{pcc}$ , or a regression approach based on the  $D_{48}$  deflection value.
- DSL in AC/PCC pavements can be estimated using either an ANN with inputs  $D_{24}$ ,  $D_{36}$ ,  $D_{48}$ ,  $H_{ac}$ ,  $H_{pcc}$ ,  $F_2$ , and  $F_3$ , or a regression approach based on the  $F_3$  shape factor.
- ANN is a powerful tool in engineering practice. The ANNs with optimized structures were found to be able to predict pavement critical stresses, strains, layer modulus, and depth to a stiff layer.
- ANNs can be much improved with the inclusion of field data into the training set.
- The pavement layer condition assessment procedures developed from this research are different from traditional deflection analysis programs in that the relationships used in estimating the condition of different layers in these procedures are independent of each other. That is, subgrade condition can be estimated without needing to know the upper layer conditions, if one chooses to do so.

- The pavement layer condition assessment procedures developed from this research are different from traditional deflection analysis programs in that some of the relationships constituting these procedures do not require all seven deflections, but only a portion of deflection basin. This feature allows the analysis of irregular deflection basins that are observed frequently in distressed pavements for layer condition assessment.

## **SUGGESTED RESEARCH**

While the condition of pavement layers has been a topic of great interest and debate for years, much is yet to be learned. Though many techniques have been developed and utilized for some time, current procedures can be enhanced. The following are several topics still in need of investigation:

- High quality field data is crucial to the prediction of pavement layer condition. More effort should be spent in the construction and data collection phase of all projects. Well documented information through the life of the project can then be used to learn about the behavior of a specific pavement type.
- The proposed ANNs and DBP based methods can be extended to multi-load deflection analysis. This additional dimension should yield more accurate and reliable estimation of pavement layer condition. The dynamic, nonlinear finite element forward model and artificial neural networks adopted in this research can be readily extended to the multi-load deflection analysis.
- Full data sets in the DataPave field database could be used to improve the effectiveness of prediction models. The current database is void of much of the

condition and layer thickness information expected. The addition of this data could further improve layer condition estimation.