Parametric Study of Fixed Beams Using ANN Model

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Abstract : The paper predicts the shear strength of high-strength steel fiber-reinforced concrete deep beams. It studies the effect of clear span-to-overall depth ratio on shear capacity of steel fiber high-strength Fixed deep beams using artificial neural network (ANN8). The three-layered model has eight input nodes which represent width, effective depth, volume fraction, fiber aspect ratio and shear span-to-depth ratio, longitudinal steel,compressive strength of concrete, and clear span-to-overall depth ratio. The model predicts the shear strength of high-strength steel fiber deep beams to be reasonably good when compared with the results of proposed equations by researchers as well as the results obtained by neural network (ANN7) which is developed for seven inputs excluding span-to-depth ratio. The developed neural network ANN8 proves the versatility of artificial neural networks to establish the relations between various parameters affecting complex behavior of steel fiber-reinforced concrete deep beams and costly experimental processes.

Keywords: Artificial neural network; Fixed Deep beam; High strength; Steel fiber; Shear span ratio; Span to depth ratio; Volume fraction; Fiber aspect ration

Introduction

The fixed beams differ from ordinary beams in their geometrical proportions and nowadays are widely used as transfer girders in multistory buildings to avoid columns for providing free space at different floor levels for park-ing. The ACI Committee 318 (2002), section 11.7.1 defines the deep beam based on two criteria: as clear span-to-depth ratio (L/D< 4) and shear span-to-depth ratio (a/d< 2). The IS: 456 (2000) describes fixed beam having clear span-to-depth ratio less than 2. ACI-ASCE Committee 426 classifies a beam with shear span-to-depth ratio (a/d) less than 1.0 as deep beam and a beam with a/d exceeding 2.5 as an ordinary shallow beam. Any beam in between these two limits is categorized as a moderate deep beam. The concrete has inherent microcracks present in it which turns into macrocracks as the members are subjected to loading. The cracks are formed within the shear span when the principal tensile stress exceeds the tensile strength of concrete. The Addition of randomly dispersed discrete steel fibers into concrete mix improves the post-cracking tensile strength of RC beams. The addition of fibers in concrete results in the reduction of crack formation and propagation (Anant and Modhera 2008). The high-strength concrete has relatively more brittleness and lack of ductility than normal strength concrete. This can be overcome by additions of fibers in high-strength concrete (HSC). It is important to understand better and predict the shear behavior of steel fiber-reinforced concrete (SFRC) fixed deep beam for its wider applications. The lack of rational design equations in various building codes, shear failure modes, and various parameters affecting the load-carrying mechanism makes the shear behavior of steel fiber-reinforced concrete

beams more complex, particu-larly in deep beams, and a topic for research (Roberts and Ho 1982). Many researchers in the past have studied the addition of steel fibers in concrete to improve the flexural as well as shear capacity of normal and deep beams. The studies support the use of steel fibers as shear reinforcement of reinforced concrete (RC) beam. The previous research is mainly carried on SFRC shallow beams (a/d> 2.5). The proposed equations are also gener-ally based on tests carried on a certain type of fibers. The behavior of SFRC deep beam in shear needs to be investi-gated for different parameters for generalized shear strength equation if steel fibers are to be used in actual structural members (Al Ta'an and Al-Feel 1990; Mau and Hsu 1987; Kotsovos 1987; Lim 1987; Narayanan and Darwish 1987, 1988; Manicka Selvem and Kuruvilla 1988; Kwak 2002; Misrayah and Banthia 2002; Shah and Mishra 2004; Gohnert 2006; Gustavo 2006). The present study aims at proving the effectiveness of artificial neural net-work to study the effect of clear span-to-overall depth ratio on shear capacity of steel fiber in high-strength deep beams for L/D limit as per IS: 456 (2000) and compare the results obtained with the equations sug-gested by previous researchers. It also highlights the importance of span-to-depth ratio (L/D) in predicting the shear strength of deep beams.

Methods : Artificial neural network

The neural networks comprise a large number of highly interconnected elements called 'neurons'. The neural network is configured for a specific application. The main advantage is that they can solve problems that do not have an algorithmic solution or for which the solu-tion is too complex. In recent past, artificial neural network (ANN) has been successfully applied in various disciplines of engineering analysis including the field of civil engineering. Sanand and Saka (2001) predicted the ultimate shear strength of RC deep beams using the artificial network. The results developed from ANN are more accurate than by ACI code and strut and tie method. Adhikari and Mutsuyoshi (2006) developed ANN for shear strength of SFRC beams and found that the accuracy of the network result increases with in-crease in number of inputs. It was found that five-input network predicts shear strength more closely than four-input networks. The accuracy of the results is found not biased with concrete strength, shear span-to-depth ratio, and beam depth. Arafa et al. (2011) showed that the de-veloped ANN model has higher potential in predicting the ultimate shear strength of both normal and high-strength deep beams when compared with calculated values using ACI code.

The major concerns of structural analysis problems like predicting different properties of concrete and load-carrying capacity have been solved mostly by using back-propagation neural network. The processing units are grouped into layers of input, hidden, and output pro-cessing units. The networks are trained so that a particu-lar input leads a specific target output. The log-sigmoid transfer function is used in multilayer networks

that are trained using the backpropagation algorithm because this function is differentiable. This transfer function takes the input and squashes the output into the range 0 to 1, according to the expression:

a ¼ 1=$^{\eth}$1 þ exp$^{-n\text{Þ}}$

Where a¼ logsig ðnÞ;n¼ net input.

The networks are adjusted based on the comparison of output and target. The batch training of network pro-ceeds by making weight and bias changes based on the entire set of input vectors. A stable set of weights adap-tively evolves will produce good results.

Experimental data

The development of neural network requires reliable data which include input parameters affecting the system and corresponding output. These data can be experi-mental test results, reliable empirical data, or theoretical results. The experimental test results of 118 tests on SFRC normal and high-strength concrete deep beams, carried by various researchers (Narayanan and Darwish 1987, 1988; Kwak et al. 2002; Shah and Mishra 2004; Gustavo 2006) have been used to develop the ANN8 model in the present study where the number stands for number of input parameters affecting the shear strength of SFRC deep beams. The data consists of 90 test results for nor-mal strength concrete (NSC) and 28 test results for HSC steel fiber-reinforced beams for different values of span-to-overall depth ratio. The basic parameters that control the shear strength of SFRC beams, based on previous research works, are beam width (b), effective depth (d), fiber volume (V_f), fiber aspect ratio (l_f/d_f), shear span ra-tio (a/d), compressive strength of concrete (f_c) and longi-tudinal reinforcement area (A_{st}), and clear span-to-depth ratio (L/D). The shear span-to-depth ratio (a/d) of 45 beams, out of total data, has shear span-to-depth ratio equal to or less than 2. The total data base also includes 19 beams having clear span-to-depth ratio less than or equal to 2 to satisfy the condition for fixed deep beam as per

Table 1 Statistic for NSC and HSC SFRC beams

Parameter	Min	Max	Mean
Width (b), mm	50	300	175
Depth (d), mm	126	610	286
Fiber volume (V_f),%	0.25	2	1.125
Fiber aspect ratio (l_f/d_f)	40	133	84.27
Shear span ratio (a/d)	0.5	5.72	2.47
Main steel (A_{st}),%	0	4.5	2.47
Compressive strength (f_c),	19	99.6	62.34
Clear span-to-depth ratio	1.5	9.88	5.43

IS: 456 (2000). Table 1 shows the statistics for input parameters for SFRC beams as per Additional file 1.

Preprocessing of data

Parametric study

The parametric study is carried out with the developed artificial neural network to evaluate the influence of pa-rameters like b, d, V_f, l_f/d_f, a/d, A_{st}, f_c, and clear L/D. The effect was studied by varying one of the input parameters with respect to varying span-to-depth ratio mainly and all other parameters are set to constant

The learning rate of networks is significantly affected by the data presented to artificial neural networks. To en-sure that all variables receive equal attention during training, the data scaling is important. Hence, the data needs preprocessing before presented for training. The scaling of the inputs is done in the range of [−1, +1] to improve the speed of learning process as these values fall in the region of sigmoid. The normalization of input and output data before presenting them to network is done by linear normalization function within the values of 0 and 1 and given by

S ¼ ½ 2ðP−P$_{min}$Þ=ð P$_{max}$−P$_{min}$Þ&−1:   ð2Þ

Training of ANN

The MATLAB (R2009a) package is used for the devel-opment of present ANN8 model. The backpropagation is most successful and widely used in civil engineering. The collected data is divided into three units, i.e., training, validation, and testing. In the present case, training set comprises 80% of data base and remaining data base is equally divided into validation (10%) and testing sets (10%).

The values of network parameters considered in this approach are as follows: number of hidden layers = 1, number of hidden units = 20, learning rate = 0.5, mo-mentum factor = 0.5, and learning cycles = 1,000. The root mean square error (R^2) was 0.924. The coefficient indicates a significant correlation.

Topology of network

The topology or architecture is obtained using trial and error method. The architecture of the network ANN8 is as shown in Figure 1.

Performance of the proposed model

The network is trained for 80% of data collected by gradually increasing the number of neurons in the hid-den layer. The performance was monitored during train-ing process as sum squared error over all the training data. The training process stops when the maximum number of epochs is reached. A comparison between experimental shear strength and corresponding values obtained by ANN8 model for 118 normal and high-strength SFRC ordinary and deep beams is shown in Figure 2. It shows that predicted shear strength is in good agreement with the experimental results.
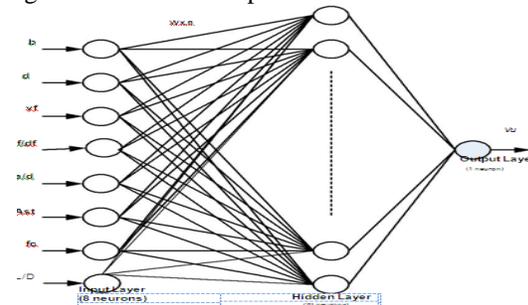

Figure 1 Three-layered feed-forward backpropagation

values. The values of L/D ratio and a/d ratio are assumed less than 2 to fit thebeam in fixed beam category.

The model is fed with some assumed data and the resulting output values of shear strength are studied. The range of parameters used in parametric study is shown in Table 2.

Results and discussion

The effect of each parameter on the shear strength of SFRC fixed beam is studied by varying influencing pa-rameters. The model is fed with the values of influencing parameters and resulting output values of shear strength
Table 2 Values of trial data

Parameter	Range
Effective depth (d; mm)	300, 350, 400, 450, 500
Fiber content (V_f;%)	0, 0.5, 1, 1.25, 1.5, 1.75, 2
Fiber aspect ratio (l_f/d_f)	50, 60, 70, 80, 90
Shear span ratio (a/d)	0.5, 1, 1.5, 2
Longitudinal steel (%)	0, 0.5, 1, 1.5, 2, 2.5
Compressive strength (f_c; MPa)	50, 60, 70, 80
Span to depth ratio (L/D)	1, 1.25, 1.5, 1.75, 2

are studied. The range of parameters used in parametric study is shown in Table 2. The results obtained by devel-oped ANN are plotted against respective parameters.

Effect of effective depth

Figure 3 shows the effect of increase in span-to-depth ratio on hear strength with increase in effective depth. It is found that for a constant volume fraction of 1% and fiber aspect ratio of 50, the shear strength of deep beam decreases as the depth of beam goes on increasing except at d = 350 mm (d/b = 2.33). The decrease in the shear strength varies from 18% to 26% for variation of depth from 300 to 500 mm. Similarly, it is noted that the shear strength decreases with increase in span-to-depth ratio (L/D) at different depths of high-strength SFRC deep beam shown in Figure 3. It resembles with the findings of Appa Rao (2007).

Effect of fiber volume fraction

The effect of fiber content on shear strength is observed from Figure 4. It shows the variation of shear strength with increase in fiber volume fraction for different values of L/D ratios. As the fiber volume increases, the shear strength is enhanced at all considered span-to-depth ra-tio. It is also noted that the shear strength decreases with the increase in L/D ratio for a volume
Figure 5 Effect of l_f/d_f at varying L/D and V_f percentage on shear

fraction. For the assumed parameters shown in Figure 4, the decrease in shear strength with increase in L/D ratio at V_f = 0.5% is 25% and with the increase in volume fraction at V_f = 2%, the decrease in shear strength is 6%. This predicts the effectiveness of steel fiber in enhancing the shear
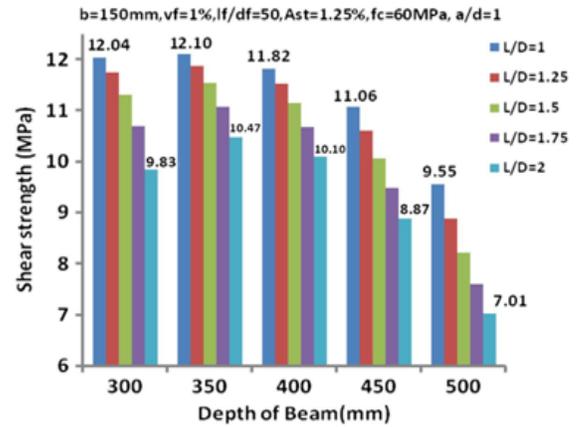

Figure 3 Effect of depth on shear strength of fixed beam at different L/D ratios. strength of high-strength deep beam. It can be seen that there is an almost linear increase in the shear strength of deep beams with increase in fiber contents as pre-dicted by Remigijus and Gediminas (2007).

Effect of fiber aspect ratio

The fiber aspect ratio is related with the geometry of the fibers. The influence of fiber aspect ratio on shear strength for different volume fraction and L/D ratio (less than 2) is represented in Figure 5. Many researchers like Narayan and Darwish (1987, 1988), Manicka Selvem and Kuruvilla (1988), Remigijus S (2007), Khuntia et al. (1999) have combined the effect of fiber aspect ratio and volume fraction in their formulations.
Figure 5 represents the effect of fiber aspect ratio with varying L/D ratio from 1 to 2 and fiber volume fraction from 0.5% to 1.5% at the interval of 0.25. It predicts that for L/D ratio <1.25, the effect of fiber aspect ratio is negligible for considered values of parame-ters. However, the shear strength goes on decreasing
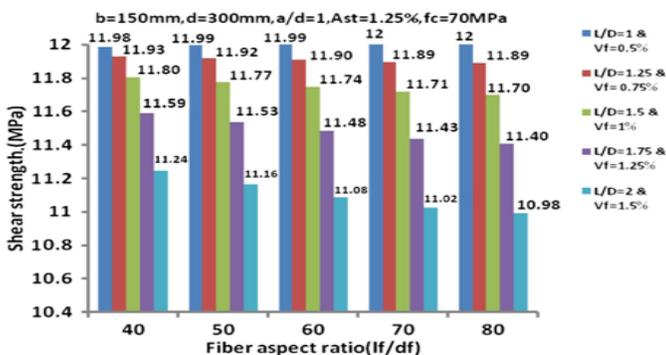Figure 4 Effect of V_f percentage at different L/D ratios on shear strength fixed beam.

strength of fixed deep beam.
with increase in fiber aspect ratio though the volume fraction of fibers and L/D ratio is increased. The de-crease in the shear strength by 0.8%, 1.6%, and 2.3% at

L/D = 1.5, 1.75, and 2, respectively, is observed for change in fiber aspect ratio from 40 to 80 from Figure 5.
Effect of longitudinal steel
Figures 6 and 7 show the variation of shear strength with increase in longitudinal steel percentage. The relation is studied for the increase in fiber content as well as L/D ratio,

respectively. Figure 6 obtained for variation of lon-gitudinal steel along with volume fraction represents

Figure 6 Effect of A_{st} percentage at different fiber volume fractions on shear strength

Figure 7 Effect of L/D at different percentages of longitudinal steel on shear strength.

increase in shear capacity of up to A_{st} =1.5% by 140%, 94%, and 48% for the range of V_f = 0.5%, 1%, and 1.5%, respectively. However, the shear strength decreases even with the increase in fiber dosage at A_{st} = 2%, 2.5%, and 3% at constant fiber aspect ratio of 50. The percentage of decrease in the shear strength at V_f= 0.5%, 1%, and 1.5% is found to be 57%, 50%, and 37%, respectively. It indicates that for lower values of longi-tudinal steel percentage, the addition of steel fibers contributes to the shear strength of high-strength deep beams Lee and Kim (2008), and longitudinal steel with 1.5% is the optimum value for the considered parameters in Figure 6. For further increase in A_{st} from 2% to 3%, the decrease in shear strength percentage at lower than
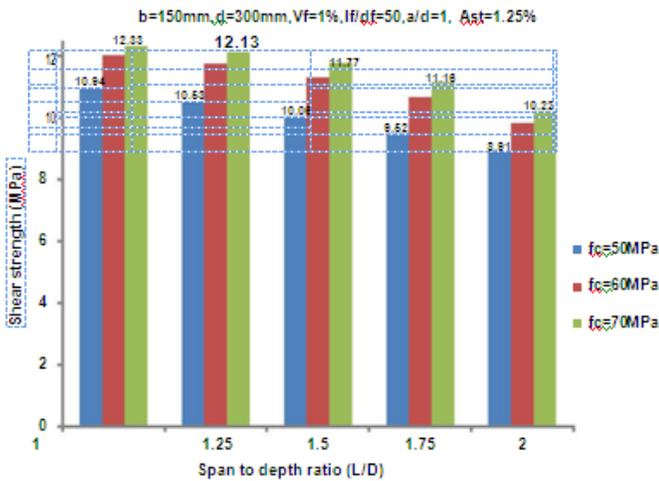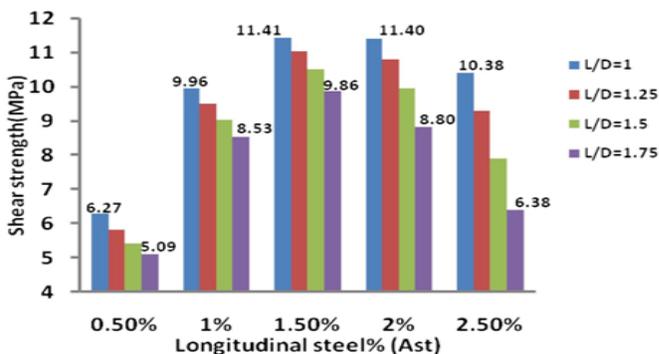

Figure 8 Effect of L/D at different compressive strength ratios on shear strength.that of longitudinal steel and for the same fiber volume fraction is observed. This helps the optimum combination of longitudinal steel and volume fraction for high-strength SFRC deep beams.

The Figure 7 shows variation of the shear strength with increase

in percentage of longitudinal steel at constant volume fraction (1%) for different L/D< 2. The increase in shear capacity is noted at A_{st} = 1.5% for all L/D ratios mentioned in Figure 7. The increase in strength by 82% and 91% is observed at L/D = 1 and 1.75, respectively.

It is observed that with the increase in span-to-depth ra-tio, the shear strength decreases at all values of longitu-dinal steel. The minimum decrease by 19% at A_{st} = 0.5% and maximum decrease by 39% at A_{st} = 2.5% is found for L/D = 1 to 1.75, respectively, as shown in Figure 7. The de-crease in shear strength is enhanced with increase in the percentage in longitudinal steel and span-to-depth ratio.
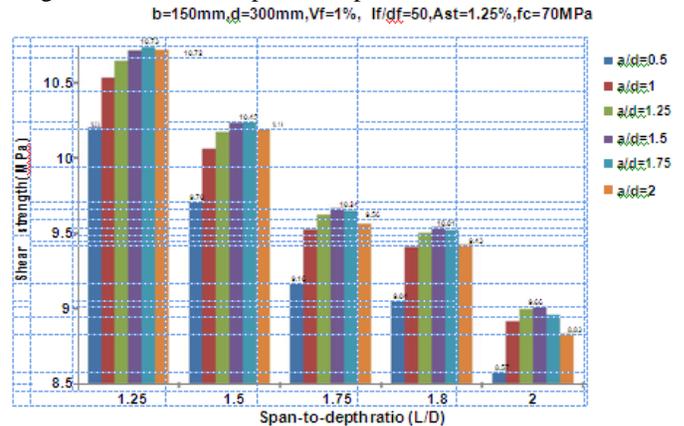

Figure 10 Effect of V_f percentage for different a/d ratios on shear strength of fixed deep beam.Page 9 of 12

Table 3 Shear strength by ANN8, ANN7, and researchers for without longitudinal steel

Effect of compressive strength

The effect of compressive strength of concrete is plotted in Figure 8 for different L/D ratios; while other parameters are V_f = 1%, a/d = 1, l_f/d_f = 50, d = 300 mm, and b = 150 mm.

It is found from Figure 8 that the shear strength of deep beam is enhanced by increase in compressive strength from 50 to 70 MPa for all L/D ratios but de-creases with increase in L/D ratio at all considered com-pressive strengths. The depth of beam is constant. The result fairly agrees with the prediction of Appa Rao et al. (2007). The decrease in shear strength for variation in L/D from 1 to 2 is found to be 19% and 17% for com-pressive strength of concrete at 50 and 70 MPa, respect-ively, for other parameters shown in Figure 8.

Effect of shear span-to-depth ratio

The positions of load from support (shear span) affect the load-carrying mechanism of the flexure member. It is now well established that the point loads are dir-ectly transferred to the support through a strut, con-verting arch action into truss mechanism with increase in depth.

The shear span-to-depth ratio effect on fixed beam for different L/D ratios is observed from Figure 9. The shear strength increases by 5%, 7%, 11%, 16%, and 12% at L/D = 1.25, 1.5, 1.75, 1.8, and 2, respectively, for vari-ation in a/d = 0.5 to 1.5. The further increase in a/d de-creases the shear strength. It is observed from Figure 9 that the shear strength is maximum at a/d = 1.5 for all L/D ratios considered. It also indicates that the

shearstrength decreases with the increase in L/D at a particu-lar a/d ratio. The average decrease in the shear strength by 16% is found with increase in L/D ratio from 1.25 to at each a/d ratio.
Figure 10 indicates the shear strength variation with
fiber volume content at different shear span ratios. It represents that at a volume fraction V_f = 1.5% and a/d = 1.5, there is 1% increase and at V_f = 2% and a/d = 1.5, the shear capacity decreases by 2%. This indicates that addition of fiber volume fraction does not affect the load-carrying mechanism.

The results obtained from ANN8 are also compared with the results obtained from the equations (Slater et al. 2012) proposed by previous researchers Narayanan and Darwish (1988), Khuntia et al. (1999), Ashour et al. (1992), and the results of ANN7 model developed using same data with the same input parameters except L/D ratio. The equations proposed by Narayanan and Darwish (1988) and Ashour et al. (1992) do not include the effect of L/D ratio but consider the contribution of longitudinal steel to shear strength in their formulations. Khuntia et al. (1999) proposes equation based on contribution of concrete strength (f_c) and steel fiber content (V_f%) to the shear strength. The constant parameters assumed are b = 150 mm, d = 300 mm, f_c = 70 MPa, a/d = 1, L/D = 1.9 and crimped-type fibers. The comparison is made for variation in fiber volume as a key factor controlling the properties of SFRC concrete. Tables 3 and 4 show the results obtained for A_{st} = 0% and 1.5% at different volume fractions, respectively.

It can be observed from Table 3 that the shear strength at different V_f percentages by ANN7 is in good agreement with the results by other researchers where parameter L/D ratio is not considered. The results by ANN8 shows greater shear strength when the effect of Table 4 Shear strength by ANN8, ANN7, and researchers for 1.5% longitudinal steel

Figure 11 Comparison of ANN8, ANN7, and researchers for without longitudinal steel.

L/D ratio is incorporated in the analysis for conditionswithout longitudinal steel. The increase in shear strength for variation in fiber volume fraction from 0.5% to 2% is observed 28%, 33%, 58%, and 86% from the comparison of ANN8 and ANN7.

Table 4 for 1.5% longitudinal steel indicates good agreement between ANN7 and Narayanan and Darwish (1988) while there is also very good agreement between
ANN8 and Ashour et al. (1992). The comparison of the results in Tables 3 and 4 shows that the equation pro-posed by Ashour et al. (1992) is more accurate to predict the results of high-strength SFRC deep beams for effect of L/D ratio.

The results are also plotted in Figures 11 and 12 which indicate that the variation in shear strength is linear for increase in fiber volume fraction as observed
  Comparison of ANN8, ANN7, and researchers with 1.5% longitudinal steel.
by ANN8. The equations of Narayanan and Darwish (1988) and Khuntia et al. (1999) do not consider the effect of L/D ratio (size effect) in their formulation and underestimate the shear strength of high-strength SFRC deep beams at various fiber volume fractions. The results by Ashour et al. (1992) show

overestimation of the strength as fiber volume fraction increases for L/D < 2.

Conclusions

The artificial neural network (ANN8) is developed and utilized to predict the shear strength of steel fiber-reinforced fixed deep beams which consists of input layer with eight neurons, hidden layer with twenty neurons, and output layer with one neuron.

The comparison between results of ANN8 with results of ANN7 and proposed equations by previous researchers reveals the reliability of neural network developed for pre-diction of shear strength of high-strength steel fiber-reinforced concrete deep beams.

The parametric study of variables affecting shear strength using the developed network shows identical variation of shear strength for a/d and L/D ratios of less than 2 as observed by various researchers through ex-perimental research. The results of variation in span-to-depth ratio show decrease in shear strength for different influencing factors like fiber content, fiber aspect ratio, longitudinal steel, depth of beam, and shear span. This also shows that the size effect is predominant in decreas-ing the shear strength and must be taken into consider-ation as an important factor in analysis and design of high-strength SFRC deep beams. The result predicted by developed ANN8 resembles with the findings of previ-ous researchers. This shows the validity and versatility of developed neural network for predicting the shear strength of high-strength SFRC fixed beam using artifi-cial neural network model.

The various parameters affecting the shear strength of SFRC fixed beams make the analysis more complex and there is need to study the behavior of high-strength SFRC fixed beams by suitable combinations of the pa-rameters. The ANN proves to be the most powerful technique to analyze the complex behavior.

Additional file

Additional file1:Statistics for input parameters for SFRC beams.
Abbreviations
a/d: shear span-to-effective depth ratio; ANN: artificial neural network;
A_{st}: longitudinal steel area, mm(); B: width of the beam, mm; f_c: compressive strength of concrete; HSC: high-strength concrete; L/D: clear span-to-overall depth ratio; l_f: fiber length, mm; l_f/d_f: fiber aspect ratio; MPa: ;
d: effective depth of beam; NSC: normal strength concrete; SFRC: steel fiber-reinforced concrete; V_f: fiber volume fraction,

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