Inverse Analysis of Pavement Structural Properties Based on Dynamic Finite Element Modeling and Genetic Algorithm

Xiaochao Tang[1] and Xiaoming Yang[2]
[1]Louisiana Transportation Research Center, Louisiana State University,
4101 Gourrier Avenue, Baton Rouge, LA 70808, USA.
Email: xtang@lsu.edu, ph.: +012257679194
[2]School of Civil and Environmental Engineering, Oklahoma State University,
319D Engineering South, Stillwater, OK 74078, USA.
Email: xmyang@okstate.edu, ph.: +014057445223

ABSTRACT

With the movement towards the implementation of mechanistic-empirical pavement design guide (MEPDG), an accurate determination of pavement layer moduli is vital for predicting pavement critical mechanistic responses. A backcalculation procedure is commonly used to estimate the pavement layer moduli based on the non-destructive falling weight deflectometer (FWD) tests. Backcalculation of flexible pavement layer properties is an inverse problem with known input and output signals based upon which unknown parameters of the pavement system are evaluated. In this study, an inverse analysis procedure that combines the finite element analysis and a population-based optimization technique, Genetic Algorithm (GA) has been developed to determine the pavement layer structural properties. A lightweight deflectometer (LWD) was used to infer the moduli of instrumented three-layer scaled flexible pavement models. While the common practice in backcalculating pavement layer properties still assumes a static FWD load and uses only peak values of the load and deflections, dynamic analysis was conducted to simulate the impulse LWD load. The recorded time histories of the LWD load were used as the known inputs into the pavement system while the measured time-histories of surface central deflections and subgrade deflections measured with a linear variable differential transformers (LVDT) were considered as the outputs. As a result, consistent pavement layer moduli can be obtained through this inverse analysis procedure.

1. INTRODUCTION

Backcalculation of flexible pavement layer properties based on falling weight deflectometer (FWD) testing has been routinely used as a tool for evaluating the structural capacities of pavements. The FWD backcalculation of pavement layer properties is essentially an inverse problem with known input signals into a system and known output signals based on which unknown system parameters are identified [1]. It is therefore possible to backcalculate a pavement layers' properties based on a known load applied to the pavement and properly measured pavement responses. Pavement responses include surface deflection and measurements from instruments installed in the pavement system.

Traditional backcalculation of pavement layer moduli involves using the measured deflection basin data, i.e. peak pavement surface deflections measured at the location underneath the impact load of an FWD and locations with certain offsets from the load. The pavement layers' moduli are obtained through an iterative process by minimizing the differences between the theoretical deflection basin and the measured deflections. Numerous computer programs have been developed to automatically backcalculate pavement layer moduli based on FWD testing, such as MODCOMP, MODULUS, WESDEF, ELMOD, and EVERCALC. Most of these programs assume a uniformly distributed FWD load and rely on linear elastic theory to solve for the layer moduli. Over the decades, significant improvements have been made in backcalculating pavement layer properties with respect to both the forward modeling and inverse analysis techniques. Non-linear material models were incorporated into the forward analysis to simulate the stress-dependent nature of unbound pavement layers, while the FWD impulse load was closely modeled through dynamic analysis. Interfaces or contacts between pavement layers were considered to deal with the bonding conditions between pavement layers. On the other hand, techniques for inverse analysis have evolved from direct reversal of closed-form solution, regression analysis, database searching, and the increasingly-used optimization approaches [2, 3, 4, 5].

Due to its significantly lower cost and greater mobility compared to FWD, the lightweight deflectometer (LWD)/portable falling weight deflectometer (PFWD) is increasingly used to test in-situ elastic modulus for quality control/quality assurance (QC/QA) of earthwork compaction. As a deflectometer-type device, various LWDs were developed and manufactured (mainly in Europe) (Hoffmann et al. 2004; Mooney and Miller 2009). The use of the LWD is primarily limited to homogenous unbound granular media instead of a layered pavement system. Using the measured peak values of load and surface deflection, the modulus is calculated on the basis of Boussinesq's theory by assuming a homogeneous, isotropic, linear-elastic half-space. Although some LWDs provide two radial deflection sensors, the majority of LWD usage is focused on one layer and a relatively homogeneous medium. Nevertheless, Senseney and Mooney [6] presented a successful example of using LWD with the aid of radial deflection sensors to backcalculate in-situ layer modulus for a two-layer system with a medium stiff soil lying over a soft clay.

The Genetic Algorithm (GA) is one of the stochastic search and optimization methods (Bäck 1996). GA mimics the adaptive process of biological system, i.e. natural