Chapter 3

ARTIFICIAL NEURAL NETWORK MODELLING

3.1 Opening remarks

Artificial Neural Networks (ANN) are widely used to approximate complex systems that are difficult to model using conventional modeling techniques such as mathematical modeling. They are applied in several civil engineering problems such as structural, geotechnical, management etc.

This chapter presents the fundamentals of ANN with basic definition, terminology used. Modeling of SFRC deep beam, process for building architecture and implementation of developed model for parametric study have been explained. It also contains the discussion on results of parametric study.

3.2 Definition of artificial neural networks

An artificial neural network is an assembly (network) of a large number of highly connected processing units, the so-called nodes or neurons. The neurons are connected by unidirectional communication channels (connections). The strength of the connections between the neurons is represented by numerical values which normally are called weights. Knowledge is stored in the form of a collection of weights. Each neuron has an activation value that is a function of the sum of inputs received from other nodes through the weighted connections. Also ANN can be defined as a form of artificial intelligence, which by means of their architecture, attempt to simulate the biological structure of the human brain and nervous system.

3.2.1 Terminology used in artificial neural network

![Figure 3.1: Typical Structure of ANN](image-url)
The Fig.3.1 represents typical neural network architecture. The definitions associated with neural networking are given in the following paragraphs.

**Neuron (artificial):** A simple model of a biological neuron used in neural networks to perform a small part of some overall computational problem. It has inputs from other neurons, with each of which is associated a weight - that is, a number which indicates the degree of importance which this neuron attaches to that input. It also has an activation function, and a bias. It is the processing element in ANN and they are called nodes also.

**Weight:** A weight, in an artificial neural network, is a parameter associated with a connection from one neuron, M, to another neuron N. It determines how much notice the neuron N pays to the activation it receives from neuron M.

**Input unit:** An input unit in a neural network, is a neuron with no input connections of its own. Its activation thus comes from outside the neural net.

**Output unit:** An output unit in a neural network is a neuron with no output connections of its own. Its activation thus serves as one of the output values of the neural net.

**Bias:** In feed-forward and some other neural networks, each hidden unit and each output unit is connected via a trainable weight to a unit (the bias unit) that always has an activation level of 1.

**Epoch:** In training a neural net, the term epoch is used to describe a complete pass through all of the training patterns. The weights in the neural net may be updated after each pattern is presented to the net, or they may be updated just once at the end of the epoch. Frequently used as a measure of speed of learning.

**Hidden layer:** Neurons or units in a feed forward net are usually structured into two or more layers. The input units form the input layer. The output units construct the output layer. Layers in between the input and output layers (that is, layers that consist of hidden units) are termed hidden layers. In layered nets, each neuron in a given layer is connected by trainable weights to each neuron in the next layer.

**Hidden unit / node:** A hidden unit in a neural network is a neuron which is neither an input layer nor an output layer.

**A learning algorithm:** It is a systematic procedure for adjusting the weights in the network to achieve a desired input/output relationship, i.e. supervised learning. The most
popular and successful learning algorithm used to train multilayer neural networks is currently the back propagation routine.

3.3 Modeling of SFRC deep beam in shear

The first requirement of any ANN modelling is collections of database related to the problem and verify its reliability. In this study, the previous experimental test results used are required to be checked for its reliability. The pre-processing of the collected data of experimental test results is explained. The adopted training process to develop a trained neural network model is explained. The training process includes defining the architecture or topology neural network and defining all neural network parameters. The predicted results from the trained model, the experimental results, and results obtained using proposed analytical method and equations suggested by previous researchers [11, 36, 37, 48] are also compared.

3.3.1 Details of experimental database

The reliable training data as possible, is required for developing a neural network. The training data consist of those input parameters affecting the system and the corresponding output parameters. These data can be experiment test data, reliable empirical data or theoretical results. The current research utilized experimental test results obtained from previous studies as given in Appendix-I.

A comprehensive study was carried out on the obtained experimental test data in order to ensure the adequacy of these data as a training data.

3.3.2 Modelling of deep beams using artificial neural network

Almost all previous experiments used in this study have identical test setup. The test setup of the experiments by earlier researchers to predict the ultimate strength of steel fiber reinforced concrete deep beams is explained below.

3.3.2.1 Setup of experimental tests

The experimental data of total 373 tests, carried on steel fiber reinforced concrete deep beams to predict the ultimate shear strength, are collected from various literature published. The data is thoroughly sorted and only those beams having failed in shear and shear span to depth ratio less than 2.5, have been considered for the training. It is found
that a number of 193 test data out of 373 resembles to criteria of deep beam as shear span to depth ratio less than 2.5.

Out of 193 tests, 160 tests were carried on normal stress concrete with $f_c < 55$MPa and 33 tests on high strength concrete with $f_c > 55$ (as per IS 456 2000) SFRC deep beams.

These experimental results were obtained from tests carried along with number of tests by Adebar et al (08), Ashour et al (08), Cucchiara et al (03), Kwak et al (04), Lim et al (08), Mansur et al(03), Rosenbusch and Teutsh (09), Sharma (03), Swammy and Jones (06), Ta’an and Murugappan (06), Narayan and Darwish (18), Madan S.K. et al (09), Uomoto (24), Kadir and Shah (04), Apparao G (06), Salana R. (12), Hockenberry et al(08), Anant Parghi et al (06), Minelli and Plizari (06), Shah and Mishra (04), Robert and Ho (09), Mandola (02), Admile et al (27). The details of the tests are given in Appendix-I.

The database selected consists of the SFRC deep beams are rectangular cross section with compressive strength ranging from 19MPa to 99MPa, Width:50mm to 305mm, Overall depth: 100mm to 1000mm, Longitudinal steel: 0 % to 4.58 %, Shear span to depth ratio: 0.4 to 2.5, Steel Fiber volume fraction: 0% to 2%, Fiber aspect ratio : 0 to 133.

![Figure 3.2: Geometrical parameters of typical SFRC deep beam](image)

The parameters of the tested beams are the width of the beam ($b$), overall depth ($D$), shear span to depth ratio ($a/d$), depth of the beam ($d$), concrete compressive strength ($f_c$), fiber volume fraction ($V_f$), fiber aspect ratio($l_f/d_f$), longitudinal steel ($A_{st}$)
The study of the pervious experimental results indicated that the tested beams showed different types of failures. In this study, those beams which failed under shear are kept for further processing. The tested beams failed with other types of failures were excluded from this study. The tested beams were subjected to two-point loading. This case provides a larger amount of data than other cases do, which is essential for better training of a network. The geometrical dimensions and reinforcement of a typical SFRC deep beam tested under two point loads is shown in Fig 3.2.

3.4 Selection criteria of experimental results and pre-processing of data

The learning of the neural network is greatly affected by the way the data is presented to the neural network. Hence; a certain amount of data processing is required before presenting the training pattern to the network. A comprehensive study was carried out on the collected experimental data results to choose the data which can be used in the training of a neural network model. As the aim of this study is to predict the shear strength of deep beams, the results of the deep beams failed under shear is kept while those results of deep beams which showed other types of failures were excluded. Applying the above selection criteria, a data base of 193 test results was obtained for normal strength SFRC deep beams and 33 test results for high strength SFRC deep beams. These data will go through other selection and pre-processing stages to obtain a reliable training data for neural network.

3.4.1 Statistics of laboratory experiments

The collected laboratory data were grouped randomly into three subsets: a training set, validation set, and the testing set. The literature do not define any criteria for division of the data base into subsets. Taking into consideration the number of parameters and heterogeneous behaviour of SFRC, large portion on the data base is required for training the ANN.

The randomly distribution of data into subsets is; training set: 90%, validation set: 05% and testing set: 05%.

The statistics of the details are as given in Table 3.1.
Table 3.1: Statistics of tests carried on Normal and High strength SFRC deep beams.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>b (mm)</th>
<th>D (mm)</th>
<th>d (mm)</th>
<th>Ast (%)</th>
<th>a/d</th>
<th>L* (mm)</th>
<th>f_c (MPa)</th>
<th>Vf (%)</th>
<th>lf/df</th>
<th>Vu (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A) Statistics of Training Data Set</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Tests</td>
<td>193</td>
<td>193</td>
<td>193</td>
<td>193</td>
<td>91</td>
<td>193</td>
<td>193</td>
<td>193</td>
<td>193</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>117.64</td>
<td>314.69</td>
<td>282.83</td>
<td>1.8</td>
<td>1.55</td>
<td>934.35</td>
<td>45.33</td>
<td>1.17</td>
<td>59.8</td>
<td>4.456</td>
</tr>
<tr>
<td>Max.</td>
<td>305</td>
<td>1000</td>
<td>910</td>
<td>4.58</td>
<td>2.5</td>
<td>4550</td>
<td>99</td>
<td>0</td>
<td>0</td>
<td>0.96</td>
</tr>
<tr>
<td>Min.</td>
<td>50</td>
<td>100</td>
<td>80</td>
<td>0</td>
<td>0.4</td>
<td>400</td>
<td>19</td>
<td>2</td>
<td>133</td>
<td>13.95</td>
</tr>
<tr>
<td>SD</td>
<td>53.43</td>
<td>155.67</td>
<td>144.72</td>
<td>1.02</td>
<td>0.693</td>
<td>24.03</td>
<td>15.28</td>
<td>5.93</td>
<td>31.87</td>
<td>2.83</td>
</tr>
</tbody>
</table>

* Data of length is available for 91 tests only.

3.5 Frequency of experimental data

The data base is examined across its range for the distribution of each parameter. The frequency distribution of all parameters is studied across the 193 high strength and normal strength reinforced concrete compressive strength test results are presented in Figure 3.3 (a) to Figure 3.3 (g). The study of distribution helps to assume range of parametric values of various parameters to study the behavior of SFRC deep beams using developed ANN. The assumed values of parameters are mentioned in section 3.7.1.

![Figure 3.3(a): Frequency for width 'b'

![Figure 3.3(b): Frequency for depth ‘d’](image-url)
Figure 3.3(c): Frequency for main steel

Figure 3.3(d): Frequency for ‘a/d’ ratio

Figure 3.3(e): Frequency for ‘f_c’

Figure 3.3(g): Frequency for volume fraction

The fig 3.3 shows that 72.50% values of width are in the range 45mm - 135mm, 91% values of depth are in the range 160 mm – 619 mm, 23% of total data base are for beams without longitudinal steel. Share span to depth is found in the range 0.5-2.0 by
78% while 84% tests are on normal strength concrete and 16% tests on higher strength concrete. The 83% tests show fiber volume fraction between 0-1%. The percentage distribution for fiber aspect ratio is 58% for the range 45-60 and 24% for the range between 75-105.

3.6 Development of ANN model

The ANN model is built by using the toolbox available in MATLAB Version 7.8.0 R 2009a [40] computing software. The neural network algorithm provided in above version are user friendly and can be quickly applied to large scale data conveniently. It also enables modeling the problem using back propagation ANN, with a wide range of transfer functions, learning techniques, network architectures, performance optimization and performance functions. [40]

The reliable training set of data was obtained by applying the selection and preprocessing criteria as mentioned in Section 3.11 above. The details of the training process which was followed in this study have been explained in following sections. The validation of the developed neural network model is discussed.

3.6.1 Strategy of Training the ANN model

The back propagation algorithm is most widely and successfully implemented in the applications of civil engineering [53, 14, 49]. Therefore, it was decided to apply Feed Forward Back Propagation Technique after pre-processing the data.

The MATLAB7.8.0 R2009a contains Neural Network Toolbox which create neural networks. These networks are good at fitting functions and recognizing the patterns. In fact the fairly simple neural networks can fit any practical problem in three ways-

a) Using Command Line Functions
b) Using Graphical User Interface (nftool)
c) Using Graphical User Interface(nntool)

In the current study, ‘nftool’, being user friendly and randomly detect the data for training, validation and testing, has been used for recognizing the pattern of ultimate shear strength of SFRC deep beams.
The various steps followed for training and creating network are as given below-

1. Using the total data base collected of 193 tests, the problem is defined for this toolbox by arranging the set of input vectors as column matrix, say \([p]\). The output or target vectors are arranged in second matrix say \([t]\). The input matrix \([p]\) has eight parameters width (\(b\)) mm, overall depth (\(D\)) mm, effective depth (\(d\)) mm, shear span – depth ratio (\(a/d\)), compressive strength of concrete (\(f_c\)) MPa, volume fraction (\(v_f\)) % and fiber aspect ratio (\(l_f/d_f\)) arranged in column and total 193 columns. The size of \([p]\) is 8 X 193. The target matrix contains the results of each experimental test arranged in matrix \([t]\) of size 1 X 193. The Input and Target matrices are then normalized by giving command-

\[
[pn, ps] = \text{mapminmax} (p), \quad \text{and} \quad [tn, ts] = \text{mapminmax} (t)
\]

The Figure 3.4 illustrates the above.

![Figure 3.4: Formation of Input and Target Matrix.](image)
2. The Neural Network Fitting Tool is then opened by giving command ‘nftool’. The following window appeared as shown in Figure 3.5.

![Figure 3.5: Neural Network Fitting Tool](image)

3. The data is selected in the data selection window as shown in Figure 3.6.

![Figure 3.6: Selection of Input and Output Data](image)
4. The total database is now divided conveniently in percentage into training: 90%, validation: 5% and testing: 5% as given in Figure 3.7. The Neural Network Toolbox automatically divides the data randomly in the prescribed percentages.

![Figure 3.7: Division of total data set](image)

5. The size of the network is finalized in this step. The number of neurons in input layer is equal to number of parameters which is eight (08) for this study as mentioned in step 1. The number of neurons are arbitrarily assumed to start the training and gradually adjusted till satisfactory training is achieved. The network size window appears as shown in Figure 3.8. In this study, the number of neurons in hidden layer after various trials are finalized as 22 in a single hidden layer only.
6. The train window is opened by clicking next and then trained. It appears as shown in Figure 3.9.

Figure 3.8: Network size window

Figure 3.9: Training of neural network.
7. The process of training is monitored for Mean Square Error, Regression Plots and Performance as shown in Figure 3.10(a) and 3.10(b) respectively.

![Figure 3.10(a): Performance plot](image1)

![Figure 3.10(b): Regression plot for trained network.](image2)
8. After satisfactory performance the results are saved in workspace of MATLAB window. The output vector is then obtained by the command: a= sim (net, p), which is also, saved in work space of created network. The results of output matrix [a] are verified with actual targets and the results showing diversity are removed from database. The revised database is again trained for better satisfactory performance. The final size of the network for this study has been finalized as 8 X 26 X 1 where, 8= number of neurons in Input Layer

26= number of neurons in Hidden Layer

1= number of neurons in Output Layer

It is apparent from the performance plot of Figure 3.10(a) that as the number of epochs increase, the MSE is decreased. The MSE is relatively stable at 4th epoch as seen from Figure 3.10(a). To minimize the errors incurred due to diversity within the dataset, it has been decided to fix the tolerance in the range of ±15%. The overall regression of 95% indicates high reliability of the parameters considered. Linear regression plot in Figure 3.10(b) depicts that the regressed samples converged as approximately 95% which is supposed to be satisfactory.

9. Figure 3.11 shows the comparison of ANN results with targeted results. The goodness of fit and R square values shows its reliability.

![Comparison between ANN result and targeted strength](image)

Figure 3.11: Comparison between ANN result and targeted strength
Linear model Poly1:

\[ f(x) = p_1 x + p_2 \]

Coefficients (with 95% confidence bounds):

\[ p_1 = 0.9961 (0.9828, 1.009) \]
\[ p_2 = 0.02918 (-0.03865, 0.09701) \]

Goodness of fit:

\[ SSE: 11.18 \]
\[ R\text{-}square: 0.9919 \]
\[ Adjusted R\text{-}square: 0.9918 \]
\[ RMSE: 0.2492 \]

3.7 Investigation of behavior of SFRC deep beams using ANN model

The developed ANN model is used to study the variations in ultimate shear capacity of SFRC deep beams of 100mm width and its behavior for parameters like fiber volume fraction (\(V_f\) %), shear span to depth ratio (a/d), depth of beam (‘d’ mm) and fiber aspect ratio (\(l_f/d_f\)) affecting the shear strength.

3.7.1 Effect of volume of steel fibers on ultimate shear capacity of SFRC deep beams

This effect of inclusion of steel fibers is studied for deep beams of grade M25, M55 and M75 (Normal strength and High strength concrete) for fiber volume fraction 0.5%, 1%, 1.5% and 2% with depths 300mm, 500mm, 600mm and longitudinal steel percentage 0%, 1.5% and 2.5%. The shear span to depth ratio (a/d) considered is 0.5, 1 and 2.
a) SFRC deep beams at Ast= 0% and a/d=0.5

i) Effect of steel fibers on M25 grade SFRC deep Beams at Ast= 0% and a/d=0.5

Figure 3.12: Effect of steel fibers on ultimate shear strength of M25 grade SFRC deep beam

Figure 3.12(a)

Figure 3.12(b)

Figure 3.12(c)

Figure 3.12: Effect of steel fibers on ultimate shear strength of M25 grade SFRC deep beam
Figure 3.12 describes the variation of shear strength of M25 grade SFRC deep beam without longitudinal steel for volume fraction 0% to 2% with different aspect ratios from 50 to 100. The following observations are made:

i) The ultimate shear strength except for a particular aspect ratio of 70, 80, 90 and for no longitudinal steel increases with increase in volume fraction for D=300mm by 25% at fiber aspect ratio 50, 12% at aspect ratio 60. It further decreases for aspect ratio 70, 80, 90 and shows increment by over 16% as seen in Figure 3.12(a).

ii) The increase in depth to 500mm, overall decrease in shear capacity at all volume fraction and aspect ratio is observed in Figure 3.12(b) compared with Figure 3.12(a). The increase in depth brings improvement in shear strength at \( \text{lf/df}= 70 \) unlike at \( D=300\text{mm} \). But, increase in volume fraction increases the shear strength at all fiber aspect ratios except 80 and 90 by 60.8%, 43.6%, 17.3% and 41%.

iii) The increase in fiber volume fraction shows enhancement in shear strength at all fiber aspect ratios but overall decrease in strength as an effect of increase in depth as found in Figure 3.12 (c). The percentage increase in shear strength is 49%, 49.7%, 40.3%, 33.5% and 63% at fiber aspect ratios 50, 60, 70, 80, 90 and 100 respectively.

ii) Effect of steel fibers on M55 grade SFRC deep Beams at \( \text{Ast}=0\% \) and \( a/d=0.5 \)

![Figure 3.13(a)](image-url)
Figure 3.13(b)

Figure 3.13(c)

Figure 3.13: Effect of steel fibers on ultimate shear strength of M55 grade SFRC deep beam

Figure 3.13 describes the shear strength variation with fiber volume fraction with different aspect ratios for Ast=0%. The findings noted are-

i) The increase in compressive strength to 55 MPa drops down the ultimate shear strength as compared with the shear strength of $f_c = 25$ MPa at D=300mm. It is also noted that fiber volume fraction does not affect the shear strength at all fiber aspect ratios for b:D=1:3 as observed in Figure 3.13(a).

ii) Figure 3.13(b) shows that the increase in fiber volume fraction has adverse effect on shear strength up to $l_f/d_f = 50, 60, 70$ at D=500mm without longitudinal steel.
But the fiber volume fraction with fiber aspect ratio greater than 70 gives shear strength to the beams and increase with increase in $V_f$ \% and $b:D=1:5$.

iii) The point noted from Figure 3.13(c) is inability to carry shear of the SFRC deep beam with Ast=0\% and D=600mm for all volume fractions and fiber aspect ratios at $b:D=1:6$. It indicates that steel fibers fails to provide shear strength and need to be added with longitudinal steel percentage for M55 grade SFRC deep beams.

iii) Effect of steel fibers on M75 grade SFRC deep Beams at Ast= 0\% and a/d=0.5

![Figure 3.14(a)](image1)

![Figure 3.14(b)](image2)
Figure 3.14(c)

Figure 3.14: Effect of steel fibers on ultimate shear strength of M75 grade SFRC deep beam.

Figure 3.14(a), 3.14(b), 3.14(c) describe the response of M75 grade SFRC deep beams with Ast=0% and depths 300mm, 500mm and 600mm. The fiber addition up to 2% without longitudinal steel is found insufficient to add to the shear strength of the specimen for the depths considered. It indicates that for higher strength concrete the combination of steel fibers and longitudinal steel required for increasing the ultimate shear strength.

b) SFRC deep beams with Ast = 1.5%, a/d = 0.5

i) Effect of steel fibers on M25 grade SFRC deep Beams at Ast = 1.5%, a/d = 0.5

Figure 3.15 represents the behavior of M25 grade SFRC deep beams with longitudinal reinforcement of 1.5% at shear span to depth ratio of 0.5.
Figure 3.15(b)

Figure 3.15(c)

Figure 3.15: Variation of ultimate shear strength for M25 grade SFRC deep beams for Ast=1.5% and a/d=0.5

Figure 3.15(a) represents the variation at depth D=300mm for M25 grade SFRC deep beams with Ast=1.5% and a/d=0.5. It shows that the increase in fiber volume fraction with fiber aspect ratio less than 70 fails to improve the ultimate shear strength above the ordinary RC deep beam (6.94 MPa) with Ast=1.5% for a/d=0.5. The fiber aspect ratio of 80 and more increases the ultimate shear strength at Vf=0% by 4%, 65.4%, 130% at l/df= 80, 90 and 100 respectively. It is also noted that increase in fiber volume fraction shows decrement at all fiber aspect ratios considered in this study.

The increase in depth to 500mm shows similar pattern of variation of ultimate shear strength as discussed above and seen from Figure 3.15(b). The increase in fiber
volume at particular aspect ratio shows fall in shear strength. Overall shear strength is increased due to increase in depth when compared with Figure 3.15(a).

Further increasing depth to 600mm, the ultimate shear strength increases above ordinary RC deep beam (9.84 MPa) for \( V_f = 0.5\% \) at all fiber aspect ratios by 51\%, 49\%, 54\%, 71\%, 97\%, 127\%. It is also, seen that the shear strength increases with increase in fiber volume fraction as shown in Figure 3.15(c).

ii) Effect of steel fibers on M55 grade SFRC deep Beams at \( \text{Ast} = 1.5\% \), \( a/d = 0.5 \)

![Figure 3.16(a)](image1)

![Figure 3.16(b)](image2)
Figure 3.16(c)

Figure 3.16: Effect of steel fibers on ultimate shear strength of M 55 grade SFRC deep beam with Ast=1.5% and a/d=0.5.

Figure 3.16 describes the variation of M55 grade SFRC deep beams at a/d=0.5 and Ast=1.5%. The Figure 3.16(a) for D=300mm suggests decrease in shear capacity with increase in fiber volume for fiber aspect ratio varying from 50 to 90 and then increases at lf/df=100.

Similar variation in shear strength is found for D=500mm in Figure 3.16(b) but with overall decrease in shear capacity as result of increase in depth. For depth D=600mm, the shear strength is achieved by adding steel fibers of aspect ratio not less than 100 as per Figure 3.16 (c).

Effect of steel fibers on M75 grade SFRC deep beams at Ast=1.5%, a/d=0.5

The high strength M75 SFRC deep beams with Ast=1.5% and at a/d=0.5 shows enhancement in ultimate shear strength at D=300mm over ordinary RC deep beam as shown in Figure 3.17(a). The shear strength increases with increase in fiber volume up to fiber aspect ratio equal to 80 after which strength declines at 90 and 100.

Figure 3.16(b) and Figure 3.16(c) reveals that combination of Ast=1.5 % and different fiber volume fractions up to 2% at a/d=0.5 do not provide shear strength to M75 grade SFRG deep beams.
Figure 3.17(a)

Ast=1.5%, a/d=0.5, fc=75MPa, D=300mm

Figure 3.17(b)

Ast=1.5%, a/d=0.5, fc=75MPa, D=500mm

Figure 3.17(c)

Ast=1.5%, a/d=0.5, fc=75MPa, D=600mm

Figure 3.17: Effect of steel fibers on ultimate shear strength of M 75 grade SFRC deep beam with Ast=1.5% and a/d=0.5.
c) SFRC deep beams at \( Ast=2.5\%, a/d=0.5 \)

i) Effect of steel fibers on M25 grade SFRC deep Beams at \( Ast=2.5\%, a/d=0.5 \)

Figure 3.18 represents the variation in ultimate shear strength for M25 grade SFRC deep beams for \( Ast=2.5\% \) at \( a/d=0.5 \) and \( D=300\text{mm} \). The effectiveness of fiber volume fraction is seen with increase in shear strength as volume fraction of fibers increases for M25 at depth= 300mm. The percentage increase is found effective at fiber aspect ratio 60 and above as shown in Figure 3.18(a). The shear strength increases by 1.5%, 29%, 72.3%, 106% and 118.5% at \( l/f/d=60, 70, 80, 90, 100 \) respectively.

![Figure 3.18(a)](image)

The change in depth to 500mm, the effect of fiber volume fraction on shear strength is observed from Figure 3.18 (b). It shows overall increase in shear strength at all volume fractions under consideration with \( Ast=2.5\% \) but indicates decrease in strength of plain RC deep beam with \( V_f=0\% \) as a result of increase in depth. It is also noted that the fiber aspect ratio adds to the shear strength when changed from 60 to 100 at all volume fractions considered.
Figure 3.18(b)

Figure 3.18(c)

Figure 3.18: Effect of steel fibers on ultimate shear strength of M25 grade SFRC deep beam with Ast=2.5% and a/d=0.5.

Figure 3.18(c) suggests that further increase in depth to 600mm, increase the shear strength considerably up to aspect ratio 90 and shows deviation from the trend at lf/df=100 at longitudinal steel 2.5%.

The Figure 3.18 proves the usefulness of fiber volume fraction for M25 grade deep beams with Ast=2.5% and a/d=0.5. The maximum shear strength attainable is found 13.04 MPa at fiber aspect ratio 100 with \( V_f = 2\% \) at a/d=0.5
ii) Effect of steel fibers on M55 grade SFRC deep Beams at Ast= 2.5%, a/d=0.5

Figure 3.19(a)

Figure 3.19(b)

Figure 3.19(c)

Figure 3.19: Effect of steel fibers on ultimate shear strength of M55 grade SFRC deep beam with Ast=2.5% and a/d=0.5
The pattern of change in ultimate shear strength for M55 grade SFRC deep beam is represented by Figure 3.19. It continues the tendency of increase in ultimate shear strength with increase in fiber volume fraction for all aspect ratios considered except the % increase for D=300mm with change in fiber content is 2%, 2.5%, 3%, 3.78%, 4.8% and 6% at fiber aspect ratios 50 to 100 as observed in Figure 3.19(a).

Figure 3.19(b) represents the variation of shear strength for D=500mm. It shows overall fall in shear strength as depth increases but rise in shear strength with increase in fiber volume fraction. Figure 3.19(c) also indicates the same type of variation at all fiber aspect ratios considered. It is noted that the effect of increase in depth is more for lower fiber aspect ratios.

iii) Effect of steel fibers on M75 grade SFRC deep Beams at Ast= 2.5%, a/d=0.

![Figure 3.20(a)](image)

![Figure 3.20(b)](image)
The effectiveness of steel fibers for high strength M75 grade SFRC deep beams is observed in Figure 3.20(a), Figure 3.20(b) and Figure 3.20(c) for increase in fiber volume fractions at depths 300mm, 500mm and 600mm respectively. It is observed that the shear strength increases for all aspect ratios with increase in fiber volume fractions at all fiber aspect ratios but comparatively decreases with increase in fiber aspect ratio. The maximum contribution to shear strength of steel fibers is found at $l_f/d_f=60$ indicating that lower fiber aspect ratios are effective for considered parameters.

![Figure 3.20(c)](image)

**Figure 3.20(c)**

**Figure 3.20:** Effect of steel fibers on ultimate shear strength of M 75 grade SFRC deep beam with $A_{st}=2.5\%$ and $a/d=0.5$.

Figure 3.20 (b) and Figure 3.20(c) indicate decrease in shear strength below the shear strength of ordinary RC deep beams and steel fiber volume up to 2% with increase in fiber aspect ratio do not contribute to raise the shear strength for $b:D > 1:3$ for considered parameters.
d) SFRC deep beams at Ast= 0% and a/d=1

i) Effect of steel fibers on M25 grade SFRC deep beams at Ast= 0% and a/d=1

Figure 3.21(a)

Ast=0%, a/d=1, f_c=25MPa, D=300mm

<table>
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<th>Fiber aspect ratio</th>
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<td>5.00</td>
<td>8.57</td>
<td>8.57</td>
<td>5.50</td>
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</table>

Figure 3.21(b)

Ast=0%, a/d=1, f_c=25MPa, D=500mm

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</table>

Figure 3.21(c)

Ast=0%, a/d=1, f_c=25MPa, D=600mm

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<th>1.50</th>
<th>2.00</th>
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</table>

Figure 3.21: Effect of steel fibers at a/d=1 for M25 grade SFRC deep beams with Ast=0%
Figure 3.21(a), Figure 3.21(b) and Figure 3.21(c) explain the behavior of M25 grade SFRC deep beams without longitudinal steel at a/d=1 for different volume fraction of steel fibers with varying aspect ratios. The observations are-

i) The individual effect of fiber volume fraction is increasing the shear strength with increase in fiber volume with all fiber aspect ratios considered.

ii) For the D=300mm, the fiber volume up to 2% with aspect ratio up to 70 impart the ultimate shear strength less than plain concrete beams (5.50MPa) and fiber volume fraction of 2% with \( \frac{l_f}{d_f} \) greater than 80 shows shear strength greater than 5.50 MPa with percentage increase in strength by 22% and 64% for fiber aspect ratio 90 and 100 respectively.

iii) Similar variation is observed at depth of 500mm and 600mm as discussed above. The effect of increase in depth causes overall reduction in shear strength for parameters assumed.

**ii) Effect of steel fibers on M55 grade SFRC deep Beams at Ast= 0% and a/d=1**

![Figure 3.22(a)](image-url)
Figure 3.22: Effect of Fiber volume fraction at a/d=1 for M55 grade SFRC deep beams with Ast=0%

Figure 3.22 explains the behavior of M55 grade SFRC deep beams without longitudinal steel at different fiber volume fractions at a/d=1. Figure 3.22(a) shows that the ultimate shear strength increases with increase in fiber volume fraction as well as the fiber aspect ratio for D=300mm. The comparison with Figure 3.21(a) indicates fall in shear strength with increase in compressive strength from 25 MPa to 55 MPa.

The increase in depth to 500mm and 600mm without addition of longitudinal steel shows unfavorable effects on shear strength of M55 grade SFRC deep beam as seen from Figure 3.22(b) and Figure 3.22(c) respectively.

iii) Effect of steel fibers on M75 grade SFRC deep Beams at Ast= 0% and a/d=1
Figure 3.23: Variation of ultimate shear strength of M75 grade deep beams without longitudinal steel at a/d=1
Figure 3.23(a), Figure 3.23(b) and Figure 3.23(c) show that plain deep beam made of high strength concrete of grade M75 has very poor performance in shear at depths 300mm, 500mm and 600mm. The inclusion of steel fibers without longitudinal steel enhances the shear capacity at D=300mm at all fiber volume fractions having aspect ratio greater than 50.

e) SFRC deep beams at Ast= 1.5% and a/d=1

i) Effect of steel fibers on M25 grade SFRC deep Beams at Ast = 1.5% and a/d=1

![Figure 3.24(a)](image-url)

**Figure 3.24(a)**

![Figure 3.24(b)](image-url)

**Figure 3.24(b)**
Figure 3.24: Variation of ultimate shear strength for M25 grade SFRC deep beams for Ast=1.5% and a/d=1

Figure 3.24 elaborates the effect of steel fibers on ultimate shear strength of M25 grade SFRC deep beams with Ast=1.5% at a/d=1 for different volume fractions and fiber aspect ratios. The shear strength of RC deep beam without steel fibers has shear strength 5.21MPa which decreases at all volume fractions of aspect ratio 50, 60 and 70. The inclusion of steel fibers of aspect ratios 80 and more increases the strength as the fiber volume increases. The percentage increase at Vf=2% is 32%, 111% and 178% for l_f/d_f =80, 90 and 100 respectively as shown in Figure 3.24(a).

The increase in depth to 500mm with Ast=1.5%, reduces the ultimate shear strength of M25 ordinary RC deep beam to 2.76MPa. The addition of steel fibers from 0.5% to 2% enhances the shear strength for all fiber aspect ratios at a/d=1 form Figure 3.24(b). The maximum achievable shear strength is 16.14MPa at V_f= 2% for l_f/d_f=100.

Further increase in depth to 600mm shows the similar pattern of variation of shear strength with decrease in overall shear strength as seen from Figure 3.24(c).
ii) Effect of steel fibers on M55 grade SFRC deep Beams at Ast= 1.5% and a/d=1

![Graph](image-url)

**Figure 3.25(a)**

**Figure 3.25(b)**

**Figure 3.25(c)**

**Figure 3.25: Variation of ultimate shear strength for M55 grade SFRC deep beams**

*for Ast=1.5% and a/d=1*
Figure 3.25(a), Figure 3.25(b) and Figure 3.25(c) describe the behavior of M55 SFRC deep beam reinforced with 1.5% longitudinal steel and a/d=1. The shear strength of ordinary RC deep beam increases with increase in depth of the section and is 2.25MPa for D=600mm. On the contrary, the shear strength due to inclusion of steel fibers goes on decreasing with increase in depth. At depth of 300mm, the improvement in shear strength is observed at all fiber volumes and higher fiber aspect ratio are required for increase in depth. The maximum attainable shear strength 17.86MPa is noted at D=300mm for \( V_f=2\% \) and \( l_f/d_f=100 \).

**iii) Effect of steel fibers on M75 grade SFRC deep Beams at Ast= 1.5% and a/d=1**

![Figure 3.26(a)](image1)

![Figure 3.26(b)](image2)
Figure 3.26(c)

Figure 3.26: Variation of ultimate shear strength for M75 grade SFRC deep beams for Ast=1.5% and a/d=1

The behavior of M75 SFRC deep beam is presented in Figure 3.26(a), Figure 3.26(b) and Figure 3.26(c) for Ast=1.5% and a/d=1. The shear strength improves in increasing fiber volume fraction at all fiber aspect ratios for D=300mm.

f) SFRC deep beams with Ast=2.5% and a/d=1

i) Effect of steel fibers on M25 grade SFRC deep Beams with Ast=2.5% and a/d=1

Figure 3.27(a)
The variation of shear strength for M25 grade SFRC deep beam at Ast=2.5% is studied from Figure 3.27 at a/d= 1. The study of Figure 3.27(a) describes that the addition of steel fibers improves the ultimate shear strength with increase in fiber volume fraction over the shear strength 2.81 MPa of ordinary RC deep beam. The fiber aspect ratio also, contributes to increase the shear strength, up to 80 and decreases at 90 and 100.

Similar variation is found for D=500mm and 600mm as observed in Figure 3.27(b) and 3.27(c) but increase in depth increases the shear strength at all fiber aspect ratio. The maximum attainable ultimate shear strength is noted at D=600mm with Vf=2% and l_f/d_f= 80.

ii) Effect of steel fibers on M55 grade SFRC deep Beams at Ast= 2.5% and a/d=1
Figure 3.28(a)

The study of Figure 3.28(a) indicates the general trend of increase in ultimate shear strength with increase in volume fraction at all fiber aspect ratios. Somehow, the shear strength for $l_d/d_f > 90$ shows declination. The percentage increase in shear strength for $l_d/d_f = 50$ to $100$ is $7.54\%$, $9\%$, $10.5\%$, $12\%$, $13.55\%$ and $14.45\%$ respectively.

Figure 3.28(b)

Figure 3.28(c)

Figure 3.28: Variation of ultimate shear strength for M55 grade SFRC deep beams for $\text{Ast}=2.5\%$ and $\text{a/d}=1$
The variation in shear strength at D=500mm and 600mm are presented in Figure 3.28(b) and Figure 3.28(c) respectively. It is evident that the fiber volume fraction causes increase in shear strength for M55 at Ast=2.5% but increase in depth shows reduction in shear strength at all fiber content and aspect ratios considered. The percentage variation in shear capacity with fiber volume from 0% to 2% is found more at D=600mm.

iii) Effect of steel fibers on M75 grade SFRC deep Beams with Ast=2.5% and a/d=1

![Figure 3.29(a)](image1)

![Figure 3.29(b)](image2)
Figure 3.29(c)

Figure 3.29: Variation of ultimate shear strength for M75 grade SFRC deep beams for Ast=2.5% and a/d=1

Figure 3.29 describes the behavior of M75 grade SFRC deep beams with Ast=2.5% and a/d=1 for different fiber volume fractions and fiber aspect ratios. Figure 3.29(a) shows the trend of increase in ultimate shear strength with increase in fiber volume fraction at all fiber aspect ratios at depth of 300mm. But the increase in shear strength up to lf/df=70 is greater than 18.22 MPa, the shear strength of ordinary RC deep beam. It indicates that the combination of Ast=2.5% and steel fibers is acceptable with fiber aspect ratio less than or equal to 70. Increase in depth to 500mm shows similar pattern of variation in ultimate shear strength and suggests effectiveness of steel fibers along with main reinforcement 2.5% at a/d=1 for M75 grade. Figure 3.29(c) shows the behavior of M75 grade SFRC deep beams at D=600mm. It is clear that addition of fibers decreases the shear strength even below the strength of ordinary M75 grade RC deep beams for the assumed parameters and cannot be recommended.
g) SFRC deep beams with $\text{Ast} = 0\%$ and $\text{a/d} = 1.5$

i) Effect of steel fibers on M25 grade SFRC deep Beams with $\text{Ast} = 0\%$ and $\text{a/d} = 1.5$

Figure 3.30(a)

Figure 3.30(b)

Figure 3.30(c)

Figure 3.30: Variation of ultimate shear strength for M25 grade SFRC deep beams for $\text{Ast} = 0\%$ and $\text{a/d} = 1.5$

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Figure 3.30 shows results for ultimate shear strength of M25 grade SFRC deep beams without main steel reinforcement with addition of steel fibers of different aspect ratios. The shear strength for plain deep beam (Ast=0% and Vf=0%) at depth of section D=300mm is 4.35 MPa as shown in Figure 3.30(a). The effect of adding fibers dosage of different aspect ratios can be seen as increase in ultimate shear strength. The addition of fibers with aspect ratios of 50, 60 and 70 with volume fractions 0% to 2% are not found sufficient to increase the shear strength greater than the shear strength of plain deep beams (4.35MPa) except for l/d=70 with Vf=2%. For greater aspect ratios of 80, 90 and 100, the ultimate shear strength obtained is greater than plain deep beams. The percentage increase for Vf=0.5% is noted as 25%, 82% and 145% for aspect ratios 80, 90 and 100 respectively.

Figure 3.30(b) indicates the shear strength variation due to increase in depth to 500mm. The effect of addition of steel fibers of different aspect ratios shows increase in ultimate shear strength greater than shear strength of plain deep beams (3.12 MPa) at D=500mm at all fiber volume fractions of different aspect ratios. The percentage increase in shear strength at lower volume fraction of 0.5% is noted as 17.6%, 24%, 57.3%, 124%, 211% and 303% at fiber aspect ratios 50, 60, 70, 80, 90 and 100 respectively. It is also noted that the ultimate shear strength decreases with increase in depth when compared with Figure 3.30(a).

Figure 3.30(c) predicts the variation of ultimate shear strength for D=600mm. It is noticed that the increase in depth to 600mm reduces overall shear strength obtained at D=500mm (Figure 3.30(b)). The variation in shear strength pattern observed is similar with the pattern obtained at D=500mm showing percentage increase at Vf= 0.5% by 25%, 37%, 60%, 91%, 123% and 150% at fiber aspect ratio 50, 60, 70, 80, 90 and 100.

The deep beams without main reinforcement gives better ultimate shear strength at a/d=1.5 at depth of 500mm for fiber volume fraction up to 2%.
ii) Effect of steel fibers on M55 grade SFRC deep Beams with Ast = 0% and a/d = 1.5

Figure 3.31 represents the behavior of M55 grade SFRC deep beams without longitudinal reinforcement at shear span to depth ratio of 1.5.
Figure 3.31(a) shows that the ultimate shear strength at D=300mm for plain deep beam has theoretically no shear strength. The addition of steel fibers from 0.5% to 2% with increase in fiber aspect ratio gradually increases the shear strength. The maximum ultimate shear strength of 8.74 MPa, achieved at D=300mm is found at $V_f=2\%$ with $l_f/d_f = 100$.

Figure 3.31(b) predicts the ultimate shear strength for M55 grade SFRC deep beams at increase in depth to 500mm. It is seen that the increase in depth shows gaining the shear strength with increase in fiber volume fraction. It is noted that for all volume fractions and fiber aspect ratios equal and greater than 80, the beams have gained the shear strength. The maximum ultimate shear strength of 5.26 MPa is achieved at $V_f=2\%$ with $l_f/d_f=100$.

The variation in ultimate shear stress for increase in depth to 600mm is shown in Figure 3.31(c). As effect of increase in depth the ultimate shear capacity is lowered as compared with Figure 3.31(a) and Figure 3.31(b). The increase in fiber volume fraction shows gaining shear strength but it can be said that maximum $V_f=2\%$ with $l_f/d_f=100$ without longitudinal steel do not suffice the requirement for positive shear strength.

### iii) Effect of steel fibers on M75 grade SFRC deep Beams with Ast= 0% and a/d=1.5

Figure 3.32 represents the behavior of M75 grade SFRC deep beams without longitudinal reinforcement at shear span to depth ratio of 1.5.
The study of Figure 3.32(a), Figure 3.32(b) and Figure 3.32(c) indicates that with increase in the fiber volume fraction without provision of longitudinal steel shows gaining of shear strength. The percentage gain of shear strength observed at $D=300\text{mm}$ at $V_f=0.5\%$ due to increase in fiber aspect ratio from 50 to 60 by 144%, from 60 to 70 by 52%, from 70 to 80 by 28.3%, from 80 to 90 by 16.2% and from 90 to 100 by 09% is recorded.

**h) SFRC deep beams with Ast= 1.5% and a/d=1.5**

i) Effect of steel fibers on M25 grade SFRC deep Beams with Ast= 1.5% and a/d=1.5

Figure 3.33 represents the behavior of M25 grade SFRC deep beams with longitudinal reinforcement of 1.5% at shear span to depth ratio of 1.5.
Figure 3.33: Variation of ultimate shear strength for M25 grade SFRC deep beams for Ast=1.5% and a/d=1.5
Figure 3.33(a) shows ultimate shear strength variation for D=300mm. It indicates increase in ultimate shear strength with increase in fiber volume fraction. For fiber aspect ratios 50 and 60, the increase in volume fraction up to 2% shows shear strength less than shear strength (4.58 MPa) of M25 grade ordinary RC deep beam with Ast=1.5% and a/d=1.5. It enhances above 4.58 MPa with increase in fiber aspect ratio equal or greater than 70. The percentage increase at $V_f=0.5\%$ is found 19.4%, 80%, 124% and 141% for aspect ratio 70, 80, 90 and 100 respectively.

With increase in depth to 500mm, the shear strength raises at all fiber aspect ratios for $V_f=0.5\%$ to 2% while shear strength of ordinary RC deep beam is reduced. The increase in shear strength is result of increase in fiber volume fraction due to increase in depth as shown in Figure 3.33(b). Further increase in depth to 600mm, causes overall increase in shear strength up to fiber aspect ratio 90 above which the strength declines with increase in fiber volume as observed in Figure 3.33(c).

**ii) Effect of steel fibers on M55 grade SFRC deep Beams with Ast= 1.5% and a/d=1.5**

Figure 3.34 represents the behavior of M55 grade SFRC deep beams with longitudinal reinforcement of 1.5% at shear span to depth ratio of 1.5.
The study of Figure 3.34(a) reveals the behavior of M55 grade SFRC deep beam for D=300mm. At compressive strength of 55MPa, the addition of steel fibers from 0.5% to 2% by volume, increases the shear capacity at all fiber aspect ratio. The increase in depth to 500mm reduces the shear strength when compared with shear strength at D=300mm. Figure 3.34(b) also shows that for increasing the shear strength requires increase in fiber aspect ratio at a/d=1.5 and Ast=1.5%. Figure 3.34(c) indicates that the fiber aspect ratio of 50 and 60 are not sufficient to contribute for increase in shear strength.

Figure 3.34: Variation of ultimate shear strength for M55 grade SFRC deep beams for Ast=1.5% and a/d=1.5
iii) Effect of steel fibers on M75 grade SFRC deep Beams with Ast= 1.5% and a/d=1.5

Figure 3.35 represents the behavior of M75 grade SFRC deep beams with longitudinal reinforcement of 1.5% at shear span to depth ratio of 1.5.

**Figure 3.35(a)**

**Figure 3.35(b)**

**Figure 3.35(c)**

**Figure 3.35: Variation of ultimate shear strength for M75 grade SFRC deep beams for Ast=1.5% and a/d=1.5**
Figure 3.35(a) shows the effectiveness of steel fibers to increase the ultimate shear strength at depth of section of 300mm. It shows increase in shear strength with fiber volume fraction above the shear strength (8.33 MPa) of ordinary RC deep beam reinforced with 1.5% longitudinal steel. The percentage increase at $V_f=0.5\%$ over 8.33 MPa is 45%, 54%, 59%, 57.7%, 46% and 43% at fiber aspect ratio varying from 50 to 100.

The increase in depth to 500mm exhibits the decrement in shear strength with increase in depth. It shows requirement of steel fibers with aspect ratio equal or more than 80 as seen from Figure 3.35(b).

Figure 3.35(c) shows the shear strength variation for $D=600mm$. The increase in fiber volume shows gaining of shear strength. But, volume fraction of 2% and fiber aspect ratio 100 with longitudinal steel 1.5% do not raise the ultimate shear capacity above ordinary deep beams.

i) **SFRC deep Beams with Ast= 2.5% and a/d=0.5**

i) Effect of steel fibers on M25 grade SFRC deep Beams with Ast= 2.5% and a/d=0.5

Figure 3.36 represents the behavior of M25 grade SFRC deep beams with longitudinal reinforcement of 2.5% at shear span to depth ratio of 0.5.

![Graph showing ultimate shear strength vs fiber aspect ratio](image-url)
Figure 3.36 shows that the ultimate shear strength increases with increase in fiber volume fraction at all fiber volume fractions and fiber aspect ratios above shear strength of ordinary M25 grade RC deep beam, except fiber aspect ratio 50 at $D=300\text{mm}$ with $a/d=0.5$. The shear strength of ordinary RC deep beam seen to be decreasing with increase in depth from 300mm to 500 mm while further increase in depth to 500mm increases the strength.

Figure 3.36(a) describes the variation of shear strength at 300mm depth. It shows that the fiber volume fraction from 0.5% to 2% enhances the ultimate shear strength for $l_d/d_f$ equal or greater than 60. The increase in depth to 500mm shows further increment in

Figure 3.36: Variation of ultimate shear strength for M25 grade SFRC deep beams for $Ast=2.5\%$ and $a/d=0.5$
shear strength for all fiber volume fractions and fiber aspect ratios as observed in Figure 3.36(b). The increase in depth to 600mm, shows similar variation in shear strength up to \( l_f/d_f = 90 \).

Figure 3.36(c) predicts the percentage increase in ultimate shear strength above the ordinary RC deep beam with \( V_f = 0.5\% \) and \( l_f/d_f = 50 \) by 178\% and 211\% for \( V_f = 2\% \) with \( l_f/d_f = 100 \). The maximum attainable shear strength is noted as 13.24 MPa for \( V_f = 2\% \) and \( l_f/d_f = 90 \).

ii) Effect of steel fibers on M55 grade SFRC deep Beams with \( A_s = 2.5\% \) and \( a/d = 0.5 \)

Figure 3.37 represents the behavior of M55 grade SFRC deep beams with longitudinal reinforcement of 2.5\% at shear span to depth ratio of 0.5.
The behavior of M55 grade SFRC with Ast=2.5% and a/d=0.5 is represented in Figure 3.37. It is observed that the ultimate shear strength shows gain of shear strength after adding steel fibers and increases with increase in fiber volume fraction. The increase in depth has reverse effect on shear strength of SFRC beam while the shear strength increases with depth for ordinary RC deep beam for the values of the variables assumed in this case.

The variation at D=300mm is shown in Figure 3.37(a). The percentage rise in shear strength at V_f=2% when increased from V_f=0.5% is 2%, 2.5%, 3.78%, 15.6% and 6.2% at fiber aspect ratio from l_f/d_f=50 to 100 highlighting the effect of fiber aspect ratio on shear strength.

Figure 3.37(b) shows similar pattern of ultimate shear strength variation at D=500mm. The difference noted is fall in shear strength as compared with shear strength at D=300mm. The percentage rise in shear strength with increase in fiber aspect ratio at V_f=0.5% is 48.87%, 33.83%, 25.4%, 18.2%, 12.11% at fiber aspect ratio 50, 60, 70, 80, 90 and 100 respectively. It suggests that the increase in fiber aspect ratio gradually decreases the ultimate shear strength.

The increase in depth to 600mm improves the strength of ordinary RC deep beam but cause overall reduction in ultimate shear strength at all fiber aspect ratios and volume fractions. The percentage increase with increase in fiber volume fraction from 0.5% to 2% at a fiber aspect ratio is found as 85%, 40%, 26.6%, 19.7%, 16%, 13.9% at l_f/d_f= 50, 60, 70, 80, 90 and 100 respectively as seen from Figure 3.37(c)
iii) Effect of steel fibers on M75 grade SFRC deep Beams with Ast= 2.5% and a/d=0.5

Figure 3.38 represents the behavior of M75 grade SFRC deep beams with longitudinal reinforcement of 2.5% at shear span to depth ratio of 0.5.

![Figure 3.38(a)](image1)

![Figure 3.38(b)](image2)

![Figure 3.38(c)](image3)

**Figure 3.38**: Variation of ultimate shear strength for M55 grade SFRC deep beams for Ast=2.5% and a/d=0.5
The behavior of M75 grade SFRC with Ast=2.5% and for a/d=0.5 is observed from Figure 3.38. The Figure 3.38(a) shows variation of ultimate shear strength of M75 grade SFRC deep beam at D=300mm. It shows that the increase in fiber volume fraction, enhances the shear strength above the ordinary M75 grade RC deep beam of depth 300mm at all fiber aspect ratios considered. The percentage increase in shear strength at V_f=0.5% over the shear strength of ordinary RC deep beam (19.32 MPa) is found as 49.6%, 54%, 50.2%, 42.7%, 31.3%, 15.9% at fiber aspect ratio 50 to 100 respectively. It is also, noticed that the percentage increase drops down with increase in fiber aspect ratio.

The variation for ultimate shear strength at D=600mm is represented in Figure 3.38(c). It shows that the increase in depth to 600mm has adverse effect on shear strength and loss of strength at Ast=2.5% at a/d=0.5.

**j) SFRC deep Beams with Ast= 2.5% and a/d=1**

i) Effect of steel fibers on M25 grade SFRC deep Beams with Ast= 2.5% and a/d=1

Figure 3.39 represents the behavior of M25 grade SFRC deep beams with longitudinal reinforcement of 2.5% and shear span to depth ratio of ‘1’.

![Figure 3.39(a)](image-url)
Figure 3.39(a) depicts that increasing the shear span ratio to ‘1’, decreases the ultimate shear strength of M25 grade ordinary deep beam with D=300 MPa, from 5.07 MPa (Figure 3.36(a)) to 3.75 MPa as result of increase in shear span to depth ratio. The inclusion of steel fibers raises the shear strength above 3.75 MPa for $\text{Ast}=2.5\%$ with all fiber volume fraction. The percentage increase in shear strength over ordinary M25 grade deep beam is found 53% at $l_f/d_f=50$ which increases to 64% at $l_f/d_f=100$. But the increase in shear capacity with volume fraction is valid up to fiber aspect ratio of ‘80’. It shows the combined effect of fiber fraction with its aspect ratio.

Figure 3.39(b) predicts the ultimate shear capacity of RC deep beam without fibers decreases to 2.48 MPa from 3.75 MPa as a result of increase in depth to 500mm.
The addition of steel fibers by 0.5% boosts the shear capacity after which the maximum percentage of increase in shear strength of 1.5% due to increase in fiber content is found at \( \text{lf/df}=80 \).

Figure 3.39(c) suggests the similar pattern for variation in shear strength at \( D=600\text{mm} \) as discussed for \( D=500\text{mm} \). It is noted that the increase in depth to 600mm also increases the ultimate shear capacity when compared with 3.39(b).

ii) Effect of steel fibers on M55 grade SFRC deep Beams with \( \text{Ast}=2.5\% \) and \( a/d=1 \)

Figure 3.40 represents the behavior of M55 grade SFRC deep beams with longitudinal reinforcement of 2.5% and shear span to depth ratio of ‘1’.

![Figure 3.40(a)](image)

![Figure 3.40(b)](image)
Figure 3.40(c)

**Figure 3.40**: Variation of ultimate shear strength for M55 grade SFRC deep beam in shear for $Ast=2.5\%$ and $a/d=1$

Figure 3.40(a) predicts the ultimate shear strength for M55 grade SFRC deep beam in shear for $D=300\text{mm}$. It is found that for M55 grade RC deep beam, the steel fiber addition by volume increases the shear strength for increase in volume fraction and fiber aspect ratio up to 90 after which the shear strength is noticed declining at $l_f/d_f = 100$.

The increase in size of the beam by increasing the depth to 500mm, decreases the shear strength at fiber aspect ratio 90 and increases the strength at $l_f/d_f = 100$. The increase in fiber volume increases the shear strength at all aspect ratios. It indicates requirement of longer fibers at $D=500\text{mm}$.

The increase in depth to 600mm proves that fibers of aspect ratio 50 are unable to contribute to the shear strength for volume fractions from 0.5% to 2%. The increase in fiber aspect ratio gradually increases the ultimate shear strength. The minimum percentage increase in shear stress is noted 19% at $l_f/d_f = 100$ as observed in Figure 3.40(c).
Effect of steel fibers on M75 grade SFRC deep Beams with Ast= 2.5% and a/d=1

Figure 3.41 represents the behavior of M75 grade SFRC deep beams with longitudinal reinforcement of 2.5% and shear span to depth ratio of ‘1’.

**Figure 3.41:** Variation of ultimate shear strength for M75 grade SFRC deep beam in shear for Ast=2.5% and a/d= 1
The Figure 3.41(a) proves the effectiveness of steel fibers for aspect ratios 50, 60, 70 where the steel fibers improves shear strength greater than shear strength (18.22MPa) of M75 grade ordinary RC deep beam of 300mm depth with Ast=2.5% and a/d=1. The use of fibers of aspect ratio 80 requires volume fraction greater than 1.5% to achieve the strength of 18.22MPa. The increase in fiber volume shows increase in shear strength at all aspect ratios.

For increase in depth to 500mm, the variation follows similar pattern of D=300mm and is shown in Figure 3.41(b) but with decrease in shear strength due to increase in depth to 500mm. The depth of 600mm greatly decrease the shear strength much below the non-fibrous deep beam with Ast=2.5% as shown in Figure 3.41(c).

k) SFRC deep beams with Ast= 2.5% and a/d=1.5

i) Effect of steel fibers on M25 grade SFRC deep Beams with Ast= 2.5% and a/d=1.5

Figure 3.42 represents the behavior of M25 grade SFRC deep beams with longitudinal reinforcement of 2.5% and shear span to depth ratio of ‘1.5’.
**Figure 3.42(b)**

**Figure 3.42(c)**

**Figure 3.42**: Variation of ultimate shear strength for M25 grade SFRC deep beam in shear for Ast=2.5% and a/d=1.5

Figure 3.42(a) predicts the variation in ultimate shear strength for D=300mm. The increase in volume fraction for fiber aspect ratio 50 and 60 decreases while at l/d=70, it remains constant at fiber volume fractions considered. For fiber aspect ratio 80, 90 and 100, the ultimate shear strength decreases as consequence of increase in fiber aspect ratio. It is also, to be noted that the shear strength increases with increase in fiber volume fraction by 1.3%, 2.8% and 5.5% at fiber aspect ratio 80, 90 and 100 respectively.

The variation in ultimate shear strength due to increase in depth to 500mm reduces the shear strength of ordinary M25 grade deep beam to 2.66MPa from 4.22MPa.
at D=300mm (Figure 3.42(a)). It is noted that the shear strength at all fiber aspect ratios increases and is almost constant at change in fiber volume fractions from $V_f=0.5\%$ to $2\%$. It indicates that the change in fiber volume fraction does not affect the shear strength with $A_{st}=2.5\%$ and $a/d=1.5\%$.

The increase in depth to 600mm increases the ultimate shear strength over ordinary RC deep beam at all fiber aspect ratio. The Figure 3.42(c) indicate that the shear strength remains almost constant with increase in fiber volume fraction. The increase in fiber aspect ratio shows decrease in shear strength.

**ii) Effect of steel fibers on M55 grade SFRC deep Beams with $A_{st}=2.5\%$ and $a/d=1.5$**

Figure 3.43 represents the behavior of M55 grade SFRC deep beams with longitudinal reinforcement of $2.5\%$ and shear span to depth ratio of $1.5$.

**Figure 3.43(a)**

**Figure 3.43(b)**
Figure 3.43(c)

**Figure 3.43:** Variation of ultimate shear strength for M55 grade SFRC deep beam in shear for $Ast=2.5\%$ and $a/d=1.5$

The behavior of M55 SFRC deep beam with $D=300\text{mm}$, is shown in Figure 3.43(a). The increase in fiber content from $V_f=0.5\%$ to $V_f=2\%$ adds to the shear strength by 16\%, 15.5\%, 22\%, 26\%, 31\% and 33\% at $l_f/d_f$ varying from 50 to 100 respectively but reduces with increase in fiber aspect ratio. The maximum achievable shear strength is observed at $l_f/d_f=70$ for $V_f=2\%$.

Figure 3.43(b) indicates that the increase in ultimate shear strength with increase in volume fraction is effective up to fiber aspect ratio 80 and further decreases. The shear strength at $D=500\text{mm}$ is less at fiber aspect ratio 50 and 60 while more at $l_f/d_f$ equal or greater than 70 at $D=300\text{mm}$.

Figure 3.43(c) indicates the ultimate shear strength variation at $D=600\text{mm}$. The increase in ultimate shear strength continues up to $l_f/d_f=90$ and then drops for all fiber volume fractions. The overall ultimate shear strength decreases with increase in compressive strength of concrete when compared with variation in Figure 3.42 for M25 SFRC deep beam.
iii) Effect of steel fibers on M75 grade SFRC deep Beams with Ast= 2.5% and a/d=1.5
Figure 3.44 represents the behavior of M75 grade SFRC deep beams with longitudinal reinforcement of 2.5% and shear span to depth ratio of ‘1.5’.

Figure 3.44(a)

Figure 3.44(b)

Figure 3.44(c)

Figure 3.44: Variation of ultimate shear strength for M75 grade SFRC deep beam in shear for Ast=2.5% and a/d= 1.5

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The overall observation of Figure 3.44 shows that the shear strength decreases with increase in depth from D= 500mm to 600mm while the ultimate shear strength decreases after addition of steel fibers at D=300mm. Figure 3.44(a) indicates that the assumed fiber volume fractions and fiber aspect ratios are found less effective for M75 and Ast=2.5% at a/d=1.5 to increase the strength above shear strength of the ordinary RC deep beams. For increase in depth to 500mm, shorter fibers of l/f/d=50, 60 and 70 are noticed as effective to raise the ultimate shear strength over ordinary deep beam as found in Figure 3.44(b). The increases in depth to 600mm, the fibers of shorter lengths up to aspect ratio 70, are effective as shown in Figure 3.44(c). But increase in fiber content increases the ultimate shear strength at all fiber aspect ratios.

I) SFRC deep beams with Ast= 0% and a/d=2

i) Effect of steel fibers on M25 grade SFRC deep Beams with Ast= 0% and a/d=2

Figure 3.45 represents the behavior of M25 grade SFRC deep beams without longitudinal reinforcement and shear span to depth ratio of ‘2’.

![Figure 3.45(a)](image-url)
Figure 3.45(b)

Figure 3.45(c)

Figure 3.45: Variation of ultimate shear strength for M25 grade SFRC deep beam in shear for Ast=0% and a/d = 2

Overall observation of Figure 3.45 reveals that ultimate shear strength of plain M25 deep beam decreases with increase in depth of beam but the shear strength after adding steel fibers show enhancement with increase in depth. Figure 3.45(a) for D=300mm, shows rise in ultimate shear strength with increase in fiber volume fraction at all fiber aspect ratio. Similar variation in ultimate shear strength is predicted for increase in depth to D=500mm as found in Figure 3.45(b). For depth of 600mm, the increase in ultimate shear strength is observed up to fiber aspect ratio of 80 after which the shear strength reduces. But the trend of increase in shear strength with increase in fiber volume continues for all aspect ratio as shown in Figure 3.45(c).
ii) Effect of steel fibers on M55 grade SFRC deep Beams with Ast= 0% and a/d=2

Figure 3.46 represents the behavior of M55 grade SFRC deep beams without longitudinal reinforcement and shear span to depth ratio of ‘2’.

Figure 3.46(a)

Figure 3.46(b)

Figure 3.46(c)

Figure 3.46: Variation of ultimate shear strength for M55 grade SFRC deep beam in shear for Ast=0% and a/d=2
Figure 3.46(a) describes the variation of ultimate shear strength of M55 SFRC beams without longitudinal steel at D=300mm. It indicates that increase in fiber volume of fiber aspect ratio of ‘50’ do not prove its usefulness in carrying the shear. The gain in shear strength is achieved at all fiber volume with fiber aspect ratio greater than 50. The percentage increase in shear strength due to change in fiber volume from 0.5% to 2% is 57.5%, 24.7%, 15.13%, 11%, 8.83% for fiber aspect ratios 60, 70, 80, 90 and 100 respectively.

Figure 3.46(b) and Figure 3.46(c) show the ultimate shear strength for D=500mm and D=600mm. The increase in depth to 500mm from D=300mm, the shear strength is achieved at higher fiber aspect ratio of 80 as compared with Figure 3.46(a). Further increase in depth to 600mm demands for fiber aspect ratio more than 100. The tendency of increase in ultimate shear strength due to increase in fiber content is observed for all depths under consideration.

iii) Effect of steel fibers on M75 grade SFRC deep Beams with Ast= 0% and a/d=2
Figure 3.47 represents the behavior of M75 grade SFRC deep beams without longitudinal reinforcement and shear span to depth ratio of ‘2’.
As apparent from Figure 3.47(a), the ultimate shear strength is increasing with increase in fiber volume fraction at all fiber aspect ratio without longitudinal steel for D=300mm. But at greater depths of 500mm and 600mm, the steel fibers without longitudinal steel fibers are not found effective as seen in Figure 3.47(b) and Figure 3.47(c).

m) SFRC deep beams with Ast= 1.5% and a/d=2

i) Effect of steel fibers on M25 grade SFRC deep Beams with Ast= 1.5% and a/d=2

Figure 3.48 represents the behavior of M25 grade SFRC deep beams with longitudinal reinforcement Ast=1.5% and shear span to depth ratio of ‘2’.
Figure 3.48: Variation of ultimate shear strength for M25 grade SFRC deep beam in shear for Ast=1.5% and a/d = 2
The variation in ultimate shear strength for D=300mm is shown in Figure 3.48(a) for M25 grade SFRC deep beams. It is seen that the addition of fibers with lower aspect ratio of ‘50’ cause reduction in shear strength at a/d=2. It also, shows rise in shear strength above shear strength of ordinary M25 grade RC deep beam with Ast=1.5%. The percentage increase in shear strength by adding 0.5% fibers, is 6.66%, 35.3%, 46.5%, at l/f/d=60, 70 and 80 respectively which afterward decreases to 36.66%, 17.6% at fiber aspect ratio 90 and 100 respectively.

The comparison between Figure 3.42(b) for a/d=1.5 with Figure 3.48(b) for a/d=2 shows that the increase in shear span to depth ratio for M25 SFRC deep beams at D=500mm shows decrease in ultimate shear strength for all volume fractions and fiber aspect ratios. The minor variation in shear strength with increase in volume fraction is predicted at all fiber aspect ratios in Figure 3.48(b). As the effect of fiber aspect ratio, the increase in shear strength is noted up to l/f/d=80 after which is shows decrement.

The increase in depth to 600mm, indicates the rise in shear strength with increase in fiber content up to l/f/d=90 and falls to 9.14MPa from 10.38MPa for Vf=0.5% at l/f/d=100 which is constant for all volume fraction from 0.5% to 2%.as shown in Figure 3.48(c).

ii) Effect of steel fibers on M55 grade SFRC deep Beams with Ast= 1.5% and a/d=2

Figure 3.49 represents the behavior of M55 grade SFRC deep beams with longitudinal reinforcement Ast=1.5% and shear span to depth ratio of ‘2’.

![Figure 3.49(a)](image-url)
Figure 3.49(b)

Figure 3.49(c)

Figure 3.49: Variation of ultimate shear strength for M55 grade SFRC deep beam in shear for Ast=1.5% and a/d = 2

The overall observations of Figure 3.49 indicates that the ultimate shear strength of M55 grade SFRC deep beams falls with increase in depth of the section for fiber aspect ratio up to 60. The increase in fiber volume fraction enhances the shear strength at all volumes of fibers considered in this study. Figure 3.49(a) predicts the effectiveness of steel fibers at D=300mm. It shows increase in ultimate shear strength at all aspect ratios with increase in fiber volume. The effect of fiber aspect ratio diminishes at l_f/d_f=90. The shear strength at D=500mm is showing similar variation in ultimate shear strength as discussed above. (Figure 3.49(b)). The increase in depth to 600mm indicates that the fibers of aspect ratio greater than 70 show their effectiveness and enhance the shear capacity. (Figure 3.49c)).
iii) Effect of steel fibers on M75 grade SFRC deep Beams with Ast= 1.5% and a/d=2
Figure 3.50 represents the behavior of M75 grade SFRC deep beams with longitudinal reinforcement Ast=1.5% and shear span to depth ratio of ‘2’.

Figure 3.50: Variation of ultimate shear strength for M75 grade SFRC deep beam in shear for Ast=1.5% and a/d= 2
Figure 3.50 predicts the ultimate shear strength variation of M75 grade SFRC deep beam for different depths. The overall observations indicate that the depth of 300mm reduces the shear strength at all fiber values (from 0.5% to 2%) and all aspect ratios from 50 to 100. Figure 3.50(a) indicates that addition of steel fibers of different aspect ratios increase with increase in fiber volume but do not improve the shear capacity above the ordinary RC deep beam (10.60 MPa) with Ast=1.5% and a/d=2. The ultimate shear strength variation presented in Figure 3.50(b) at D=500mm shows satisfactory results by increasing the ultimate shear strength above shear strength of ordinary deep beam(4.73MPa). The percentage increase in shear strength at $V_f=0.5\%$ with increase in fiber aspect ratio is found as 33.8%, 42%, 56%, 72.5%, 79%, 66.8% at $L_f/d_f= 50, 60, 70, 80, 90, 100$ respectively. This indicates that the increase in fiber aspect ratio contribute to increase the ultimate shear strength. Figure 3.50(c) shows that the steel fiber contribution to increase the ultimate shear strength at D=600mm is useful at fiber aspect ratio equal or greater than 80.

n) SFRC deep beams with $Ast= 2.5\%$ and $a/d=2$

i) Effect of steel fibers on M25 grade SFRC deep Beams with $Ast= 2.5\%$ and $a/d=2$

Figure 3.51 represents the behavior of M25 grade SFRC deep beams with longitudinal reinforcement 2.5% and shear span to depth ratio of ‘2’
Figure 3.51: Variation of ultimate shear strength for M25 grade SFRC deep beam in shear for Ast=2.5\% and a/d= 2

Figure 3.51(a) is meant for ultimate shear strength variation of M25 SFRC deep beam with Ast=2.5\% and shear span to depth ratio ‘2’. It is noted that the ultimate shear capacity of the deep beam is maximum even at low fiber volume of 0.5\% and low fiber aspect ratio of ‘50’ and 60 and decrease with increase in volume fraction of fibers. The increase in fiber aspect ratio beyond ‘60’ decreases the ultimate shear capacity. The increase in ultimate shear strength beyond the shear capacity of ordinary M25 grade deep beam is achieved by increasing the depth to 500mm up to fiber aspect ratio ‘90’ as observed in Figure 3.51(b). Similar behavior is followed with increase in depth to 600mm as confirmed from Figure 3.51(c).
ii) Effect of steel fibers on M55 grade SFRC deep Beams with Ast= 2.5% and a/d=2

Figure 3.52 represents the behavior of M55 grade SFRC deep beams with longitudinal reinforcement 2.5% and shear span to depth ratio of ‘2’

![Graph](image_url)

Figure 3.52(a)

![Graph](image_url)

Figure 3.52(b)

![Graph](image_url)

Figure 3.52(c)

Figure 3.52: Variation of ultimate shear strength for M55 grade SFRC deep beam in shear for Ast=2.5% and a/d= 2
The overall observation for M55 grade SFRC deep beams show that there is increase in shear strength with increase in steel fiber content at all fiber aspect ratios under consideration. Figure 3.52(a) shows that the enhancement in shear capacity can be achieved up to fiber aspect ‘70’ as further increase in fiber aspect ratio starts dropping down the shear strength.

The increase in depth of section to 500mm continues the effect of fiber aspect ratio up to ‘80’ as seen from Figure 3.52(b) but the tendency of increasing shear strength is observed with increase in fiber volume fraction. Similar pattern of variation in ultimate shear strength is observed at D=600mm in Figure 3.52(c). The maximum shear strength attainable at \( V_f = 0.5\% \) is 5.42MPa, 6.98MPa, 7.03MPa and at \( V_f = 2\% \) is 6.38MPa, 8.12MPa, 8.30MPa at fiber aspect ratio ‘70’.

iii) Effect of steel fibers on M75 grade SFRC deep Beams with Ast= 2.5% and a/d=2

Figure 3.53 represents the behavior of M75 grade SFRC deep beams with longitudinal reinforcement 2.5% and shear span to depth ratio of ‘2’
The observation of Figure 3.53 shows that ultimate shear strength of ordinary M75 grade deep beam with Ast =2.5% and a/d=2 goes on decreasing with increase in depth from 300mm to 600mm from 14.84MPa to 8.21MPa. But the addition of steel fibers increase the shear strength with increase in depth at all fiber aspect ratios.

Figure 3.53(a) shows the variation in ultimate shear strength at 300mm. Though, the steel fibers increase the strength with fiber volume fraction, it is not raised above the
shear strength of ordinary deep beam at D=300mm. Similarly, the shear strength decreases with increase in fiber aspect ratio from 50 to 100.

Figure 3.53(b) describes the shear strength variation at D=500mm. It is found that the shear strength is increased above strength of ordinary M75 deep beam of 500mm depth up to l/d_f=80 after which it decreases. Further increase in depth to 600mm predicts enhancement in ultimate shear strength for all volume fractions and fiber aspect ratio as shown in Figure 3.53(c).

3.7.2: Effect of longitudinal steel (Ast %) on ultimate shear strength of SFRC deep beam

o) SFRC deep beam in shear at a/d= 0.5

i) For M25 grade for SFRC deep beam in shear at a/d= 0.5

The comparison between Figure 3.12(a), 3.15(a) and 3.18(a) shows the variation in ultimate shear strength at Ast= 0%, 1.5% and 2.5% at D=300mm. At Ast=0%, the SFRC deep beams exhibits satisfactory ultimate shear strength over the plain deep beams at low fiber aspect ratio. The increase in ‘Ast’ to 1.5% requires higher fiber aspect ratio above ‘80’. Further increase in Ast to 2.5%, the shear strength increases for fiber aspect ratios greater than or equal to ‘70’. It shows that higher shear performance needs longer fibers at a/d=0.5 with Ast=0%.

Figure 3.12(b), 3.15(c) and 3.18(b) describe the variation at D=500mm. It shows that increase in Ast to 1.5% enhances the ultimate shear strength at l/d_f greater than ‘70’. Further increase in Ast to 2.5% also exhibits increase in shear strength at depth of 500mm.

The variation pattern for D=600mm is shown in Figure 3.12(c), Figure 3.15(c) and Figure3.18(c). The increase in Ast form 0% to 2.5% increases the ultimate shear strength.

It can be concluded that for low normal strength concrete M25 grade SFRC deep beams in shear, the ultimate shear strength increases with increase in longitudinal steel from 0% to 2.5% at all depths 300mm, 500mm and 600mm at a/d =0.5.
ii) For M55 grade SFRC deep beam in shear at a/d=0.5

Figure 3.13(a), Figure 3.16(a) and Figure 3.19(a) show variation of ultimate shear strength for M55 grade SFRC deep beam in shear at a/d=0.5 and D=300mm, 500mm and 600mm. The enhancement in ultimate shear strength for Ast=0% is due to provision of steel fibers at all fiber volume fractions and fiber aspect ratios. The increase in ‘Ast’ to 1.5% and then to 2.5% increases the shear strength at D=300mm. At D=500mm and no longitudinal steel, Figure 3.13(b) shows failure of deep beams in shear for $l_\ell/d_\ell$ less than ‘80’. The addition of Ast=1.5%, increases the shear strength at all fiber aspect ratios. The Figure 3.16(c) and 3.19(c) also show the excellent performance at D=600mm. It can be concluded that the increase in longitudinal steel, increases the ultimate shear strength at a/d=0.5.

iii) For M75 grade SFRC deep beam in shear at a/d=0.5

Figure 3.14(a), 3.17(a) and 3.17(a) show that M75 grade SFRC deep beam fails in shear at Ast=0% for all volumes and aspect ratios. Increase in Ast to 1.5% indicate increase in shear strength at D=300mm. The observations of above figures at D=500mm and 600mm at a/d=0.5 indicate that the inclusion of longitudinal steel up to 2.5% do not improve the shear strength of M75 grade SFRC deep beam in shear. It can be concluded that for M75 grade SFRC beam with $b/D$ greater than 1:3, the effect of Ast is not observed.

p) SFRC deep beam in shear at a/d=1

i) For M25 grade SFRC deep beam in shear at a/d=1

Figures 3.21(a), Figure 3.24(a) and Figure 3.27(a) predicts the variation of ultimate shear strength at D=300mm. The increase Ast to 1.5% adds to the strength at all fiber volumes for $l_\ell/d_\ell$ greater than 80. The Figure 3.27(a) shows the shear strength increased for all volume fractions and all $l_\ell/d_\ell$ ratios with Ast=2.5%. It thus shows that at a/d=1 and D=300mm, increment in longitudinal steel increases the ultimate shear strength capacity.

The observation of Figure 3.21(b), Figure 3.24(b) and Figure 3.27(b) shows that increase in Ast brings increase in shear strength at $l_\ell/d_\ell$ greater than 90 for Ast up to 1.5% while at Ast=2.5%, the increase in shear strength can be observed at all fiber aspect.
ratios. It is observed at D=600mm, that the shear strength is achieved at $l_f/d_f > 80$ and increase in Ast to 2.5%, gives strength at all volumes and aspect ratio under consideration. It can be concluded that for Ast=0% longer fibers are required for all depths at M25 grade and a/d=1.

ii) For M55 grade SFRC deep beam in shear at a/d=1

From Figure 3.22(a), Figure 3.25(a) and Figure 3.28(a) show increase in ultimate shear strength with increase in Ast up to 2.5% at D=300mm. Figure 3.22(b) suggests that the minimum required fiber aspect ratio is 80. Figure 3.25(b) and Figure 3.28(b) suggest increase in shear strength with increase in Ast.

At D=600mm, the ultimate shear strength increases at Ast=1.5% with $l_f/d_f = 70$ and for all aspect ratios considered at Ast=2.5%. It can be concluded that the ultimate shear strength increases with increase in Ast for M55grade SFRC deep beam at a/d=1.

iii) For M75 grade SFRC deep beam in shear at a/d=1

Observations of Figure 3.23(a), Figure 3.26(a) and 3.29(a) predicts that the shear strength at D=300mm increases with increase in Ast to 1.5% for all volumes and aspect ratios. The increase in shear strength is observed at Ast= 2.5% for fiber aspect ratios up to 70 at D=300mm. Figure 3.23(b) Figure 3.26(b) and Figure 3.29(b) predicts increase in shear strength at higher value of Ast=2.5% and for $l_f/d_f$ up to 70 after which it decreases for D=500mm.

Figure 3.23(c), Figure 3.26(c) and 3.29(c) show that ultimate shear strength increases with Ast=2.5% with fiber aspect ratio greater than 60. It confirms that for higher strength concrete such as M75 grade, the longitudinal steel 2.5% needs fibers of $l_f/d_f$ up to 70.

q) SFRC deep beam in shear at a/d= 1.5

i) For M25 grade SFRC deep beam in shear at a/d=1.5

The comparison of Figure 3.30(a), Figure 3.33(a) and Figure 3.36(a) describes the variation of ultimate shear strength at D=300mm. Figure 3.30(a) with Ast=0% requires $l_f/d_f$ greater than 70 to increase the strength more than plain M25 grade deep beam. The provision of Ast= 1.5% increase overall shear strength at all fiber aspect ratios. Further
increase in longitudinal steel to 2.5%, increases the shear strength with comparatively lower aspect ratios at D=300mm.

Figure 3.30(b), Figure 3.33(b) and Figure 3.36(b) show that the ultimate shear strength increases marginally at Ast=1.5% which decreases with increase in Ast to 2.5% at D=500mm at higher aspect ratios more than 80.

Figure 3.30(c), Figure 3.33(c) and Figure 3.36(c) shows that the beam possesses the shear strength at Ast=0% which increases considerably at Ast=1.5% but comparatively decreases for provision of Ast=2.5% at D=600mm. It can be concluded that the combination of Ast and steel fibers required for achieving the shear strength at depths=300mm, 500mm, 600mm.

ii) For M55 grade SFRC deep beam in shear at a/d=1.5

Figure 3.31(a), Figure 3.34(a) and Figure 3.37(a) describes the behavior at D=300mm for M55 grade SFRC deep beam. The comparison shows that the ultimate shear strength increases with increase in Ast to 2.5% at all fiber volumes and aspect ratios.

Figure 3.31(b), Figure 3.34(b) and Figure 3.37(b) show that addition of longitudinal steel with steel fibers increases the shear strength at all volume fractions and fiber aspect ratios at D=500mm. Figure 3.31(c), Figure 3.34(c) and Figure 3.37(c) indicate that provision of longitudinal steel 0f 1.5% increase the shear strength for lf/df > 70. Further increase in Ast to 2.5% imparts the shear strength at all fiber volumes and aspect ratios at D=600mm.

It can be concluded that the ultimate shear strength improves with increase in Ast for M55 grade SFRC deep beam in shear.

iii) For M75 grade SFRC deep beam in shear at a/d=1.5

Figure 3.35(a), 3.38(a) show increment in shear strength with increase in longitudinal steel to 2.5% at D=300mm. The comparison between Figure 3.35(b) and Figure 3.38(b) indicate rise in shear strength with increase in Ast to 1.5% and requires fiber aspect ratio more than 70. Somehow, the shear strength decreases with further increase in Ast to 2.5%.
Figure 3.35(c) and Figure 3.38(c) suggest that increase in shear strength for the beam without fibers. But fails in shear when steel fibers are added at D=600mm. It can be concluded that M75 SFRC deep beams performs well at Ast=1.5% with a/d=1.5.

r) SFRC deep beam in shear at a/d=2

i) For M25 grade SFRC deep beam in shear at a/d=2

Figure 3.45(a), Figure 3.48(a) and Figure 3.51(a) show variation in ultimate shear stress at a/d=2 with D=300mm. The shear strength at Ast=1.5% is found less than the strength of ordinary M25 deep beam in shear. The increase in Ast to 2.5% increases the shear strength at lower aspect ratios but decreases for l/f/df greater than 70 at D=300mm. The comparison between Figure 3.45(b), Figure 3.48(b) and Figure 3.51(b) indicate linear increase in shear strength for Ast=0% and D=500mm for all fiber volume fractions. The increase in Ast to 1.5% increases the shear strength up to fiber aspect ratio‘70’. Further increase in Ast to 2.5%, increases the shear capacity at D=500mm. The shear strength for D=600mm is seen from Figure 3.45(c), Figure 3.48(c) and Figure 3.51(c). Increase in ultimate shear strength at Ast=1.5% over fibrous beam without longitudinal steel up to l/f/df=70 after which it goes on decreasing as effect of fiber aspect ratio. Further increase in Ast to 2.5% at D=600mm shows increase in shear strength above shear strength at Ast=1.5% up to l/f/df=60.

It can be concluded that the increase in steel percentage increases the shear strength up to fiber aspect ratio of ‘70’.

ii) For M55 grade SFRC deep beam in shear at a/d=2

Figure 3.46(a), 3.49(a) and 3.52(a) indicate that with increase in Ast=1.5%, enhances the ultimate shear strength at all fiber volumes and aspect ratios considered. Further increase in Ast to 2.5% show increase in shear strength at fiber aspect ratios up to 70 at D=300mm.

Figure 3.46(b), 3.49(b) and 3.52(b) show similar variation at D=500mm. The shear strength at D=600mm is observed from Figure 3.46(c), 3.49(c) and 3.52(c) which indicate increase in ultimate shear strength at l/f/df > 70. The increase in steel to 2.5% increases the shear strength over the shear strength at Ast=1.5%. It can be concluded that increase in longitudinal steel increases the shear strength at lower aspect ratios.
iii) For M75 grade SFRC deep beam in shear at a/d=2

The variation of M75 higher strength SFRC deep beam at D= 300mm can be observed from Figure 3.46(a), Figure 3.49(a) and Figure 3.53(a). The increase in Ast=1.5% and 2.5% show decrease in shear strength with addition of steel fibers.

Figure 3.46(b), Figure 3.49(b) and Figure 3.53(b) indicate that the ultimate shear strength at D=500mm increases with increase in longitudinal steel percentage. The Figure 3.50(c) and Figure 3.53(c) also indicate increase in ultimate shear strength with increase in longitudinal steel.

3.7.3 Effect of shear span to effective depth ratio (a/d) on ultimate shear strength of SFRC deep beam in shear

3.7.3.1: For M25 grade SFRC deep beams in shear

i) With longitudinal steel, Ast=0%

Figure 3.12(a), Figure 3.21(a), Figure 3.30(a) and Figure 3.45(a) show decrease in ultimate shear strength of M25 grade SFRC deep beam without longitudinal steel with D=300mm an increase in shear span to depth ratio. It is observed that ultimate shear strength decreases with increase in shear span to depth ratio, but shows improvement at l/f/d=100.

Figure 3.12(b), Figure 3.21(b), Figure 3.30(b) and Figure 3.45(b) indicate results of shear strength for d=500mm. Similar observations as for 300mm are noted for D=500mm. Figure 3.12 (c), Figure 3.21(c), Figure 3.30(c) and Figure 3.45(c) show results for D=600mm. It indicates that the ultimate shear strength falls up to a/d=1.5 and shows increment at a/d=2 at Ast=0% and M25 compressive strength.

ii) With longitudinal steel, Ast=1.5%

Figure 3.15(a), Figure 3.24(a), Figure 3.33(a) and Figure 3.49(a) describes the behavior of M25 SFRC deep beam in shear reinforced with Ast=1.5% and D=300mm at different aspect ratios. These figures predict increase in shear strength with increase in a/d ratio from 0.5 to 1.5 up to l/f/d=80. Further increase in a/d to 2 decreases the shear strength for D=300mm.
Figure 3.15(b), Figure 3.24(b), Figure 3.33(b) and Figure 3.49(b) compares the variation in ultimate shear strength at D=500mm. It indicate that the ultimate shear strength goes on increasing with increase in a/d ratio to 1.5 for all volume fractions and aspect ratios. With further increase id a/d to 2, the shear strength raises up to lf/df=70 only. Figure 3.15(c), Figure 3.24(c), Figure 3.33(c) and Figure 3.49(c) for D=600mm show increase in shear strength with change in a/d from 0.5 to 1 at all aspect ratios. Further increase in a/d to 1.5 also, enhances the shear strength but up to lf/df=80 and decrement is found at a/d =2.

It can be concluded that the increase in a/d from 0.5 to 1 and 1.5(up to lf/df=70) increases the ultimate shear strength for Ast=1.5%, and M25 concrete.

iii) With longitudinal steel, Ast=2.5%

Figure 3.18(a), Figure 3.27(a), Figure 3.42(a) and Figure 3.51(a) represents the variation at D=300mm. The observation show that the increase in a/d to 1, increases the shear strength at all fiber aspect ratios but up to l/d1=80 for a/d=1.5. The ultimate shear strength decreases with a/d=2.

Figure 3.18(b), Figure 3.27(b), Figure 3.42(b) and Figure 3.51(b) represent the variation at D=500mm. It shows increase in shear strength with increase in a/d up to 1 and increases in shear strength up to lf/df=70 for a/d=1.5.

Figure 3.18(c), Figure 3.27(c), Figure 3.42(c) and Figure 3.51(c) for D= 600mm, give rise to shear strength for aspect ratios up to 1 and then decreases at a/d=1. The increase in a/d ratio is effective for lower aspect ratios up to 70.

It can be concluded that the a/d ratio is effective in increasing the ultimate shear strength for up to a/d=1 for lf/df from 50 to 100. It is also, effective in increasing the shear strength at a/d=1.5 but up to lf/df= 70. The shear strength decreases at a/d=2.

3.7.3.2: For M55 grade SFRC deep beams in shear with longitudinal steel

i) With longitudinal steel, Ast=0%

Figure 3.13(a), Figure 3.21(a), Figure 3.31(a) and Figure 3.46(a) represents variations of ultimate shear strength for a/d=0.5 to 2 at D=300mm. Increase in a/d to 1, increases the
ultimate shear strength effectively for all lf/df ratios considered in this study. The shear strength is observed reduced at a/d=1.5 and again enhances at a/d=2 for D=300mm.

**ii) with longitudinal steel, Ast=1.5%**

Figure 3.13(b), Figure 3.21(b), Figure 3.31(b) and Figure 3.46(b) show increment in ultimate shear strength at a/d =1 which further decreases with increase in a/d to 2 up to lf/df= 70.

The rise in shear strength is found for a/d =1 for D=600mm as seen in Figure 3.13(c), Figure 3.21(c), Figure 3.31(c) and Figure 3.46(c). It is also, found that the shear strength falls for a/d> 1. It can be concluded that the ultimate shear strength decreases with increase in a/d for M55 concrete SFRC deep beam without longitudinal steel.

Figure 3.16, Figure 3.25, Figure 3.34 and Figure 3.39 represents shear strength variation for M55 grade SFRC deep beam with Ast=1.5% and depths D= 300mm, 500mm, 600mm. It shows decrement in ultimate shear strength with increase in a/d ratio at D=300mm.

On the contrary, increase in ultimate shear strength is found with increase in a/d up to 1.5 for D=500mm, which further increases with increase in a/d to 2. For D=600mm, the ultimate shear strength is observed increasing with increase in a/d up to 1.5. It is found that shear strength increases at a/d=2 up to lf/df=80.

It can be concluded that the increase in ultimate shear strength is expected in M55 grade SFRC deep beam with Ast=1.5%.

**iii) with longitudinal steel Ast=2.5%**

The observations of Figure 3.37, Figure 3.40, Figure 3.43 and Figure 3.49 describes the effect of a/d ratio on M55 grade SFRC deep beam with Ast=2.5%. The shear strength is observed decreasing with increase in a/d ratio up to 1.5 for all aspect ratio while decreases up to lf/df=70 for a/d=2 for D=300mm. Similar observations are noted for variation in ultimate shear strength for D=500mm up to a/d=1.5 while increase in shear strength is observed at a/d=2 up to l/f/d_f=60.

It can be concluded that the ultimate shear strength for M55 concrete SFRC deep beam decreases with increase in a/d ratio up to 1.5 and increases ata/d=2 beyond l/f/d_f=60.
3.7.3.3: For M75 grade SFRC deep beams in shear with longitudinal steel

i) with longitudinal steel, Ast=0%

Figure 3.14, Figure 3.23, Figure 3.32 and Figure 3.50 are studied to find out the variation of ultimate shear strength of M75 grade SFRC deep beam without longitudinal steel with change in shear span-depth ratio at D=300mm, 500mm, 600mm. The observations found that increase in a/d ratio increases the shear strength at D=300mm while for other depths of (500mm and 600mm) the beam fails in shear for the parameters considered.

ii) with longitudinal steel, Ast=1.5%

Figure 3.17, Figure 3.26, Figure 3.35 and Figure 3.50 are observed to find the variation in ultimate shear strength for M75 grade SFRC deep beam with Ast=1.5% at D=300mm, 500mm, 600mm, with change in a/d ratios. The increase in a/d ratio decreases the ultimate shear strength for D=300mm. It shows increment in shear strength with increase in a/d ratio at all fiber aspect ratios for D=500mm. The shear strength at D=600mm shows failure of beam in shear mode for a/d up to 1.5 with assumed parameters but shows shear strength at a/d=2 for lf/df equal or greater than 70.

iii) with longitudinal steel, Ast=2.5%

Figure 3.36, Figure 3.41, Figure 3.41 and Figure 3.53 reveals the variation of ultimate shear strength for M75 grade SFRC deep beam with Ast=2.5% and D=300mm, 500mm and 600mm. It is found that increase in a/d decreases the shear strength at D=300mm. The shear strength at D=500mm is found increasing with increase in a/d to 2 but the strength achieved is less than the shear capacity of ordinary M75 RC deep beam. This suggests that for high strength concrete like M75 and Ast=2.5%, the fibers of aspect ratio equal or less than 70 are preferable.

3.7.4 Effect of compressive strength (f_c) of concrete on ultimate shear strength of SFRC deep beams in shear

The Figure 3.54 to Figure 3.62 presents the behavior of SFRC deep beams in shear with variation in compressive strength of normal strength (f_c<55 MPa) as well as high strength concrete (f_c>55MPa) [26] for different volume fraction of fiber aspect ratio (l_f/d_f) ‘80’ and different shear span-depth ratios (a/d=0.5 to 2) with varying longitudinal steel percentages (Ast=0% to 2.5%).
3.7.4.1 Effect of compressive strength on SFRC deep beam with $V_f=0.5\%$ and $A_{st}=0\%$

Figure 3.54(a) 

Figure 3.54(b) 

Figure3.54(c) 

Figure 3.54: Effect of compressive strength on SFRC deep beam in shear ($V_f=0.5\%$, $A_{st}=0\%$)

Figure 3.54 describes the effect of concrete grade on ultimate shear strength of SFRC deep beam without longitudinal reinforcement ($A_{st}=0\%$) for $D=300\text{mm}$, $500\text{mm}$ and $600\text{mm}$. Figure 3.54(a) shows that for $D=300\text{mm}$ (b:D=1:3), the increase in normal strength concrete (NSC) grade up to 35MPa shows gain in shear strength while it goes on decreasing with increase in compressive strength up to high strength concrete (HSC) grade of 65MPa. For the cross sectional dimensions in the proportion b:D=1:5 (Figure3.54(b)), the increase in compressive strength brings enhancement in ultimate shear strength for all NSC range up to 55MPa at all a/d ratios and up to 75MPa at a/d=0.5. Further increase in depth to 600mm (Figure 3.54(c)), similar observations are noted with a difference of increase in shear strength up to 75MPa at a/d=0.5 and 1. It
shows that the increase in concrete grade of SFRC deep beam without tension steel and low volume fraction of 0.5%, increases the ultimate shear strength as depth increases for NSC but the improvement in shear strength is observed at a/d<1 for HSC deep beams with V_f =0.5%.

**3.7.4.2 Effect of compressive strength on SFRC deep beam with V_f =0.5% and Ast=1.50%**

The effect of compressive strength along with inclusion of Ast=1.5% and V_f =0.5% is shown in Figure 3.55. For the proportion of cross sectional dimensions, b:D = 1:3, the shear falls up to 35MPa while it shows rise for NSC as well as HSC grade SFRC deep beams for all a/d ratios as observed in Figure 3.55(a).

**Figure 3.55(a)**

**Figure 3.55(b)**

**Figure 3.55(c)**

**Figure 3.55:** Effect of compressive strength on SFRC deep beam in shear (V_f=0.5%, Ast=1.50%)
Figure 3.55(b) shows rise in shear strength with rise in concrete grade at a/d=0.5 for NSC as well as HSC but decreases with increase in compressive strength for NSC range and increases for HSC grades with b:D=1:5. Figure 3.55(c) indicates that the shear capacity increases with increase in compressive strength for NSC range at a/d=0.5 and the effect diminishes as a/d increases for normal strength SFRC deep beams for b:D = 1:6. The increase in concrete grade for HSC is also, showing rise in shear strength for considered values of parameters.

3.24.3 Effect of compressive strength on SFRC deep beam with V_f =0.5% and Ast= 2.50%

The effect of compressive strength with Ast=2.5% and V_f =0.5% is observed in Figure 3.56. For depth D=300mm, the ultimate shear strength is observed increasing with compressive strength for a/d = 0.5 to 1.5 for NSC and HSC while it decreases only
for NSC and increases for HSC at a/d=2 (Figure 3.56(a)). The shear strength is found decreasing with increase in compressive strength up to 65MPa for D=500mm while it also shows decrement in shear strength at all compressive strength for the assumed parametric values as observed from Figure 3.56(b) and Figure 3.56(c).

3.24.4 Effect of compressive strength on SFRC deep beam with $V_f=1\%$ and Ast= 0%

![Figure 3.57(a)](image)

![Figure 3.57(b)](image)

![Figure 3.57(c)](image)

Figure 3.57: Effect of compressive strength on SFRC deep beam in shear ($V_f=1\%$, Ast=0%)

The variation in ultimate shear strength with change in compressive strength for SFRC deep beam with $V_f=2\%$ but without main steel (Ast=0%) is shown in Figure 3.57. The comparison of Figure 3.54 (for $V_f=0.5\%$, Ast=0%) and Figure 3.57 (for $V_f=1\%$, Ast=0%) indicates similar pattern of variation in shear strength at all depths considered but shows increase in shear strength as effect of increase in fiber volume fraction from 0.5\% to 1\%. Figure 3.57(a) shows initial increase in shear strength at 35MPa which
further decreases till 65MPa and then rises again at 75MPa. For D=500mm (b:D= 1:5), the ultimate shear strength is found increased with compressive strength for NSC and decreased for HSC as seen from Figure 3.57(b). Further increase in depth D=600mm (b:D= 1:6), brings enhancement in shear strength for HSC at a/d= 0.5 and 1.

3.7.4.5 Effect of compressive strength on SFRC deep beam with $V_f=1\%$ and $Ast=1.50\%$

Figure 3.58 describes the ultimate shear strength variation for change in compressive strength of SFRC deep beam in shear with steel fiber content of aspect ratio ‘80’ and longitudinal steel 1.5%. The comparison between Figure 3.55 (for $V_f=0.5\%$, Ast=0%) and Figure 3.58(for $V_f=1\%$, Ast= 1.50%) shows similar pattern of variation in shear strength.

Figure 3.58: Effect of compressive strength on SFRC deep beam in shear ($V_f=1\%$, Ast=1.50%)
For D=300mm, the shear strength of SFRC deep beam decreases at 35MPa and increases for remaining compressive strengths at all a/d ratios as shown in Figure 3.58(a). The increase in depth to 500mm, rises the strength up to 45MPa at a/d=0.5 and at 35MPa for a/d=1. Somehow, the shear strength decreases at all other compressive strengths for NSC as well as HSC SFRC deep beams. (Figure 3.58(b)).

Further increase in size to 600mm, improves the ultimate shear strength for NSC up to 45MPa at a/d=0.5 to 1 and decreases for remaining concrete grades till 65MPa. The increase in shear strength is observed with increase in concrete compressive strength to 75MPa at all a/d ratios considered.

3.7.4.6 Effect of compressive strength on SFRC deep beam with $V_f=1\%$ and $Ast=2.50\%$

![Figure 3.59(a)](image1)

![Figure 3.59(b)](image2)

![Figure 3.59(c)](image3)

Figure 3.59: Effect of compressive strength on SFRC deep beam in shear ($V_f=1\%$, $Ast=2.50\%$)
Figure 3.59 describes the influence of compressive strength on ultimate shear strength of SFRC deep beams in shear with steel fiber content 1% and longitudinal steel 2.50%. The increase in ultimate shear capacity is noticed for cross sectional dimension in the proportion b:D= 1:3, in Figure 3.59(a) with increase in compressive strength at all a/d ratios. The increase depth to 500mm changes the trend except a/d=0.5. The shear strength decreases with increase in compressive strength up to 65MPa and increases at 75MPa for a/d>0.5 as shown in Figure 3.59(b).

Figure 3.59(c) shows that the provision of depth D=600mm also, shows decrease in shear strength with increase in compressive strength for all a/d ratios except at 35MPa for a/d=0.5.

3.7.4.7 Effect of compressive strength on SFRC deep beam with $V_f=2\%$ and Ast= 0\%

![Figure 3.60(a)](image1)

![Figure 3.60(b)](image2)

![Figure 3.60(c)](image3)

Figure 3.60: Effect of compressive strength on SFRC deep beam in shear ($V_f=2\%$, Ast=0\%)
The addition of steel fiber fraction of 2% at D=300mm shows increment in shear strength of SFRC deep beam without main steel up to 35MPa after which it decreases with increase in concrete grade as seen in Figure 3.60(a). It is also, observed from Figure 3.60(b) that at D=500mm, the ultimate shear strength is increased due to increase in compressive strength up to 65MPa while the provision of depth D=600mm, shows increment for 75MPa at a/d=0.5 and 1 (Figure 3.60(c)). The comparison between Figure 3.54, Figure 3.57 and Figure 3.60, for Ast=0%, shows similar pattern of variation in shear strength and affected by effect of volume fraction of steel fibers.

3.7.4.8 Effect of compressive strength on SFRC deep beam with $V_f=2\%$ and Ast=1.50%

Figure 3.61 shows behavior of SFRC deep beams with 2% fiber content and without main steel, due to change in compressive strength of concrete. The variation pattern is similar to earlier cases for $V_f=0\%$ and 1% seen in Figure 3.58 and Figure 3.56.

Figure 3.61: Effect of compressive strength on SFRC deep beam in shear ($V_f=2\%$, Ast=1.50%)
The increase in compressive strength shows decrease in ultimate shear strength for NSC steel fiber reinforced deep beam in shear of depth D=300mm up to 45MPa after which it increases with ‘fc’ for 55MPa and HSC up to 75MPa as shown in Figure 3.61(a). The increase in size of the beam to D=500mm, decreases the shear strength for increase in compressive strength for whole range of NSC and increases the shear strength for HSC (fc> 55MPa). It is noted that the increase in shear strength at 25MPa and 35MPa is mainly an effect of increase in depth as observed in Figure 3.61(b).

Further increase in depth to 600mm and increase in concrete strength reverses its behavior at a/d=0.5 and 1, showing increase in shear strength for NSC and decrease in shear strength for HSC. It is noted that the shear strength for a/d=1.5 and 2 for HSC is increasing with increase in concrete strength.

3.7.4.9 Effect of compressive strength on SFRC deep beam with \( V_f =2\% \) and Ast=2.50%

Figure 3.62 shows the variation of shear strength of SFRC deep beam in shear with compressive strength for steel fiber fraction 2% and Ast=2.5%. Figure 3.62(a) indicates that the shear strength enhancement is achieved with increase in concrete grade at a/d=0.5 to 1.5 at D=300mm while it decreases for NSC up to 85MPa and again increases at a/d=2 for HSC (> 55MPa) as shown in Figure 3.62(a).
The increase in compressive strength at D=500mm, shows decrease in shear strength up to 45MPa and then rises up to 75MPa at all a/d ratios considered as observed in Figure 3.62(b). Increasing the depth to D=600mm, the variation in concrete strength shows decrease in shear strength with increase in concrete grade at a/d=1 to 2 for NSC as well as HSC. The shear strength initially increases at 35MPa for a/d=0.5 but then decreases with increase in compressive strength up to 65MPa.

From the above discussions on Figure 3.54 to Figure 3.62, it is found that-

i) The increase in shear strength with increase in concrete strength for SFRC deep beams with Ast=0%, is beneficial for NSC with increase in depth.

ii) At Ast=1.5% and D=300mm, initial decrease in shear strength at 35 MPa but increase in shear strength is observed at a/d=1 to 2. At D=500mm, decrease in shear strength for NSC range and increase for HSC is observed while at D=600mm, the decrease in shear strength is up to 65MPa.

iii) At Ast= 2.5% and D=300mm, the increase in compressive strength rises the shear strength at all a/d ratios while at D=500mm, fall in shear strength for NSC and rise in shear strength for HSC is observed. The shear strength is found decreasing at D=600mm for a/d=1 to 2.
3.8: Concluding remarks

The above sections reveal the versatility, advantages over minor disadvantages and robustness of artificial neural networks in the field of structural engineering for non-homogeneous data and complex problems. It is also, to be noted that very few researchers have used the neural networking for steel fiber reinforced concrete deep beams with limited parameters. The studies of influence of various parameters, individually or in combinations, describe the behavior of SFRC deep beam in shear for the range of parameters considered in this study.