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Applications of Neural Network for Optimum Asphaltic Concrete Mixtures

MOHAMMED H. ALAWI[a] and MAHER I. RAJAB[b]
[a]Civil Engineering Dept., [b]Computer Engineering Dept.
University of Umm Al-Qura
[a]P.O. Box 7398 Mecca, KSA, [b]P.O. Box 5555, Mecca, KSA
KINGDOM OF SAUDI ARABIA

Abstract: - Neural Networks technology provides several reliant analysis in many science and technology applications. In particular neural network is often applied to the development of statistical models for intrinsically non-linear systems, since neural networks behave better in complex conditions. In this research, applications of neural networks in determination of optimum bitumen content, Marshall Stability and Marshall Quotient of asphaltic concrete mixtures were investigated. To determine the properties of asphaltic concrete mixtures using neural networks, samples were collected from different regions in Mecca area during construction and tested at laboratories of Umm Al-Qura University for bitumen content, gradation of aggregate, Marshall Stability, Marshall Quotient determination. The conventional models for asphaltic concrete mixtures were developed on the basis of data collected. Part of the data set was used for validation. Suitability of using neural networks in developing a neural network model of the OBC, Marshall Stability and Marshall Quotient for asphaltic concrete mixtures was found; the models were developed and validated.

Keywords: - Neural networks, Optimum bitumen content, Marshall Stability, Marshall Quotient.

1 Introduction

One of the main transportation systems in Saudi Arabia is the road system, which is developed in rapid manner. The road construction program still currently under way in all regions of Saudi Arabia. The main function of this road is to connect the cities, towns and villages as possible through out the kingdom so; it is necessary to have roads with excellent pavement from structure and functional point of view.

In the last five plans of Saudi Arabia, the Ministry of Transportation (MOT) [1] did perform many projects and strong infrastructure of ways with billions of riyals cost. It is considered as long-term national investment. The Ministry of planning statistics in Saudi Arabia stated that the kingdom paid more than 4,000 billion riyals through 27 years. From that it can be noticed how the investment in the roads network is huge. The kingdom established giant roads network. In the year 1950 the network roads increased from 240 km to reach more than 187000 km in the year 1998 [2].

The design of asphalt paving mixtures (the upper layers of road) involves the selection and proportioning of materials to obtain a mix that will produce a durable pavement with the ability to carry the anticipated traffic loads without undergoing excessive distortion or displacement. The mix design should also provide for sufficient air voids and workability to allow for additional compaction under traffic loads and efficient placement of the mix [3].

British Standards BS 598 recommends that the O.B.C. is calculated from the average values of maximum Marshall Stability, maximum compacted density of the mixture, and that the porosity value ranges from 3 to 5%. Besides, the optimum value obtained should be below 4mm flow. Finally, adopting the criteria of the Asphalt Institute [4] a minimum VMA value of 14% should be attained for a bituminous mixture with nominal maximum aggregate particle size of 19 mm, and that the compacted mixture remains within the upper and lower limits for the voids filled with bitumen (%VFB) of 75% and 65% respectively for heavily trafficked surfacing. The MOT specifications in Saudi Arabia, recommends that the optimum bitumen content same as

British Standards BS 594 except for voids ratio (porosity) varying from 4 to 7%.

The O.B.C is defined as the optimum percentage of bitumen needed for a specific asphaltic concrete mixture. Marshall Stability is representing the ability of specimens to sustain loads. While as Marshall Quotient (M.Q.) values (Stability/Flow) are a good indicator of the mixture resistance to rutting and are directly related to creep stiffness. These three variables are important parameters in design of wearing course and base course of asphaltic concrete mixtures (upper layers of road).

Some empirical formulas were developed for determination of optimum bitumen content (OBC) [4,5]. [6] estimates optimum bitumen content (OBC) from aggregate gradations of asphaltic concrete mixtures in Mecca area using Neural Networks. They concluded from the study that the OBC_{NN} model prediction was fairly close to the corresponding actual values of optimum bitumen content with the average error of 1.80%. The correlation coefficients of 0.9802 and 0.9679 were obtained for the testing data for optimum bitumen content prediction. The results indicated that the OBC_{NN} model could predict the optimum bitumen content of asphaltic concrete mixtures with adequate accuracy required for practical design purpose. This model helps transportation and highway engineers to predict the optimum bitumen content of asphaltic concrete mixtures without conducting costly and time consuming experimental tests.

Estimation of Marshall Stability from optimum bitumen content (OBC) and aggregate gradations of asphaltic concrete mixtures in Mecca area using neural network studied by [7].Checking errors were calculated using two training algorithms: the back propagation (BP) and cascade correlation (CC). They concluded that the prediction model was fairly close to the corresponding actual values of optimum bitumen content with an average error of 3.841%. The correlation coefficients of 0.9792 and 0.9749 were obtained for the training and testing data for stability prediction. Also it is found that the training algorithm of CC yielded slightly more accurate forecasts compared to that of the BP.

In the present study, conventional models for optimum bitumen content, Marshall Stability and Marshall Quotient of asphaltic concrete mixtures were developed based on the experimental data and neural network.

2 Method

Loose mixtures (53 samples, averaging of 159 samples), which were used in this research. These samples were collected from different regions in Mecca area during the construction of new roads and tested at asphalt laboratory of Umm Al-Qura University for bitumen content, gradation of aggregate determination. Compaction for 75 blows each side at 150^{o}c temperature was started. Density of compacted mix, voids, voids in mineral aggregate (VMA), and voids filled with bitumen (VFB) were calculated. Finally Marshall Stability and Marshall Flow were measured. These mixtures were made using 60/70 pen. grade bitumen binder. The aggregate gradation of all bituminous mixtures lies within the upper and lower limits gradation of grade A wearing course for heavy traffic (Table 1) [MOT], as well as stability, flow, voids, VMA, VFB within Ministry of Transportation (M.O.T) specification (Tables 2) [MOT].

Table 1. M.O.T. specifications for Gradation of wearing course, class A.

Sieve Size Designation	M.O.T. specification limits (% Passing)
¾"	100
½"	80 - 95
3/8"	-
# 4	48 - 62
# 10	32 - 45
# 40	16 - 26
# 200	4 - 8

Table 2. M.O.T in Saudi Arabia design criteria (review form MRDWS 410D.c) for wearing course class A of heavy traffic.

Mix properties	Criteria
Compaction (No. of blows each end of specimen)	75
Marshall Stability, kg (min)	1000
Marshall Flow (mm)	2.0-3.5
Loss of Marshall Stability, % (Max.)	25
Voids in mix, %	4.0-7.0
Marshall mixing temperature, ºC	155-165
Marshall Compaction temperature, ºC	140-150
Voids in mineral aggregate, min	15
Voids filled with bitumen, %	65-75

The work presented here is based on a neural network model of three layer multi-layer perceptron architecture. The successful applied neural network model is of 3-15-3 multi-layer perceptron MLP, as shown in Fig.1: where three inputs in the input layer, fifteen hidden nodes (units), and three nodes in its output layer. The OBC, Marshall Stability and Marshall Quotient are the three predictions of the NN-based model. The data collected was divided into two parts: training data files, and test data files. Training data were used to train and also to verify the neural networks model's performance during training. Different test experiments were applied to measure the performance of the trained neural model. The predicted neural networks results are correlated with the actual data for Optimum Bitumen Content (OBC), Marshall Stability, and Marshall Quitent MQ, section 3.

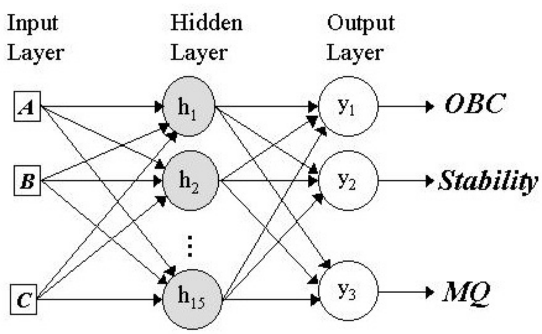

Fig.1. Structure of the neural network: 3-15-3 multi-layer perceptron.

3 Results and Discussion

One of the main issues encountered in NN is determination of the structure of the neural network in the number of hidden layers and the number of hidden neurons in each hidden layer. In most reported applications, the number of hidden layers and the number of hidden neurons are determined based on experience. Very often several arbitrary architectures are tried, and one giving the best performance is selected.

The optimum bitumen content of asphaltic concrete mixture (OBC) and Marshall stability are greatly influenced by several parameters: (i) Aggregate (type- size- shape- roughness- angularity – texture – gradation - absorption), (ii) Filler (type – shape – size - quantity), and (iii) bitumen (type – penetration - viscosity). Consequently developing models for OBC, Marshall Stability and Marshall Quitent of asphaltic concrete mixture requires an extensive understanding of the relation between these parameters and the properties of the resulting matrix. However, in this research most of these factors were fixed because the materials were used from the city of Mecca and the properties of these materials and gradations, job mix formula, mixture design were based on the specifications of Ministry of transportation in Saudi Arabia (MOT).

The input data for neural networks model has been chosen as percentage of course aggregate, I_1 which is basalt type (igneous rock), percentage of fine aggregate, I_2 (natural sand), and percentage of filler, I_3 (ordinary Portland cement type 1) and the output is the percentage of optimum bitumen content (OBC), Marshall stability and Marshall Quitent.

The successful NN parameters for learning rate, momentum are found as 0.5, 0.9, respectively; Table 4. Different NNs parameters were experimented using sigmoid function transfer function and 3 to 25 hidden nodes; Table 3. According to the network run statistics, the smallest NN-RMS error reached is 0.0005. Table 3 shows the characteristics of the feed-forward NN model trials, while Table 4 shows the characteristics of the most successful NN model.

Table 3. Characteristics of NN testing model trials. OBC, stability, and MQ for 13 tested data.

Hidden Nodes	η	α	NN RMS Error	Correlations		
				OBC	Stability	MQ
3	0.7	0.8	0.003	0.626	0.749	0.586
4	0.7	0.8	0.003	0.478	0.300	0.112
6	0.7	0.8	0.003	0.585	0.559	0.311
9	0.7	0.8	0.003	0.587	0.562	0.380
9	0.1	0.5	0.003	0.505	0.2350	0.150
10	0.7	0.8	0.003	0.605	0.508	0.564
13	0.7	0.8	0.003	0.586	0.439	0.508
14	0.7	0.8	0.003	0.530	0.377	0.255
15	0.7	0.8	0.003	0.633	0.548	0.602
15	**0.5**	**0.9**	**0.0005**	**0.970**	**0.969**	**0.862**
20	0.7	0.8	0.003	0.574	0.498	0.329
25	0.7	0.8	0.003	0.575	0.521	0.343

Table 4. Summary of the successful NN model structure of OBC, stability, and MQ.

Data Sets*		Network parameters	
I_1	% of course aggregate	Hidden Nodes	**15**
I_2	% of fine aggregate	Learning rate	**0.5**
I_3	% of filler	Momentum rate	**0.9**
O_1	% optimum bitumen content OBC	Maximum iterations	241,831
O_2	Stability	Converged error	0.0005
O_3	Marshall Quitent		

* I = Input layer O = output layer

Figures 2, 3 show the comparison of predicted and experimental values for OBC. Similarly, Figures 4, 5 and Figures 6, 7 shows the comparisons between the predicted and the actual experimented values of Stability and Marshall Quotient, respectively. Trained data are verified in Figures 2, 4, 6 whereas tested data are verified in Figures 3, 5, 7. From these figures it can be noticed that the prediction can be seen as fairly close to the corresponding actual values for optimum bitumen content, Marshall Stability and Marshall Quotient. The successful NN model, Table 4, demonstrates the highest correlation coefficients of 0.970, 0.969, and 0.862 for OBC, Marshall Stability, and MQ, respectively.

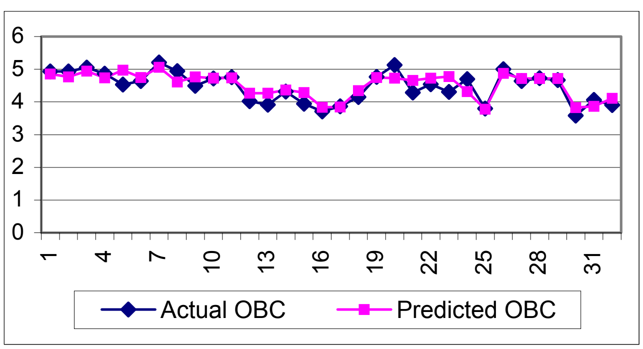

Fig.2. Comparison of actual and predicted values of optimum bitumen content *OBC* for trained data.

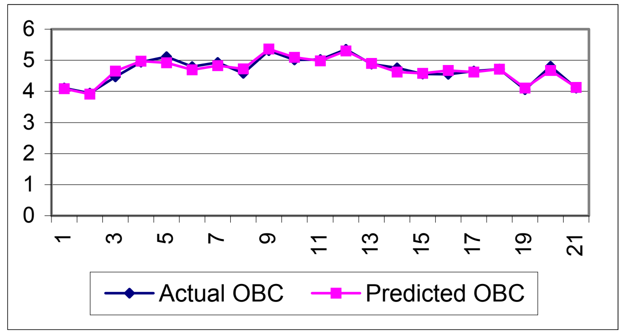

Fig.3. Comparison of actual and predicted values of *OBC* for tested data.

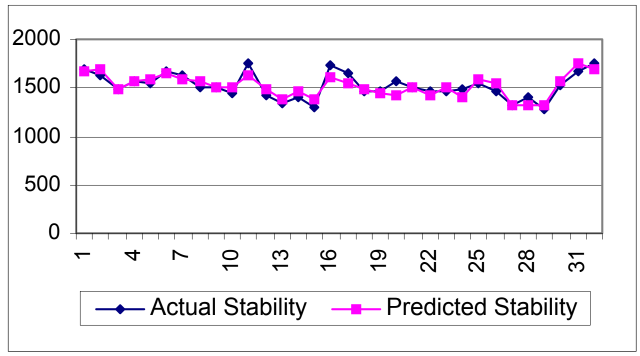

Fig.4. Comparison of actual and predicted values of *stability* for trained data.

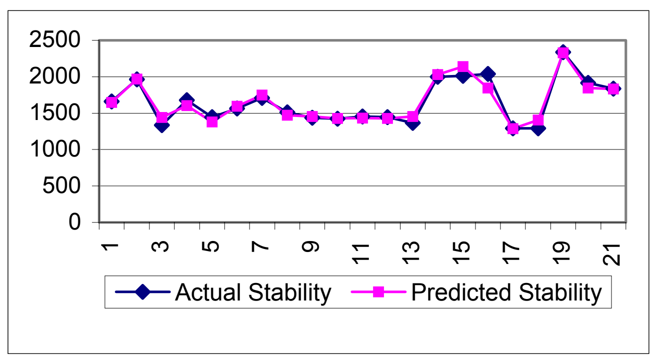

Fig.5. Comparison of actual and predicted values of *stability* for tested data.

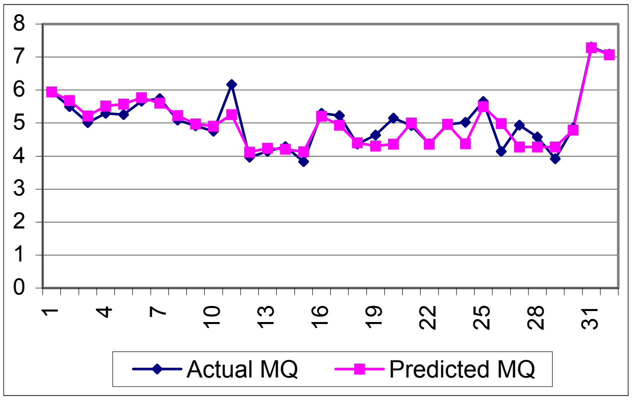

Fig.6. Comparison of actual and predicted values of *MQ* for trained data.

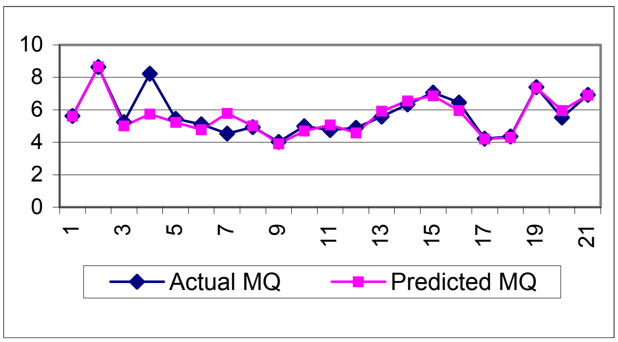

Fig.7. Comparison of actual and predicted values of *MQ* for 21 tested data.

4 Conclusions

Using the back-propagation learning rule for the data set, the developed neural networks model for the optimum bitumen content (OBC_{NN}), Marshall Stability and Marshall Quotient of asphaltic concrete mixtures was found and a model was developed and validated. However OBC_{NN}, Marshall Stability and Marshall Quotient model used more data input, it produced better performance with considerably less expense and effort to decide a priori on the class of input-output relationships.

The OBC_{NN}, Marshall Stability and Marshall Quotient model prediction was fairly close to the corresponding actual values. The successful NN mode demonstrates the highest correlation coefficients of 0.970, 0.969, and 0.862 for OBC, Marshall Stability, and MQ, respectively.

The results indicated that the OBC_{NN}, Marshall Stability and Marshall Quotient model could predict the optimum bitumen content of asphaltic concrete mixtures with adequate accuracy required for practical design purpose. Transportation and highway engineers can use this model to predict the optimum bitumen content, Marshall Stability and Marshall Quotient of asphaltic concrete mixtures quickly without conducting costly and time consuming experimental tests.

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