ANFIS MODEL TO PREDICT THE FLEXURAL PERFORMANCE OF HSC BEAMS STRENGTHENED WITH FRP LAMINATES

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Abstract: Strengthening of RC structure using Fibre Reinforced Polymer (FRP) shows better promise for executing their service life.The main objective of this work is to evaluate the flexural behaviour of reinforced High Strength Concrete(HSC) beams.A total of 15 beams of 150 mm X 250 mm in cross-section and 3000 mm in length is considered for this study.All beams were tested under two point loading.The principal variables are percentage steel ratio, thickness of FRP and type of FRP. Theperformance parameterswere evaluated in terms of strength, fitness and ductility. The test results shows that beam strengthen with FRP laminates exhibits increase strength,flexural stiffness and ductility.Adaptive NeuroFuzzy Inference System (ANFIS)based modelling has been proposed to predict the performance characteristics of beams and the predicted results showed good agreement with those of experimental results.

***Keywords*- ANFIS, Ductility, FRP, High Strength Concrete, Strengthening.**

I. INTRODUCTION

An increasing number of reinforced concrete structures when it reaches the end of their service life due to deterioration of concrete and reinforcements caused by environmental factors and the widespread application of deicing salts or due to increase in applied loads. Thee deteriorated structures may be structurally deficient or functionally absolute and most are now in serious need of extensive rehabilitation or replacement.

Strengthening can be used as cost-effective alternative to the replacement of these structures is he feasible solution. Fibre Reinforced Polymer (FRP) laminates or wraps are well suited to this application because of their high strength-to-weight ratio, worthy fatigue characteristics and outstanding resistance to corrosion. Application of FRP in civil engineering structures has been growing rapidly in recent years and is becoming an effective and promising solution for strengthening the deteriorated concrete members.

The application of FRP poses minimal modification of the geometry, aesthetics and utility of the structure. Installation of externally bonded upgradation system using FRP is fast and intensive less labour. Several studies on the behaviour of reinforced concrete beams strengthened with FTP laminates provides valuable information regarding the strength, deformation, ductility and long-term performance of FRP strengthening systems.

II. RESEARCH SIGNIFICANCE

The present research study has been undertaken to propose an Adaptive Neuro-Fuzzy Interface System (ANFIS) model to predict the performance of Glass Fibre Reinforced Polymer (GFRP) laminated High Strength Concrete (HSC) beams.

III. LITERATURE REVIEW

Attariet al, (2012)examined the effectiveness of external bonding systems FRP (GFRP/CFRP). Parameters considered in the study aredissimilar strengthening configurations (unidirectional glass and carbon fibres with some U-anchorages / of bidirectional glass–carbon fibre hybrid fabric).A total of seven RC beams cast and tested.The effect of GFRP/CFRP on flexural strength, stiffness and ductility are studied. An analytical model was proposed to predict the flexural strength of FRP strengthened RC beams. The authors concluded that the GFRP/CFRP laminated beams show significant enhancement in flexural strength when compared to that of the reference beams.

Reza Mahjoub and Syed Hamid Hashemi (2010) conducted experimental and analytical studies concerning the effect of external bonding of Carbon Fibre Reinforced Polymer (CFRP) laminates on flexural strength of high strength concrete beams. Six concrete beams of size 150mm x 250mm x 3000mm were considered for the study. The principal variables considered are different layouts of CFRP laminates and tensile steel reinforcement ratio. All the beams were tested under two-point loading until failure. The authors concluded that the CFRP strengthened HSC beams exhibit enhanced load carrying capacity when compared to that of control beam and also the analytical results showed good agreement with those of experimental results.

Tan (2009) carried out analytical and experimental investigations on glass FRP-strengthened RC beams under the combined effect of sustained loading and tropical weathering. The author concluded that FRP strengthened RC beams under sustained loads exhibited larger deflections and crack widths, when subjected to tropical weathering at the same time. Also the author concluded that the FRP strengthened RC beam showed decrease in deflection and crack width when compared to the control beam. Both the strength and ductility of beams under sustained loads decreased with longer weathering periods.

EI Maaddawy (2007) presented the results of an experimental study conducted to evaluate the performance of reinforced concrete beams repaired with carbon fibre reinforced polymer (CFRP) sheets under corrosive environmental conditions. The author concluded that the deflection capacity of the beams decreased as corrosion progressed after repair. The deflection capacity of the repaired beams was on an average 45% lower than that of the control beam.

HedongNiu and Zhishen Wu (2006) analysed the effect of interface bond properties on the performance of FRP-strengthened reinforced concrete (RC) beams in terms of concrete cracking, interface stress transfer and failure mechanisms using nonlinear fracture mechanics based finite element analysis. The authors concluded that, low stiffness may be helpful to distribute more uniform stresses in both steel and FRP sheets, which may help to relieve local stress concentrations and reduce the likelihood of debonding in practice.

Hamadet al., (2004) conducted experimental and Analytical studies on the bond strength of reinforcement in FRP wrapped HSC beams. For the study ten HSC beams, 240 x 305 x 2000 mm were cast and tested. Four point bending system was used to produce a constant moment region in the middle third of the test specimen. The variables considered in the investigation were the FRP sheet / wrap type (glass or carbon), the configuration 1 strip, 2 stripof the FRP sheets in the splice region. The authors reported that the employ of GFRP / CFRP sheets to the soffit of beams modifed the brittle mode of failure to a ductile one, allowing more bar lugs along the spliced bars to participate in the stress transfer between steel and concrete.

El-Hacha (2004) investigated the feasibility of using near surface mounted CFRP strengthening on RC beams. The author reported that a full composite action between the NSM strips and the concrete could be achieved. An increase in the flexural capacity of the strengthened RC beams was observed.

IV. ADAPTIVE NEURO-FUZZY INTERFACE SYSTEM (ANFIS) MODEL

ANFIS presents a much better learning ability for a similar networkcomplexity, a much smaller convergence error is achieved, and although theconvergence is slower the smallness of error in ANFIS is able to compensatethe fact. It can achieve highly non-linear mapping, far superior to multilayerperceptions and other common linear methods of similar complexity. It requires fewer adjustable parameters than those required in otherNeural Networks structures.

ANFIS, as modeling system, consists of three distinct divisions, first one is the inputparameters and membership functions, second division is the adaptive neuro-fuzzy inference system, last division is the output parameter and the defuzzifier.Schematic view of adaptive neuro-fuzzy inference system is presented in Fig.1.

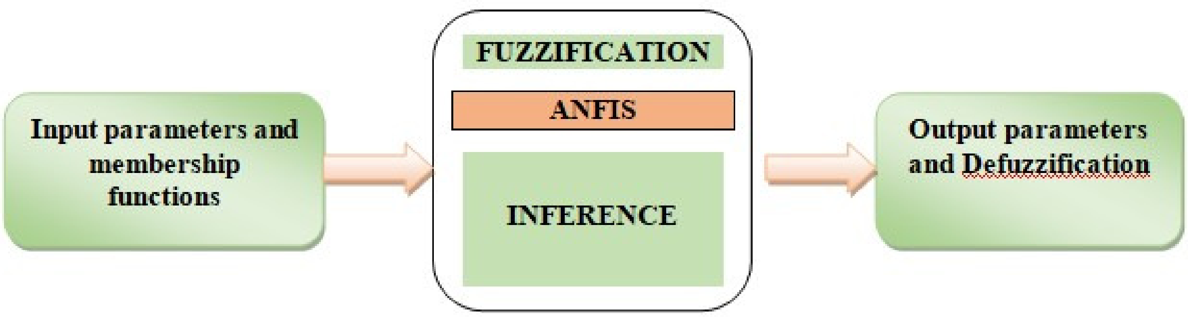

Fig.1 Schematic View of Adaptive Neuro-Fuzzy Inference System

V. DEVELOPMENT OF ANFIS MODEL

ANFIS model will predict one output parameter although it has many numbers of input parameters. Hence, each prediction parameter requires a separate ANFIS object to be generated and named as fisobjects. Each of the input parameters is associated with countable number of membership functions. These membership functions are used to fuzzify the input data and evaluate the membership of the given crisp input value.

Generalized bell membership function was selected for the input data and constant membership function was selected for the output. The number of membership functions was two per parameter for most of the cases. The choice of membership functions was made by conducting a trial run of the ANFIS objects generated using several alternative functions like triangular membership function, trapezoidal membership function, pi membership function, sigmoid membership function, generalized bell membership function, Gaussian membership function, S-Shaped membership function etc.. The performance of certain membership functions is good for certain data patterns. The present data showed minimum error levels for generalized bell input membership function. The ANFIS objects (Fig. 2) developed for predicting various parameters related to the GFRP laminated beams predicted data with varying degrees of errors.

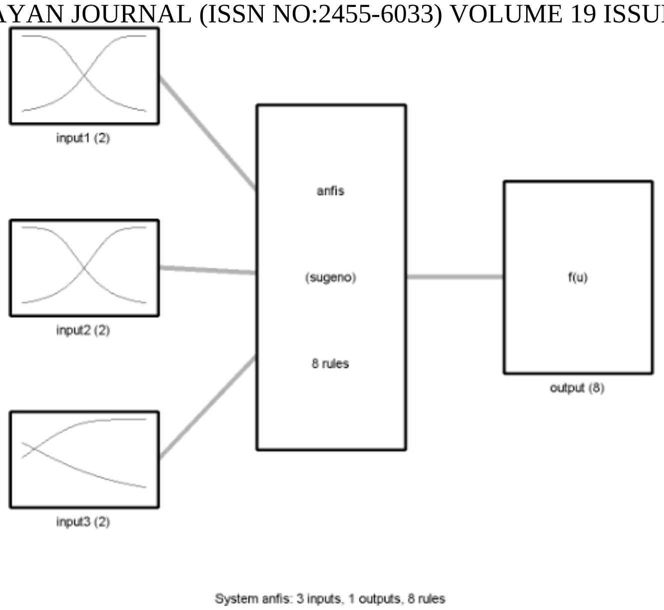

Fig. 2 Schematic view of ANFIS Object for Performance Parameters

The input parameters supplied to the ANFIS objects were steel ratio, type of GFRP laminate and thicknesses of GFRP laminate. The output parameters are yield load, deflection at yield load, ultimate load and deflection at ultimate load. Loading the train data and test data, generation of FIS and grid partition are presented in Figs. 3 to 5.The training and test data used for developing the Fuzzy Inference System are presented in Table 1 and the predicted results through ANFIS are presented in Table 2.

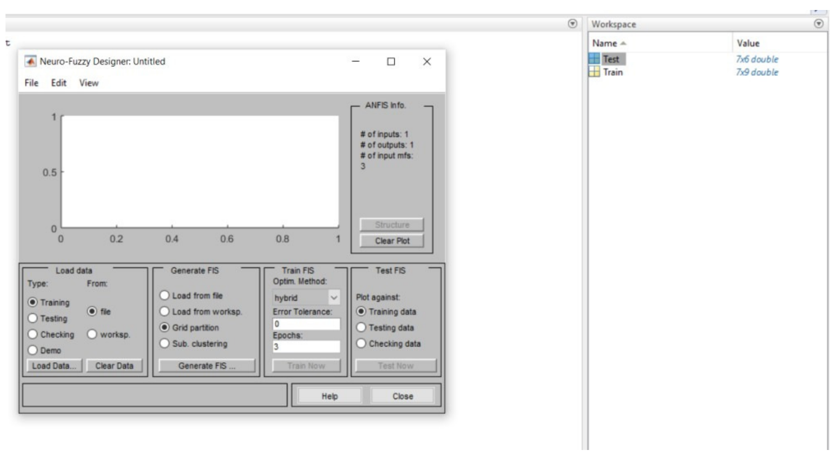

Fig. 3 Load Train and Test Data

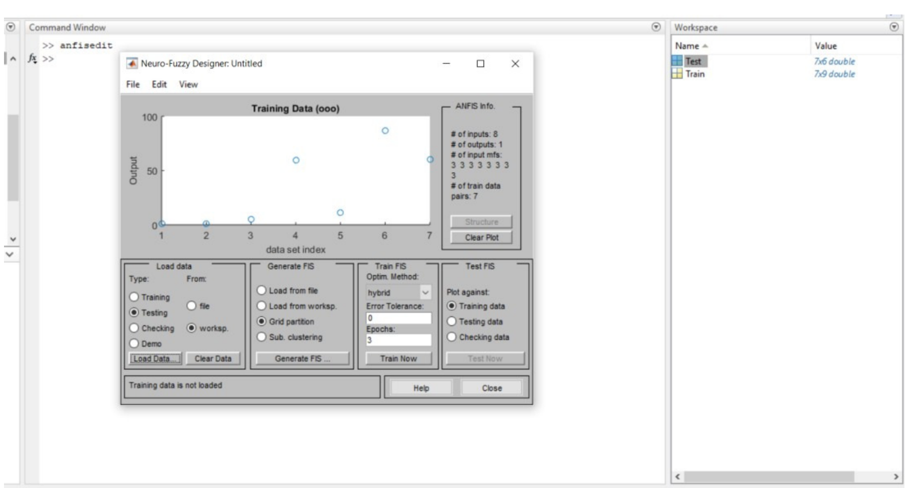

Fig. 4 Generate FIS

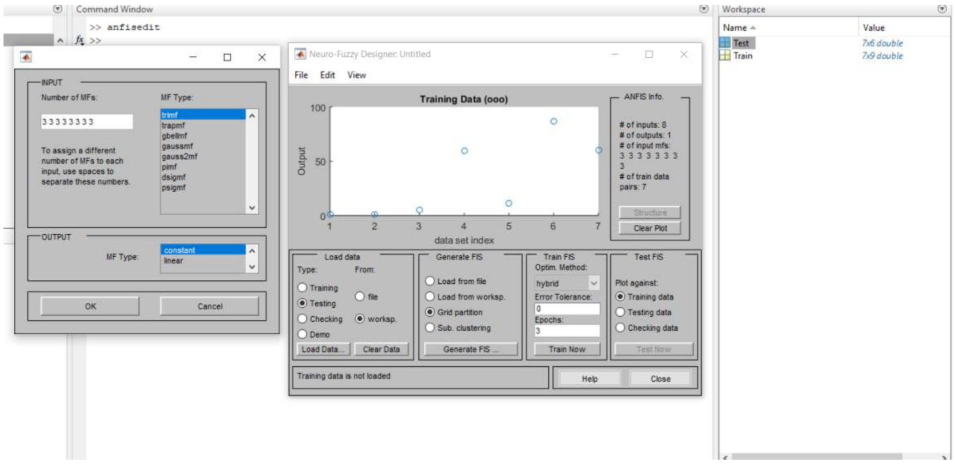

Fig. 5 Generate FIS via Grid Partitioning

Table 1 ANFIS Input and Target Parameters

%Steel Ratio	0.419	0.628	0.905	0.419	0.628	0.905	0.419	0.628	0.905	0.419	0.628	0.905	0.419	0.628	0.905
FRP Type	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2
FRP Tk	0	0	0	3	3	3	5	5	5	3	3	3	5	5	5
Yield Load	30.43	35.99	45.78	52.55	52.11	40.34	52.66	52.30	59.82	62.00	43.22	43.43	54.43	75.02	79.32
Deflection at Yield Load	8.58	10.91	11.39	10.54	9.34	42.75	10.53	11.59	11.54	13.65	9.45	11.89	12.63	14.30	13.27
Ultimate Load	40.35	50.43	67.28	70.62	79.64	52.76	62.45	64.24	87.07	99.45	76.65	65.76	97.81	103.98	111.72
Deflection at Ultimate Load	20.09	32.91	45.58	54.34	56.83	32.90	35.60	57.82	60.11	64.23	35.45	50.00	56.39	62.67	63.00
Data	Train Data	Train Data	Train Data	Train Data	Train Data	Train Data	Test Data	Train Data	Train Data	Train Data	Test Data	Test Data	Test Data	Train Data	Train Data

Table 2 ANFIS Predicted Results

%Steel Ratio	FRP Type	FRP Thickness	Yield Load	Deflection at Yield Load	Ultimate Load	Deflection at Ultimate Load
0.419	0	0	30.43	8.58	40.35	20.09
0.628	0	0	35.99	10.91	50.43	32.91
0.905	0	0	45.78	11.39	67.28	45.58
0.419	1	3	52.55	10.54	70.62	54.34
0.628	1	3	52.11	9.34	79.64	56.83
0.905	1	3	40.34	42.75	52.76	32.90
0.419	1	5	52.66	10.53	62.45	35.60
0.628	1	5	52.30	11.59	64.24	57.82
0.905	1	5	59.82	11.54	87.07	60.11
0.419	2	3	62.00	13.65	99.45	64.23
0.628	2	3	43.22	9.45	76.65	35.45
0.905	2	3	43.43	11.89	65.76	50.00
0.419	2	5	54.43	12.63	97.81	56.39
0.628	2	5	75.02	14.30	103.98	62.67
0.905	2	5	79.32	13.27	111.72	63.00

Adaptive Neuro-Fuzzy Inference System (ANFIS) based model provided reasonable accuracy in predicting the flexural characteristics of GFRPstrengthenedHSC beams.The Root Mean Square Error (RMSE) range from 0.597 to 3.863.

VI. CONCLUSIONS

GFRP laminates properly bonded to the soffit of reinforced high strength concrete beams enhance the ultimate strength substantially. Good correlation was observed between the experimental results and thosepredicted through ANFIS modeling. This was evident from root mean square error range from 0.597 to 3.863. Also ANFIS tool proved to be an effective tool in predicting the performance parameters of GFRP strengthened HSC beams.

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