The Application of SCT for Concrete Mix Proportions Prediction

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ABSTRACT

This study helps to achieve concrete mix proportions by using Soft computing techniques like equation-driven and artificial neural networks.Traditional concrete mix design methods consumes more time and it involves various trails and design parameters, this may leads new concrete mix designers struggle to choose the water-cement ratio and superplasticizer amount. These difficulties lead for failure to achieve optimum concrete mix proportions. In this case study manually developed optimal concrete mix proportions of different parameters are used to generate coefficeints to predict concrete mix proportions using Gauss elimination techniques with minimal human effort. Likewise optimum weighted matrices are also developed by ANN approach. Thus, fresh civil engineers can predict concrete mix proportions using coefficients or weighted matrices.Hence, rather than conduction more number of samples of different mix proportions to be tested, soft computing techniques can be used to predict optimum concrete mix proportions.

Keywords—Concrete Mix; ***E***quation Driven Technique; ANN;

I. INTRODUCTION

"Concrete, being a vital component of all infrastructures, is a composite material consisting of sand (fine aggregate), cement (binder), coarse aggregate (crushed or gravel stones), water, and admixtures (optional). The process of determining the optimal proportions of these ingredients is known as concrete mix design. In this regard, the Bureau of Indian Standard recommends the use of IS-10262-2009 code for designing concrete mix proportions. However, this code involves complex graphs and tables, requiring a high level of expertise in interpolation and graph reading. Traditionally, deciding mix proportions using conventional methods is time-consuming and demands a considerable amount of human resources, making it impractical for smaller and medium-sized projects [1]. To address these challenges, our present study aims to overcome these difficulties by adopting soft computing techniques. Specifically, we employ an equation-driven technique and Artificial Neural Network (ANN) as soft computing approaches.

The equation-driven technique involves generating coefficients through the Gauss elimination method to predict concrete mix proportions. On the other hand, the ANN approach is a data-driven method that learns from known examples, storing the results in a weighted matrix based on the acquired knowledge [2]. This fundamental idea is applied in our study to estimate new concrete mix proportions, particularly those involving fly ash. By leveraging soft computing techniques, our study seeks to develop an optimum concrete mix proportion dataset for various input parameters. This approach not only streamlines the process but also eliminates the monotony and inefficiency associated with conventional methods. Ultimately, our goal is to enhance the efficiency and accuracy of concrete mix design for improved project outcomes."

Numerous articles have explored the application of soft computing techniques in predicting concrete mix proportions and related properties. For instance [3] utilized a feed-forward supervised ANN model to predict concrete mix proportions, finding that it effectively addresses situations where conventional laboratory approaches encounter difficulties. The ANN technique demonstrates its capability to generalize and predict mix proportions accurately.

The employed a feed-forward supervised ANN model to predict strength characteristics of fly ash embedded cement concrete discussed in [4]. Their developed ANN model proved successful in predicting compression, shear, and flexure strength of fly ash concrete without relying on laboratory experiments or complex equations, yielding results within acceptable limits and minimizing errors. In another study, [5] applied a back propagation neural network model to predict the mix proportion for M25 grade concrete. They found that the ANN technique outperformed regression analysis, offering more efficient results. Explored the use of fuzzy logic, ANFIS, and feed-forward back propagation neural networks to study the compressive strength of ready mix concrete [5]. Their findings suggest that the ANN model, especially when incorporating additional parameters, provides easily usable and less scattered appraisal esteem results. The prediction of mechanical properties of cement containing class C fly ash using ANN and regression techniques demonstrated in [6].

Comparing the predicted values of regression models, they found that feed-forward networks closely aligned with the test results. Moreover, in [8] highlighted Genetic Algorithms and Artificial Neural Networks as major soft computing techniques in the civil engineering field highlighted in [8]. These techniques serve as time-saving computing tools, effectively replacing time-consuming conventional approaches.

II. PROPOSED METHODOLOGY

In this study, the concrete mix design is based on the utilization of specific materials conforming to relevant standards. Ordinary Portland cement (OPC) adheres to (IS 12269-1987), while fine aggregate (IS 383-1970), coarse aggregate (IS 383-1970), portable water (IS: 456-2000, section 5.4), and Superplasticizer (IS: 9103 - 1999) are also incorporated. Additionally, fly ash, conforming to (IS 3812 -2003 part 1), is explored as a potential replacement for OPC as a binding material. The concrete mix design follows the guidelines of IS 10262-2009, encompassing both reinforced cement concrete and plain cement concrete. The cement content adheres to the prescribed limits in table 5 of IS 456-2000 and IS 10262-2000, with consideration for minimum and maximum cement content values.

Various scenarios are examined during the concrete mix design process. Slump values of 75 mm and 100 mm are tested, while the aggregate size is kept constant at 20 mm. Different exposure conditions, such as mild, moderate, and severe, as well as varying degrees of supervision (good and fair), are taken into account. Moreover, the study explores the influence of different zones of fine aggregate (zones 1, 2, 3, and 4) and the effects of using both rounded and angular shaped aggregates on the proportions of concrete mix ingredients. Furthermore, fly ash is introduced as a partial replacement for cement content at three different levels: 10%, 20%, and 30%. This replacement is analyzed to understand the variations in the concrete mix proportions. To assess the overall performance of the mix, different grades of concrete ranging from 15 Mpa to 40 Mpa (15, 20, 25, 30, 35, and 40 Mpa, respectively) are considered.

The concrete mix proportions for different sets of input parameters were initially determined manually, following the IS 10262-2009 norms. The input parameters included fly ash, minimum and maximum cement content, water content, grade designation, nominal size of aggregate, slump value, exposure condition, degree of supervision, type of aggregate, specific gravity of cement, fine and coarse aggregate, water absorption of fine and coarse aggregate, zone of fine aggregate, and purpose of concrete. On the other hand, the output parameters comprised the quantity of cement, fly ash, water, fine and coarse aggregate, water-cement ratio, and Superplasticizer.

The methodology employed for predicting concrete mix design using ANN is visually presented in Figure 1. To facilitate the training and prediction processes of Artificial Neural Networks (ANN), over 400 sets of data were generated and Topology of ANN model used for predicting concrete mix proportion is presented in figure 2.Additionally, the same dataset was used for generating coefficients through the Gauss elimination method. .In this process, the 'backslash' function of MATLAB was effectively utilized to develop coefficients for forecasting concrete mix proportions through the Gauss elimination technique.

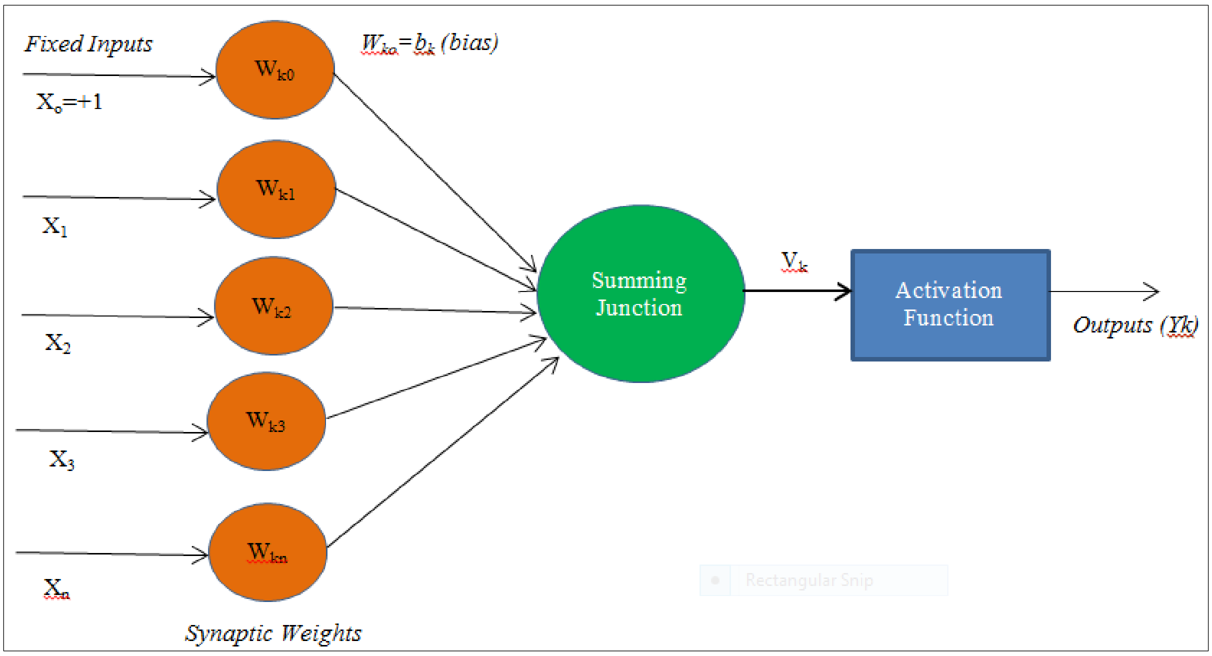

Figure 1.The General mathematical model of Artificial Neural Network

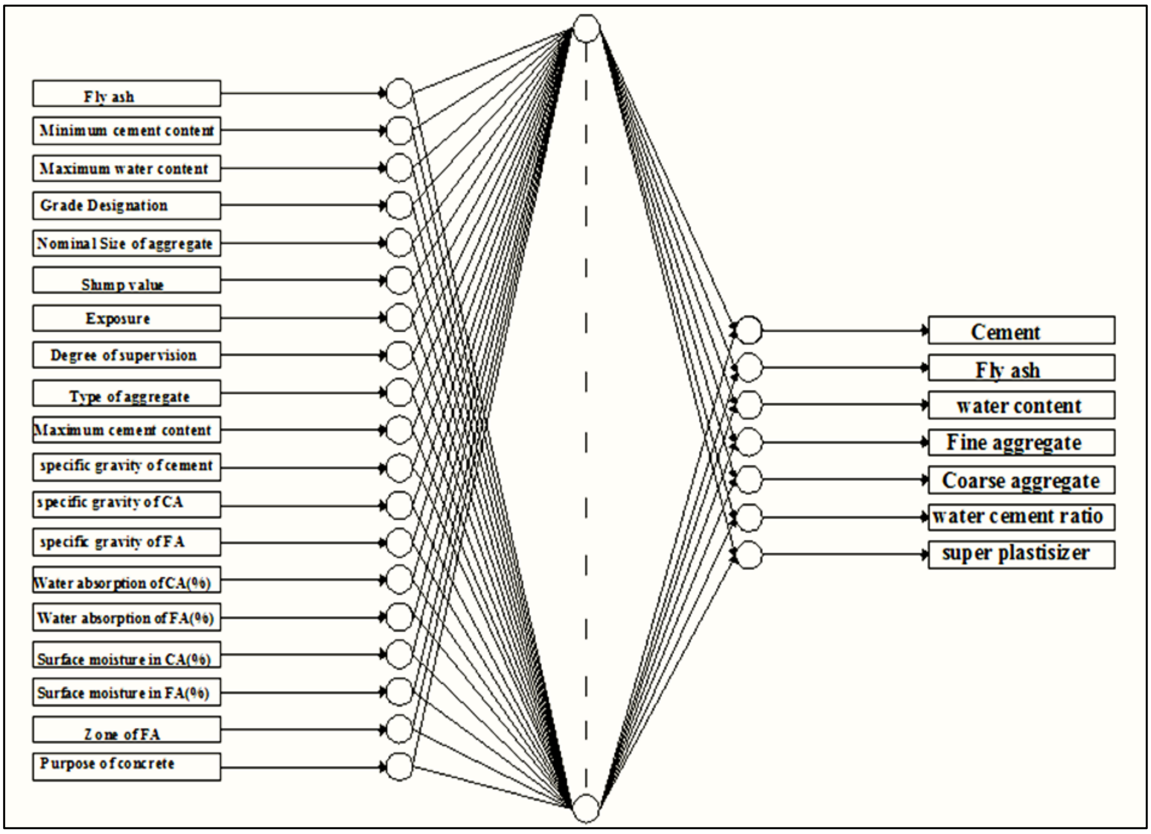

Figure 2. Specific ANN Topology

III. RESULTS AND ANALYSIS

In this study, the concrete mix design optimization is pursued using two distinct approaches: an equation-driven technique and an Artificial Neural Network (ANN) approach. The ANN topology utilized for predicting the concrete mix proportions is represented in Figure 3. To validate the developed optimum weighted matrix of the ANN for different mix proportions, Table No. 1 presents the corresponding values. Additionally, Table No. 2 displays the coefficients obtained from the equation-driven technique used to forecast concrete mix proportions. In Table No. 3, a comprehensive comparison is made between the results obtained by manually applying the IS 10262-2009 code and those predicted through the equation-driven technique and ANN approach. The training convergence curve, depicted in Figure 4, showcases the supervised training process of the ANN, plotting Epoch versus Mean Square Error (MSE), which demonstrates a reduction in MSE with the increasing number of epochs.

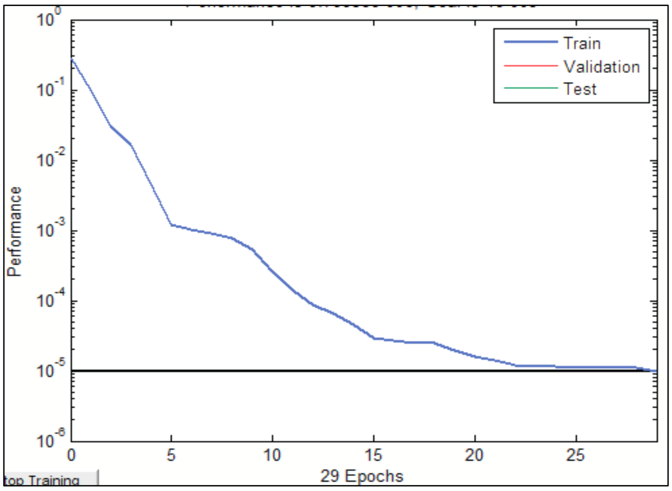

Figure 3. Convergence curve for artificial neural networks

Table No. 1: Properties of Concrete Mixing Components Used to Verify the ANN and Equation-Driven Approach

Sl. No	Type of aggregate (Angular=1, Rounded=2)	Degree of quality control (Good=1, Fair=2)	Slump	Sand zone	Type of exposure (mild=1, Moderate=2, Sever=3)	Purpose of concrete (RCC=1, PCC=2)
1	1	1	75	1	1	1
2	2	2	100	2	2	2
3	2	1	75	3	3	1
4	1	2	100	4	2	2
5	2	1	75	1	1	1
6	1	2	100	2	3	2
7	2	1	75	3	1	1

Table No. 2: Sample Results of Equation-Based Method for Calculating Coefficients

Sl. No	Cement	Fly ash	Water content	Fine aggregate	Coarse aggregate	Water cement ratio	Super plasticizer
1.	1	1.5872	0.0001	0.2699	0.5203	0.0041	0.02
2.	1	0.0013	0.0007	0.0417	0.1307	0.0941	0.02
3.	1	0.0133	0.0005	0.7693	0.9862	0.8767	0.02
4.	1	0.0041	0.0002	0.0454	0.0695	0.0689	0.02
5.	1	0.0001	0.0001	0.0001	0.0001	0.0001	0.02
6.	1	0.0001	0.0167	0.0209	0.0419	0.0183	0.02
7.	1	0.0046	0.0001	0.0300	0.0260	0.0295	0.02
8.	1	0.0007	0.0002	0.0021	0.0008	0.0008	0.02
9.	1	0.0014	0.2089	0.2941	0.5673	0.1931	0.02
10.	1	0.0001	0.0001	0.0001	0.0001	0.0001	0.02
11.	1	0.0001	0.0001	0.0001	0.0001	0.0001	0.02
12.	1	0.0001	0.0001	0.0001	0.0001	0.0001	0.02
13.	1	0.0001	0.0001	0.0001	0.0001	0.0001	0.02
14.	1	0.1224	0.3228	0.3164	0.3207	0.0487	0.02
15.	1	0.0001	0.0001	0.0001	0.0001	0.0001	0.02

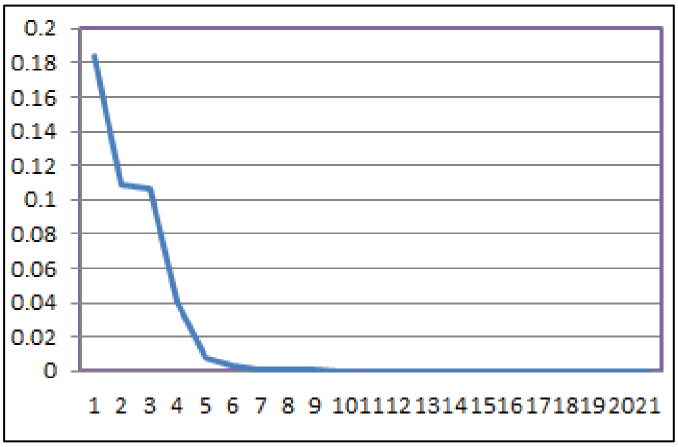

Figure 4. Epoch-time curve against mean-square error

The Figure 4 provides a graphical representation of MSE versus epochs, illustrating the variation in MSE between predicted data from the ANN and experimental data during the training process. It is evident from this graph that the value of MSE decreases as the epoch number increases, indicating the improvement in accuracy during training. The results obtained from the equation-driven technique and ANN approach exhibit high accuracy when compared to the manual approach, with success rates of 96% and 93%, respectively. These findings emphasize the successful application of soft computing techniques in predicting concrete mix proportions effectively.Comparison of obtained concrete mix proportions between IS 10262 -2009 Code, Equation Driven Technique and Artificial Neural Networks are shown Table No. 3 to 4 respectively.

Table No. 3 Obtained concrete mix proportion proportions using IS 10262- 2009 Code

Sl no	Proportion of Cement	Flyash content	Water content	Proportion of Fine aggregate	Proportion of coarse aggregate	Water cement Ratio	Super Plasticizer content
1	1	0.111	153.26	1.81	3.12	0.36	0.02
2	1	0.429	132.66	3.908	6.306	0.442	0.02
3	1	0.25	157.73	1.725	3.81	0.37	0.02
4	1	0.111	153.26	2.235	4.198	0.45	0.02
5	1	0.25	153.26	2.282	4.402	0.42	0.02
6	1	0.111	153.26	1.783	3.832	0.4	0.02
7	1	0.111	157.70	1.533	3.387	0.37	0.02

Table No. 4 Predicted concrete mix proportions using Equation Driven Technique

Sl no	Proportion of Cement	Flyash content	Water content	Proportion of Fine aggregate	Proportion of coarse aggregate	Water cement Ratio	Super Plasticizer content
1	1	0.104	153.63	1.890	3.139	0.370	0.02
2	1	0.423	132.69	3.548	6.414	0.474	0.02
3	1	0.25	157.73	1.754	3.436	0.35	0.02
4	1	0.104	153.57	2.33	4.313	0.45	0.02
5	1	0.263	153.55	2.369	4.538	0.423	0.02
6	1	0.105	153.57	1.852	3.973	0.41	0.02
7	1	0.104	157.73	1.54	3.517	0.35	0.02

Table No. 5 Predicted concrete mix proportions using Artificial Neural Networks

Sl no	Proportion of Cement	Flyash content	Water content	Proportion of Fine aggregate	Proportion of coarse aggregate	Water cement Ratio	Super Plasticizer content
1	1	0.111	153.26	1.732	3.225	0.36	0.02
2	1	0.428	132.26	2.87	4.896	0.36	0.02
3	1	0.269	157.72	1.809	4.082	0.38	0.02
4	1	0.111	153.26	1.698	3.424	0.37	0.02
5	1	0.25	153.33	2.139	3.621	0.37	0.02
6	1	0.111	153.26	1.535	2.981	0.36	0.02
7	1	0.111	157.7	1.501	3.11	0.43	0.02

IV. CONCLUSION

This study lead to the conclusion that soft computing techniques can be effectively utilized for predicting concrete mix proportions, especially in scenarios where the traditional manual approach becomes challenging. The investigation demonstrates the capability of these techniques to establish relationships between various uncertain parameters and multiple input/output criteria. The advantage of using soft computing techniques lies in their ability to provide optimum concrete mix proportions without the need for iterative procedures. This approach significantly reduces manual involvement and minimizes the associated errors. Moreover, the predicted results from both the equation-driven technique and the ANN approach closely align with the manually derived conventional results based on IS 10262:2009 standards. This close correlation encourages the adoption of soft computing techniques for deriving optimum concrete mix proportions. The implications of these findings are particularly significant for less experienced civil engineers or structural engineers. The user-friendly nature of soft computing techniques empowers these professionals to effectively forecast concrete mix proportions without extensive expertise, making it a valuable tool in the field of concrete mix design.

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