



Sensitivity analysis of crack propagation in pavement bituminous layered structures using a hybrid system integrating Artificial Neural Networks and Finite Element Method



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ABSTRACT

The paper presents results of sensitivity analysis to crack propagation of a pavement bituminous layered structure using the Finite Element Method (FEM) and Artificial Neural Networks (ANN).

The performed preliminary study determined stresses and displacements in the pavement layer system. The pavement structure consisting of asphalt layers, a base layer, subbase and subgrade layers was analyzed as a 2D finite element model using the ABAQUS computer software. The second method, i.e. the extend Finite Element Method was applied, to simulate cracking process of the bituminous layer of a road surface. The pavement model was subjected to static load. Both linear and non-linear material properties of the pavement layers were considered to discuss crack propagation sensitivity in the pavement layers.

A hybrid system integrating Artificial Neural Networks (ANN) and FEM was considered to model the material of asphalt layers in flexible pavements. The tests for Radial Basis Function (RBF) and Multi-Layer Perceptron (MLP) networks were carried out. In the formulated model the ANN requires inputs such as: layers thickness, load value and the Young's moduli of each layer creating the pavement. The data for the ANN were obtained from Finite Element Method analysis. The aim of the network learning process as non-destructive testing was to evaluate the pavement material behavior and estimation of the crack propagation sensitivity. The main conclusion is that cracking considerably increases with a decrease in the thickness of bituminous layer B2. The thickness of the asphalt layer B1 has much less considerable effect on the cracking of the subgrade layer.

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1. Introduction

Asphalt pavement cracking poses a serious problem for the development of road infrastructure. The phenomenon concerns worn-out roads as well as relatively new roads that are used in accordance with contractor specifications. The occurrence of cracking in multilayered road pavements results from numerous factors, such as strength parameters of particular layers, their thickness, load and production technology applied.

The present study is an attempt at the application of an FEM-ANN system to predict cracking sensitivity in a subgrade layer (Fig. 1). The system is based on MLP and RBF networks. The applied

input variables included asphalt pavement layer parameters and different load modes. The expected output network response would predict a crack occurrence. The Abaqus-calculated numerical analysis results were used as learning data.

2. Numerical analysis

In recent years, considerable advances in the numerical analysis of crack propagation, particularly in layer materials can be observed [2–7]. The layered composites can include metallic [8–11] and ceramic layers [12–14]. An influence of temperature effects on crack initiation and propagation in layered composites is also important [15–20]

Among others, numerical analyses are applied to investigate road pavement structures using the FEM [21–23].

In addition to that, a growing interest in the application of ANNs to identify processes such as wear or cracking can be observed

Abbreviations: ANN, Artificial Neural Network; MLP, Multi-Layer Perceptron; RBF, Radial Basis Function; FEM, Finite Element Method.

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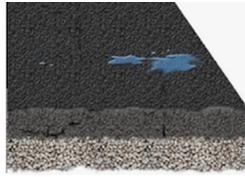


Fig. 1. Cracked asphalt [1].

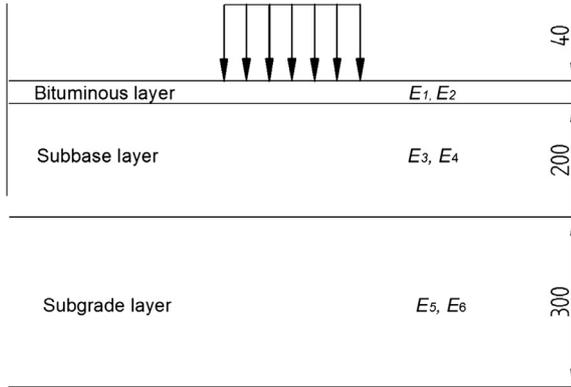


Fig. 2. Layer system used in the numerical analysis.

Table 1
Layer material properties.

Layer	Modulus of elasticity (MPa)	Poisson's ratio
Bituminous layer 1 (B1)	2000–5000	0.3
Bituminous layer 2 (B2)	1500–4000	0.3
Sub-base 1 (SB1)	200–600	0.35
Sub-base 2 (SB2)	100–300	0.35
Fill 1 (F1)	60–100	0.35
Fill 2 (F2)	30–60	0.35

[24–26]. Also, there are studies wherein the design of a neural model is based on experimental tests combined with the FEM [27].

Saltan and Sezgin [28] tested a FEM–ANN system to model bituminous layer material properties. The results they obtained show that both ANNs and the FEM can be effectively applied to problems of this kind. The hybrid system is particularly useful when investigating the behavior of complex flexible pavement layers. Given the ANN capability of solving complex non-linear problems, such studies offer promising results.

Numerical analyses were conducted using Abaqus v.6.11. A 2D model of a multi-layer asphalt pavement structure was made (Fig. 2). The model consisted of bituminous layers, subbase and subgrade layers as well as fills. For the presented bituminous layer thickness values, preliminary FEM-based studies were conducted; the results obtained were then modified in order to create a vast database of neural network input variables. Layer material parameters are listed in Table 1. The modulus ranges were being changed in the numerical computations in the ranges as shown in this table.

The two-dimensional numerical analysis of the cracking process was performed using the extended finite element method (X-FEM) with the triangular traction–separation rule for description of the cracking process (Fig. 3).

The area below the chart corresponds to element failure energy.

Crack propagation in bituminous layers is shown in Fig. 4. It should be emphasized that FEM-based analyses had a qualitative character and were aimed at collecting a vast database that could then be used in neural network learning. Based on these data,

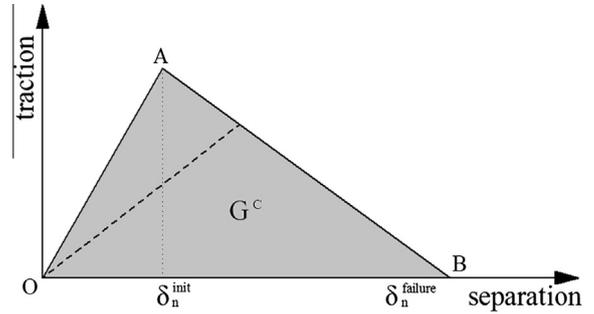


Fig. 3. Traction–separation failure criterion [29]. Here, A is the damage initiation point, δ_n^{init} is the node displacement corresponding to the damage initiation, and $\delta_n^{failure}$ is the displacement corresponding to failure (the total loss of rigidity in finite element) and crack propagation process.

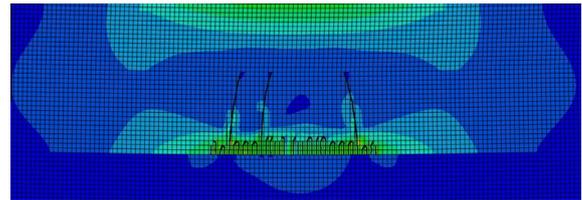


Fig. 4. Crack propagation paths.

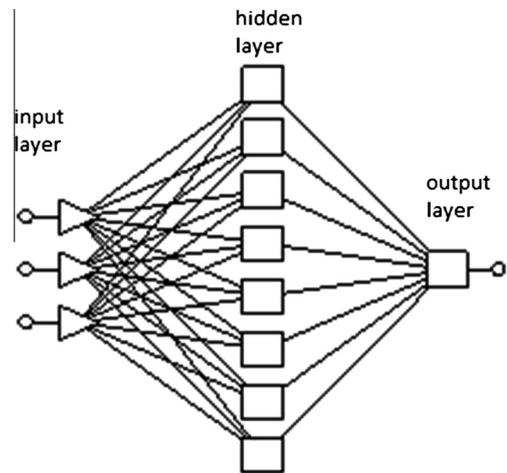


Fig. 5. Artificial Neural Network diagram.

the neural network should be able to correctly classify an event of cracking and potential crack propagation.

Fig. 5 shows the diagram of an artificial neural network used in the analyses. The network consists of three layers: an input layer responsible for entering the data into the network, a layer with hidden neurons that realize the consecutive stages of converting the input data into output data and, finally, an output layer that determines the network output values. The number of neurons in the input layer corresponds to the number of learning variables. The neurons present in the successive layers are combined into paths for sending data within the network.

The model of a single neuron located in the layer consists of two elements: summing and activating. The neuron converts a particular input signal into a single output signal. The application of an ANN to classification task consists in determining the weights of connections between neurons located in the adjacent layers. The weight determination process is called “ANN learning.” The

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