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Precision of back-calculation analysis and independent parameters-based models in estimating the pavement layers modulus-Field and experimental study

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HIGHLIGHTS

- Effect of load level has been considered in the back-calculation analysis precision.
- A new back-calculation analysis method has been presented and compared to ELMOD.
- Proposed method had higher conformity to destructive testing results than ELMOD.
- Models were developed based on the independent variables achieved in FWD test.

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ABSTRACT

The main objectives of this research were to present new method of back-calculation analysis and to compare the obtained results with destructive testing. Several sections in Shush-Andimeshk and Semnan-Damghan highways were evaluated by ground penetrating radar for estimating the layer thickness and falling weight deflectometer (FWD) 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 laboratory results. Based on these investigations the proposed method had higher conformity to destructive testing results than conventional back-calculation method. In addition to back-calculation based models, models were developed based on the independent variables such as surface curvature index and base damage index. Using the latter models the layer modulus can be estimated without using the complicated back-calculation analysis methods.

1. Introduction

The basis of pavement management system (PMS) and any maintenance operation is the data achieved from the evaluation of the pavement performance. Non-destructive testing (NDT) is one of the most appropriate methods for assessing road condition. NDT technologies have been widely used as quality control tools for pavement evaluation [1,2].

Among all NDT methods, the falling weight deflectometer (FWD) is one of the most useful and popular techniques used to evaluate the pavement structural capacity [3,4]. In FWD device, an impulse load is applied to the surface of pavement and the resulted response at a series of radial distances is recorded by some geophones. An FWD device can apply loads from about 1300 to over 25,000 kg based on the device used [5,6]. Due to several advantages such as the short testing duration, the ability to cover a large number of testing locations, little disturbance in material, the lack of human intervention and especially better simulation of the effect of the load from a moving tire, FWD devices are currently used by highway and airport agencies more than any of the other NDT devices [5,7].

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

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obtained 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. For example indices such as surface curvature index (SCI), structural health index (SHI) and modified structural index (MSI) were estimated from FWD measurements and were used to make the necessary decisions about maintenance strategies [8–11]. Furthermore, several models have been presented by various researchers which can be used to estimate layers elastic moduli using the aforementioned deflection basin parameters [12].

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 [13]. These programs vary in terms of complexity, back-calculation algorithm, simplifications and other related assumptions. Conventional procedures, which are still widely used, disregard inertia effects and time-dependent layer properties and use the peak values of FWD deflections and mostly consider the linear behavior and isotropic properties [14]. There are a lot of programs in the field of back-calculation analysis that researchers have used in various studies. In this regard programs such as BISDEF, BAKFAA, EVERCALC, ELSDF, MODULUS and ELMOD have been widely used in back-calculation analysis [7,15].

In this research, the results of back-calculation analysis performed by ELMOD software and a new proposed method has been compared with laboratory testing results that have been accomplished on the field extracted cores. Estimating the modulus of elasticity through back-calculation analysis requires the selection of an appropriate algorithm or program. Although with the present PC processors, back-calculation analysis is not a time-consuming procedure but learning and proper utilization of the program might be time-consuming. 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 ELMOD program.

Moreover, 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. There are limited research works in literature that have considered the effect of load level in FWD test on the outputs of back-calculation analysis. This parameter has been considered as one of the main independent parameters in the modelling process. Finally similar models were developed to estimate the base and subgrade layers modulus. There have been concerns among practitioners and the research communities about the adequacy of the resilient moduli determined by back-calculation analysis methods. Usually two methods have been imparted in literature to validate the back-calculated moduli [16–18]. In the first method field-measured stresses and strains have been used to quantify the reliability of back-calculated moduli, while in the second method attempts have been made by researchers to verify back-calculation results with results from the laboratory testing [17–19]. In the current study the second method was considered and the obtained results from the NDT evaluations were compared and verified by laboratory or destructive evaluations.

2. Research methodology

Several data were collected to implement the research sequences and obtain the intended objectives. The needed data were gathered by NDT tests including the ground penetrating radar (GPR) and FWD. Two major highways including the Shush-Andimeshk located in south of Iran, Khoozestan province, and Semnan-Damghan in north of Iran, Semnan province were chosen as case studies. Several stations were chosen to perform NDT analysis. At some of these stations, destructive evaluation was accomplished by drilling cores and excavating the asphalt, base and subgrade layers materials. The layers moduli were estimated by two back-calculation analysis methods including ELMOD program as a conventional method and a new method that was proposed by combining and some modifications in a number of previously presented theoretical approaches. Apart from the aforementioned studies, models were developed to estimate the asphalt, base and subgrade layers modulus based on the deflection basin parameters (i.e. independent parameters-based models). A model was presented to estimate laboratory modulus that frequently used as a main design variable in determining the overlay thickness. Also a model has been presented for determining the effect of load magnitude on the back-calculated modulus. The final part of this research related to the validation of developed models by comparing the outcomes of NDT and non-destructive testings.

3. Field tests and data collection

3.1. Non-destructive tests

3.1.1. FWD

The FWD device used in this study was a Dynatest 8000, which applied an impact load in 25 to 30 ms to the pavement and measured the resultant deflections with 9 geophones. Also, this device was able to automatically measure and record the air and asphalt temperatures. The deflection data recorded by FWD are presented in Table 1. Three different loads of 40, 50 and 60 kN were applied at each tested station. For each load the drops were repeated 8 times and the deflections were recorded. Since the NDT survey was conducted in 4-lane divided highways, the FWD test was performed in the right or heavy vehicle lane.

3.1.2. GPR

The GPR device, type Mala was used to determine the thickness of the existing pavement layers. The GPR test was conducted according to ASTM D6432-11 standard [16]. During this test 1.3 scan/m was performed and the obtained results were gathered by Ground software. Furthermore, the Reflex-Win software was used for analyzing the obtained radargrams.

Information about the studied stations, including the station code, mileage and pavement layers thickness are presented in Table 2. According to this table, data from 20 stations in Shush-Andimeshk and Semnan-Damghan highways were used for field and laboratory tests.

Fig. 1a shows an example of the GPR test results. As shown in the right side of this figure, during this test an electromagnetic wave dispatched from a transmitting antenna into the existing pavement structure. The wave is reflected from the boundary between two different layers. The boundary between each pavement layer is detected from the wave amplitude changes as shown

Table 1
FWD device specifications.

Parameter	Value
Applied Load (kN)	40–50–60
Radius of loading plate (mm)	150
No. of drops at each station	8
No. of geophones	9
Geophones arrangement (cm)	0–20–30–45–60–90–120–150–180
Tested lane	Right lane (Heavy vehicle lane)