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RESEARCH PROJECT TITLE
Development of Asphalt Dynamic Modulus Master Curve Using Falling Weight Deflectometer Measurements

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Development of Asphalt Dynamic Modulus Master Curve Using Falling Weight Deflectometer Measurements

tech transfer summary

A neural networks methodology was developed based on a synthetically generated viscoelastic forward solutions database to predict asphalt concrete relaxation or dynamic modulus master curve coefficients from falling weight deflectometer deflection-time history data.

Background

The new American Association of State Highway and Transportation Officials (AASHTO) Mechanistic-Empirical Pavement Design Guide (MEPDG) and the associated software (AASHTOWare Pavement ME Design, formerly known as DARWin ME) represents a major advancement in pavement design and analysis. The MEPDG employs master curves based on time-temperature superposition principles to characterize the viscoelastoplastic properties of asphalt concrete (AC) materials.

The MEPDG recommends the use of AC dynamic modulus, |E*|, as the design parameter. The standard laboratory procedure for AC dynamic modulus testing requires time and considerable resources.

Problem Statement

In the MEPDG and Pavement ME Design flexible pavement rehabilitation analysis, the pre-overlay-damaged master curve of the existing AC layer is determined by first calculating an “undamaged” modulus and then adjusting this modulus for damage using the pre-overlay condition. If the damaged AC |E*| master curve of an in-service pavement can be derived from the time histories of routinely collected falling weight deflectometer (FWD) deflection data, it would not only save lab time and resources, but it could also lead to a more accurate prediction of the pavement’s remaining service life.

Objective

The objective of this feasibility study was to develop frameworks for predicting AC relaxation modulus (E(t)) or |E*| master curves from routinely collected FWD time history data. According to the theory of viscoelasticity, if AC E(t) is known, |E*| can be calculated (and vice versa) through numerical interconversion procedures.

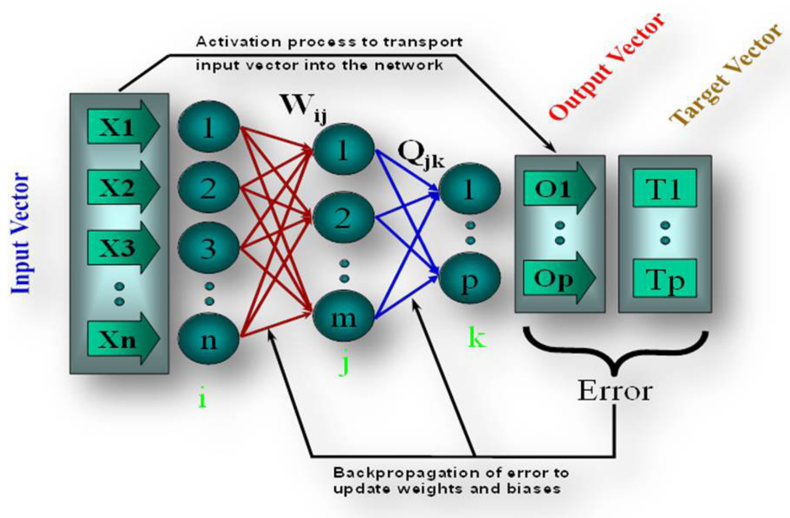
Research Methodology

The overall research methodology involved the following steps:

Step 1: Conduct numerous viscoelastic (VE) forward analysis simulations by varying E(t) master curve coefficients, shift factors, pavement temperatures, and other layer properties.

Step 2: Extract simulation inputs and outputs and assemble synthetic database.

Step 3: Train, validate, and test neural network (NN) inverse mapping models to predict E(t) master curve coefficients from single-drop FWD deflection-time histories.



Enlarged view of generic network architecture: 156-h-1

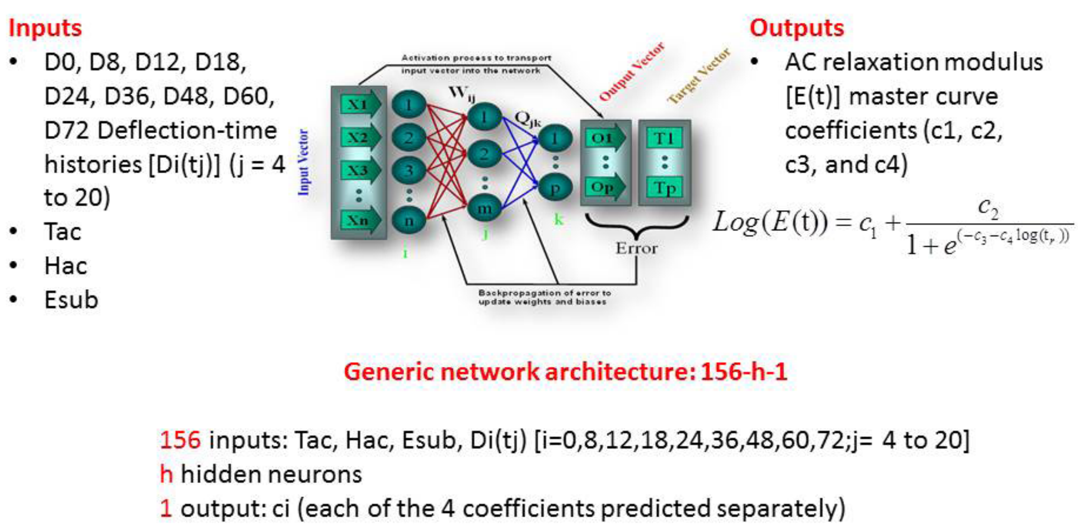
A computationally efficient VE forward analysis program developed by Michigan State University (MSU) researchers was adopted in this study to generate the synthetic database.

Several case studies were conducted to establish detailed frameworks for predicting AC E(t) master curves from single-drop FWD time history data. Case studies focused on full-depth AC pavements as a first step to isolate potential backcalculation issues that are only related to the modulus master curve of the AC layer.

For the proof-of-concept demonstration, a comprehensive full-depth HMA analysis was carried out through 10,000 batch simulations of the VE forward analysis program. Anomalies were detected in the comprehensive raw synthetic database and eliminated through imposition of certain constraints on the sum of E(t) sigmoid coefficients, c1 + c2. NN inverse analysis was carried out considering time history data only from sensors close to the load plate and from all of the FWD sensors.

Key Findings

- Except for the first two or three time intervals, deflection-time histories at all other time intervals considered in the analysis were predicted by the forward NN models with very high accuracy (R-values greater than 0.97).
- The NN prediction accuracies for all four E(t) master curve coefficients (c1, c2, c3, and c4) were higher when considering the full-pulse deflection-time



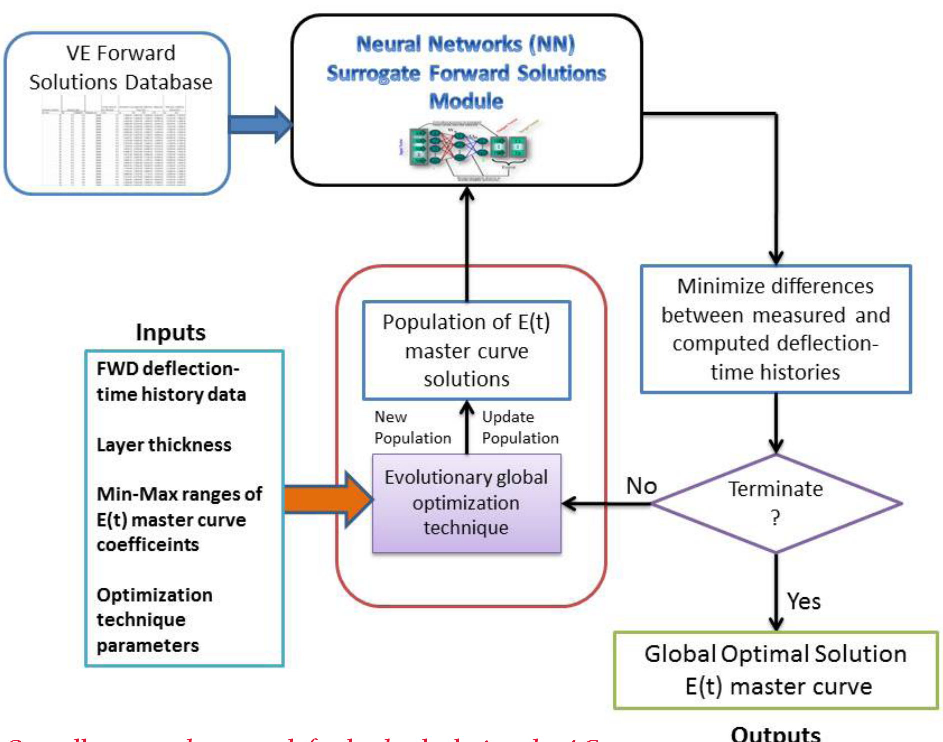
Inputs, outputs, and generic network architecture details for the NN inverse mapping models considering data from all FWD sensors and pre-peak deflection-time data history data from all FWD sensors as opposed to considering only pre-peak deflection-time history data.

- Although the study findings demonstrate the potential of NNs to predict the E(t) master curve coefficients from single-drop FWD deflection-time history data, the current prediction accuracies are not sufficient to recommend these models for practical implementation.
- This feasibility study was restricted to the prediction of E(t) master curve coefficients based on single FWD tests performed at a single temperature. Consequently, the prediction of time-temperature superposition shift factors (a1 and a2) was omitted. By including the AC temperature profile information at the time of FWD testing in the generation of the synthetic database using the enhanced version of the VE forward analysis program, it may be possible to backcalculate the entire E(t) master curve, including the shift factors, from FWD deflection-time histories.

Recommendations

Considering the complex nature of the investigated problem with all of the uncertainties involved, including the possible presence of dynamics during FWD testing (related to the presence and depth of the stiff layer, inertial and wave propagation effects, etc.), limitations of current FWD technology (integration errors, truncation issues, etc.), and the need for a rapid and simplified approach for routine implementation, future research recommendations are provided to make a strong case for an expanded research study:

- Because a significant portion of the pavements in Iowa are composite pavements (typically portland cement concrete (PCC) overlaid with HMA), future research should include the development/adaptation of a composite pavement VE or time-domain dynamic forward solver.
- The proposed NN-based framework computes E(t) master curve coefficients based on single-drop FWD test data (i.e., single FWD test performed at a single temperature). Using this approach, it is only possible to accurately backcalculate certain portions of the E(t) (i.e., at high frequencies or short times). According to recent research studies, longer pulse durations need to be employed in the FWD test (which will result in long-duration deflection-time history) or we need to conduct FWD tests at different pavement temperatures (during different times of the day or seasons) and use the concept of time-temperature superposition to accurately predict the entire E(t) master curve.
- Apart from the use of NNs for the inverse analysis of viscoelastic asphalt layer properties from FWD time history data, future research should also consider the use of an evolutionary global optimization technique (particle swarm optimization, differential evolution, etc.) in combination with the VE forward solver.



Overall proposed approach for backcalculating the AC E(t) master curve from FWD deflection-time history data using an evolutionary global optimization search scheme

Implementation Readiness/Benefits

The primary benefit of this research will be to eventually characterize and document the Iowa AC-mix damaged master curve parameters in the Pavement Management Information System (PMIS), which could then be used by city, county, and state pavement engineers in conducting flexible pavement rehabilitation analysis and design.