Expert Systems with Applications 37 (2010) 4660–4670

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Prediction of Marshall test results for polypropylene modified dense bituminous mixtures using neural networks

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ARTICLE INFO

Keywords:
Neural networks
Polypropylene
Stability
Flow
Marshall Quotient
Parametric study

ABSTRACT

This study presents an application of neural networks (NN) for the prediction of Marshall test results for polypropylene (PP) modified asphalt mixtures. PP fibers are used to modify the bituminous binder in order to improve the physical and mechanical properties of the resulting asphaltic mixture. Marshall stability and flow tests were carried out on specimens fabricated with different type of PP fibers and also waste PP at optimum bitumen content. It has been shown that the addition of polypropylene fibers results in the improved Marshall stabilities and Marshall Quotient values, which is a kind of pseudo stiffness. The proposed NN model uses the physical properties of standard Marshall specimens such as PP type, PP percentage, bitumen percentage, specimen height, unit weight, voids in mineral aggregate, voids filled with asphalt and air voids in order to predict the Marshall stability, flow and Marshall Quotient values obtained at the end of mechanical tests. The explicit formulation of stability, flow and Marshall Quotient based on the proposed NN model is also obtained and presented for further use by researchers. Moreover parametric analyses have been carried out. The results of parametric analyses were used to evaluate mechanical properties of the Marshall specimens in a quite well manner.

1. Introduction

Types of bituminous mixtures are many and varied. They range from simple surface treatments to more expensive hot bituminous mixtures using high quality aggregates. For better type of pavements, dense bituminous concrete is generally produced where carefully proportioned amounts of fines, sand and coarse aggregate are heated and mixed with hot asphalt cement and then carried to the site, placed in the prepared roadbed while still hot (must be at least 125 °C) and rolled to guarantee a dense and relatively permanent bituminous concrete.

Asphalt concrete was originally developed in the USA to meet the need for stiff and strong pavements to carry the heavy loads and high tire pressures of aircrafts. In the UK asphalt concrete is used for airfields and is often termed as Marshall asphalt. Asphalt concrete derives its strength and stability primarily through aggregate interlock and to a lesser extent through the sand/filler/bitumen mortar. The composition of asphalt concrete is determined by the USA Asphalt Institute Marshall mix design procedure (The Asphalt Institute, 1988). The concepts of the Marshall method of designing paving mixtures were formulated by Bruce Marshall, formerly bituminous engineer with the Mississippi State Highway Department. The US Corps of Engineers, through extensive research and correlation studies, improved and added certain features to Marshall's test procedure, and ultimately developed mix design criteria (The Asphalt Institute, 1988). Since 1948, the test has been adopted by organizations and government departments in many countries, sometimes with modifications either to the procedure or to the interpretations of the results.

The Marshall test consists of the manufacture of cylindrical specimens 102 mm in diameter and 64 mm high by the use of a standard compaction hammer and a cylindrical mould. The specimens are compacted using the compactive effort applicable to the loading conditions. For roads and streets with low tire pressures, the materials are compacted on two faces, utilizing fifty blows of a 4.53 kg hammer dropped from a 45.72 cm height. For a 200 psi tire pressure, 75 blows of the hammer on each face is used. The specimens are tested for their resistance to deformation at 60 °C at a constant rate of 50.8 mm/min in a test rig. The jaws of the loading rig confine the majority but not the entire circumference of the specimen. The top and the bottom of the cylinder is unconfined. Because of this fact, the stress distribution in the specimen during testing is extremely complex (Tapkın, 1998).

Two properties are determined from the Marshall test. These are:

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0957-4174/$ - see front matter
doi:10.1016/j.eswa.2009.12.042

(a) The maximum load the specimen will carry before failure, which is known as the Marshall stability.
(b) The amount of deformation of the specimen before failure occurred, which is known as the Marshall flow.

The ratio of stability to flow is known as the Marshall Quotient. Marshall Quotient is a sort of pseudo stiffness which is a measure of the material's resistance to permanent deformation (Tapkın, 1998).

From the Marshall design procedure, the aim is to obtain the optimum bitumen content. In order to find the optimum bitumen content, the designer has to find the below mentioned values from the test property curves.

From these data curves, bitumen contents are determined which yields the following:

(a) Maximum stability.
(b) Maximum unit weight.
(c) The median of limits for percent air voids.
(d) The median of limits for voids filled with asphalt.

The testing procedure in order to determine the optimum bitumen contents is very time consuming and needs skilled workmanship. On the other hand, at the end of the Marshall test only stability and flow values of the specimens can be obtained physically. The specific gravity of mixture, theoretical specific gravity, voids in mineral aggregate (V.M.A.), voids filled with asphalt (V_f) and air voids (V_a) are obtained by carrying out extra calculations. Therefore if the researchers can obtain the stability and flow values of a standard mix by the help of another means, the rest of the calculations will just be mathematical manipulations. Neural networks can be a suitable mean to obtain the stability and flow values obtained at the end of Marshall test procedure.

The first aim of this study was to review available literature on the application of neural networks in pavement engineering researches. Second, the possibilities of improving the mechanical properties of asphalt mixtures by the utilization of polypropylene fibers were explored. Then a short background on neural networks was stated out. Next, the main focus of this study, which is the prediction of stability, flow and Marshall quotient values of asphalt specimens obtained from a series of Marshall test using neural networks based on experimental results was given in the numerical application part. Finally, in order to obtain the main effect plot, a wide range of parametric study has been performed by using the well trained NN model.

2. Historical background of neural network applications in pavement engineering

Very detailed information about the applications of traffic engineering can be found in the relevant literature (Tapkın, 2004). At this point, it is important to state out, one by one, the relevant important neural network applications in the pavement engineering area.

In a study by Ritchie, Kaseko, and Bavarian (1991), a system that integrates three artificial intelligence technologies: computer version, neural networks and knowledge-based system in addition to conventional algorithmic and modeling techniques were presented. Kaseko and Ritchie (1993) used neural network models in image processing and pavement crack detection. Gagarin, Flood, and Albrecht (1994) discuss the use of a radial-Gaussian-based neural network for determining truck attributes such as axle loads, axle spacing and velocity from strain-response readings taken from the bridges over which the truck is traveling. Eldin and Senouci (1995) describe the use of a BP algorithm for condition rating of roadway pavements. They report very low average error when compared with a human expert determination. Cal (1995) uses the backpropagation algorithm for soil classification based on three primary factors: plastic index, liquid limit, water capacity, and clay content. Razaqpur, Abd El Halim, and Mohamed (1996) present a combined dynamic programming and Hopfield neural network bridge-management model for efficient allocation of a limited budget to bridge projects over a given period of time. The time dimension is modeled by dynamic programming, and the bridge network is simulated by the neural network. Roberts and Attoh-Okine (1998) use a combination of supervised and self-organizing neural networks to predict the performance of pavements as defined by the International Roughness Index. Tutumluer and Seyhan investigated neural network modeling of anisotropic aggregate behavior from repeated load triaxial tests (Tutumluer & Seyhan, 1998). The BP algorithm is used by Owusu-Ababia (1998) for predicting flexible pavement cracking and by Alsugair and Al-Qudrah (1998) to develop a pavement-management decision support system for selecting an appropriate maintenance and repair action for a damaged pavement. Kim and Kim (1998) used artificial neural networks for prediction of layer module from falling weight deflectometer (FWD) and surface wave measurements. Shekharan (1998) studied the effect of noisy data on pavement performance prediction by an artificial neural network with genetic algorithm. Attoh-Okine (2001) uses the self-organizing map or competitive unsupervised learning model of Kohonen for grouping of pavement condition variables (such as the thickness and age of pavement, average annual daily traffic, alligator cracking, wide cracking, potholing, and rut depth) to develop a model for evaluation of pavement conditions. Lee and Lee (2004) presents an integrated neural network-based crack imaging system to classify crack types of digital pavement images which includes three types of neural networks: image-based neural network, histogram-based neural network and proximity-based neural network. In an article by Mei, Gunaratne, Lu, and Dietrich (2004), it is presented a computer-based methodology with which one can estimate the actual depths of shallow, surface-initiated fatigue cracks in asphalt pavements based on rapid measurement of their surface characteristics. Ceylan, Guclu, Tutumluer, and Thompson (2005) has investigated the use of artificial neural networks as pavement structural analysis tools for the rapid and accurate prediction of critical responses and deflection profiles of full-depth flexible pavements subjected to typical highway loadings. Bosurgi and Trifiro (2005) has described a procedure that has been defined to make use of the available economic resources in the best way possible for resurfacing interventions on flexible pavements by using artificial neural networks and genetic algorithms. Attoh-Okine (2005), in his paper, presents the application of functional equations and networks to incremental roughness prediction of flexible pavement.

3. Use of polypropylene fibers in asphalt concrete mixtures

The main applications of polymer fiber reinforcement in the modern era have begun in early 1990s. Brown et al. have enriched the development of this kind or research (Brown, Rowlett, & Boucher, 1990). They have stated out the potential of some kind of fibers in improving the tensile and cohesive strength of asphaltic concrete on account of developing greater tensile strength when compared to bitumen. Also some other researchers believe that some type of fibers create physical changes to modifiers which has a preferable effect on drain-down reduction than polymer modifiers do (Maurer & Malasheskie, 1989; Shao-Peng, 2006). In another study, fracture mechanics approach was utilized to assess