# PREDICTION OF STEEL FIBRE REINFORCED CONCRETE (SFRC) STRENGTH USING ARTIFICIAL NEURAL NETWORK (ANN) MODELS, RESPONSE SURFACE METHODOLOGY (RSM) MODELS AND THEIR COMPARATIVE STUDY

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***Abstract: There is various methodologies and mathematical models developed to predict the steel fiber reinforced concrete strength (SFRC) and these methods are prominently used in their time. Due to enhancement in the technology new mathematical models are developed and compared them with the old ones, as per their fit and comparative betterment, these methods become significant for the use by the scientists, researchers and mathematicians. In the research paper discussed here has an objective to develop a new mathematical approach to predict the SFRC strength using two newly introduced models namely Artificial Neural Network Simulation (ANN) and Response surface methodology (RSM) to analyse Aspect ratio, Aggregate-cement ratio, Water-cement ratio, Percentage of fibre and Control strength (referred to as five pi terms).***
***The comparison of these two methods with experimental strength shows the output for the best fit, the study further extended to compare between these two models with each other to find best fit out of these two models. The calculation of the influence of pi terms, mentioned above to predict the SFRC, make this study more fruitful.***

***Keywords: ANN model, RSM model, π -terms, SFRC strength.***

## 1. INTRODUCTION

*1.1 Artificial Neural Network Simulation.*
There are three major layers in Artificial Neural Network Simulation namely input layer, hidden layer and output layer. Its nodes represent neurons of the brain. The specific mapping performed depends upon the architecture and synaptic weight values between the neurons of ANN network. An artificial neural network is highly distributed representation and transformation that works in parallel. The control is distributed by highly interconnected. It is utmost important to compare the data generated through, experimentally observed data and ANN data to validate the phenomenon.
Procedure for Artificial Neural Network Phenomenon.

The separation of the observed data from the experimentation is done into two parts viz. input data or the data of independent π −terms and the output data that is the data of dependent π − terms. The input data

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and output data are then imported to the program. Through principle component analysis, the normalized
data is uncorrelated. This is achieved by using "prestd" function. Testing, validation and training the three major categories of the input and output data. The common practice is to select initial 75% training, last 75% data for validation and middle overlapping 50% data for testing. This is achieved by developing a proper code.

1. The data is then stored in structures for training, testing and validation.
2. Looking at the pattern of the data feed forward back propagation type neural network is chosen.
3. This network is then trained using the training data. The computational errors in the actual and target data are computed and then the network is simulated.
4. The uncorrelated output data is again transformed on to the original form by using "poststd" function.
5. After simulating the ANN, it is found that experimentally observed values are very close and in good agreement with the ANN predicted values.

Figure 1 shows simple multilayer feed forward network for ANN and Figure 2 depicts the flow diagram of ANN simulation.

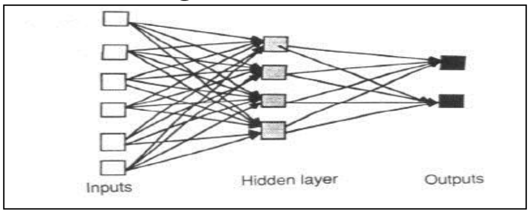


Figure 1 Simple multilayer feed forward network (ANN)

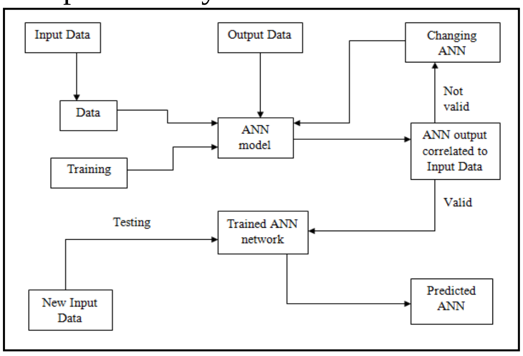


Figure 2 ANN Simulation flow diagram

*1.2 Response Surface Methodology (RSM) Models*

Response surface methodology (RSM) is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the aim is to optimize this response [14-15].
The objective of Response Surface Methodology is:

- How is a particular response affected by a given set of input variables over some specified region of interest?
- What values of the inputs will yield a maximum (or minimum) for a specific response?
- What is the relationship response-factors like close to this maximum (or minimum)?

For instance, suppose we wish to find the levels of two factors $x1, x2$, that maximize the response variable y of a process:

$$y = f(x_1, x_2) + \varepsilon \text{ (Noise)}$$

The surface represented by $\eta = f(x_1, x_2)$ is called a response surface, graphically represented as a solid surface in a three-dimensional space. In the contour plot, lines of constant response are drawn in the $x_1, x_2$ plane, which help visualize the shape of the response surface. Each contour corresponds to a particular height of the response surface. Such a plot is helpful in studying the levels of $x_1$ and $x_2$ that result in changes in the shape or height of the response surface. [ 16]

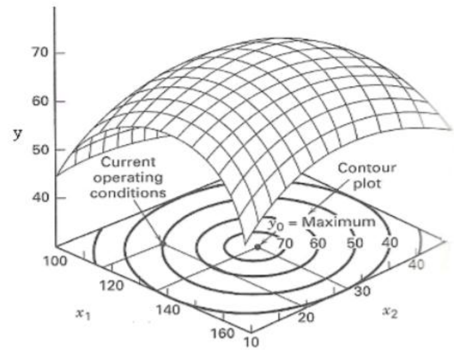


Figure 3 Contour Plot

As an important subject in the statistical design of experiments, the Response Surface Methodology (RSM) is a collection of mathematical and statistical techniques useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response [17]. As per the dimensional analysis, following π terms are developed. These π terms are dimensionless hence it is very easily possible to convert into three groups. These groups are converted into 3 dimensions in space to develop response surface [1] [3]

*1.2.1 Steps in Response Surface Methodology*

- To find a suitable approximation for the true functional relationship between y and the set of independent variables (usually, a low-order polynomial in some region of the independent variables: first-order model, or second-order model if there is curvature in the system).
- To estimate the parameters in the approximating polynomials (to find the maximum response, for instance).
- To do the response surface analysis in terms of the fitted surface. If the fitted surface is an adequate approximation of the true response function, then analysis of the fitted surface will be approximately equivalent to analysis of the actual system.

*1.2.3 Response Surface Design*

As per the dimensional analysis, six π terms are developed. These π terms are dimensionless hence it is very easily possible to convert into three groups. These three groups are converted into 3 dimensions in space to develop response surface. Hence,

$X = \prod_{i=1}^{3} \pi_i$ , $Y = \prod_{i=4}^{5} \pi_i$, $Z = \pi_{01}$

The ranges of input X, Y and output Z are more variant. Hence by using scaling principle, the above X, Y and Z values are scaled as follows:

$x = X / \max(X), \; y = Y / \max(Y), \text{and} \; z = Z / \max(Z)$

*1.2.4 RSM Model Development*

The experimental data are collected, with the process parameter levels set as given in observation table to study the effect of process parameters over the output parameters.

The experiments are designed and conducted by employing response surface methodology (RSM). The selection of appropriate model and the development of response surface models have been carried out by using statistical software, “MATLAB R2009a”.

The best fit regression equations for the selected model are obtained for the response characteristics, viz., prediction of SFRC Strength. The response surface equations are developed using the field data and are plotted (figure to) to investigate the effect of process variables on various response characteristics. Table 1 shows the comparison of the values of dependent π -terms, computed by experimentation, ANN and RSM models. The table 1 reflects the performance analysis of three models and their comparative analysis, for the sake of brevity we have

considered first and last fifteen readings out of total 495 readings. The values of R squared error in ANN, number of iterations, values of the regression coefficients for dependent pi terms and the plots of the actual data and target data for the dependent pi terms are shown in Figures for all response/ dependent variables.

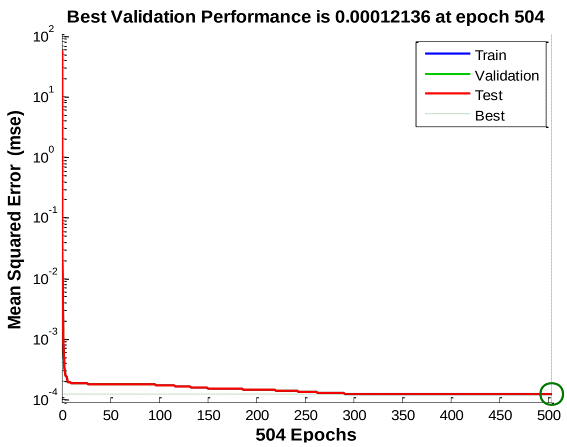


Figure 4 Best validation performance .

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It can be seen that the highest change takes place in strength, because of the $\pi$ term $\pi_5$(control strength) whereas the least change takes place due to $\pi_4$. (Aspect Ratio) Thus, $\pi_5$ related to control strength Variables is most important $\pi$ term.

Linear model Poly55:

$$\begin{aligned} f(x,y) = {} & p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 \\ & + p21*x^2*y + p12*x*y^2 + p03*y^3 + p40*x^4 + p31*x^3*y \\ & + p22*x^2*y^2 + p13*x*y^3 + p04*y^4 + p50*x^5 + p41*x^4*y \\ & + p32*x^3*y^2 + p23*x^2*y^3 + p14*x*y^4 + p05*y^5 \end{aligned}$$

Using this Linear model, one yields the mathematical model to predict the SFRC strength using RSM methodology is given by following formula

$$\begin{aligned} \psi_{RSM} = {} & 20.93 + 38.43x - 0.9203y + 7.285x^2 - 7.838xy - 2.23y^2 \\ & - 31.62x^3 - 7.281x^2y + 0.7373xy^2 + 0.6571y^3 + 14.18x^4 \\ & + 6.735x^3y + 0.351x^2y^2 + 2.28xy^3 + 0.09493y^4 - 1.862x^5 \\ & - 1.247x^4y + 0.04662x^3y^2 - 0.6144x^2y^3 - 0.5488xy^4 + 0.1536y^5 \end{aligned} \quad (1)$$

Table 1: Performance analysis of RSM Model, ANN Model and Comparison of Experimental and predicted strength (out of 509 reading first and last 14 are reported here)

| Sr No | Experimental | ANN Model | % Error (ANN) | RSM Model | % Error (RSM) |
|---|---|---|---|---|---|
| 1 | 35.9 | 38.5987 | 7.52 | 33.57538 | 6.48 |
| 2 | 39.06 | 39.2254 | 0.42 | 33.67901 | 13.78 |
| 3 | 39.74 | 39.1644 | 1.45 | 33.75272 | 15.07 |
| 4 | 39.6 | 37.3213 | 5.75 | 33.50206 | 15.40 |
| 5 | 35.3 | 34.3013 | 2.83 | 33.39898 | 5.39 |
| 6 | 42 | 38.9383 | 7.29 | 33.60545 | 19.99 |
| 7 | 36.83 | 37.3213 | 1.33 | 33.50206 | 9.04 |
| 8 | 42.74 | 39.2254 | 8.22 | 33.67901 | 21.20 |
| 9 | 37.21 | 38.5987 | 3.73 | 33.57538 | 9.77 |
| 10 | 34.9 | 34.3013 | 1.72 | 33.39898 | 4.30 |
| 11 | 38.43 | 27.745 | 27.8 | 39.71496 | 3.34 |
| 12 | 37.4 | 28.8231 | 22.93 | 39.83753 | 6.52 |
| 13 | 37.5 | 30.2178 | 19.42 | 39.92473 | 6.47 |
| 14 | 45.47 | 34.9614 | 23.11 | 50.02989 | 10.03 |
| … | … | … | … | … | … |
| … | … | … | … | … | … |
| 496 | 2.87 | 2.48 | -7.951 | 1.964132 | 20.8 |
| 497 | 2.77 | 2.15 | -5.08 | 1.989413 | 7.47 |
| 498 | 3.04 | 3.68 | 3.3104 | 2.963371 | 19.47 |
| 499 | 2.69 | 3.11 | 3.0076 | 2.795792 | 10.1 |
| 500 | 2.55 | 3.33 | 2.7036 | 2.628019 | 21.08 |

| | | | | | |
|---|---|---|---|---|---|
| 501 | 3.82 | 3.4 | 4.4983 | 3.026657 | 10.98 |
| 502 | 3.82 | 2.97 | 4.3142 | 2.855499 | 3.86 |
| 503 | 4.1 | 3.14 | 4.1259 | 2.684142 | 14.52 |
| 504 | 3.96 | 3.18 | 4.2223 | 3.065614 | 3.6 |
| 505 | 3.54 | 2.83 | 4.0866 | 2.892254 | 2.2 |
| 506 | 3.54 | 3.04 | 3.9522 | 2.718694 | 10.57 |
| 507 | 3.54 | 4.25 | 11.1336 | 3.77511 | 11.71 |
| 508 | 3.96 | 4.39 | 11.2961 | 3.953649 | 9.94 |
| 509 | 2.55 | 4.25 | 11.5593 | 3.514886 | 17.3 |

Table 2 $R^2$- Value for the ANN and RSM model for the best fit.

| Model | $R^2$-Value |
|---|---|
| ANN | 0.7569 |
| RSM | 0.6775 |

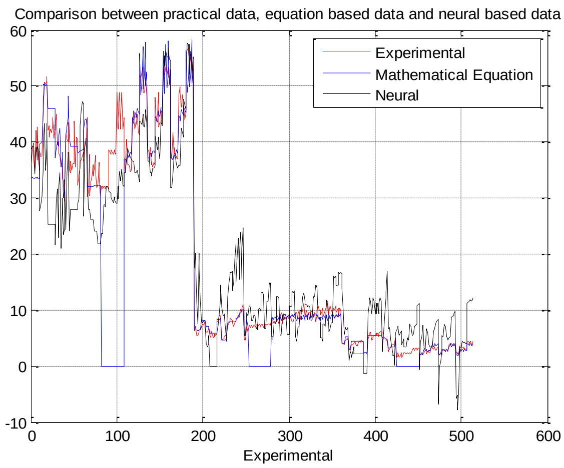


Figure 5 Comparisons between experimental data, ANN and RSM for predicted strength

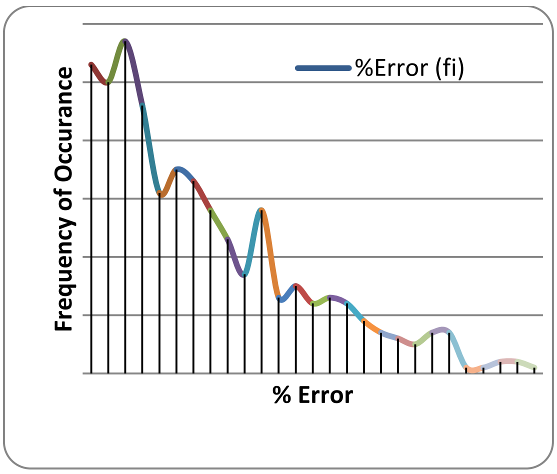


Figure 6 % Error vs Frequency graph for Pi01: predicted SFRC Strength

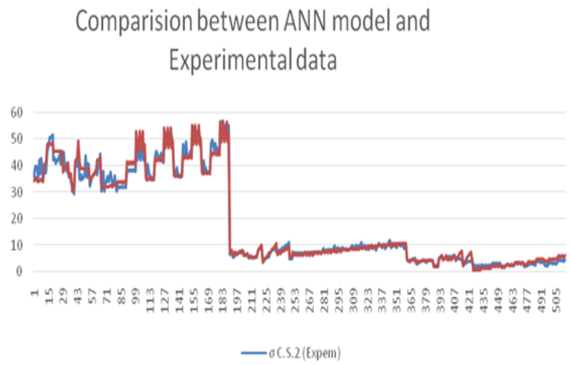


Figure 7 Graphical comparison between ANN Model and RSM -based model for prediction of SFRC strength

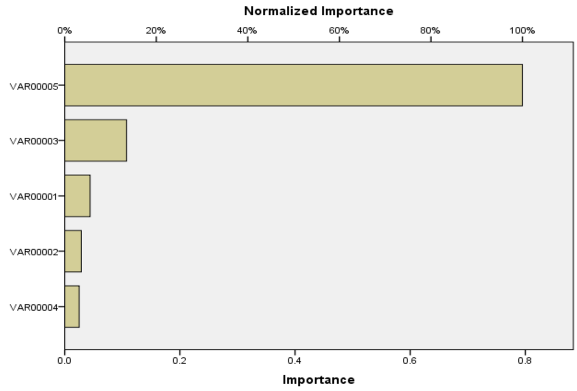


Figure 8 Importance of π terms in ascending order

## 2. CONCLUSION AND FUTURE WORK

1. ANN Simulation model and RSM models are developed for prediction of SFRC strength, using strength of controlled concrete, percentage of fibers, aspect ratio, aggregate cement ratio and water cement ratio can very well be used in prediction of compressive strength, flexural strength and split tensile strength of SFRC using the five parameters listed above.
2. The significance of these models can very well be seen from the data presented in Table 1 where the experimental strength with the predicted RSM strength and the predicted ANN simulation strength are well compared Figure 7. Figure 8 notify the importance of independent π terms. Control strength π5 is the most influencing terms in this model.
3. RSM model developed for predicting strength of SFRC, using strength of controlled concrete, percentage of fibers, aspect ratio, aggregate cement ratio and water cement ratio can very well be used in prediction of compressive strength, flexural strength and split tensile strength of SFRC using the five parameters listed above.
4. The importance of these models can be observed from % Error vs Frequency graph for predicted SFRC Strength. developed for prediction of compressive strength, Flexural strength and split tensile strength when compared with own observed experimental strength it is observed that predicted strengths and observed experimental strength are close to each other. It clearly indicates the reliability of RSM models developed to calculate predicted strength.

5. After studying both the models and their comparison with the experimentation, it is clearly observed that both the models are significant and fit for predicting the SFRC strength but as shown in table 2 , the R2- Value of ANN model is more than that of RSM model, further from the % error graph, one can conclude that the ANN model is perfectly fit over the RSM model.

*Conflicts of interest*
There is no conflict of interest.

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