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Precision of Elastic Moduli Prediction Using Back-Calculation and Independent Parameters Models in Comparison with Experimental Studies

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ABSTRACT: Pavement condition assessment requires structural evaluation that can be achieved using Falling Weight Deflectometer (FWD). This paper focused attention to the FWD results. The main objective of this research is to present a new method to estimate the pavement layers elastic modulus and to investigate its precision considering the experimental test results. To this end, several sections in Shush-Andimeshk and Semnan-Damghan highways were evaluated by ground penetrating radar (GPR) for estimating the layer thickness and falling weight deflectometer test at different load levels for estimating the elastic moduli of pavement layers. At the same sections, some cores were extracted and tested to measure the elastic modulus using the indirect tensile and dynamic triaxial methods for bound and unbound layers, respectively. The FWD data were analyzed by ELMOD6.0 software as a conventional back-calculation method. Furthermore, a new method was proposed by implementing a code using BASIC programming language and the obtained results were compared with those from ELMOD6.0 and experimental results. Based on these investigations the proposed method could precisely estimate the experimental moduli. Some models were present to estimate laboratory modulus (assumed as real modulus) considering the back-calculated modulus. In addition to back-calculation based models, models were developed based on the independent variables such as surface curvature index (SCI) and base damage index (BDI). Using the latter models, the layer modulus can be estimated without using the complicated back-calculation analysis methods. The final part of this research related to the validation of developed models. Validation of these models showed that they were sufficiently reliable to predict the real elastic moduli.

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1- Introduction

The Falling Weight Deflectometer (FWD) is most commonly used to evaluate road pavement structural condition for pavement maintenance and rehabilitation [1]. Generally, there are two methods for determining the parameters representing the structural condition of pavement from FWD test. The first method is presenting the model based on parameters from FWD outputs (e.g. deflection basin parameters) and the second method is based on back-calculation. In the last decade, a lot of research has been done based on the first method. Many models were presented that define the pavement condition directly without the need for back-calculation analysis from FWD outputs [2-7]. The second method is based on back-calculation analysis that have been used widely. The back-calculation analysis is based on an iterative process performed by the assumed layer moduli and the trial and error algorithm. This process has been usually done by back-calculation analysis programs [1].

In this research, the precision of back-calculation analysis performed by ELMOD software and a new proposed method has been evaluated considering the results of experimental tests that have been accomplished on the field extracted cores. The main advantage of the suggested method is to back-calculate the pavement layer modulus using a simple algorithm needing less time than other conventional methods like the ELMOD program. Estimating the modulus of elasticity through back-calculation analysis requires the selection of an appropriate algorithm or program. Besides, learning and proper utilization of the program might be a time-consuming and tedious process. Therefore, the use of mathematical models in estimating the layer modulus, without the need for time-consuming back-calculation analysis will considerably reduce the analysis time in both research and real practice. Hence, at the second part of this study, models were developed based on independent parameters obtained from deflection basin that enable to directly predict the layer moduli using FWD outputs without using the back-calculation analysis.

2- Methodology

In this study, several data were collected to implement the research sequences and obtain the intended objectives. The needed data were gathered by NDT tests including the GPR[1] and FWD. Two major highways including the Shush-Andimeshk, Khoozestan province, and Semnan-Damghan, Semnan province were chosen as case studies. At some of these stations, destructive evaluation was accomplished by drilling cores and excavating the asphalt, base and subgrade layers' materials. The layer modulus was estimated by two back-calculation analysis methods including ELMOD program as a conventional method and a new method that was

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1 ground penetrating radar

proposed by combining and some modifications in a number of previously presented theoretical approaches. Apart from the aforementioned solutions, models were developed to estimate the asphalt, base and subgrade layers' modulus based on the deflection basin parameters (i.e. independent parameters-based models).

3-Results and Discussion

Two method was presented in this research. The first method is based on back-calculation analysis. In this study, in order to evaluate the accuracy of the proposed method and ELMOD program, the elastic modulus of asphalt, base and subgrade layers were determined in laboratory and compared with those obtained from back-calculation analysis. The results are shown in the Table 1. RMSE[1] parameter was calculated and used as accuracy criterion. So the accuracy of the proposed method is higher.

Table 1. Evaluating the accuracy of the proposed method and ELMOD compared to laboratory data

Layer	RMSE (MPa)	
	ELMOD	Presented method
Asphalt	2637	2363
Base	521	445
Subgrade	142	168

Three mathematical functions were presented to relate the LAB and back-calculated or FWD moduli. Equations 1 to 3 gives the relationship between the FWD and LAB modulus obtained for asphalt, base layer and subgrade, respectively.

$$\frac{E_{FWD}}{E_{LAB}} = 0/0036P^2 - 0/3973P + 12/35 \quad ,R^2 = 0/52 \tag{1}$$

$$\frac{E_{FWD}}{E_{LAB}} = 0/038P - 0/094T + 4/177 \quad ,R^2 = 0/7 \tag{2}$$

$$\frac{E_{FWD}}{E_{LAB}} = -0/014P - 0/051T + 4/733 \quad ,R^2 = 0/85 \tag{3}$$

Result showed that the ratio of FWD to laboratory moduli at different testing loads was changed. The FWD modulus of subgrade were closer to laboratory results at higher loading levels, whereas the reverse was true for the base layer. Since for the base and subgrade layers the least error was observed at load magnitudes of 40 and 60 kN, respectively. These loads were selected as the basis loads for estimating the FWD modulus at other loading ranges. Equations 4 and 5 were presented from the FWD data to estimate the base and subgrade moduli in force of 40 and 60 kN.

$$\frac{E_P}{E_{40}} = 0/016P - 0/01T + 0/748 \quad ,R^2 = 0/7 \tag{4}$$

$$\frac{E_P}{E_{60}} = -0/0078P + 1/4951 \quad ,R^2 = 0/65 \tag{5}$$

The second method presented in this study, is based on independent parameters. The models presented in Equations 6 to 8 estimate the asphalt, base and subgrade moduli with the use of parameters obtained directly from FWD measurements.

$$\log E_{ac} = -1/438 \log SCI - 0/904 \log H_{ac} + 0/65 \log \sigma$$
$$+0/761 \log BDI + 3/074 \quad ,R^2 = 0/7, SEE = 0/0762 \tag{6}$$

$$E_{base} = 1327/1 \delta_{base}{}^2 - 2203/3 \delta_{base} + 1054/4 \quad ,R^2 = 0/86 \tag{7}$$

$$E_{SG} = 0/8455 E_{S\min} - 5/8423 \quad ,R^2 = 0/76 \tag{8}$$

Validation of these models in Table 2 showed that they were sufficiently reliable to predict the real elastic moduli, except Equation 1. For this type of data, the RMSE of lower than 25% has been usually suggested as the allowable threshold [8].

Table 2. Validation of the models

Layer	RMSE(%)	Criterion(%)	Validity
Equation(1)	66	25	not ok
Equation(2)	23	25	ok
Equation(3)	23	25	ok
Equation(4)	13	25	ok
Equation(5)	9	25	ok
Equation(6)	12	25	ok
Equation(7)	18	25	ok
Equation(8)	13	25	ok

Conclusions

Based on the obtained results and performed analysis, the following conclusions could be drawn:

1. By combining and some modifications in previous back-calculation analysis algorithms, a new method was proposed by implementing a code in BASIC programming language. In comparison to experimental results the presented method resulted in more precise estimation of layer moduli than ELMOD program. However, the layer moduli estimated by both methods were to some extent overestimate.
2. Comparing between the changes of FWD to laboratory moduli ratios for various pavement layers showed that the FWD modulus of asphalt and subgrade layers were closer to laboratory results at higher loading levels, whereas the reverse was true for the base layer. Considering these data models were presented that normalized the FWD modulus obtained at a specific load to other loading levels.
3. Apart from the aforementioned models, three separate models were presented based on independent parameters for determining the modulus of asphalt, base and subgrade layers. These models estimated the layer modulus using the parameters such as the applied load in FWD test, deflection basin parameters and Poisson's ratio.
4. Finally, comparison between the studied back-calculation methods and the independent parameters-based models revealed that independent parameters-based models make modules faster and easier to estimate. But the accuracy of the back-calculated methods is higher.

1 Root Mean Square Error

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