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NEURAL NETWORKS METHOD APPLIED TO THE PROPERTY STUDY OF STEEL-CONCRETE COMPOSITE COLUMNS UNDER AXIAL COMPRESSION

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Abstract- In this paper, a new type of steel-concrete composite member, concrete-filled core steel tube with outer angle steel plank reinforced concrete stub column, is proposed and a series of nonlinear 3-D(three-dimensional) full-range numerical calculations under axial compression are carried out, some important factors are analyzed, such as the strength of the concrete, the steel tube and the angle steel, the volume ratio of the steel tube and the angle steel to the overall column, position coefficient(the ratio of the diameter of the core steel tube to the overall width of the column section). RBFNNs(Radial Basis Function Neural Networks) are employed for calculated the loading capacity of the concrete-filled core steel tube with outer angle steel plank reinforecd concret stub columns under axial compression, and the prediction results based on RBFNNS are compared with theoretical formula calculation results. The maximum and minimum error ratio of prediction is 12.32% and 4.17%, respectively.

Index terms: Steel-concrete composite column, Angle steel plank, Core steel tube, Neural networks, RBFNNs

I. INTRODUCTION

The use of concrete-filled steel-tube(CFT) columns, as shown in Fig. 1, for the construction of high-rise buildings, bridges, barriers, etc. has become increasingly popular in recent years. These columns have demonstrated higher axial load capacity, better ductility performance,larger energy absorption capacity and lower strength degradation than conventional reinforced concrete and steel hollow section columns[1]. The enhancement of structural properties of CFT columns is mainly due to the composite action of steel hollow section and core concrete. The confining effect by the steel hollow section causes the core concrete to behave in a triaxial compressive stress state while the core concrete prevents the wall of the steel hollow section from buckling inward[2].

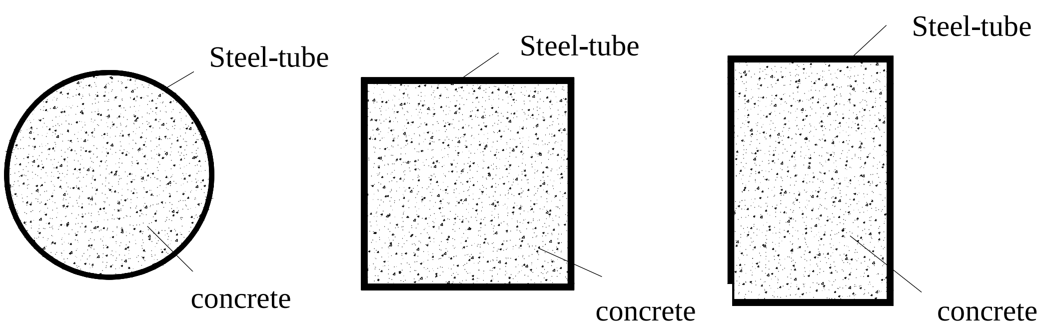


Figure 1. Common section forming of concrete-filled steel tube column

Although CFT columns are suitable for tall buildings in high seismic regions, their use has been limited due to the complicated joint of column and RC(reinforcement concrete) beam and taking additional measures for steel fire-resistant and corrosion-resistant.

The concrete-filled core steel tube reinforced concrete column, as shown in Fig. 2, was proposed by zhao et al.[3], which has attracted many researchers [4-7]. The composite column with inside concrete filled steel tube may have advantages over either pure steel or reinforced concrete columns , with the inner concrete enhancing the stability , the tube confining the core concrete to a triaxial compressive stress state , and the outer concrete protecting the steel tube from high temperature , corrosion , etc. However, the reaction to axial compressive load is different between the peripheral reinforced concrete of the column and the concrete confined by the core steel tube.

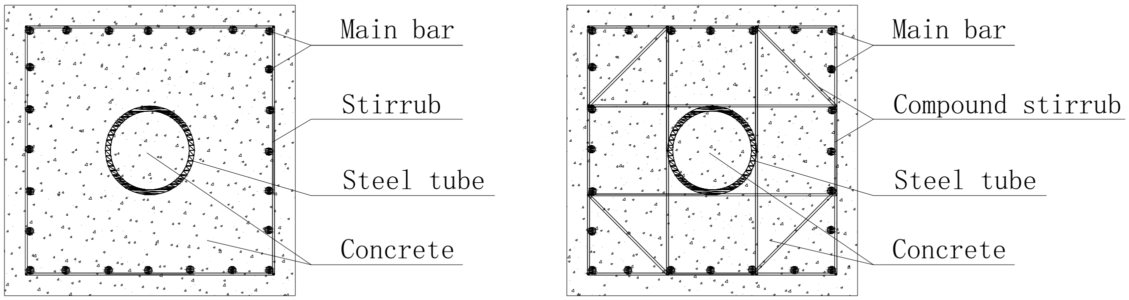


Figure 2. Common section forming of the concrete-filled core steel tube reinforced concrete column

Zhao et al. had studied 38 the rectangle concrete columns reinforced by the concrete-filled core steel tube and the main influence factors of column ductility were researched under the cyclic reversed loading test[3]. Lin et al. and Cai et al. also made some rectangle concrete columns reinforced by the concrete-filled core steel-tube, and established the load capacity formula of the column under axial compression and the limit value of the axial compressive ratio of calculation through the axial compression test and the cyclic reversed loading test of node model [8, 9].

Generally, the concrete-filled steel tube(CFT) and peripheral reinforced concrete of the concrete-filled core steel-tube reinforced concrete column could work together until damaged [8]. However, the reaction to axial compressive load is different between the reinforced concrete column and the column with inside concrete-filled steel tube,which is due to the peripheral concrete of the composite column confined by the rectangular transverse reinforcement different from the concrete of the composite column confined by circular steel tube. Nie et al. analysed the influences of the transverse reinforcement ratio on the function of the composite column and the transverse reinforcement ratio in critical state was derived[10].

Nie proposed the limits of the volume transverse reinforcement ratio as the failure criterion of the composite column, it was that the internal and external part could work together until the destruction when the volume transverse reinforcement ratio higher than the limits of the volume transverse reinforcement ratio, otherwise the external precede to damage. This theory seems to really solve the difficult of research and application of concrete-filled steel tube. however the limits of the volume ransverse reinforcement ratio is too large to achieve in engineering application. Nie also suggested that using the concrete ultimate strain out of the concrete-filled steel tube as the failure criterion of the composite column[11]. Obviously, it does not take full advantage of the loding capacity of the composite column with inside concrete-filled steel tube.

This paper presents a new type of concrete-steel composite column, concrete filled steel tube with outer steel plank reinforced concrete column, as shown in Figure 3., based on reviewing plentiful domestic and foreign researches on concrete-steel composite columns and analying the shortcomings of existing composite members. It is the evolution and development of this composite column based on steel encased concrete column and core steel-tube reinforced concrete column developed in recent years. It has better properties than existing composite members. Especially, the locations of the tube and angle steel lead to effectively improve the shearing, bending, torsion and bearing capacity of column components, improve the ductility and tenacity and make it have good mechanical performance.

In this paper, a concrete-filled steel tube with outer steel plank reinforced concrete stub column is proposed. The rectangular transverse reinforcement in the concrete-filled core steel-tube reinforced concrete column is replaced with the batten plate, as shown in Fig. 7, and the longitudinal main steel bars is substituted by angle steels in the four corner of the composite column. The angle steels with batern plate can provide the outer concrete of the composite column enough restriction corresponding with one in the core steel tube to work together until the composite columnb failure. Tests for specimens were carried out. A series of nonlinear full-range numerical calculation were completed for the composite column in axial compression condition. Here, some important factors are analyzed, such as the strength of the core concrete, the steel tube and the angle steel, the volume ratio of the steel tube and the angle steel, position coefficient. Finally, the loading capacity of the concrete-filled core steel-tube with outer steel plank stub column is forecasted with the experience formula and artificial neural network.

II. EXPERIMENTAL RESULTS FOR CONCRETE-FILLED CORE STEEL TUBE WITH OUTER STEEL PLANK COLUMN UNDER AXIAL COMPRESSION

This paper presents an experimental study on the behavior and strength of concrete-filled steel tube with outer steel plank reinforced concrete stub columns. Three column specimens were tested under axial load. The objectives of these tests were to investigate the centrally loaded behavior of this new type of composite column, and to derive a method to evaluate the ultimate strength.

a. Test specimens

Parameters for the tests are as follows:(1)concrete strength f_c (f_c=39.75MPa),called the axial compressive strength of concrete, is determined by prisms with dimensions of 150 mm×150 mm ×300 mm, f_c is the strength adopted in design according to the Chinese standard. The prism compressive strength f_c is less than the cylinder compressive strength f_c', and the ratio of them is approximately equal to 0.95;(2) tube diameter-to-thickness ratio(D/t=133/4.5=29.56); (3) the ratio of angle steel section(ρ_{as}=0.358%, 0.528% and 0.743% , respectively for specimen AC-1,AC-2 and AC-3), defined as the ratio of angle steel section area (A_{as}) to gross area (A_c+A_s), where A_c is the areas of concrete, A_s is the total section area of steel tube and angle steel. Cross-sections of test specimens and test specimens are shown in Fig. 3.

Figure 3. Cross-sections of test specimens and test specimens

b. Test setup and procedure

All the tests were performed on a 5000 kN capacity universal testing machine. The test setup and instrument layout are shown in Fig. 4. Eight strain gauges were glued to the flange of four angle steel at mid-height to measure the axial and lateral strains. Four strain gauges were glued to the external surface of the steel tube to measure axial deformations and perimeter expansion of the steel tube wall. Before testing, two 20mm thick clamping plates were bolted to the top and bottom of the specimens to enhance the strength at the ends. Two displacement transducers were placed between the top and bottom clampingplates to measure the axial deformation. Two displacement transducers were also used to measure the lateral deflection at one-third height of specimens. A computerized data-acquisition system was used to collect the load,the deformation and strain data.

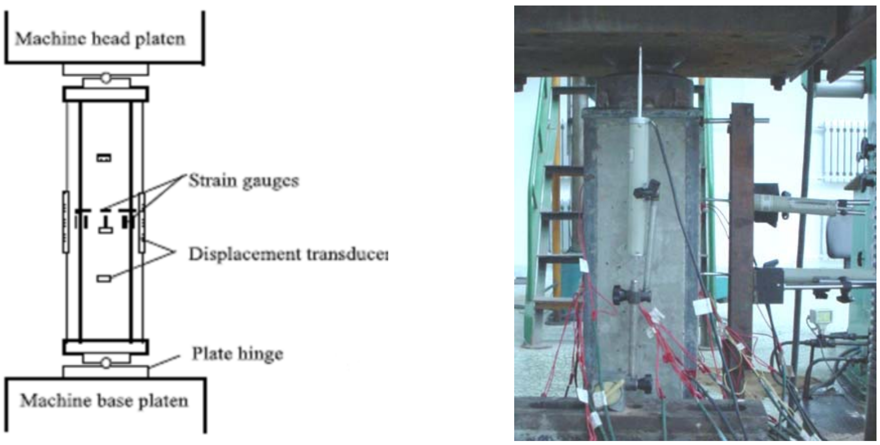


Figure 4. Test setup and instrumentation layout

c. Experimental results

For stub specimens, all the specimens behaved in a relatively ductile manner and testing proceeded in a smooth and controlled way. All the angle steel crinkled seriously when the test terminated. The typical structural behaviour of the tested columns is represented in Fig. 5 by the relationship between the axial load and the displacement at the top of columns.

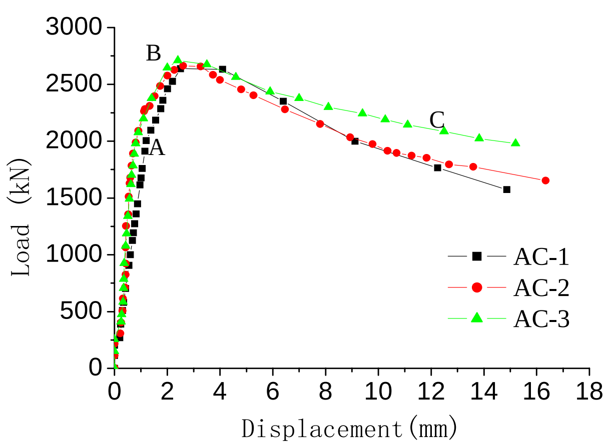
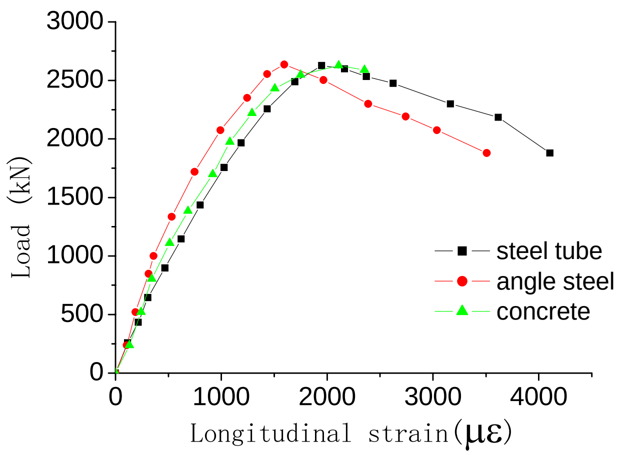
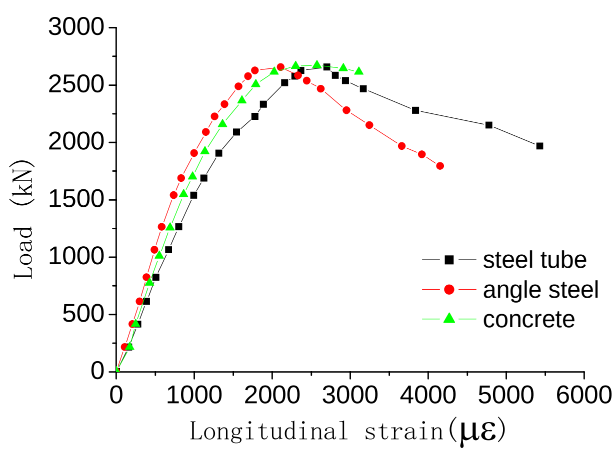


Figure 5. Load-displacement relationship of columns

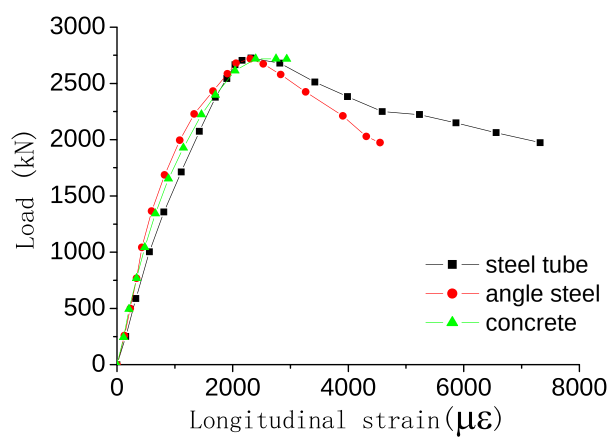
This figure shows quite clearly that the compressive behavior of stub specimens can basically be described as follows(a)elastic stage, the initial part(OA) of the loading , displacement was small, and steel tube, angle steel and concrete were in elastic working condition; (b)elastic-plastic stage, AB part, in this stage, the steel tube first yielded and the core concrete took the main responsibility of the load increment and micro crack expanded, deformation was nonlinear. To B, angle steel and stirrup yielded one after another into the elastic-plastic stage; (c)plastic stage, BC part, steel tube, angle steel and stirrup yielded and concrete was crushed and specimens were into the failure stage.



(a)



(b)



(c)

Figure 6. Load-longitudinal strain relationship of specimens

(a)for specimen AC-1, (b)for specimen AC-2, (c)for specimen AC-3

The load-longitudinal strain curvs for steel tube, angle steel and concrete of specimens for AC-1, AC-2 and AC-3 are shown in Fig. 6. In elastic stage, longitudinal deformations of steel tube, angle steel and concrete of specimens were in consistent condition at the same load level. It was to say that steel tube, angle steel and concrete of column could work together during the initial partof the loading. Entering the decline period of the loading, three curves appeared obvious separation phenomenon, suggesting their deformation were not synchronous.

III. CONCRETE-FILLED CORE STEEL TUBE WITH OUTER STEEL PLANK COLUMN FEM MODEL

The typical sections of concrete-filled core steel-tube reinforced concrete columns are shown in Fig. 2. In this paper, we used batten plates instead of the rectangular transverse reinforcement, and the angle steels, instead of main steel bars, were welded with batten plates, as shown in Fig. 7. The model parameters were defined as, the width *b* and height *h* of the section both were 200 mm, the volume ratio of the steel tube to concrete and the yield strength of steel tube and the other parameters were shown in Table 1.

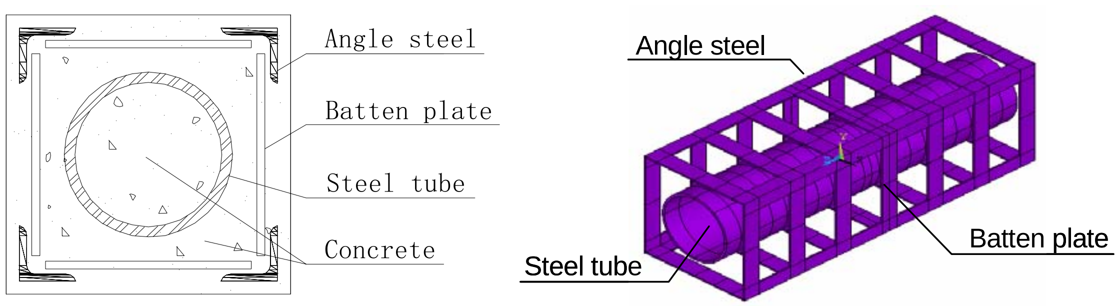


Figure 7. Common section forming of concrete-filled core steel tube with outer steel plank reinforced concrete column

The angle steels with batern plate can provide the outer concrete of the composite column enough restriction corresponding with one in the core steel tube to work together until the composite columnb failure. A series of nonlinear full-range numerical calculation were completed for the composite column in axial compression condition.

Table 1: Parameters of the FEM model

Concrete strength(MPa)	-	C20	C30	C40	C50
Strength of steel tube(MPa)	-	235	288	345	400
Sectional ratio of steel tube	3.56%	4.05%	4.54%	5.02%	5.50%
Possition coefficient of steel tube k	0.45	0.50	0.55	0.60	0.70
Batten plate width(mm)	-	10	20	30	40
Batten plate strength(MPa)	-	235	345	400	500
Sectional ratio of angle steel	1.44%	1.77%	2.07%	2.49%	2.91%
Angle steel strength(MPa)	235	345	359	400	500

IV. RESULTS OF NUMERICAL CALCULATION AND ANALYSIS

a. Effect of concrete strength

Fig. 8 shows the relationships of the loads acting on the column axially and longitudingnal strain at the different grades of concrete strength. It is seen that the loading capacity of the column, in other parameters under the condition of constant , increase with the increase of the concrete strength of the column. The coincidence of the curves for elastic stage is not well good, this shows that the composite stiffness of the columns under axial compression in elastic stage only depends on the elastic modulus of the material and the dimension of the cross section of the column.

The curve of the loading capacity and the concrete strength of the column is shown in Fig. 9, in which the loading capacity and the concrete strength of the column is in a linear relationship.This suggests that steel tube, angle steel and battern plate had little restriction effect on the bearing capacity of the column at the different concrete strength and it was limited or invalid for changing the grade of concrete strength. This shows that the core steel tube and peripheral angle steel plank on concrete constraints on concrete strength are not sensitive

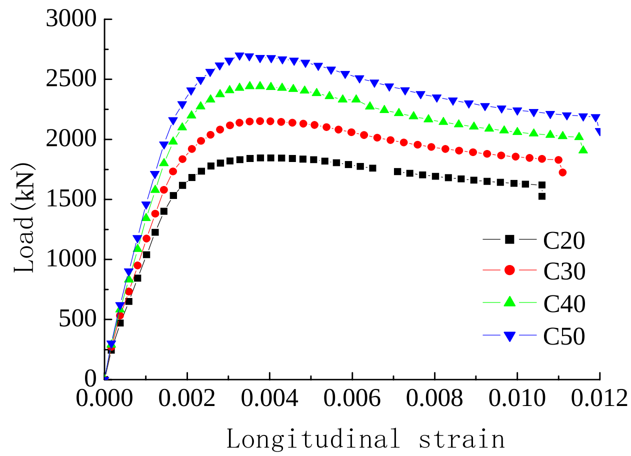


Figure 8. Load-longitudingnal strain curves at diferent concrete grade

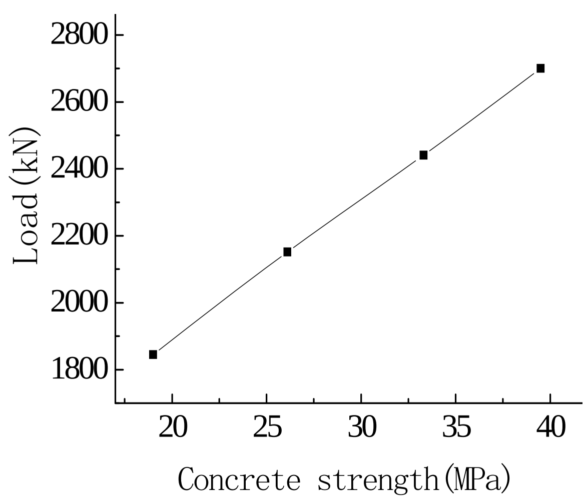


Figure 9. Loading capacity-concrete strentgh relationship of the composite column

b. Effect of the yield strength of the core steel tube

Fig. 10 shows the relationships of the loads acting on the column axially and longitudingnal strain at the yield strength of core steel tube for 235MPa, 288MPa, 345MPa and 400MPa. It is seen that the loading capacity of the column, in other parameters under the condition of constant , increases with the increase of the yield strength of steel tube. The coincidence of the curves in the elastic stage is very good, this shows that the composite stiffness of the columns in axial compression in the elastic stage doesn't change and only depends on the elastic modulus of the material and the dimension of the cross section of the column.

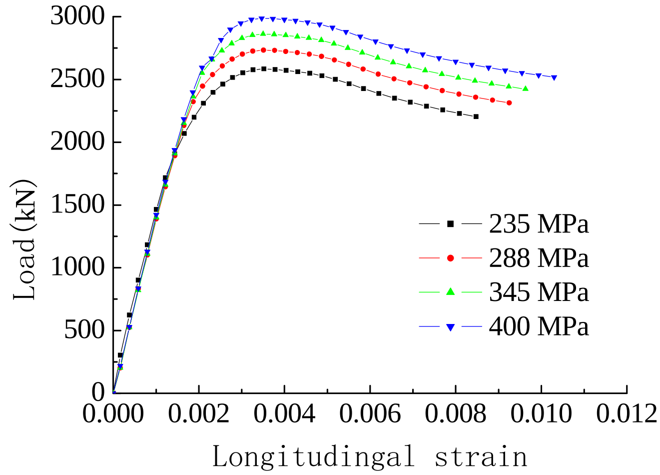


Figure 10. Load-longitudingnal strain curves at the different strength of the core steel tube

c. Effect of the steel tube ratio

The steel tube ratio in this paper is defined as the ratio of the cross section area of the steel tube to the overall one of the column. Fig. 11 shows the relationship of the load acting on the column axially and longitudingnal strain at the different steel tube ratio of 3.56%, 4.05%, 4.54%, 5.02% and 5.50%. It is seen that the loading capacity of the column, in other parameters under the condition of constant , increases with the increase of the steel tube ratio. The coincidence of the curves in the elastic stage is not very well, this shows that the composite stiffness of the columns under axial compression in elastic stage not only depends on the elastic modulus of the material and the dimension of the cross section of the column but also on the steel tube ratio.

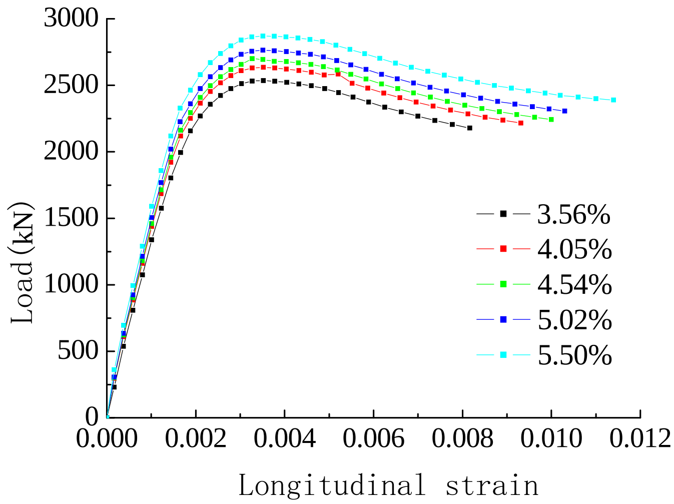


Figure 11. Load-longitudingnal strain curves at the different steel tube ratio

d. Effect of position coefficient

The position coefficient in this paper is defined as $\kappa = D / B$, where D is the diameter of the steel tube and B is the overall width of the column. Fig. 12 shows the load-longitudingnal strain curves at the different value of the position coefficient. It means that change of position coefficients had a influence not only on the ultimate bearing capacity of column but also on the coincidence of the curves in the elastic stage. With the increase of the load, the components of the column,such as steel tube, angle steel, etc., start to yield, and the value of the position coefficients is bigger, the plastic deformation of the column is bigger. That is to say the column has a better ductility.

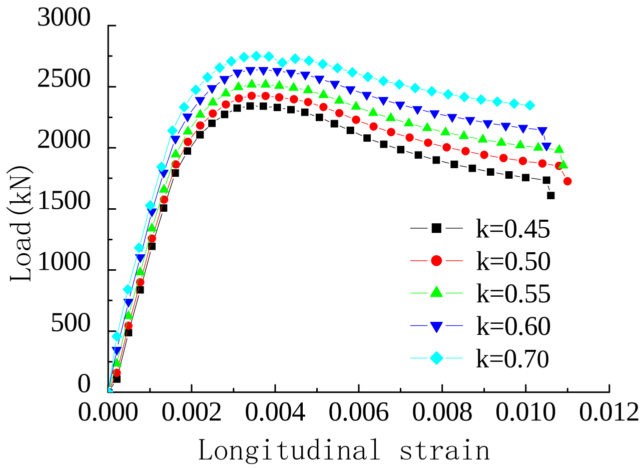


Figure 12. Load-longitudingnal strain curves at the different value of the position coefficient $\kappa = D / B$

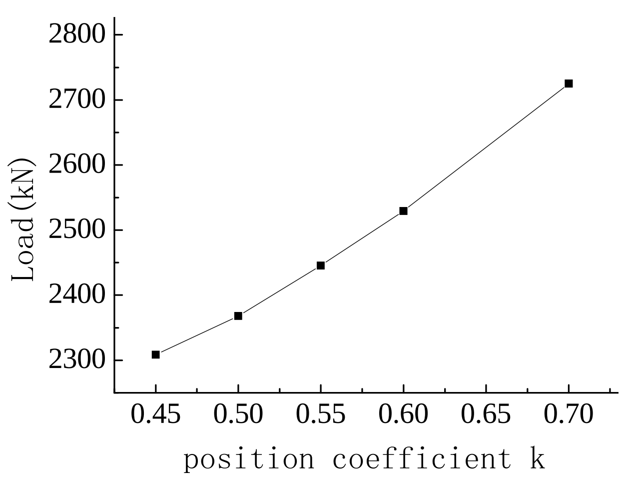


Figure 13 Loading capacity- position coefficient of the composite column

The position coefficient ,as defined above, reflects the relative ratio of the cross section area of the steel tube to the the peripheral concrete of the composite column, the value of the position coefficient is greater, the core constrained concrete part is bigger accounting for the entire section, and vice versa. Generally, the concrete strength confined by steel tube is greater than the one by angle steel plank, Fig. 13 shows that with the increase of the coefficient of position the bearing capacity of the column are obviously increase.

e. Constraint effect of batten plate

The cross section area and the strength of the batten plate have different level influence on the constraint effect of column. Fig. 14 shows the load-longitudingnal strain curves at the different width of the batten plate. It is seen that the loading capacity of the column, in other parameters under the condition of constant , increases with the increase of the width of the batten plate, however, affecting a little. The coincidence of the curves in the elastic stage is very good, this shows that the composite stiffness of the columns in axial compression in the elastic stage doesn't change and only depends on the elastic modulus of the material and the dimension of the cross section of the column.

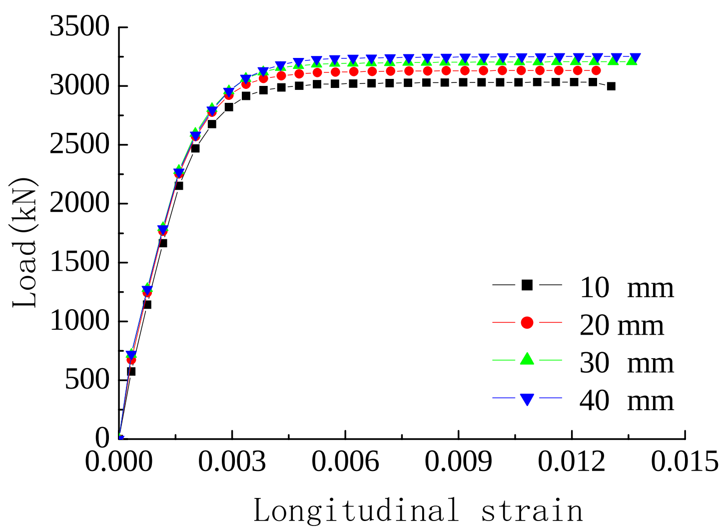


Figure 14. Load-longitudingnal strain curves at the different value of the position

The coincidence of the curves in the elastic stage is very good, this shows that the composite stiffness of the columns in axial compression in the elastic stage doesn't change and only depends on the elastic modulus of the material and the dimension of the cross section of the column.

Fig. 15 shows the load-longitudingnal strain curves at the different yield strength of the batten plate. It reveals that the loading capacity of the column, in other parameters under the condition of constant, increases significantly with the increase of the strength of the batten plate.

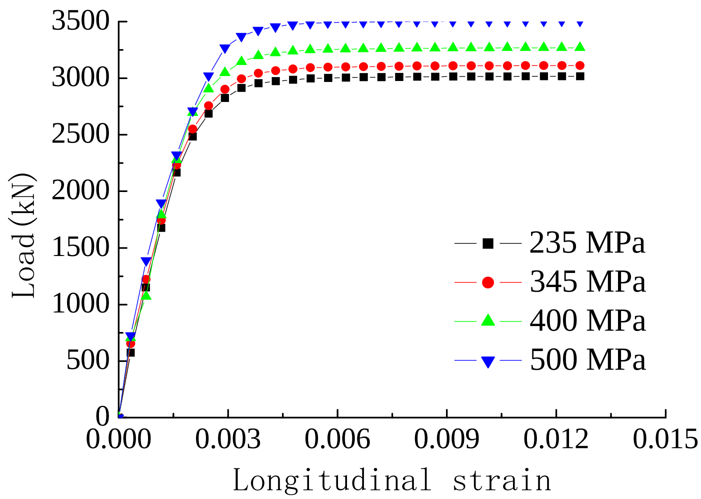


Figure 15. Load-longitudingnal strain curves at the different value of the position

f. Constraint effect of angle steel

The angle steel was the main source of the constraint of the lateral concrete. The ratio of the angle steel section area to the overall cross section area of the column has siginificant effect on the constraint effect to the peripheral concrete . Fig. 16 shows the relationship of the load acting on the column axially and longitudingnal strain at the different angle steel ratio of 1.44%, 1.77%, 2.07%, 2.49% and 2.91%. It is seen that the loading capacity of the column, in other parameters under the condition of constant , increases with the increase of the angle steel ratio. The coincidence of the curves in the elastic stage is not very well, this shows that the composite stiffness of the columns under axial compression in elastic stage not only depends on the elastic modulus of the material and the dimension of the cross section of the column but also on the steel tube ratio

Fig. 17 shows the relationships of the loads acting on the column axially and longitudingnal strain at the yield strength of angle steel for 235MPa, 345MPa, 359MPa, 400MPa and 500MPa. It is seen that the loading capacity of the column, in other parameters under the condition of constant , increases with the increase of the yield strength of angle steel. The coincidence of the curves in the elastic stage is very good, this shows that the composite stiffness of the columns in axial compression in the elastic stage doesn't change and only depends on the elastic modulus of the material and the dimension of the cross section of the column.

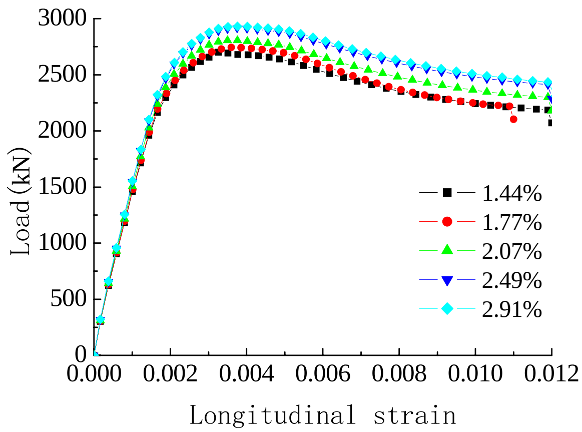


Figure 16 Load-longitudingnal strain curves at the different angle steel ratio

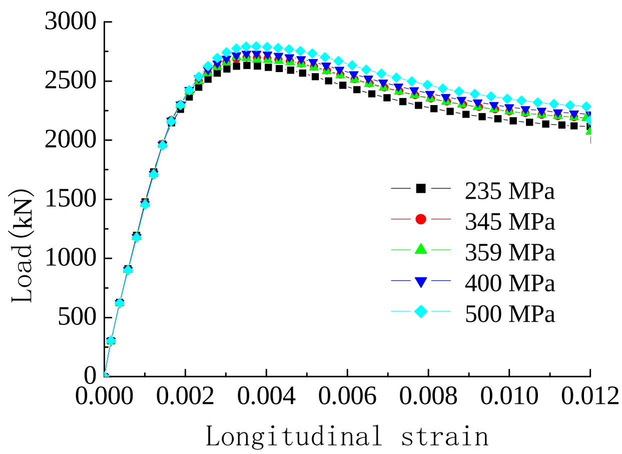


Figure 17. Load-longitudingnal strain curves at the different yield strength of the angle steel

V. STRENGTH PREDICTION OF CONCRETE-FILLED STEEL TUBE WITH OUTER STEEL PLANK REINFORCED COMPOSITE COLUMN

a. Theory prediction model

The practicall formula of calculating the loading capacity of concrete-filled steel tube with outer steel plank reinforced column can be expressed as

$$N_u = f_s A_s + (1+0.5\lambda_t) f_c^e A_c^e + (1+1.8\xi) f_c^i A_{cs} \quad (1)$$

$$\lambda_t = \frac{\rho_{stir}}{1-\rho_s} \times \frac{f_y}{f_c^e} \quad (2)$$

$$\xi = \frac{f_c^i A_c^i}{f_a A_a} \quad (3)$$

where N_u is the axial loading capacity, λ_t is the influence coefficients of the constraint of batten plate to the column strength, and ξ is the constraint of steel tube to the column strength.

b. Neural network prediction model

RBFNNs have a three-layer architecture with no feedback, as shown in Fig. 18. The input layer is made up of N nodes (N dimension of the input vector x = (x_1, x_2 ,… x_N) $\in R^N$); their connections to the hidden nodes are not weighted and implement a fan-out of the input components to the hidden layer. This last consists of H hidden neurons (radial basis units), with radial activation functions. The detail infermation of the RBFNNs can reference to Ref. [12-15].

In this paper such network was used as a classier, consequently the dimension of the output layer is equal to the number of fault classes to be detected. Here, the RBFNNs was used predicted the strength of the column based on measurement datum. The load was simulated by MATLAB 6.5 neural network toolbox and the general design function newrb was adopted. The technique used here aims to test the efficacy of global or local vibration parameters and their different combinations as input to Radial Basic Function neural networks for accurate prediction of the strength of the column.

The RBFNNs was employed as the calculate tool of the compressive strength of the column. The experimental results were analyzed carefully, and the items for forecast the strength were concrete strength, strength and sectional ratiao of steel tube, position coefficient (k), batten plate width, batten plate strength, strength and sectional ratiao of angle steel. Both training and testing datum were selected for the RBFNNs form the FEM results. The suitable topology finalized for the plateau stress model was 7-5-1 (7 neurons in the input layer, 5 neuron in the hidden layer and 1 neuron in the output layer). The activation functions used are hyperbolic tangent, ‘Gaussian’ in the hidden layer.

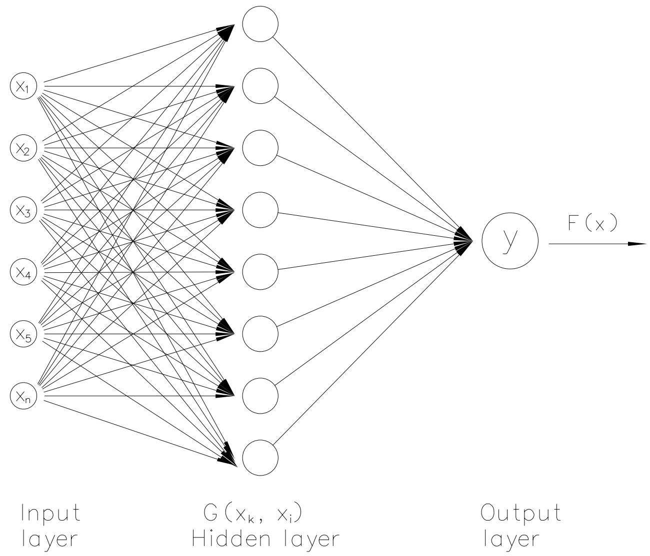


Figure 18. Structure of the radial basis function network

c. Result of the prediction

Table 2. summarizes the evaluation of the theory results and the RBFNNs prediction results. Though the train with the samples, the mean square error of $0.857x10^{-3}$ was achieved in 543 iterations or epoch. Due to the initialization of the weights with small random values in ANN, the prediction results for the same network is little different in each case. The simulation results of the three trials are averaged for this characteristic. The maximum and minimum error ratio of prediction is 11.32% and 4.17%, respectively. It proves that the network had a widely application prospect in forecasting the strength of the concrete-filled tube with outer steel reinforced concrete column.

TABLE 2. Predict results of theory and RBFNNs

Column code	Concrete strength	Sectional ratio of steel tube%	Position coefficient of steel tube	Batten plate width	Batten plate strength	Sectional ratio of angle steel%	Angle steel strength	Theory value (kN)	RBFNNs prediction value(kN)	Error ratio %
Z-1	C30	3.17	0.33	12	310	2.01	345	2466.2	2667.3	7.54
Z-3	C20	4.03	0.47	18	360	2.87	400	2461.4	2568.5	4.17
Z-5	C50	2.65	0.30	10	210	1.76	500	2549.3	2874.7	11.32

VI. CONCLUSIONS

This paper presents a new type of concrete-filled core steel tube with outer steel plank reinforced column. Through a series of 3-D nonlinear FEM calculation, some important factors are analyzed, such as the strength of the core concrete, the steel tube and the angle steel, the volume ratio of the steel tube and the angle steel, position coefficient. RBFNNs are employed for calculated the strength of the concrete-filled core steel tube with outer steel plank reinforced column, it shows that the neural network forecasting the loading capacity of the columns has a clear advantage as reasonable structure, quick convergence and high accuracy. The maximum and minimum error ratio of prediction is 11.32% and 4.17%, respectively. It reveals that the neural network has a widel application prospect in forecasting the loading capacity of the concrete-steel composite columns.

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