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Testing on Axial Compression of Damaged RC Columns Reinforced by Winding Steel Wire

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Abstract. Four groups of specimens of damaged RC columns reinforced by winding steel wire were tested for axial compressions. One group was undamaged RC columns; the others were damaged RC columns, the width of crack developing was regarded as damage index, they were respectively 0.3mm, 1.0mm and 1.5mm, the helically-wound method was adopted for reinforcement, and winding spacing was 50mm. The testing results showed that under reinforcement the load of damaged columns improved a bit in comparison with undamaged ones, but with a little range, however, the strain of longitudinal reinforcement, stirrup and concrete could improve greatly, which indicated that it had a good effect to reinforce the damaged columns by winding steel wire, meanwhile, the ductility of damaged columns was improved apparently.

1. Introduction

RC columns are most important and widely used load-bearing members in buildings, if the damage occurs in RC columns, which will affect severely the bearing capacity and normal use of buildings. Presently, there are many methods used in the reinforcement of RC columns, for instance, enlarging section[1-2], steel-encased strengthening[3-5], pasting fiber cloth[6-8], and winding steel wire[9], etc., in which the study on reinforcement of damaged RC columns by winding steel wire is less concerned. For the reinforcement effects of damaged RC columns by winding steel wire, 12 specimens of RC columns are adopted for axial compressions test, in which three specimens are used for comparison, nine specimens are reinforced by winding steel wire, the width of crack developing is regarded as damage index, the indexes are appointed respectively as 0.3mm, 1.0mm and 1.5mm, through the axial compression test, the bearing capacities of RC columns, the strains of bars and concrete under different damages are compared, the reinforcement effects by winding steel wire are explored from load-bearing and ductility, the testing can provide references for practical engineering in the utilization of reinforcing technology by winding steel wire.

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2. Testing

2.1Specimens Design

In accordance with Chinese *Code for Design of Concrete Structures* (GB 50010-2010), and *Code for Design of Strengthening Concrete Structure* (GB 50367-2013) [10-11], the design for specimens is as the follows: Testing RC columns are chosen with slenderness ration $L_0/b=5$, the section of columns is given as 240mm×240mm, the height is 1200mm, concrete grade is C30, the thickness of protection layer is 25mm, longitudinal bars HRB335 are used, 4 bars are placed, the diameter of longitudinal bars is 12mm, stirrups are HPB300, the stirrups are set close at both ends of columns with the spacing 100mm, in the middle of columns the spacing of stirrups is 150mm, in order to prevent the heads and feet of columns from damage owing to compressing during the testing, the steel plates with the section of 240mm×240mm, and the thickness of 10mm are put at the both ends of columns, the specimens design is shown as Fig.1. Strain gauges are mainly placed on the longitudinal bars, stirrups in the middle of RC columns and the surface of RC columns. There are 22 strain gauges on the stirrups of each column, 4 gauges on longitudinal bars, and 1 gauge for each surface of concrete, which are used to test the strain distributions of concrete, longitudinal bars and stirrups when the RC columns are compressed. The actual tensile strength of stirrup is 338N/mm^2, and the tensile strength of longitudinal bar is 376 N/mm^2, all of the specimens are concreted at one time with the concrete mixture ration C30, the cubic test blocks with the size 150mm are maintained under natural condition, the compressive strength is measured as 36.4MPa.

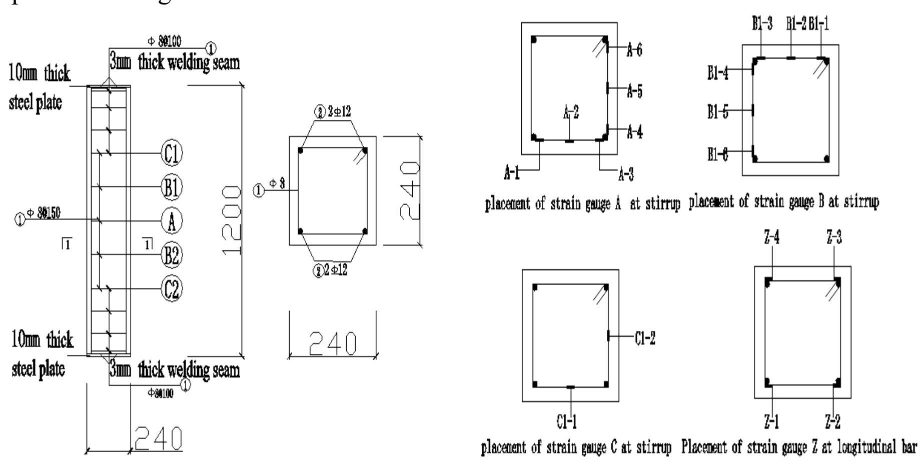

Fig.1 Specimens design

2.2Reinforcement Plan by Winding Steel Wire

In the testing, galvanized steel wire ropes with normal diameter 4mm, type 1x13, namely, 1 strand, and 6 strands in total, are adopted, the section area is 12.56mm^2, after actual measurement, the elastic modulus of rope is $1x10^5$MPa, and the tensile strength is 1761.9MPa, the ultimate strain is 0.0129l. The selected ropes keep suitable section in size, soft in form and, wound easily. Winding process goes as the follows: surface treatment → whitening → steel wire rope → fastener fixing → 50mm spacing for winding helically → fastener fixing the other end of steel wire rope. Detailed operation is that after polishing the surfaces of RC columns with sandpaper, the whiting is painted, then, the ropes are preloaded, and tension force is controlled under 1kN or so, making the ropes very tightened to the surfaces of concrete.

2.3Testing Loading

The testing was carried out with 500t hydraulic servo long column machine at Xi'an University of Technology. Static data acquisition instrument TDS-303 was used for strain collection. When testing, the compared RC columns were preloaded 3 times by 0.2Nu（Nu referring to estimated ultimate load）, which mainly was to examine if the strain gauges and displacement gauges were working normally, meanwhile, adjusting the centering of specimens. Then, the loading was given at the speed of 1KN/s, load holding was kept 3 minutes for each 100KN, after 700KN, the load holding was kept 10 minutes for each 10KN, which was mainly for watching cracks. When approaching peak load, the loading was turned as displacement control by 0.2mm/min, until damage occurred. The initial loading plan for reinforced RC columns was as same as the prepared columns, the loading would stop till the target cracks appeared, then reinforcement was made, afterwards preloading was conducted, again formal loading was put at the speed of 1KN/s, when approaching peak load, the loading was turned as displacement control by 0.2mm/min, until damage occurred. When testing, the Static data acquisition instrument was used to collect the data of concrete, longitudinal bars, stirrups and, displacement gauges, the data of loading displacement was recorded by loading system, damaged shapes and processes were observed and recorded. Testing and data acquisition instruments were shown as Fig.2.

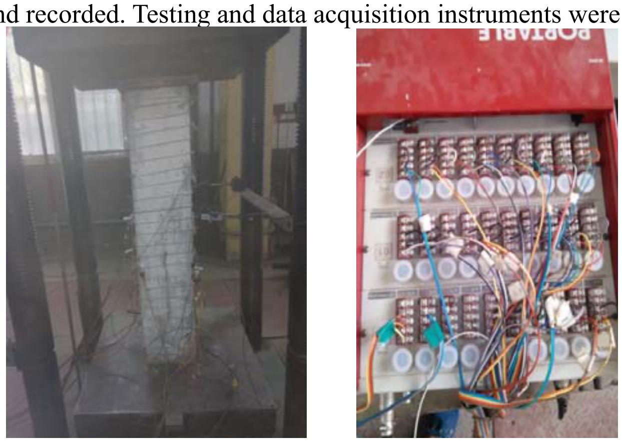

Fig.2 testing machine and date acquisition instrument

3. Testing Results and Analysis

3.1Testing Phenomena

At the beginning of loading, the compared columns had no apparent change, along with ultimate loading, tiny and vertical cracks appeared at the head of columns, when approaching peak value 2000KN, the vertical cracks were enlarging and increasing in numbers, accompanying the noise of frizzling, simultaneously, the larger cracks tended to run through, when damage happening, a lot of vertical cracks appeared in the column shaft, these cracks developed larger and longer, meeting together at the edges of adjoining surfaces of column, along with the clear voice of cracking, pieces of concrete were falling in big blocks.

In the process of loading reinforced columns, the original cracks took place at the initial loading began to develop and crack slowly, the cracks became larger clearly when reaching crack-load, the loading raised a bit slow, and the other tiny cracks appeared gradually when the loading increased, when approaching the peak value, the cracking of concrete was sounded, the steel wire rope was tightened, accompanying the frizzling sound of stretching, the cracks became in more and dense, but there were no concrete blocks dropping, after the peak loading, the loading decreased slowly, the upper-middle part of columns swelled apparently, along with the frizzling sound of steel wire rope stretching, pieces of concrete dropped continuously, the cracks got much more and denser, when the loading was given continuously, pieces dropped constantly from each damaged concrete surface, the edges of steel wire rope sank into concrete column, the coarse aggregate of concrete collapsed, but the steel wire rope was tightened all the time, the loading decreased till the column was damaged totally. Meanwhile, it could be found in comparison that the more damage occurred (1.5mm cracks), the faster the loading decreased and the pieces of concrete dropped. When releasing the steel wire rope, it could be found that concrete was broken and in loose condition, there dropped the concrete over large areas, and the longitudinal bars were exposed. The typical damage form was shown as Fig.3.

(a)compared column (b)column with 0.3mm (c)column with1.0mm(d)column with1.5
wide crack wide crack mm wide crack

Fig.3 Typical forms of damage

3.2Testing Data Analysis

Reinforcing the damaged RC columns with steel wire can improve the load-bearing capacity, the ultimate load of compared columns is about 2000.6KN, when the width of cracks is 0.3mm, the ultimate load is 2066.8KN or so, the load-bearing capacity of reinforced columns is improved by 3.2% versus the compared specimens. When the width of cracks is 1.0mm, the ultimate load is about 2043.6KN, the load-bearing capacity of reinforced columns is increased by 2.1% versus the compared specimens. When the width of cracks is 1.5mm, the ultimate load is about 2019.6KN, the load-bearing capacity of reinforced columns is improved by 1.0% versus the compared specimens. Testing data are shown as Tab.1.

TABLE.1 TESTING DATA

Specimen number	Crack width/mm	average value of cracking load/KN	Ultimate load/KN	average value of ultimate load /KN
Z-1	0		2001	
Z-2	0	810	1993.7	2000.6
Z-3	0		2007.1	
Z-4	0.3		2064.5	
Z-5	0.3	800	2073.2	2066.8
Z-6	0.3		2062.8	
Z-7	1.0		2045.8	
Z-8	1.0	810	2033.4	2043.6
Z-9	1.0		2051.6	
Z-10	1.5		2010.2	
Z-11	1.5	800	2019.7	2019.6
Z-12	1.5		2028.9	

The load-displacement curves of reinforced columns by winding steel wire are shown as Fig.4, it can be seen from the curves that initial curves display the stage of centering and adjusting of testing machines, afterwards, the load-displacement curves of specimens rise straight, namely, the elastic stage, when approaching peak value, the compared columns hardly reflect plasticity, the curves decrease directly, the value of displacement is about 10.4mm, the reinforced column with damage index 0.3mm shows a certain plastic property, its curve declines in a slow trend, the value of displacement in declining stage comes to 5mm, and 15mm in total. The reinforced column with damage index 1.0mm also has plastic stage, but it shows less at the stage of curve declining, the value of displacement is 4mm or so, and 14mm in total. The reinforced column with damage index 1.5mm also keeps plastic stage, comparing with the previous two damaged indexes, the value of displacement at the stage of curve declining is smaller, which is about 3mm, and 13mm in total. The peak stresses of reinforcement by winding steel wire become smaller as the damage occurs greater, but all of which display fine ductility, the load declining is a gentle process relatively, therefore, the damage to concrete reinforced by winding steel wire is a kind of ductile fracture.

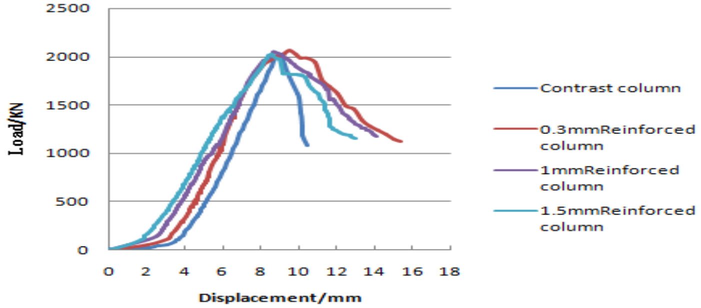

Fig.4 Typical load-displacement curve

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Referring to the load-strain curves during the RC columns being compressed, it can be found from the figure that the load-strain cure of non-reinforcement columns rises evenly, the curve is almost close to a straight line, which keeps steep at the stage of declining. When the RC columns are compressed to ultimate load, the strain value at the positions of longitudinal bars is -2700 in maximum, and the strain value of stirrups at damaged positions is 2496 in maximum, the maximum strain value of concrete is 1861.

As for the RC columns reinforced by wingding steel wire, it can be found from the stirrup load-strain figure that the load-train curves at the initial stage increase almost in a straight line, when reaching peak value, the load of compared columns declines faster, the curves are rather steep, the maximum strain value is 2496, the load of reinforced column with damage index 0.3mm declines slowly, the strain is increased continuously, the curve is flat, the maximum strain value is 7180, the stirrup strain increases by 187.6%. The load of reinforced column with damage index 1.0mm declines slowly, the curve is flat, and the maximum value of ultimate strain is 5820, the stirrup strain increases by 135.1%. The load of reinforced column with damage index 1.5mm decreases faster than both of previous reinforced RC columns, in comparison with the compared columns, which still keeps flat curves apparently, the value of ultimate strain is 3925, the stirrup strain increases by 57.2%l. the typical stirrup load-strain is shown as Fig.5.

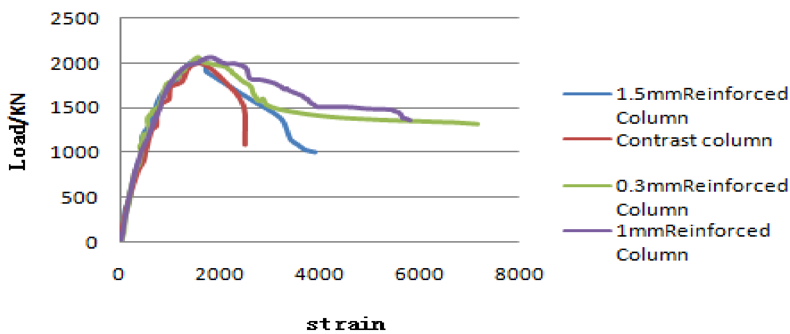

Fig. 5 Typical stirrup load-strain

From the Fig. of load-strain of concrete it can be found that the curves of load-strain tend to be straight lines in initial rising, when reaching peak values, the concrete strain of Reinforced RC column with damage index 0.3mm does not reach the maximum, and the load decreases slowly, meanwhile, the strain increases constantly, the curve tends to be flat, then, the column is damaged, and the strain reaches to the maximum value -2900, the curve decreases, the concrete strain raises by 55.9% in comparison with the compared columns. When peak value appears on the reinforced RC column with damage index 1.0mm, the strain does not reach the maximum, then, the load decreases, however, the strain increases, the curve leans a bit, when the strain comes to maximum value -2380, the strain value reduces along with the decreasing of load, the concrete strain raises by 27.9% in comparison with the compared columns. When peak value appeares on the reinforced RC column with damage index 1.5mm, the concrete strain almost reaches to the maximum, and the strain begins to reduce along with the decreasing of load, the curve becomes quite steep, the value of ultimate strain is -2120, and the concrete strain still rises by 13.9% in comparison with the compared columns. The typical load-strain of concrete is shown as Fig.6.

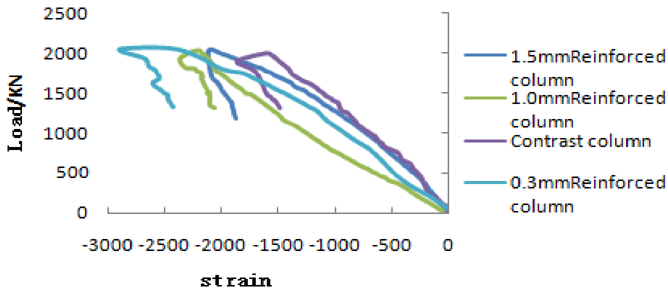

Fig.6 Typical load-strain of concrete

The curves of longitudinal bars load-strain are shown as Fig.7. It can be found from the Fig. that the curves of load-strain tend to be straight lines in initial rising, when reaching peak values, the curve of compared columns decreases directly, nevertheless, the reinforced RC column with damage index 0.3mm still keeps a longer flat curve, ductility performs very clearly, and the ultimate strain is -6200, the strain of longitudinal bars raises by 129.6%. after the reinforced RC column with damage index 1.0mm reaches to the ultimate strain, the curve keeps flat and extends for a while, afterwards, begins to decline, the value of ultimate strain is -4590, the strain of longitudinal bars raises by 70%. However, after the reinforced RC column with damage index 1.5mm come to peak load, the curve just extends a little longer, ductility performance increases a bit comparing with the both of previous specimens, the declining stage gets rather steeper, the value of ultimate strain is -4190, the strain of longitudinal bars raises by 55.1%. To sum up, the steel wire rope can restrain the lateral deformation of RC column, it can develop fully the material properties of steel bars and concrete, and improve the ductility of construction members.

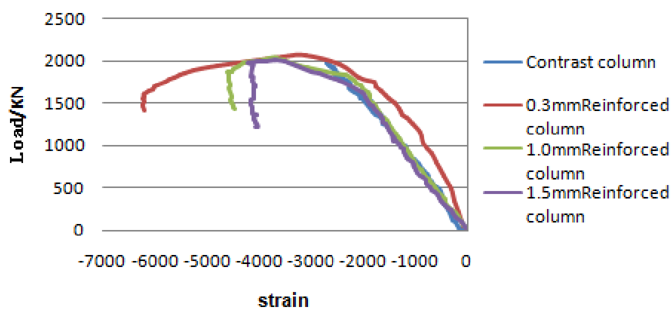

Fig.7 Typical longitudinal bar load-strain

4. Conclusions

(1) The load-bearing capacity of damaged columns reinforced by winding steel wire can be increased certainly in comparison with undamaged RC columns, but with a little increasing extent.

(2) Comparing with the undamaged RC columns, the surface of concrete, the strains of longitudinal bars and stirrups at fractures are all improved greatly, it can be proved that reinforcing the damaged RC columns by winding steel wire will increase its ductility to a larger extent.

(3) The bigger the damage indexes are given, the lower the load-bearing capacity, the less the vertical deformation capacity of RC columns will be, accordingly, the strain values

of concrete, longitudinal bars and stirrups will reduce along with the increasing of damage index.

5. Acknowledgements

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