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Full Length Research Paper

An experimental study of steel fibre reinforced concrete columns under axial load and modeling by ANN

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Concrete is a construction (building) material of which its usage in different fields has become widely spread by growing due to some of its effectiveness such as being easily shaped, resistance against physical and chemical outer effects, economical and having convenience in production. As a result of being widespread, it has been understood that concrete will serve more effective than the expected classical quality of it if it is consolidated with new techniques and new materials against outer physical and chemical effects. Different techniques are being developed to meet the requirement of various effects which exist in places where they are used. One of these techniques is to use steel fibre that has high technical properties. In addition to this, fibres which are produced from different materials may also be used with the concrete. As the day passes, the usage fields of the concrete that is produced by consolidating with different amount of steel fibre are increasing. In this study, the behaviours of ferroconcretes with steel fibre and without steel fibre were investigated under the axial load as experimentally. At the experimental stage, axial force-unit shortening ratios were obtained by loading 4 items of prismatic column samples with 160 × 160 × 840 mm dimension as axially in the mechanism that has load control in it. ANN model was done by data obtained from experimental study. Backpropagation algorithm was used in this study. ANN was designed as one input, one hidden layer and two output layers. 75 of 112 obtained data were used as training data whereas the rest was used as test data. Data was normalized and modelled by Matlab NNToolbox and obtained data were compared with experimental results by SPSS statistical programme. When the comparison was made between the results of the experiments, it was determined that there was no significant increase in the carrying power of the elements. The same results were obtained by ANN model. Since $p > 0.05$ as the result of the statistical analysis done in the 95% confidence interval between data obtained from experiments and ANN model, the reliability of the ANN model was proven.

Key words: Artificial Neural Network, steel wire/fibre, ferroconcrete column, axial load effect, column with fibre.

INTRODUCTION

Concrete with fibre that is produced by substituting different ratios and certain properties of steel fibre into normal concrete is increasing performance of traditional concrete by compensating the most of the drawbacks of it. The most important positive subject for behaviour of the ferroconcrete may be improvement of crispy property concrete that forms the ferroconcrete. Various researches (Sukontasukkul et al., 2005; Ayers and Van, 2003) showed that steel fibre increases ductile; first split resistance, pull resistance, bending carry power resistance, fatigue resistance, cutting resistance and elasticity module of normal concrete in significant amount. Today, researches (Ramesh et al., 2003; Sheikh, 1982) about this topic concentrate on the effect of using steel fibre to the behaviour regarding to detrital and split development. Especially, the limitation effect of fibre on the splits of axial loaded elements creates a wound effect for an element

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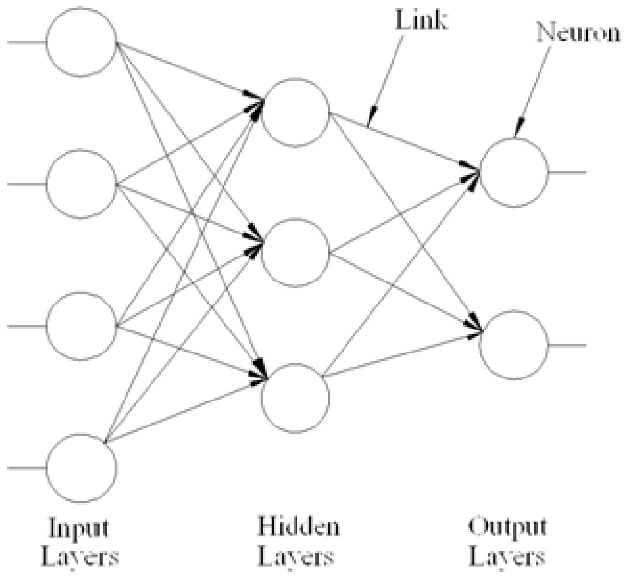

Figure 1. Artificial Neural Network Model.

under the pressure. With this formed effect, ductile of element and henceforth ductile of system increases. This result is supported by research done by Shah and Rangan (1970). The studies about ferroconcrete columns with steel fibre (Craig et al., 1984) generally shows that cutting and moment capacities, pulling resistance, ductile and bonds of the elements increase and henceforth improve split control.

Ferroconcrete columns are the most important carrier elements of frame systems that is made up of column and tendinous in the ferroconcrete buildings. Columns have important roles in earthquake and wind load apart from axial load carrying. If ferroconcrete columns present the ductile behaviour it will be very important for absorbing and consuming the energy that appeared at the time of the effect of the earthquake.

In the present study, behaviour and deformation differences formed on ferroconcrete columns produced by having various steel fibre ratios according to TS 500 were investigated. For different fibre percentages, normal force-deformation graphics obtained from experiments were drawn including comparisons. Experimental values of tested columns were compared with the calculated values. So, the validity of ferroconcrete calculation basis was investigated for column with steel fibre stirrup.

Axial load carrying capacity of manufactured concrete, axial load-deformation curves and time durations belong to these criterions and were recorded as the result of the experiments. By comparing the results of the experiments with theoretical values, appropriateness of the results were inquired with SPPS statistical packet program version 13 according to Variance analysis and T-test. It has been seen that reliability was found in 95% reliance interval.

Artificial Neural Network

Artificial Neural Network is a kind of information processing technology which is constructed as the result of imitation of the thinking and working abilities of the human brain (Oztemel, 2003; Cogurcu et al., 2008). What is intended for artificial neural network is a model of biological neural network. So, an artificial system will be brought about which imitates the functionality of the biological neural network. Three components were included in artificial neural network structure as neuron, connections and weights. In Figure 1, structure and components of the ANN was shown.

Artificial neural networks utilises data and results related with real life problem area or samples during learning process. Variables regarding to real life problem area constitute input sequence of artificial neural network whereas results regarding to real life obtained from these variables constitute target outputs sequence that artificial neural network must reach. The pattern that is required to be learned by ANN determines the relation between input and output in this training set and the weights of the ANN project in this pattern. In order to train ANN, lots of numbers of input and related output sequences are needed. The whole data that consists of the pairs of input and output sequence and used in training of ANN is known as “training set” (Cogurcu et al., 2008).

The basic operation done in learning process of ANN is to change the values of weights (Cogurcu et al., 2008). The aim is to adjust the weights of the ANN to produce output sequence related with all input sequences correctly (Celik and Arcaklioglu, 2004). It is possible to think this as an arrangement of the coefficients of the input that comes to neuron. So, ANN becomes a presenter of real life pattern according to the utilised input and output.

The mechanism which enables ANN to adjust the weights in network for producing required outputs is known as “learning algorithm” or “learning rule” (Figure 2) (Cogurcu et al., 2008).

In a simple expression, an ANN learns by doing error. Three main steps exist in the learning process of ANN. These are (Rumelhart et al., 1986): a. Calculation of outputs; b. Comparison of these outputs with target outputs and calculation of error; c. Changing weights and repeating the process

At the beginning of the learning process, the weights of the ANN are randomly assigned. Inputs are transferred to the hidden and output layer starting from input layer by being processed. So, ANN produces an output sequence under the effect of weights, total and transfer functions. The calculated difference between these outputs and target outputs is known as “error”. This error is used in network to compensate the difference between the weights weights of ANN and required outputs (Figure 3) (Caudill, 1987).

There are lots of actively used learning algorithms. These learning algorithms may vary with the ANN archi-

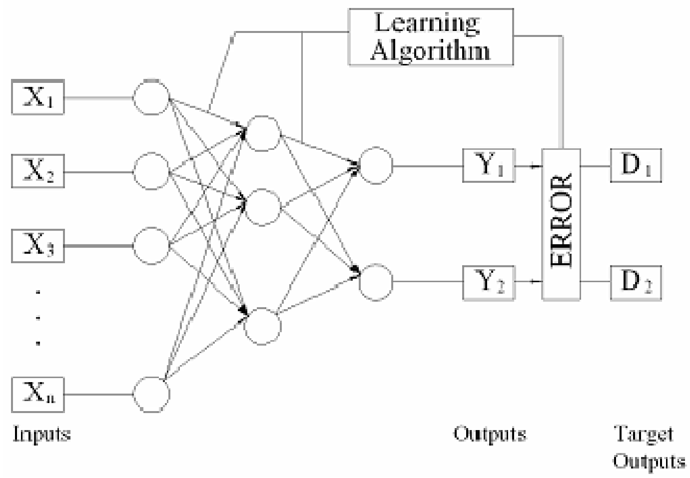

Figure 2. Learning process and learning algorithm. X_{ij}=Inpus, Y_{ij}=Outputs, D_{ij}= Targets.

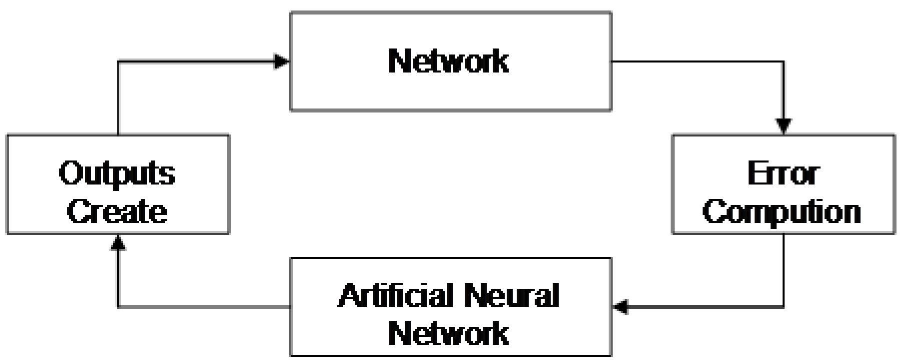

Figure 3. Calculation of error at the learning process.

tecture according to quantity of the problems. Hebb, Delta, Backwards Chaining (Generalized Delta), Kohonen, Hopfield and Energy function are mostly used learning algorithms among more than 100 types.

Since backward chaining is the most commonly used in optimisation and evaluation problems, we used it as learning algorithm in the present study.

ANN has been applied successfully in lots of areas starting from the guess of electrical charge and river flow, wind energy control, automotive sector to construction sector. Especially in construction sector, its usage in modelling and classification of the experimental studies increases day by day (Korres et al., 2002; Yuanwang et al., 2002; Jurado and Saenz, 2001; Başbuğ, 1994; Elmandooh and Ghobarah, 2003; Hadi and Li, 2004).

ElMandooh and Ghobarah (2003) investigated the applicability of the non-axial and nonlinear model of reinforced concrete column under periodical and dynamical load in their study. They developed their study based on plastic model and determined latitudinal deformation and calculation values in previously determined model with variations of effect of axial load (Başbuğ, 1994).

Hadi and Li (2004) investigated reinforced concrete columns that are manufactured from concrete with high resistance and have lots of advantages regarding to rigidity and durability. These reinforced concrete columns show crispy and fragile properties and less ductility under the periodical and instant load. Since it is not possible to meet axial load every time and the eccentric effect of the load, they investigated the behaviours of the reinforced concrete columns of buildings under the eccentric load, their load conveying capacity and deformation properties when they are powered by galvanized steel plate (Hadi and Li, 2004).

MATERIAL AND METHOD

The concrete produced according to Turkish ready concrete standard, mould, equipment steel, axial loading mechanism, load cell and LDVT were used in the experimental study.

A personal computer with Pentium 4, 2.6 GHz intel processor,

Table 1. Properties of column sample used in experiment.

Sample number	Column cross-section (mm)	Concrete Pressure Resistance f_c (MPa)	Longitudinal equipment		Latitudinal equipment		Fibre rate (kg/m^3)
			Diameter (mm)	f_y (MPa)	Diameter (mm)	f_y (MPa)	
1	160x160	20.4	11.26	548.6	7.74	440	0
2	160x160	20.8	11.26	548.6	7.74	440	20
3	160x160	24.5	11.26	548.6	7.74	440	40
4	160x160	23.2	11.26	548.6	7.74	440	60

162 GB SATA Hard disc, 512 MB 400 MHz RAM and 128 MB GForce Display Card and Matlab packet program version 6.5 Neural Network Toolbox were used as ANN software development material.

SPSS version 13 packet program was used to carry out the statistical analysis.

Experimental study

In the experimental study of this research, 4 items steel fibre consolidated reinforced concrete columns with stir-up and 4 items reinforced concrete columns with stir-up were tested under the axial load.

General properties of the elements used in experiment

Columns were chosen as elements with 160 mm × 160 mm cross-sections and 840 mm height. The variables in the experimental study were determined as the change of the amount of the fibre (N/m^3) in concrete ratio.

The experiment program was made up 4 items of column members. Columns were separated into 4 classes (1, 2, 3 and 4) according to the change of the amount of the fibre in the concrete. Steel fibre ratio was thought to be 0.0, 200, 400 and 600 N/m^3 (Table 1). The quality of the concrete used in experiment was 20 MPa pressure resistances according to the TS 500 - 2000. The ratio of the water to the cement and the dosage of the concrete were 0.49 and 3500 N/m^3, respectively.

The values of concrete pressure resistance of concretes with and without different amount of steel fibres were obtained from 3 each cylindrical concrete sample where each of them has 150 × 300 mm size. The average values of concrete pressure resistance of elements are given in Table 1.

The experimental flowing resistance of the longitudinal and latitudinal equipments used in experiments were taken as 3 samples for each diameter and tested according to the TS-EN 10002/1/2004 steel pull test under the Universal Pull Experiment Tool in the laboratory of Selcuk University Engineering and Architecture Faculty Machine Engineering. The average values of the results were given in Table 1.

The properties of fibre used in preparation of the concrete are: Wire (fibre) type Dramix RC 80 / 60 BN, wire (fibre) diameter 0.75 mm, height 60 mm, both terminal are twisted and class C type A cold pull (Figure 4).

In Figure 5, equipment order of the experiment elements are shown. Ready concrete was used as column concrete. The concretes of all elements were poured as vertical, done with great care. Prepared column samples were taken out from the mould 1 day after concrete pouring and the maintenance of them was done till 21st day. They were kept at room temperature till 28th day. The preparation of the experiment members is shown in Figure 6.

Experiment mechanism and measurement tools

All elements were tested under the axial load in construction laboratory of Selcuk University, Engineering and Architecture Faculty, Civil Engineering Department. The speed of axial loading on column done by engine was chosen as 10 kN. Load cell was used as recorder. Displacement measures (LVDT's) were used to measure vertical and horizontal displacements at points that are certain and determined according to specific interval on each loading level in the experiments that were done until reaching the fall down loading (Figure 7).

Evaluation of experiment results

Total unit shortening ratio that belongs to columns graphics drawing were found as shown in Formula 1 at the end of the experiments. It is the ratio of average of differences of measurement values LVDTs numbered L4, L12 that measure vertical displacement on the upper head of column and LVDTs numbered L0, L5 that measure vertical displacement on the bottom head of column in case of any displacement in rigid side to the column total height, h (Yılmaz, 2001; Kaltakci et al., 2007).

$$\varepsilon = \frac{(\delta_4 - \delta_5) + (\delta_{12} - \delta_0)}{2h} \quad (1)$$

Figure 8 includes the drawing of axial force-deformation graphics of each column. The common property of the graphics is that all samples present similar behaviour.

Artificial Neural Network Model

In this study, the steel fibre contribution was taken as input parameter whereas deformation and load were taken as output parameters. The designed ANN model according to these parameters is shown in Figure 9. Neuron numbers in hidden layer were tested for different values and network with 30 neurons were chosen as it gives the most appropriate result.

112 data was obtained from experiment and 75 of them were chosen for training (Selection "e" in Table 2) whereas 37 of them were chosen for test data (Selection "t" in Table 2); they were both chosen at random. Training speed and error ratio of ANN were 0.5 and 0.0001, respectively whereas backward chaining feedback algorithm was used as learning algorithm.

Input and output values obtained as experimentally are given in Table 2. Training and test data graphics and performance after 5000 epoch in Matlab NN Toolbox program are shown in Figure 10.

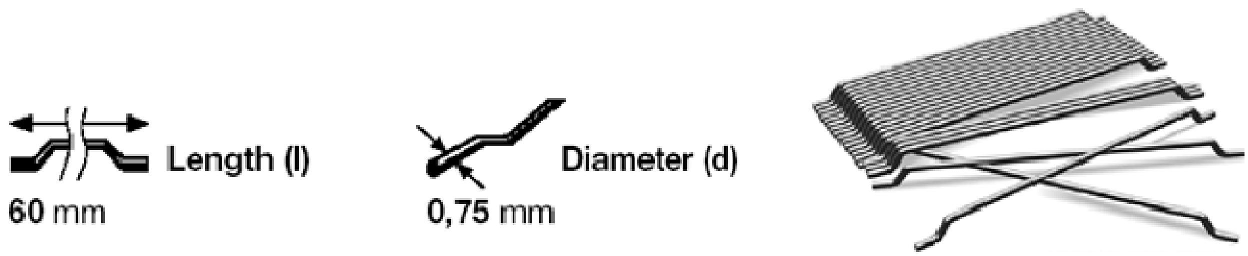

Figure 4. The geometry of fibre consolidated to the concrete.

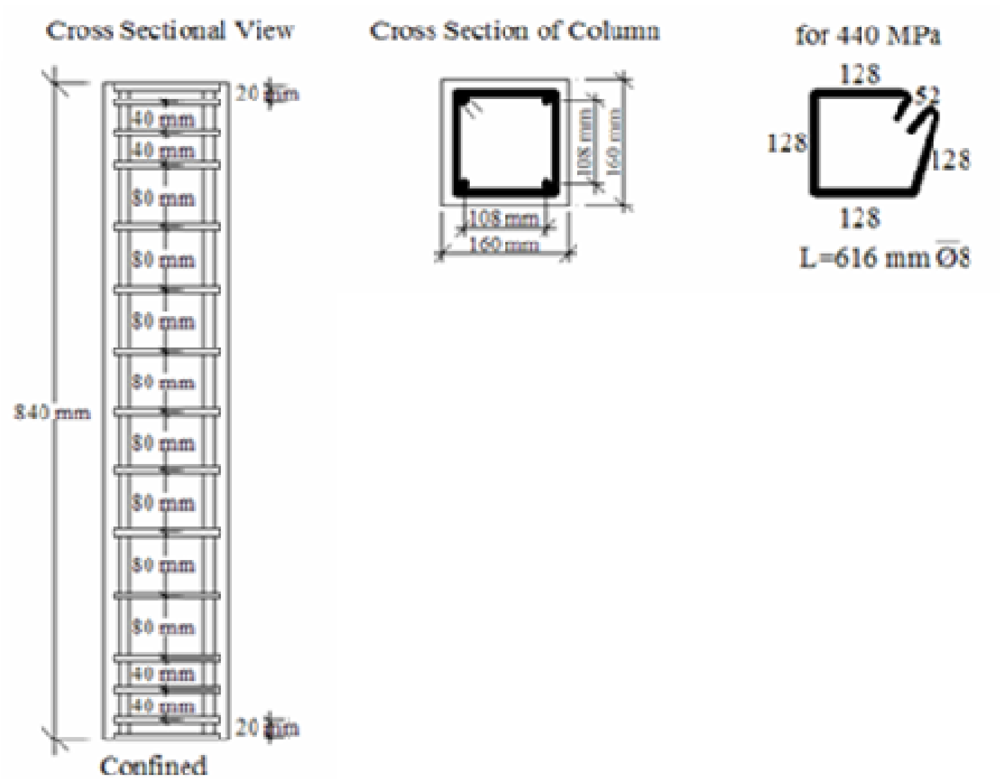

Figure 5. The dimensions and equipment schema of the used column samples.

Figure 6. The preparation of the experiment elements.

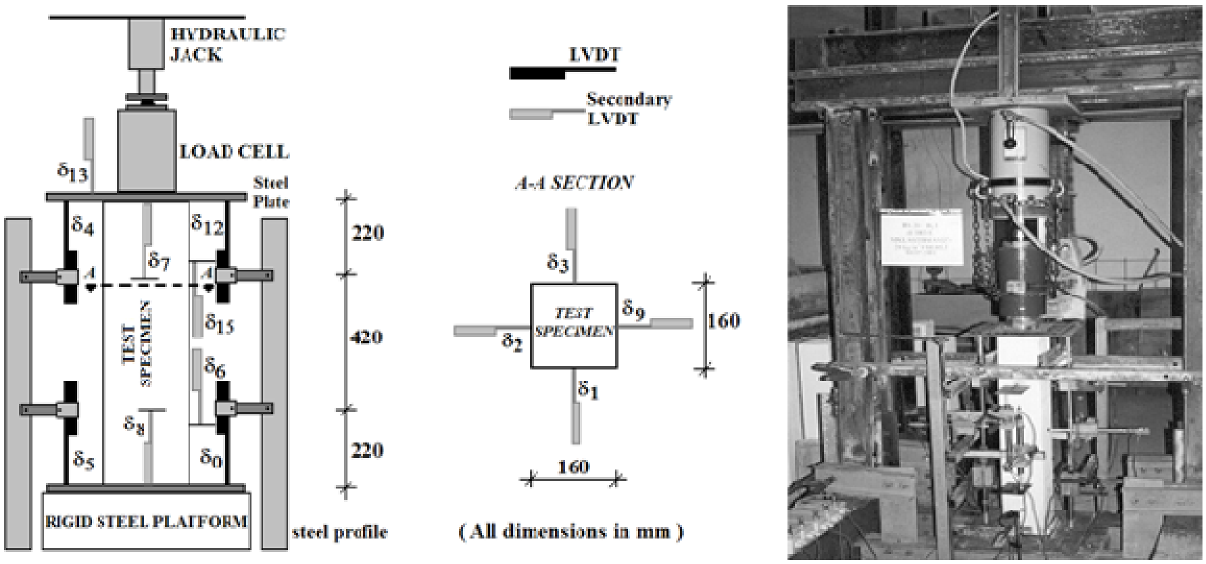

Figure 7. Placements of LVDT and a picture of experiment schema.

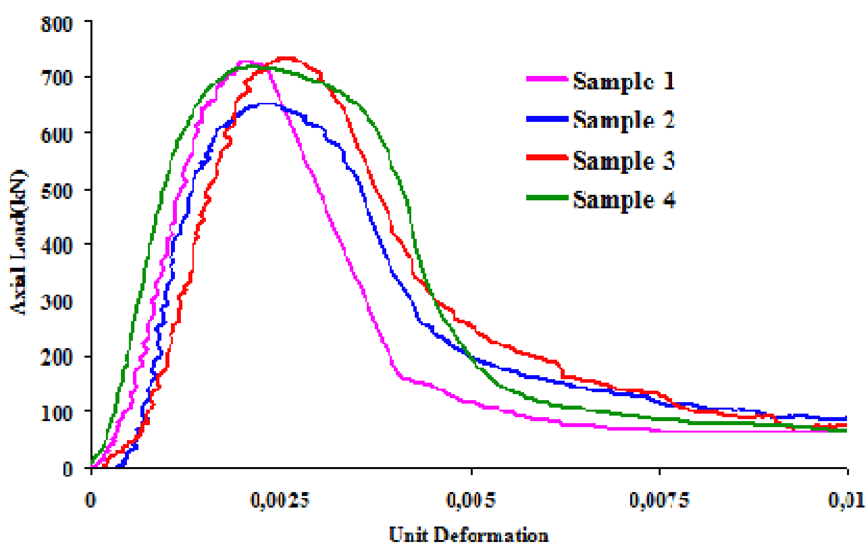

Figure 8. Graphics of Axial load-Unit Shortening Obtained from Experiments

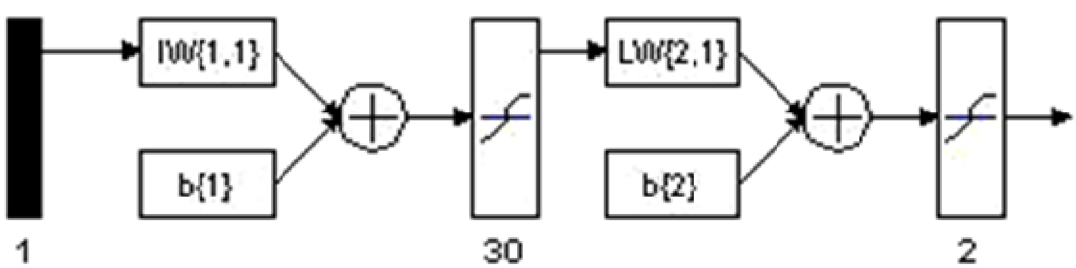

Figure 9. The designed ANN model.

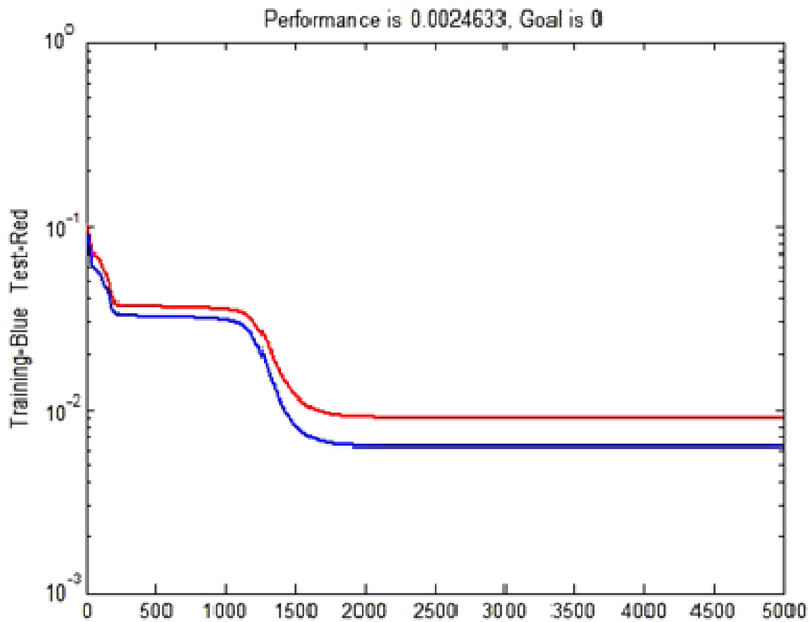

Figure 10. Graphics of training and test after 5000 epoch.

Table 2. Experimental data.

No	Selection	Input	Experimental outputs		No	Selection	Input	Experimental outputs	
		Steel fiber	Deformation	Load			Steel fiber	Deformation	Load
1	e	0	0.0000	0.0000	57	e	20.0000	0.0255	29.8650
2	e	0	0.0005	102.3000	58	e	20.0000	0.0275	29.0400
3	t	0	0.0015	647.9550	59	t	20.0000	0.0275	29.0400
4	e	0	0.0021	727.6500	60	e	40.0000	0.0002	0.0000
5	e	0	0.0040	178.8600	61	e	40.0000	0.0005	42.7350
6	t	0	0.0041	163.5150	62	t	40.0000	0.0015	480.3150
7	e	0	0.0041	162.8550	63	t	40.0000	0.0025	733.2600
8	e	0	0.0041	161.2050	64	e	40.0000	0.0036	561.6600
9	t	0	0.0041	159.5550	65	t	40.0000	0.0045	314.3250
10	e	0	0.0041	157.9050	66	e	40.0000	0.0055	214.3350
11	t	0	0.0042	156.2550	67	e	40.0000	0.0065	157.0800
12	E	0	0.0043	153.1200	68	e	40.0000	0.0077	112.8600
13	t	0	0.0044	150.6450	69	e	40.0000	0.0085	91.9050
14	e	0	0.0045	149.1600	70	t	40.0000	0.0095	74.0850
15	e	0	0.0055	97.5150	71	e	40.0000	0.0105	74.0850
16	e	0	0.0064	78.2100	72	e	40.0000	0.0115	60.3900
17	e	0	0.0075	66.8250	73	t	40.0000	0.0125	51.6450
18	e	0	0.0076	66.0000	74	e	40.0000	0.0135	45.8700
19	t	0	0.0105	65.3400	75	e	40.0000	0.0145	42.7350
20	t	0	0.0115	58.9050	76	t	40.0000	0.0155	38.6100
21	e	0	0.0124	43.5600	77	e	40.0000	0.0164	35.4750
22	t	0	0.0135	40.2600	78	e	40.0000	0.0175	31.3500
23	e	0	0.0145	37.9500	79	e	40.0000	0.0184	29.0400
24	e	0	0.0156	34.6500	80	t	40.0000	0.0196	27.3900
25	t	0	0.0165	33.0000	81	t	40.0000	0.0205	26.5650
26	e	0	0.0180	32.1750	82	e	40.0000	0.0215	24.9150
27	e	0	0.0178	0.0000	83	e	40.0000	0.0225	22.6050
28	t	20	0.0003	0.0000	84	t	40.0000	0.0235	22.6050

Table 2. Contd.

29	e	20	0.0003	2.4750	85	e	40.0000	0.0245	22.6050
30	e	20	0.0015	554.4000	86	t	40.0000	0.0255	20.1300
31	t	20	0.0016	568.0950	87	e	40.0000	0.0265	20.9550
32	e	20	0.0025	648.7800	88	e	40.0000	0.0275	20.1300
33	e	20	0.0025	647.1300	89	e	40.0000	0.0276	3.3000
34	t	20	0.0035	523.0500	90	t	60.0000	0.0000	0.0000
35	e	20	0.0036	477.8400	91	e	60.0000	0.0005	210.3750
36	t	20	0.0055	174.0750	92	e	60.0000	0.0015	675.3450
37	e	20	0.0055	171.6000	93	t	60.0000	0.0025	712.3050
38	e	20	0.0076	111.2100	94	t	60.0000	0.0035	647.9550
39	e	20	0.0077	112.0350	95	e	60.0000	0.0045	311.0250
40	t	20	0.0096	91.0800	96	e	60.0000	0.0056	136.9500
41	e	20	0.0097	85.4700	97	e	60.0000	0.0065	104.7750
42	e	20	0.0115	71.7750	98	t	60.0000	0.0075	86.9550
43	e	20	0.0116	70.9500	99	e	60.0000	0.0081	80.5200
44	t	20	0.0137	52.3050	100	t	60.0000	0.0096	71.7750
45	e	20	0.0137	53.1300	101	e	60.0000	0.0105	65.3400
46	e	20	0.0155	54.7800	102	e	60.0000	0.0115	57.2550
47	e	20	0.0155	55.6050	103	e	60.0000	0.0125	53.9550
48	t	20	0.0176	49.9950	104	e	60.0000	0.0135	51.6450
49	e	20	0.0177	49.1700	105	e	60.0000	0.0145	42.7350
50	e	20	0.0195	40.2600	106	e	60.0000	0.0155	42.7350
51	e	20	0.0196	39.4350	107	t	60.0000	0.0165	44.3850
52	t	20	0.0216	35.4750	108	t	60.0000	0.0175	44.3850
53	e	20	0.0216	34.6500	109	t	60.0000	0.0185	44.3850
54	e	20	0.0235	30.6900	110	e	60.0000	0.0195	46.6950
55	e	20	0.0236	31.3500	111	e	60.0000	0.0205	48.3450
56	t	20	0.0255	29.8650	112	e	60.0000	0.0215	49.9950

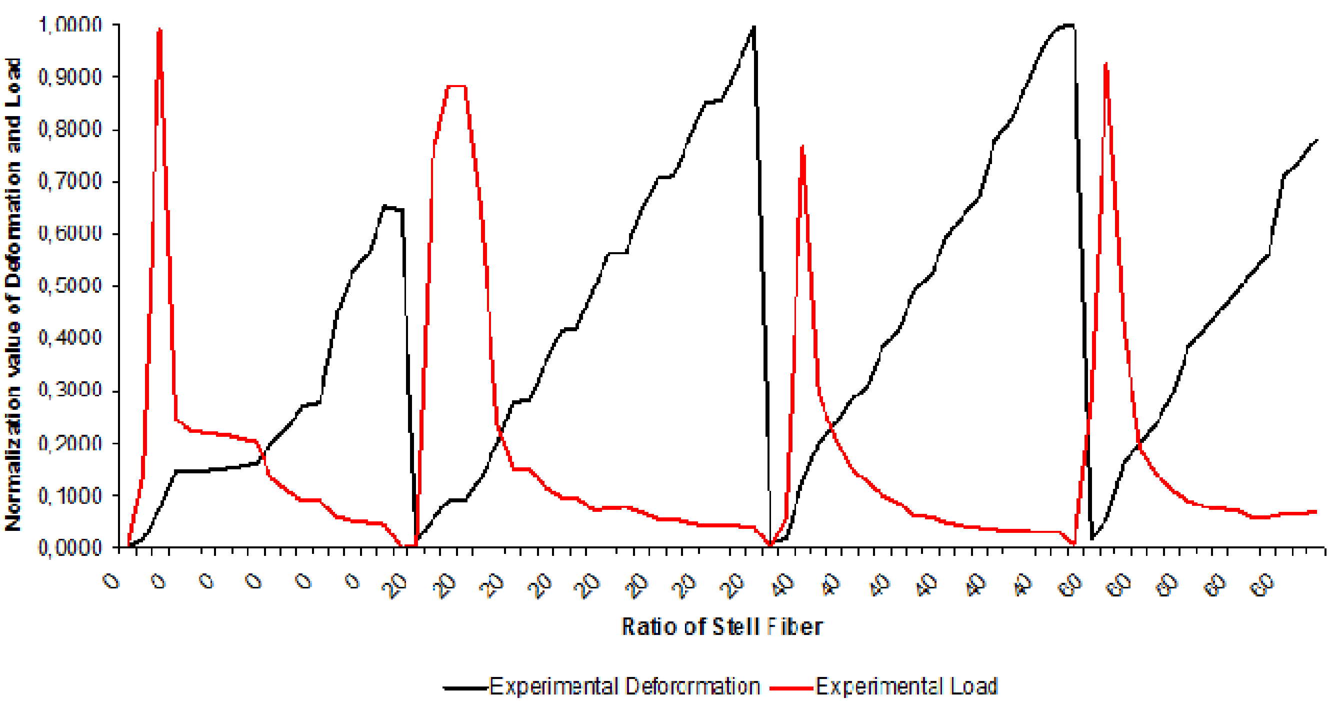

Figure 11. The load and deformation graphics obtained by experimentally.

Table 3. ANN training and test data.

No	Selection	Input	ANN Outputs		No	Selection	Input	ANN Outputs	
		Steel Fiber	Deformation	Load			Steel Fiber	Deformation	Load
1	e	0	0.0000	0.3373	57	e	20.0000	0.0252	29.0371
2	e	0	0.0010	124.9915	58	e	20.0000	0.0271	29.0371
3	t	0	0.0019	564.9475	59	t	20.0000	0.0274	29.9757
4	e	0	0.0027	711.5995	60	e	40.0000	0.0002	0.0440
5	e	0	0.0038	168.9871	61	e	40.0000	0.0005	36.7070
6	t	0	0.0046	161.6545	62	t	40.0000	0.0014	483.9956
7	e	0	0.0038	168.9871	63	t	40.0000	0.0025	732.5707
8	e	0	0.0046	168.9871	64	e	40.0000	0.0035	569.4497
9	t	0	0.0046	154.3219	65	t	40.0000	0.0045	323.0744
10	e	0	0.0046	154.3219	66	e	40.0000	0.0054	141.9591
11	t	0	0.0046	154.3219	67	e	40.0000	0.0062	154.0286
12	e	0	0.0046	146.9893	68	e	40.0000	0.0079	102.7004
13	t	0	0.0057	154.3219	69	e	40.0000	0.0085	80.7026
14	e	0	0.0074	146.9893	70	t	40.0000	0.0096	73.7660
15	e	0	0.0052	88.3285	71	e	40.0000	0.0104	80.7026
16	e	0	0.0068	73.6633	72	e	40.0000	0.0115	51.3722
17	e	0	0.0074	5.4701	73	t	40.0000	0.0127	51.3722
18	e	0	0.0074	6.9366	74	e	40.0000	0.0134	41.1066
19	t	0	0.0102	51.6655	75	e	40.0000	0.0140	36.7070
20	t	0	0.0115	51.6655	76	t	40.0000	0.0156	44.4356
21	e	0	0.0121	65.5974	77	e	40.0000	0.0142	36.7070
22	t	0	0.0129	44.3329	78	e	40.0000	0.0167	29.3744
23	e	0	0.0151	43.5996	79	e	40.0000	0.0192	26.4414
24	e	0	0.0157	34.1699	80	t	40.0000	0.0198	28.3038
25	t	0	0.0157	29.6677	81	t	40.0000	0.0207	28.3038
26	e	0	0.0176	34.2432	82	e	40.0000	0.0214	25.7379
27	e	0	0.0176	0.7039	83	e	40.0000	0.0225	26.8373
28	t	20	0.0004	0.5133	84	t	40.0000	0.0236	22.6431
29	e	20	0.0007	2.4931	85	e	40.0000	0.0239	22.4378
30	e	20	0.0020	567.2499	86	t	40.0000	0.0255	21.1179
31	t	20	0.0013	565.2555	87	e	40.0000	0.0261	22.7751
32	e	20	0.0020	655.2411	88	e	40.0000	0.0272	21.5285
33	e	20	0.0020	655.2411	89	e	40.0000	0.0253	4.8395
34	t	20	0.0037	528.5925	90	t	60.0000	0.0000	0.7333
35	e	20	0.0034	486.6647	91	e	60.0000	0.0000	215.2851
36	t	20	0.0059	169.2951	92	e	60.0000	0.0011	719.3281
37	e	20	0.0067	163.9569	93	t	60.0000	0.0024	731.8668
38	e	20	0.0075	119.2281	94	t	60.0000	0.0036	65.9861
39	e	20	0.0075	119.5214	95	e	60.0000	0.0045	336.2730
40	t	20	0.0096	88.6365	96	e	60.0000	0.0056	131.8475
41	e	20	0.0095	88.2112	97	e	60.0000	0.0061	109.8497
42	e	20	0.0111	65.9201	98	t	60.0000	0.0096	93.9306
43	e	20	0.0114	65.9201	99	e	60.0000	0.0078	80.5193
44	t	20	0.0131	57.7809	100	t	60.0000	0.0096	71.9328
45	e	20	0.0131	56.1677	101	e	60.0000	0.0105	71.9768
46	e	20	0.0155	58.3675	102	e	60.0000	0.0111	50.0010
47	e	20	0.0155	58.3675	103	e	60.0000	0.0125	58.5215
48	t	20	0.0186	50.4483	104	e	60.0000	0.0133	58.5215
49	e	20	0.0180	43.7023	105	e	60.0000	0.0147	44.2596
50	E	20	0.0186	41.5025	106	e	60.0000	0.0166	49.9350

Table 3. Contd.

51	e	20	0.0194	41.5025	107	t	60.0000	0.0165	44.5895
52	t	20	0.0213	35.7831	108	t	60.0000	0.0165	44.5895
53	e	20	0.0216	29.0371	109	t	60.0000	0.0190	44.5895
54	e	20	0.0235	29.0371	110	e	60.0000	0.0180	48.6591
55	e	20	0.0235	29.0371	111	e	60.0000	0.0194	48.9891
56	T	20	0.0258	29.9757	112	e	60.0000	0.0166	48.9891

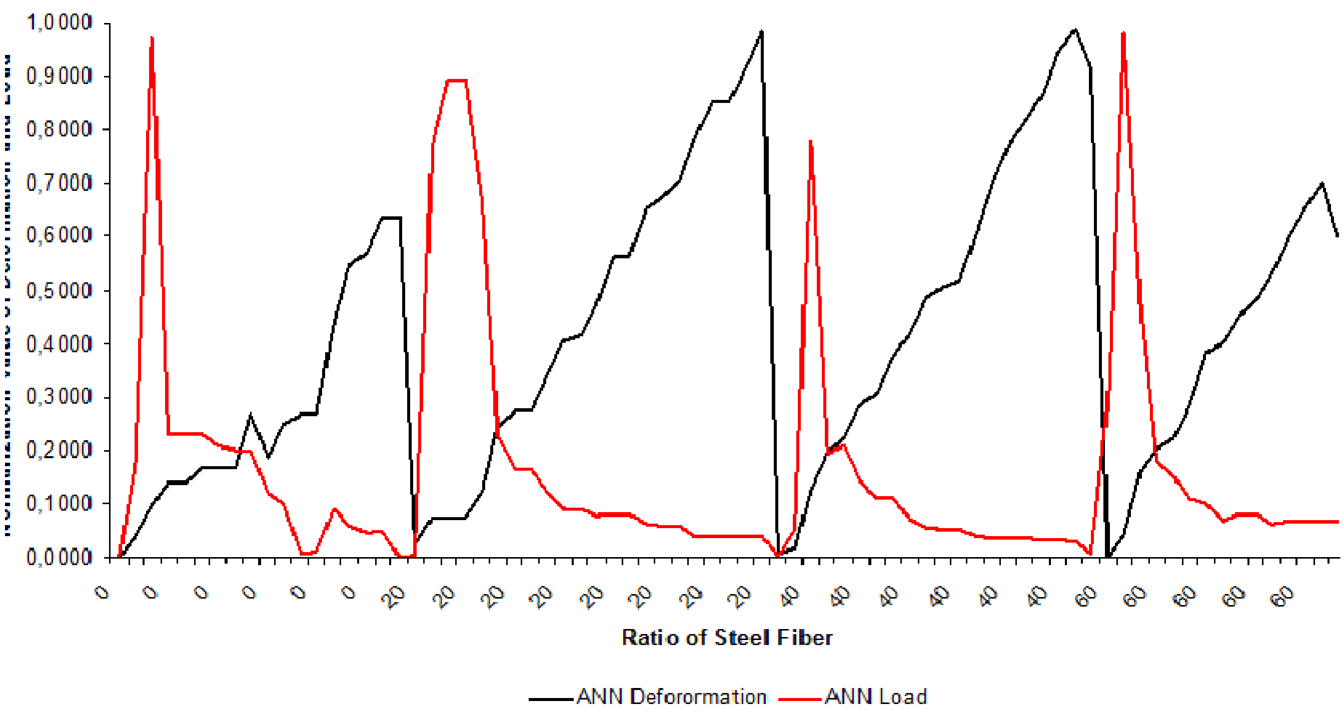

Figure 12. The training load and deformation graphics obtained by ANN

CONCLUSION AND DISCUSSION

From the experimental study done and related analytical study, it has been observed that using different amount of steel fibre in concrete only increases the material ductile to some amount but has no significant increase in carrying power of samples tested under axial load. The effects of steel fibre were appeared at the fall down behaviours of the columns. While columns with no steel fibre present so much crispy behaviours and make the concrete loses carrying properties by creating fall in it, columns with different steel fibre ratio have ductile behaviours before falling down.

Experimental data were normalised and modelled by Matlab NNToolbox program. Normalised data and experimental data obtained from experiments on columns were applied to ANN model and the results are shown in Table 3. Obtained data and experimental results are analysed with SPSS statistical programme and the results are shown in Table 4.

Table 4. Statistical results of training and testing data obtained by SPSS software.

	Training			Testing		
	t	**df**	**Sig.(p)**	**t**	**df**	**Sig. (p)**
Deformation	0.137	148	0.891	-0.060	72	0.953
Load	0.037	148	0.970	0.338	72	0.736

When the comparison was made for the results obtained from experiment, it was observed that there was no significant difference between them. The same results were obtained by ANN model. Since $p > 0.05$ (Table 4) as the result of the statistical analysis done in the 5% reliance interval between data obtained from experiments and ANN model, the reliability of the ANN model was proven.

Normalized loading and deformation data were compared as graphically regarding to prepared ANN model with training and test data. Having done comparisons as

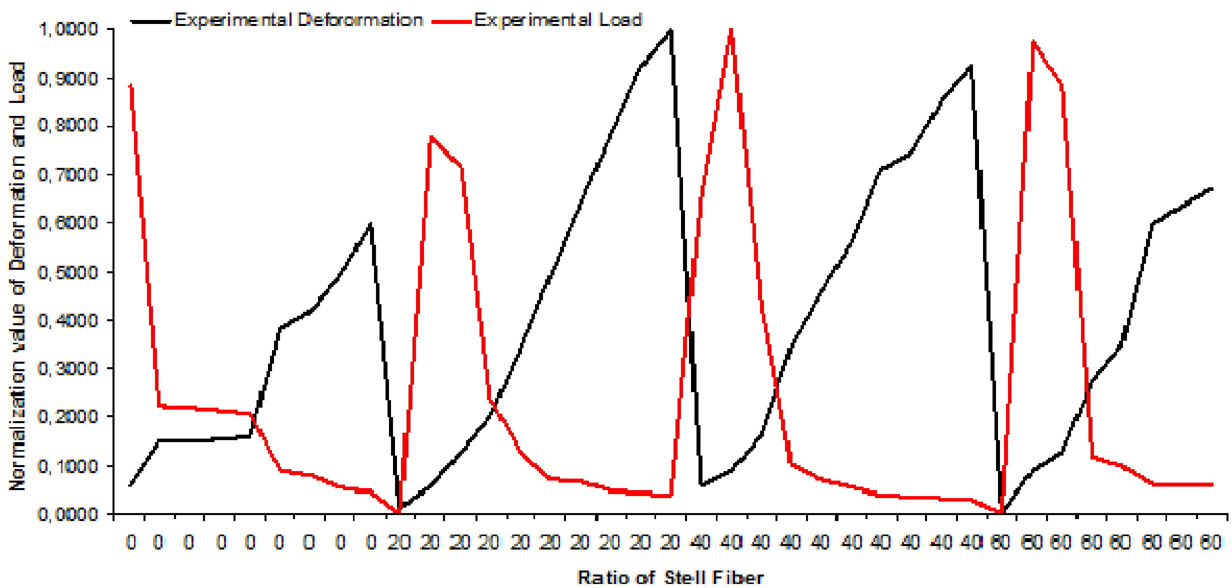

Figure 13. The test load and deformation graphics obtained by experimentally.

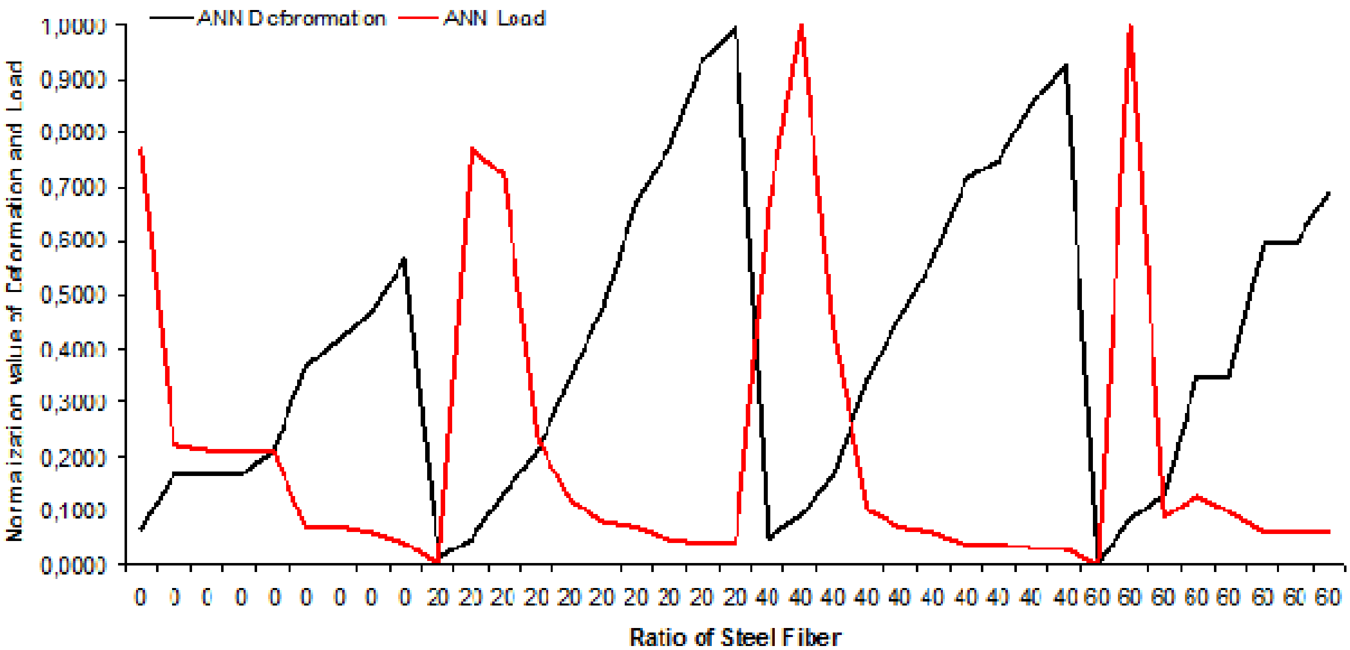

Figure 14. The test load and deformation graphics obtained by ANN

shown in Figures 11, 12, 13 and 14, the results showed the similarities between experimental study and ANN model and supported reliability of the model.

It was observed that the experimental results of Figure 11 and ANN training results of Figure 12 were close to each other in terms of load and deformation values.

It was observed that the experimental data of Figure 13 and ANN test results of Figure 14 were very close to each other in terms of load and deformation values.

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