Concrete Mix Design Using Neural Network

Rama Shanker, Anil Kumar Sachan

***Abstract*—**Basic ingredients of concrete are cement, fine aggregate, coarse aggregate and water. To produce a concrete of certain specific properties, optimum proportion of these ingredients are mixed. The important factors which govern the mix design are grade of concrete, type of cement and size, shape and grading of aggregates. Concrete mix design method is based on experimentally evolved empirical relationship between the factors in the choice of mix design. Basic draw backs of this method are that it does not produce desired strength, calculations are cumbersome and a number of tables are to be referred for arriving at trial mix proportion moreover, the variation in attainment of desired strength is uncertain below the target strength and may even fail. To solve this problem, a lot of cubes of standard grades were prepared and attained 28 days strength determined for different combination of cement, fine aggregate, coarse aggregate and water. An artificial neural network (ANN) was prepared using these data. The input of ANN were grade of concrete, type of cement, size, shape and grading of aggregates and output were proportions of various ingredients. With the help of these inputs and outputs, ANN was trained using feed forward back proportion model. Finally trained ANN was validated, it was seen that it gave the result with/ error of maximum 4 to 5%. Hence, specific type of concrete can be prepared from given material properties and proportions of these materials can be quickly evaluated using the proposed ANN.

***Keywords*—**Aggregate Proportions, Artificial Neural Network, Concrete Grade, Concrete Mix Design.

I. Introduction

CONCRETE is the most commonly used building material. It has the advantage of being formed into any desired shape conveniently. The method of concrete mix design consists of selection of optimum proportion of cement, fine and coarse aggregate and water to produce a concrete of specified proportion. Mix design in the strict sense of the word is not true: the materials used are variable in a number of respects and many of their properties cannot be assessed truly quantitatively, so that we are really making no more than an intelligent guess at the optimum combinations of the ingredient on the basis of the relationships established [1]. Further, it is practically impossible to achieve the design strength of the mix in the field and what is realized in the field is somewhat around the design strength [2]. Therefore, that in order to obtain a satisfactory mix we must check the estimated proportion of the mix by making trial mix and, if necessary, make appropriate adjustments to the proportion until a satisfactory mix has been obtained [3].

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In this paper artificial neural network (ANN) approach has been adapted to solve this problem.

II. Factors Governing Concrete Mix Design

Compressive strength is one of the most important properties of concrete and influences many other describable properties of the hardened concrete. Because the strength of concrete is adversely and significantly affected by the presence of voids in the compacted mass, it is vital to achieve a maximum possible density [4]. This requires a sufficient workability. Workability depends on a number of interacting factors: water content, aggregate type and grading, aggregate/ cement ratio and finesse of cement. The desired workability also depends on the compacting equipment available at the site. The compressive strength tends to increase with the decrease in size of aggregate. IS 456:2000 and IS 1343:1980 recommend that the nominal size of the aggregate should be as large as possible [5], [6]. The durability of concrete is its resistance to the aggressive environmental conditions. High strength concrete is generally more durable than low strength concrete. In the situations when the high strength is not necessary but the conditions of exposure are such that high durability is vital, the durability requirement will determine the water-cement ratio to be used. The grading of aggregate also influences the mix proportions for a specified workability and water-cement ratio. Coarser the grading leaner will be mix which can be used. The type of aggregate influences strongly the aggregate-cement ratio for the desired workability and stipulated water cement ratio. An important feature of a satisfactory aggregate is the uniformity of the grading which can be achieved by mixing different size fractions. The degree of control can be estimated statistically by the variations in test results. The variation in strength results from the variations in the properties of the mix ingredients and lack of control of accuracy in batching, mixing, placing, curing and testing. The lower the difference between the mean and minimum strength of the mix lower will be the cement-content required. The factor controlling this difference is termed as quality control.

III. Factors Governing Concrete Mix Design

The grade of concrete refers to its characteristic strength. The concrete mix is designed for a target mean strength so that the concrete manufactured with an assumed degree of quality control confirms to the requirement of strength. The type of cement influences the rate of development of strength of the concrete as well as durability under aggressive environment. High strength ordinary Portland cement is preferred for concrete of high compressive strength. Strength of concrete mix depends upon water/cement ratio. However, concrete mixes having high cement content give rise to increase shrinkage. Cracking and creep of concrete also increase with increase in cement paste. Hence, proportion of cement should be optimum. The grading of aggregate influences the mix proportion for a desired strength and workability. The strength of a fully compacted concrete with a given water to cement ratio in independent of the grading of aggregate but it affects the workability of a concrete. The aggregate of coarser grading requires more fines to produce a cohesive concrete. Aggregate of finer grading affects workability as the total surface area increases, resulting in the requirement of more water. Since the combined aggregate is obtained by mixing fine and coarse aggregate in suitable proportion, the grading of both fine and coarse aggregate are important and should be controlled.

IV. Method for Concrete Mix Design

The Bureau of Indian Standards recommends a set of procedure for design of concrete mix [5]. The following basic steps are involved in the mix design [3].

1) Determine the mean strength from the characteristic strength
2) Determine the water to cement ratio from strength requirement and check for the requirement of durability.
3) Determine water content from the requirement of workability.
4) Determine the cement content and check for the requirement of durability.
5) Determine the relative proportion of coarse and fine aggregates from their characteristics.
6) From the concrete mix proportion so obtained, trial mixes with suitable adjustments are made to arrive at the final mix proportions.

V. Numerical Procedure

The proportions of all ingredients were calculated according to provisions of IS codes [7]-[10] for a standard concrete (grade M25 to M55) [5]. At least six cubes (one set) were prepared with dimension 150 x 150 x 150 mm using the calculated ingredients. The average 7 days and 28 days compressive strengths were evaluated by destructive test. Hence, data is generated for one set of concrete cubes. One set data comprised weight of cement, water, fine aggregate, coarse aggregate 10mm and 20mm, fineness modulus of fine aggregate, fineness modulus of coarse aggregates, characteristic strength of design mix, targeted strength, grade of cement, workability of concrete, compressive strength at 7 days and 28 days. A number of sets were prepared by changing the proportion of ingredient and 7 days, 28 days compressive strengths were evaluated. Hence, data were generated for each set of concrete. An artificial neural network was prepared using these data sets. The inputs of ANN were finenesses modules of fine and coarse aggregates, target strength of design concrete, workability of concrete and grade of cement and outputs were weight of cement, water, fine aggregate, coarse aggregate of 10mm and 20mm sizes.

VI. Neural Network

Neural network is defined as a mathematical model composed of a large number of processing elements organized into layers. They process many inputs simultaneously, strengthening some, weakening others, to get the desired output. The neural network technique is particularly useful for determining a nonlinear system with a number of variables [10]. No predefined mathematical relationship between the variables was assumed. Instead the neural network learns by examples fed. In structural engineering, neural networks have been used successfully in diverse fields such as structure control, design of expert systems, sub structural identifications and sequential analysis of tall buildings etc. [11].

A. Configuration of the Neural Network

Neural network model was chosen with neurons in all layers fully connected in the feed forward manner. Sigmoid function was used as an activation function and the back propagation model-learning algorithm was used for training. The inputs consist of six parameters: finenesses modules of fine and coarse aggregates of 10mm and 20mm, target strength of design concrete, workability of concrete and grade of cement and output were weight of cement, water, fine aggregate, 10mm coarse aggregate and 20mm coarse aggregate. With the help of these input and output; ANN was trained using feed forward back proportion model in MATLAB environment. One hidden layer is chosen in which the number of neurons is decided in the learning process by trial and error. Since the training of neural network comprises an essential step in its performance, a sufficiently large data base should be generated for the training process. The performance in the term of generalization and prediction qualities of neural network depend significantly on the training data and the domain these data cover.

B. Training

Increasing the number of the training patterns provides more information about the shape of the solution surface, and thus increases the accuracy that can be achieved by the network. A large training pattern set, however, can sometimes overwhelm certain training algorithm, thereby increasing the like hood of an algorithm becoming struck in a local error minimum. Deciding the number of training patterns is thus a trial and error procedure. The distribution of the training pattern within the problem domain can have a significant effect on the learning and generalization performance of the network. Since ANN is not usually able to extrapolate, the training patterns should go at least to the edges of the problem domain in all dimensions. The number of hidden layers and the number of neurons have been varied to study their effect on the least mean square error. The general guideline for choosing the number of hidden layers is the fact that the size of the intermediate layers must be large enough to allow a proper separation of elements of the training set and restricted enough for the network to have a good chance to generalize properly. After several trials, number hidden layers and number of neurons in each hidden layer were decided and network was finalized for validation.

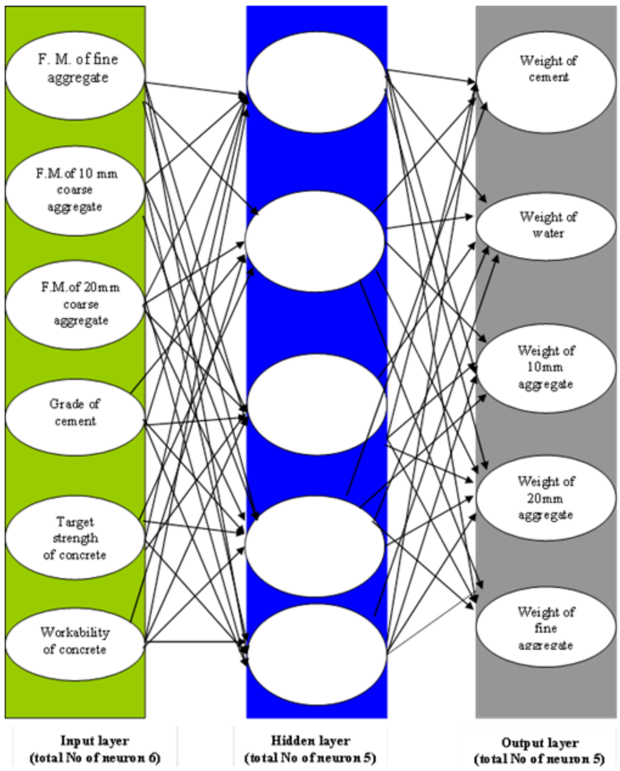

Fig. 1 Configuration of ANN

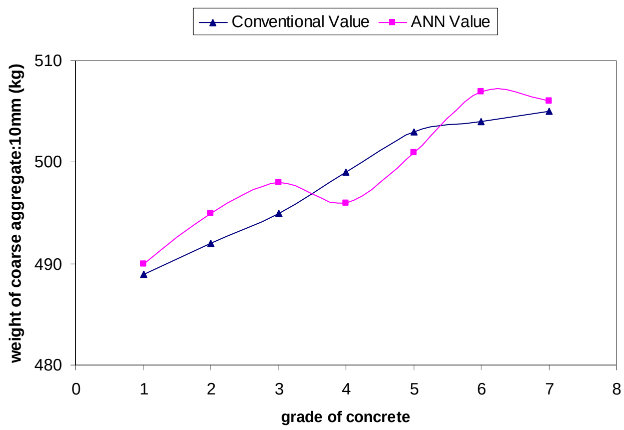

Fig. 2 Comparison of cement/weight per meter cubic concrete for various mix grades

C. Validation

Neural network has been tested for the data which it was trained and it had been observed that there was very close agreement between the value of the data set and that obtained from the neural network. A good neural network should also be capable to provide satisfactory solution to the problem for which it has not been trained. Validation of network was done for a number of data sets which were different from training data. For this purpose values of the data set were considered which comprised the material properties of 43 grade of cement, fineness modules of fine aggregate = 2.05, coarse aggregate (10 mm) = 6.42,coarse aggregate (20 mm) = 7.11, and workability = 60 mm in terms of slump. Keeping the material properties and workability constant, the proportion of different ingredients were obtained forM25, M30, M35, M40, M45, M50, and M55 grade concrete from the data set (not used in training). The proportions of different ingredients were also obtained by trained ANN using above inputs. These values were compared and the compassions are shown in Figs. 2-5. It was found that the proportions of ingredient from data set were in close agreement with the output values of ANN.

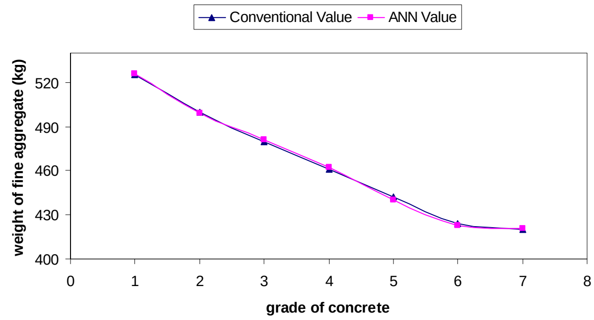

Fig. 3 Comparison of fine aggregate weight per meter Cubic concrete obtained from ANN and conventional method for various mix grades

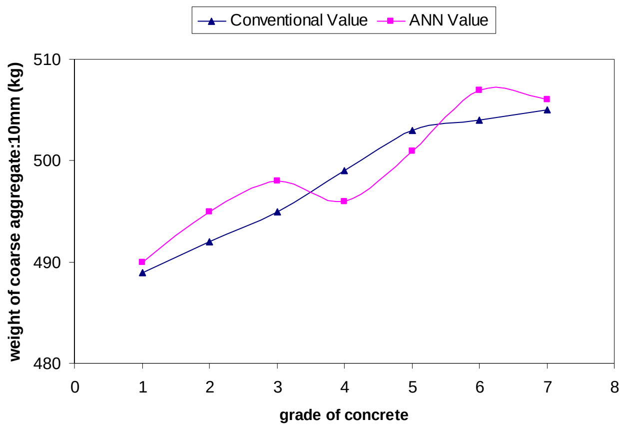

Fig. 4 Comparison of 10 mm coarse aggregate/weight per meter cubic concrete for various mix grades

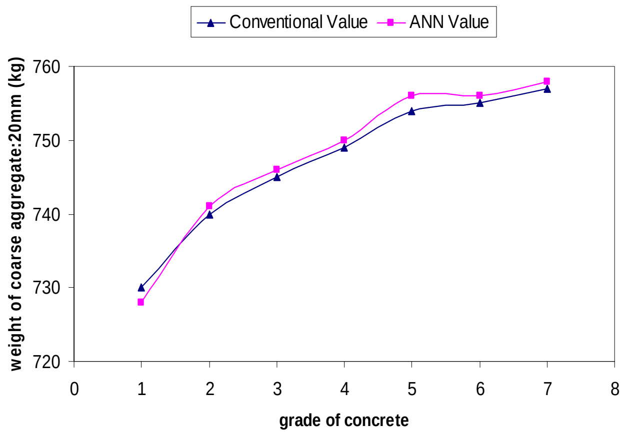

Fig. 5 Comparison of 20 mm coarse aggregate/weight per meter cubic concrete for various mix grades

VII. Design Steps

The steps to be followed to arrive at the proportions of ingredients for one cubic meter of standard concrete mix are summarized in this section.

Step 1. Evaluate the fineness modules (F.M.) of fine and coarse aggregates (10 mm and 20 mm)

Step 2. Evaluate the target strength of the design concrete using characteristic strength, risk factor and standard deviation.

Step 3. Determine the other input parameters: workability and grade of cement.

Step 4. These values (finenesses modulus of fine and coarse aggregates, target strength, grade of cement and workability) can be given as input in trained and validated ANN.

Step 5. Evaluate all outputs of ANN: Weight of cement, water, fine aggregate, coarse aggregate 10mm and 20mm.

VIII. Discussion

There were six input parameters and five output parameters in developed ANN. The proposed ANN was validated and outputs predicted by developed neural network were fairly accurate in a range of 95 to 98%. The developed neural network is simple and yields good results for standard concrete. There will be no requirement of tables and graphs for the design of concrete mix.

IX. Conclusion

An ANN has been developed using finenesses modulus of fine and coarse aggregates, target strength of design concrete, workability of concrete and grade of cement as inputs and weight of cement, water, fine aggregate, 10 mm coarse aggregate and 20 mm coarse aggregate as outputs. The design trials can be reduced using developed ANN. This is quite simple and is particularly useful in saving calculation time and effort. Concrete can be made in the most economical manner using proposed approach.

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