Backcalculation of pavement layer parameters using Artificial Neural Networks

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Received 7 January 2003; accepted 11 November 2003

In this paper, a new formulation based on Artificial Neural Networks (ANN) is presented for backcalculation of pavement layer moduli. In structural analysis of flexible pavements, the procedures as Layered Elastic Theory, Equivalent Layer Thickness (ELT), and Finite Elements Method (FEM) generally have complex formulations and give approximate results. Therefore, it is extremely difficult to perform realistic analysis for flexible pavements, especially in view of modelling the material properties of layers in these methods. Setting the finite element mesh and iteration procedure of backcalculation takes rather long time. The proposed ANN procedure requires significantly less computation time. ELT method is used for simplicity. It is impossible or very hard to model the visco-elastic and non-linear behaviour of layer materials in layered elastic theory. The use of ANN is proliferating with high rate in simulation. The ability of ANN is to learn complex non-linear relationships. A new formulation using ANN is presented here.

Non-destructive Testing (NDT) and backcalculating pavement layer moduli are well-accepted procedures for the evaluation of the structural capacity of pavements1. NDT enables the use of a mechanistic approach for pavement design and rehabilitation because in situ material properties can be backcalculated from the measured field data through appropriate analysis techniques2. In order to backcalculate reliable moduli, it is essential to accomplish several deflection tests at different locations along the highway sections having the same layer thicknesses1. But, it is not sufficient to do this. If the deflection basin is realistically modelled, elastic pavement layer moduli obtained from backcalculation will reflect actual pavement behaviour. In deflection measuring methods, commercially available devices are the Dynaflect, Road Rater and Falling Weight Deflectometer (FWD). The most common property found by NDT is the elastic modulus of each pavement layer.

Flexible pavements are layered systems with better materials on top where the intensity of stress is high and inferior materials at the bottom where the intensity is low. Flexible pavements are constructed of bituminous and granular materials. Bituminous materials possess both the elastic property of a solid and the viscous behaviour of a liquid. An asphalt mixture is a visco-elastic material whose behaviour depends on the time of loading. Also, a granular layer has non-linear elastic behaviour. So, it is very difficult to model the complete flexible pavement using traditional methods. In these methods, especially in layered elastic theory and FEM, the mathematical formulations are complex configuration and based on non-realistic assumptions as being in ELT method. Here, a new formulation formed using ANN is presented.

Each layer is homogeneous, isotropic, linearly elastic with an elastic modulus and a Poisson’s ratio, the material is weightless and infinite in a real extent in layered elastic theory3. These assumptions are used for simplicity. The principle of ELT is to transform a system consisting of layers with different moduli into an equivalent system where all layers have the same modulus and on which Boussinesq’s equations may be used4. This method gives nonrealistic results because of its assumptions.

In recent years, one of the most important and promising research field has been “Heuristics from Nature”, an area utilizing some analogies with natural or social systems and using them to derive non-deterministic heuristic methods and to obtain very good results. ANN method is among the heuristic methods.

Experimental

Backcalculation of pavement layer moduli

Backcalculation generally refers to an iterative pro-
procedure whereby the layer properties of the pavement model are adjusted until the computed deflections under a given load agree with the corresponding measured values. The measured deflections are usually obtained by any NDT procedure.

FWD is popularly used now-a-days to measure the surface deflections of pavements. FWD delivers a load to a pavement surface. The deflections are measured at several points of observation around the load. If layer elastic moduli are found so that the analytic deflections nearly coincide with measured deflections, the set of elastic moduli may be considered to represent average elastic moduli of real pavement structure.

Efficient methods are required to determine the structural properties of existing pavements realistically from non-destructive test data. NDT is one of the most efficient methods and is being increasingly used by pavement engineering community. Pavement structural properties may be generally stated in terms of resilient modulus which is a key element in mechanistic pavement analysis and evaluation procedures. Even if the deflections are measured very accurately, unless backcalculation procedure is realistic, accurate results can not be obtained in backcalculation of pavement layer moduli.

**FWD testing device**

In order to simulate the truck loading on pavements, a circular mass is dropped on the pavement from a certain height. The height is adjusted according to the desired load level. Underneath the circular plate a rubber pad is mounted to prevent shock loading. Seven geophones are generally mounted on the trailer (the number of geophones can change). When the vertical load is applied on the pavement, the geophones collect the deflection data. Using the calibration factors, the bytes can be converted to real deflections.

Benkelman beam and dynaflect which are most commonly used devices in the developing countries, give the information about underneath the centre of circular mass (i.e. these devices give one deflection data in each measurement) whereas the FWD gives the information about other six points (or more points) which are away from the circular plate. Therefore, the effect of the wheel loading can also be seen in other points.

The FWD is a trailer mounted device which applies a load to the pavement surface through a circular plate. FWD testing has been established world-wide as one of the most effective tools for measuring deflections for pavement evaluation purposes.

There are many types of FWDs which can apply similar loading. The time of loading varies between 0.025 and 0.030 sec; the applied loads vary between 6.7-156 kN. The loads are generally applied in a sinusoidal form. The loading time of 0.030 sec represents duration of a load pulse produced by a wheel moving at a speed of 30 km/h. ± 0.023 mm deviations can be seen from the FWD measurements. Typically, 200-300 FWD measurements can be made in a day.

**Artificial Neural Networks**

Neural networks are composed of simple elements operating in parallel. These elements are inspired by biological nervous systems. As in nature, the network function is determined largely by the connections between elements. A neural network can be trained to perform a particular function by adjusting the values of the connections (weights) between the elements. Commonly, neural networks are adjusted or trained so that a particular input leads to a specific target output. Such a situation is shown in Fig. 1. Here, the network is adjusted, based on a comparison of the output and the target, until the network output matches the target. Typically, many such input/target output pairs are used to train a network. Batch training of a network proceeds by making weight and bias changes based on an entire set (batch) of input vectors. Incremental training changes the weights and biases of a network as needed after presentation of each individual input vector. Incremental training is sometimes referred to as “on line” or “adaptive” training. Neural networks have been trained to perform complex functions in various fields of application including pattern recognition, identification, classification, speech, vision, and control systems. Today, neural networks can be trained to solve problems that are difficult for conventional computers or human beings.

![Fig. 1 — Basic principle of Artificial Neural Networks](image)
Backcalculation using Artificial Neural Network

A typical flexible pavement in which wearing course, base and subgrade exist was chosen for the study (Fig. 2). For simplicity, base layer thickness is assumed to be constant, whereas thickness of wearing course changes. Elastic modulus for the asphalt concrete is assumed to range from 1000-4000 MPa. For the base layer and subgrade, the elastic moduli are assumed as 500 and 100 MPa. Poisson’s ratios for asphalt concrete, base and subgrade are chosen as 0.30, 0.40 and 0.45, respectively.

In order to develop an ANN model, the deflection bowl has to be known whereas the elastic modulus, Poisson’s ratio and layer thickness are unknown. Such an approach is just opposite of the forward analysis. Back-propagation algorithm was employed for learning.

The ANN modeling consists of two steps. First step is to train the network; second step is to test the network with data, which were not used for training. The processing of adaptation of the weights is called learning. During the training stage the network uses the inductive-learning principle to learn from a set of examples called the training set. Learning methods can be classified as supervised and unsupervised learning. In supervised learning, for each input neuron there is always an output neuron. However, for the unsupervised learning it is enough only to have input neurons. In this study, data sets included 114 data. These data sets are obtained from the earlier studies of one of the authors. For training step, 95 data (approximately 80%) were selected, and for testing 19 data (approximately 20%) were selected.

Log-sigmoid transfer function was used as the activation function for hidden layers and output layers. The values of the training and test data were normalized to within the range from 0 to 1. Levenberg-Marquardt Back-propagation Training was repeatedly applied until the evaluation standard was reached. Deflections chosen for input values were not normalized because their values vary between 0 and 1. Only output values were normalized. For this purpose, layer thickness values were divided with 100 and elastic moduli values were divided with 5000.

Case study

In Fig. 3, seven deflection values were employed in the input layer, and the asphaltic concrete elastic modulus as well as the thickness of bituminous mixture was represented in the output layer. The radial locations of seven deflections in cm are 0, 30.5, 61, 91.5, 122, 152.5, 183. The network is then trained using 95 run results. Furthermore, 19 data sets, which were considered previously in the training process, were used to test the trained network. These results indicate that the ANN can be effectively used to determine the layer thickness.

As was proved Terzi et al., most optimal topology was determined as the configuration 7-4-2. The configuration is shown in Fig. 3. The decrease in mean square error (MSE) epochs during the training process is shown in Fig. 4. Comparison of the output variable values from the model with target values is presented in Figs 5 and 6. The regression curves $R^2$ of individual output variables are shown in Figs 5 and 6.

Formulations from the case study

$E_i$ (summation function of neuron $i$) and $F_i$ (activation function of neuron $i$) values were obtained so that weight values are substituted in summations and activation functions in each neuron belong to hidden layer because developed model in the Case Study is in
configuration of model 7-4-2. Activation function was chosen log-sigmoid as shown from $F_i$ function. In output neurons, summation functions are only selected as output values which are layer thickness and elastic modulus. For this purpose, purelin was chosen as activation function. To estimate the elastic modulus and the layer thickness of bituminous layer using the Case Study, the following formulations can be used:

For $E_1$ to $E_4$ and $F_1$ to $F_4$ represent summation function and activation function of each neuron at hidden layer, respectively. Then, layer thickness and elastic modulus of bituminous layer can be computed as follows:

Surface Thickness=$\left( 121.0621 * F_1 - 77.3562 * F_2 + 3.273 * F_3 + 51.9575 * F_4 + 1.5035 \right) * 10 \quad \ldots (9)$

Surface Modulus=$\left( -213.1245 * F_1 + 140.4794 * F_2 - 7.0734 * F_3 - 83.6671 * F_4 \right) * 5000 \quad \ldots (10)$

**Conclusions**

ANN is especially appropriate for investigating the complex deflection basin form in evaluating the structural capacity of the flexible pavements, taking the ability of ANN to learn complex non-linear pavement behaviour. The proposed model is useful for backcalculating the layer thickness and the elastic modulus of a bituminous layer of a flexible pavement. Formulation of the model has been obtained from formulations of selected functions (i.e. summation and activation) used in the ANN model and weights of neurons. By changing the architecture of ANN and the func-
tions, different formulations can be obtained. Also, the developed model produces equations based on the real results, not the assumptions. However, different formulations can be obtained using data sets measured on pavements with different layer properties. Many engineering problems can be formulated using this methodology. The new methodology can help highway agencies for evaluating the structural capacity of flexible pavements. These models will provide simplicity in solutions of the problems which are based on assumptions.

References