Prediction of Properties of Self Compacting Concrete Using Artificial Neural Network

Abdul Raheman*, Prof. P. O. Modani**

*(M E Structural Engineering, Department of Civil Engineering, B N College of Engineering, Pusad
** (Department of Civil Engineering, B N College of Engineering, Pusad

ABSTRACT

This study deals with artificial neural network (ANN) modeling to predict properties of the SCC. Data developed experimentally for SCC. The data used in the models are arranged in the format of seven input parameters that cover the contents of cement, sand, coarse aggregate, fly ash sand, water and water/powder ratio, superplasticizer dosage and an output parameter that is compressive strengths at 7 days, 28 days, 90 days, slump flow, T50 cm, V-funnel and L-Box. respectively for ANN. The importance of different input parameters is also given for predicting the strengths at various ages using neural network. It was observed that the ANN model can predict the properties of the SCC quite well with correlation coefficients, with very low root mean square errors and also check for different Epoch with the use of Neuro Solution Software. This study shows that, as an alternative to classical modeling techniques, the ANN approach can be used to accurately predict the performance parameters of SCC.

Keywords - artificial neural network, compressive strength, learning rate, self-compacting concrete.

I.   INTRODUCTION

Self-Compacting Concrete (SCC), which flows under its own weight and does not require any external vibration for compaction, has revolutionized concrete placement. Self compacting concrete (SCC) is a mixture of new concrete technologies used in developed countries, such as Japan, Europe and the United States of America (Ouchi Masahiro, 2003). SCC first developed and used in Japan since 1989 (Okumura Hajime and Ouchi Masahiro, 2003), in order to obtain concrete structure which has high durability and easy to pour the concrete mix into every corner of the mold, eliminating the noise pollution generated by the vibrator, produce smooth concrete surface without any additional finishing work, and need less manpower. The hardened concrete of SCC is dense, homogeneous and has the same properties and durability as conventional concrete.

The mix design principles of SCC, as compared to conventional concrete, contains: lower coarse aggregate content, increased paste content, low water- Powder ratio, increased superplasticiser, and sometimes a viscosity modifying admixture.

There is no standard method for SCC mix design and many academic institutions, ready-mixed industries; precast and contracting companies have developed their own mix proportioning methods. Mix designs often use volume as a key parameter because of the importance of the need to over fill the voids between the aggregate particles. Some methods try to fit available constituents to an optimized grading envelope. Another method is to evaluate and optimize the flow and stability of first the paste and then the mortar fractions before the coarse aggregate is added and the whole SCC mix tested. So in doing trial and error technique requires a long time and needs more concrete material to overcome the problems, need a tool for evaluating concrete mix composition of SCC.

In recent years, ANNs have been applied to many civil engineering applications with some degree of success. ANNs have been applied to geotechnical problem like prediction of settlement of shallow foundations. Researchers have also used ANN in structural engineering. Some researchers have recently proposed a new method of mix design and prediction of concrete strength using neural network. Also, several works were reported on the use of neural network based modeling approach in predicting the concrete strength. Some attempts have been made to describe the compressive strength properties using traditional regression analysis tools and statistical models . ANN is applied to many structural engineering problem such as [1] modeling flexural behavior of Fiber Reinforced Concrete beams [2], predicting large deflection response [3], flexible pavement thickness modeling [4] and many more. Artificial neural network is considered as one of the most important applications of artificial intelligence, which found considerable importance in practical problems. They attempt to simulate the human thinking in solving a particular problem.

However, the development of neural network models for predicting the strength of SCC has not been fully investigated. Artificial neural network (ANN) has been proposed as an alternative method for solving certain difficult problems in selecting the best mix proportion for required characteristics where the conventional techniques

have not achieved the desired speed, accuracy and efficiency.

Therefore, the objective of the present study was to examine the potential of ANN for predicting the 28-day compressive strength and workability of SCC mixtures, with the data obtained experimentally. The complex relationship between mixture proportions and engineering properties of SCC was generated based on data obtained experimentally. It was observed that the neural network could effectively predict compressive strength in spite of intricate data and could be used as a tool to support decision making, by improving the efficiency of the process

II.   ARTIFICIAL NEURAL NETWORK

A neural network, also known as a parallel distributed processing network, as computing paradigm that is loosely modeled after structures of the brain. It consists of interconnected processing elements called nodes or neurons that work together to produce an output function. The output of a neural network relies on the cooperation of the individual neurons within the network to operate. Processing of information by neural networks is characteristically done in parallel rather than in series (or sequentially) as in earlier binary computers on Von Neumann machines. Since it relies on its member neurons collectively to perform its function, a unique property of a neural network is that it can still perform its overall function even if some of the neurons are not functioning. In other words it is robust to tolerate error or failure. (See fault tolerant) Additionally, neural networks are more readily adaptable to fuzzy logic computing tasks than are Von Neumann machines.

Neural network theory is sometimes used to refer to a branch of computational science that uses neural networks models to simulate or analyze complex phenomena and/or study the principles of operation of neural networks analytically. It addresses problems similar to artificial intelligence (AI) except that AI uses traditional computational algorithms to solve problems whereas neural networks use 'networks of agents' (software or hardware entities linked together) as the computational architecture to solve problems. Neural networks are trainable systems that can "learn" to solve complex problems from a set of exemplars and generalize the "acquired knowledge" to solve unforeseen problems as in stock market and environmental prediction .i.e., they are self-adaptive systems.

Traditionally, the term neural network has been used to refer to a network of biological neurons. In modern usage, the term is often used to artificial neural networks, which are composed of artificial neurons or nodes. The term 'Neural Network' has two distinct points:

Biological neural networks are made up of real biological neurons that are connected or functionally-related in the peripheral nervous system or the central nervous system. In the field of neuroscience, they are often identified as groups of neurons that perform a specific physiological function in laboratory analysis.

Artificial neural networks are made up of interconnecting artificial neurons (usually simplified neurons) designed to model (or mimic) some properties of biological neural networks. Artificial neural networks can be used to model the modes of operation of biological neural networks, whereas cognitive models are theoretical models that mimic cognitive brain functions without necessarily using neural networks while artificial intelligence are well-crafted algorithm that solve specific intelligent problems (such as chess playing, pattern recognition, etc.) without using neural network as the computational architecture.

2.1 MODEL OF AN ARTIFICIAL NEURON:

The human brain no doubt is a highly complex structure viewed as a massive, highly interconnected network of simple processing elements called Neurons. Every component of the model bears a direct analogy to the actual components of a biological neuron and hence is termed as Artificial Neuron. It is this model which forms the basis of the Artificial Networks.

From fig. 1.2, x_1, x_2, x_3, ... c are the n inputs to the artificial neuron. w_1, w_2, w_3 ... w_n are the weights attached to the input links.

A biological neuron receives all inputs through the dendrites, sums them and produces an output if the sum is greater than the threshold value. The input signals are passed on to the cell body through the synapse, which may accelerate or retard an arriving signal. It is this acceleration or retardation of the input signals modeled by the weights. An effective synapse, which transmits a stronger signal, will have a correspondingly larger weight while a weak synapse will have smaller weights. Thus, weights here are Multicative factors of the inputs to account for the strength of the synapse. Hence, the total input I received by the soma of the artificial neuron is

$$I = w_1 x_1 + w_2 x_2 + \ldots\ldots + w_n x_n$$
$$= w_i x_i$$

To generate the final output y, the sum is passed on to the non-linear filter Φ called as Activation function or Transfer function or Squash function, which releases the output.

$$Y = \Phi(I)$$

A very commonly used Activation function is the Threshold function. In this sum is compared with a threshold value θ. If the value of I is greater than θ, then the output is 1 else it is 0.

**Abdul Raheman / International Journal of Engineering Research and Applications
(IJERA)   ISSN: 2248-9622   www.ijera.com
Vol. 3, Issue 4, Jul-Aug 2013, pp. 333-339**

$$Y= \Phi \ (\ \textstyle\sum w_i \ x_i - \theta), \quad \ldots\ldots \ ($$

i=1 to n)

Where, Φ is the step function known as Heaviside function and is such that

$$\Phi(I)=1, \ I>0$$
$$=0, \ I<0$$

2.2. Sigmoidal Function:

This function is a continuous function that varies gradually between the asymptotic values 0 and 1 or -1 and +1 and is given by

$$\emptyset \ (I) = 1/ \ (1+e^{-\grave{a}t})$$

Where $\propto$ is the slope parameter, which adjusts to the abruptness of the functions as it changes between two asymptotic values. Sigmoidal functions are differential, which is an important feature of Neural Network Theory.
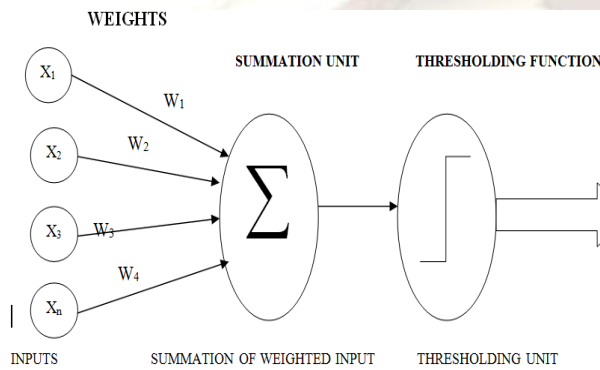

Fig 2.1 Simple model of an artificial network

III.   ANN METHODOLOGY

Artificial Neural Network models are specified by topology, node characteristics and training or learning rules. These rules specify an initial set of weights and indicate how weights should be adopted during improvement of convergence performance [4]. Broadly there are two types of ANN models namely supervised and unsupervised. In case of supervised both input patterns and output patterns are known during training [5]. The present paper adopts feed forward supervised ANN model for prediction of 'Concrete mix proportion'. The possible training parameters are number of iterations (epoch) learning rate, error goal and number of hidden layers. These parameters are varied until a good convergence of ANN training is obtained and there by fixing the optimal training parameters. These optimal parameters are used for testing and validation process. The general computational ANN model is always represented by a term topology which represents number of neurons in input layer, hidden layer and output layer as depicted in the figure [2.1]. However the numbers of neurons in the input layer and output layer are determined based on the problem domain depending upon number of input variables and number of output or target variables. The number of hidden

layers and neurons in hidden layer are fixed during the training process. The specific ANN topology model adopted in this research work is depicted in the fig [3.1].
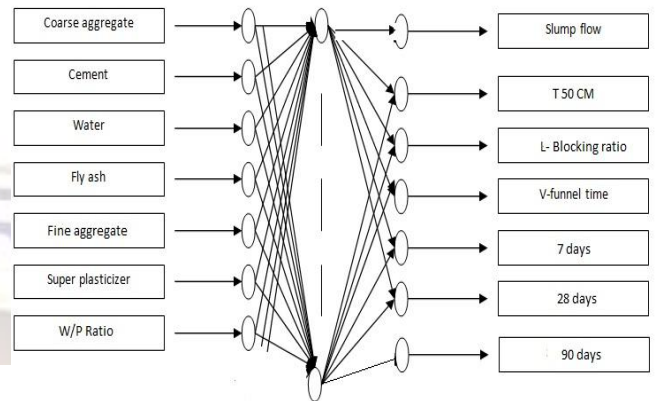

Fig 3.1 Topology to predict properties of SCC

The model's success in predicting the behavior of SCC mixtures depends on comprehensiveness of the training data. Availability of large variety of experimental data was required to develop the relationship between the mixture variables of SCC and its measured properties. The basic parameters considered in this study were cement content, sand content, coarse aggregate content, fly ash content, water-to-powder ratio and superplasticizer dosage. A database of 31 mixes from the experimentally was retrieved having mixture composition with comparable physical and chemical properties. The ANNs were designed using 31 pairs of input and output vectors for strength prediction, the predicted results obtained from neural network were compared with the experimental values obtained experimentally. The training of ANNs was carried out using pair of input vector and output vector. The complete list of input and output data is given in Table 7.1 and Table 3.2.

Table 3.1
Input Data

Mix	Cement (Kg/m3)	Fly ash (Kg/m3)	F.A (Kg/m3)	C.A (Kg/m3)	Water (Kg/m3)	S.P. (%)	W/p ratio
1	270	128	936.00	893.00	112.00	0.80	0.45
2	270	128	936.00	740.00	112.00	1.00	0.45
3	348	115	970.00	804.00	185.00	1.00	0.40
4	348	115	970.00	666.00	185.00	1.20	0.40
5	330.36	178.60	875.16	739.44	179.74	5.97	0.43
6	330.85	180.56	857.57	739.44	180.05	6.02	0.42
7	331.33	182.47	840.00	739.44	180.38	6.08	0.45
8	330.36	180.56	875.16	754.18	180.05	6.08	0.44
9	330.85	182.47	857.57	754.18	180.38	5.97	0.43
10	331.33	178.60	840.00	754.18	179.74	6.02	0.43
11	330.85	178.60	875.16	768.88	180.38	6.02	0.42
12	331.33	180.56	857.57	768.88	179.74	6.08	0.45
13	330.36	182.47	840.00	768.88	180.05	5.97	0.46
14	331.33	182.47	875.16	739.44	180.05	6.02	0.46
15	330.36	187.60	857.57	739.44	180.38	6.08	0.46
16	330.85	180.56	840.00	739.44	179.74	5.97	0.42
17	330.85	182.47	875.16	754.18	179.74	6.08	0.42
18	331.33	178.36	857.57	754.18	180.05	5.97	0.42
19	330.36	180.56	840.00	754.18	180.38	6.02	0.42
20	331.33	180.56	875.16	768.88	180.38	5.97	0.42
21	330.36	182.47	857.57	768.88	179.74	6.02	0.42
22	330.85	178.60	840.00	768.88	180.05	6.08	0.42
23	215	230	960.00	813.00	202.00	4.45	0.45
24	308	196	939.00	795.00	232.00	6.30	0.46
25	349	170	939.00	795.00	217.00	7.29	0.42
26	411	135	830.00	861.00	202.00	7.64	0.37
27	263	235	960.00	813.00	224.00	6.20	0.46
28	411	125	960.00	813.00	197.00	7.60	0.44
29	295	215	960.00	813.00	229.50	2.55	0.45
30	337	175	960.00	813.00	210.00	3.00	0.43
31	397	115	960.00	813.00	188.00	3.50	0.43

Table 3.1

Output Data

Mix	Slump flow (mm)	T50cm (sec)	V-funnel T5min c (sec)	L-box Blocking ratio(H2/H1)d	7- days (MPa)	28-days (MPa)	90-days (MPa)
1	720	1.65	5.08	0.97	19.40	27.78	35.33
2	620	2.61	6.22	0.90	15.20	22.58	27.25
3	670	2.37	6.01	0.92	28.16	38.07	46.07
4	620	2.15	6.86	0.90	23.50	32.00	39.22
5	680.00	2.10	5.10	0.78	22.23	33.54	48.40
6	740.00	1.95	4.55	0.79	30.22	43.55	57.30
7	745.00	4.00	5.20	0.77	30.10	43.80	63.80
8	750.00	2.03	5.40	0.85	26.20	38.45	61.30
9	695.00	4.00	5.43	0.82	29.35	39.53	50.45
10	740.00	2.54	5.60	0.83	34.91	42.00	53.10
11	750.00	2.20	6.70	0.89	32.65	39.35	61.10
12	705.00	4.85	5.50	0.84	33.35	40.45	55.90
13	772.50	2.00	4.90	0.81	38.46	40.00	55.30
14	725.00	2.47	4.95	0.79	26.25	35.11	57.30
15	720.00	1.98	4.70	0.80	30.40	38.20	65.60
16	747.50	2.38	5.68	0.84	30.47	39.12	53.60
17	717.50	2.10	5.80	0.83	24.22	41.34	52.90
18	715.00	1.97	6.90	0.84	26.70	34.46	47.30
19	705.00	1.90	6.02	0.87	31.35	31.35	59.26
20	725.00	2.77	6.22	0.86	28.65	33.55	51.53
21	705.00	1.94	5.98	0.88	28.22	32.60	56.60
22	700.00	1.90	6.78	0.78	25.34	36.90	58.45
23							
24							
25							
26							
27							
28							
29							
30							
31							

Evaluating the design mixes of SCC using ANNs is the aim of this study; an ANN model is constructed, trained, tested, and validated in the Neuro solution software using the available test data of concrete mix-designs. The ANN model evaluated the various properties of SCC. Architecture of ANN uses seven neurons in the input layer, one hidden layer with several neurons, and seven unit output layers. While the input layer consists of six neurons that are the amount of cement (kg/m3), coarse aggregate (kg/m3), Fine aggregate (kg/m3), fly ash (kg/m3), Superplastisizer (lit/m3), water cement ratio (%) and Water Powder ratio (%). The hidden layer uses sigmoid activation, and the output layer consists of seven neuron that are compressive strength of SCC at 7,28 and 90 days, slump flow, T50 cm, V-funnel and L-Box.

The data were randomly divided into a training phase, testing phase, and validation phase. Back propagation neural network is a three-layered

feed forward architecture. The three layers are input layer, hidden layer and output layer

IV.   RESULTS AND DISCUSSION

The acceptance / rejection of the model developed are determined by its ability to predict the properties of SCC. Also, a successfully trained model is characterized by its ability to predict properties value for the data it was trained on.8 fold cross validation is used to predict the properties of SCC for the data set used in this study. The cross validation is the method of accuracy of a classification or regression model. The input data set is divided into several parts (a number defined by the user), with each part intern used to test a model fitted to the remaining part. The correlation coefficient, root mean square error (RMSE), and mean absolute error is used to judge the performance of the neural network approach in predicting the strength. Neural networks can be effective for analyzing a system containing a number of variables, to establish patterns and characteristics not previously known

In the present study, Mix design of SCC using ANN using Neuro Solution Software has been carried out. The objective of this study is to predict various properties of SCC

After Training the given data, the train neural network diagram is obtained as shown in Fig. 4.1. A graph also obtains which gives the error of each step of the training and summarizes the number of epoch in each state (The graph below shows the MSE (mean square error) Vs Epoch). This data is shown in Graph.4.1
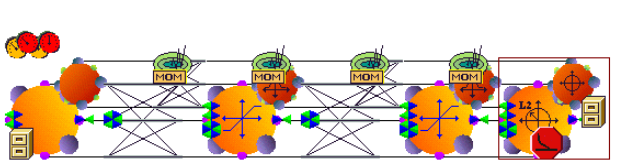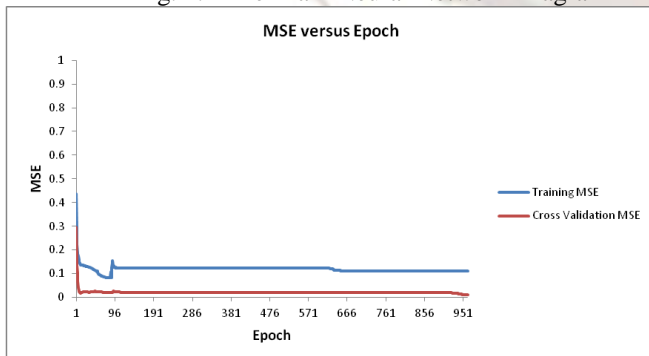

Fig. 4.1 The Train Neural Network Diagram

Fig. 4.2 The Graph Mean square error Vs Epoch

After testing data a graph obtains, this graph gives the relation between the input values (i.e. output parameters) that we gave and predicted output which are given by the Neuro solution
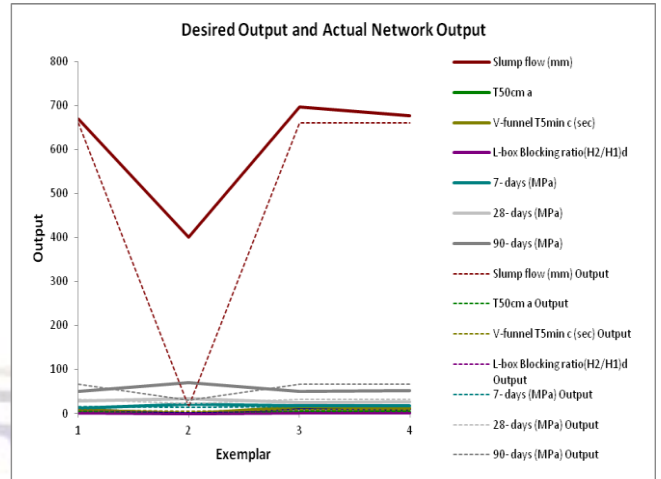

Fig. 4.3 The Graph Output vs. Exemplar

Table 4.1
Predicted output which is given by the Neuro solution

Mix	Slump flow (mm)	T50cm (sec)	V-funnel T5min c (sec)	L-box Blocking ratio(H2/H1)d	7-days (MPa)	28-days (MPa)	90-days (MPa)
23	609.035	1.56	4.29	0.89	12.59	20.36	58.78
24	657.9325	4.55	4.31	0.84	19.68	38.97	66.62
25	744.4819	4.43	4.45	0.90	30.42	45.87	70.20
26	785.4451	3.80	7.18	0.89	38.88	46.06	70.20
27	662.4961	1.96	4.27	0.87	14.87	26.94	66.91
28	754.057	4.99	6.74	0.83	37.07	46.29	70.15
29	732.1142	4.85	4.26	0.94	18.02	44.84	70.36
30	741.5921	5.24	4.28	0.89	26.28	46.24	70.22
31	770.6168	5.20	5.76	0.841371	36.85095	46.31	69.12

**Abdul Raheman / International Journal of Engineering Research and Applications
(IJERA)   ISSN: 2248-9622   www.ijera.com
Vol. 3, Issue 4, Jul-Aug 2013, pp. 333-339**

V.   CONCLUSION

In this study, the Artificial Neural Network is used for prediction of Properties of SCC. The back propagation neural network has been developed for prediction of SCC. Effect of various parameters like W/C ratio, w/p ratio, admixtures, has been studied. Present study shows that back propagation neural network could be trained for future prediction of SCC properties. The predicted properties of SCC from neural network are very close to the actual properties of SCC measured experimentally.

Following observations were made regarding neural network-
1.Cement, FA, CA, fly ash, water, w/p ratio, sp were given as input and compressive strength of SCC at 7,28 and 90 days, slump flow, T50 cm, V-funnel and L-Box was estimated using different structures of ANN. These can be used to train the neural network for getting the estimated values of SCC.

2. Predicted values and experimental output values of properties of SCC for different combination of Concrete mix ingredient depicted. The Correlation coefficient is 0.999 between estimated values of properties of SCC and predicted values of same from ANN. The present study signifies the strong accuracy of predicted values. All the results obtained in this study supports usage of ANN.

3. And also to be able to train a neural network, there must be either a logical linear relation or a logical non linear relation between the input and output.

This study of Artificial Neural Network model will provide an efficient and rapid means of obtaining optimal solutions to predict the optimum mix proportions for specified strength and workability for sustainable SCC. It is possible to produce SCC mix design with various compositions for a given range of targeted slumps and compressive strength and others properties. The application of ANN in the field of SCC mix design is very appropriate in order to preserve and disseminate valuable experience and innovation efficiently at reasonable cost.

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