Analysis of Concrete Columns With Shape Memory Alloy Reinforced

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Abstract. Shape memory alloy (SMA) is a kind of intelligent material with both perception and driven function. SMA can effectively self-repair the concrete cracks and improve the damping energy dissipation ability of concrete structure. In this paper, SMA is used to reinforce concrete columns based on the memory effect. The plain concrete columns, the winding SMA undriven concrete columns and the winding SMA driven concrete columns are subjected to axial compression test. By the axial compression experiment which measure the strain and ultimate bearing capacity values of concrete columns. The results show that the winding SMA driven concrete columns have better anti cracking performance and higher ultimate bearing capacity than that of the winding SMA undriven concrete columns. At the same time, the winding SMA undriven concrete columns have better anti cracking performance and higher ultimate bearing capacity than that of the plain concrete columns.

Introduction

At present, most of the buildings in our country are using concrete structure, which has become the most widely used structure in the world [1]. Concrete is a porous brittle material, because the influence of the surrounding environment will inevitably appear cracks and local damage, and this will reduce the structural service life even threat the structural safety. Usually, concrete structure is working with cracks. However, if the plastic degeneration of concrete member is too big which can cause steel corrosion, it can reduce the bearing capacity and the reliability of the structure. The columns, beams and slabs are the most important components in the concrete frame structure, and their quality is crucial to the safety of the structure [2]. During the construction of cast-in-situ concrete structure, the beams and slabs are poured as a whole which can improve their seismic capacity. However, concrete columns are more prone to problems. First of all, the ductility of the concrete which used to pour columns is relatively poor, so it is very prone to brittle failure. Second, the structure of the column will be restricted by the used space, and the cross section of column cannot be too large, otherwise it will cause the decline of seismic capacity and bearing capacity [3]. And this phenomenon will make the column produce cracks and endanger the safety of the whole building, so we need to reinforce the concrete columns.

SMA is a new kind of functional material, and it is recognized by people because of its special shape memory effect. The shape memory effect refers to that the material deforms at low- temperature martensite state, because the material can remember its former shape in high-temperature austenitic state, so it will restore to the former shape after heating. In addition to shape memory effect, SMA also has damping effect, super elastic effect and resistance characteristic. SMA can effectively repair the cracks of concrete and thereby improve crack resistance of concrete to ensure the structural safety[4]..

Experimental investigation

Materials and Equipments

Cement is the ordinary 425 # portland cement. Coarse aggregate is gravel, particle size 5-15mm, continuous gradation. Fine aggregate is fine sand. In order to make the experimental results more convincing, all concrete columns use the same batch with the same mix ratio. Concrete strength grade is C30, the design value of axial compressive strength is 14.3MPa, the elastic modulus is 30.0GPa, and the Poisson ratio is 0.2.

SMA used in experiment is the Ni-Ti alloy with a diameter of 2mm SMA is shown in Fig.1.

(1) Concrete pressure testing machine. The concrete pressure testing machine is shown in Fig.2.

(2) Static resistance strain gauge. Static resistance strain gauge is used to measure the strain of the resistance strain gauge on the concrete specimen. It is shown in Fig.3.

(3) Multimeter. The multimeter is used to control the voltage at boths ends of the SMA and measure the temperature of the SMA. It is shown in Fig.4.

(4) Resistance strain gauge. Resistance strain gauge is used to reflect the deformation of concrete specimens under the external force. It is shown in Fig.5.

Fig 1. Shape memory alloy wire

Fig 2. Concrete pressure testing machine

Fig3. Static resistance strain gauge

Fig.4 - Multimeter

Fig 5. Resistance strain gauge

The preparation of concrete columns

Three groups of concrete columns are prepared in the experiment. The first group is the plain concrete column. The second group is the winding SMA undriven concrete column. It does not produce the restoring force, that is it does not produce ring compressive stress applied to the column. The third group is the winding SMA driven concrete column. SMA produces restoring force after ohmic heating and generates ring compressive stress to the wrapped column to achieve the purpose of reinforcement. The slenderness ratio of concrete column is 3. The diameter d of the concrete column used in the experiment is 100mm and the height h is 300mm. Concrete columns use C30 concrete at the time of preparation, and the slump is 10 mm measured by the slump test. The SMA skeleton is shown in Fig.6. Pouring concrete column with SMA is shown in Fig.7.

Arrangement of strain gauges

In order to measure the transverse and longitudinal strain of concrete columns, we need symmetrically arrange two groups of strain gauges in the middle parts of the concrete column. Each group had two strain gauges. One gauge was transverse ,the other was longitudinal, and the two strain gauges were perpendicular to each other. For the convenience of experiment records, we specified that the first group of transverse and longitudinal strain of the two strain gauges were strain 1 and strain 2 and the second group of transverse and longitudinal strain of the two strain gauges were strain 3 and strain 4. When the strain gauges had been pasted, the axial compression tests of the concrete columns could be carried out after the adhesive agent was completely cured, and the strain values of the strain gauges were measured by the static resistance strain gauge.

Procedures

In this paper, three groups of concrete columns were carried out the axial compression experiment. We measured the ultimate bearing capacity and strain of the concrete columns, and observed failure modes of concrete columns. The heating mode of SMA adopted in this paper was that directly energize to heat to SMA. In this experiment, the pressure testing machine was used to load the concrete column. In order to ensure the accuracy of the loading and obtain good experimental results, the ultimate bearing capacity of the concrete column need to be estimated before loading according to the material properties of concrete columns. Because of the strength grade of concrete column was C30, the ultimate bearing capacity of the same strength grade of the standard test block was about:

$$N=PS=30\times\pi d^2/4=30\times 3.14\times 100^2/4=235kN \quad (1)$$

Therefore, the ultimate bearing capacity of concrete column was about 235kN, which could determine the loading scheme by this load. The experiment adopted the method of hierarchical loading, and the load of each stage was increased by 5kN. The loading speed was controlled by 5KN/min, and the time of each load was 1 minutes. The concrete operation steps were as follows: firstly, the concrete column was placed on the bearing plate to ensure the axial compression of the concrete column. Then started from 0 kN, according to the rule of 0 kN →5 kN →10 kN →15 kN to load. When the load of each stage was stable, the corresponding load value was recorded. We measured the corresponding strain values by the static resistance strain gauge and observed the state changes of the concrete column. For the concrete column strengthened with SMA , heated to SMA when cracks occured on column , and made it produce the restoring force acting on the concrete column. The loading scheme is shown in Fig.8.

Fig 6. SMA skeleton

Fig 7. Pouring SMA concrete column

Fig 8. Loading concrete column

Mechanism analysis

For the ordinary concrete column, the interior of the concrete column will appear minor cracks resulting in horizontal deformation under axial load. When the axial compressive stress reaches $0.6f_c$, the internal cracks of concrete columns interconnect and become macro cracks. If the compressive stress reaches the concrete compressive strength, the concrete column will destroy because the cracks of the internal formation result in overall instability.

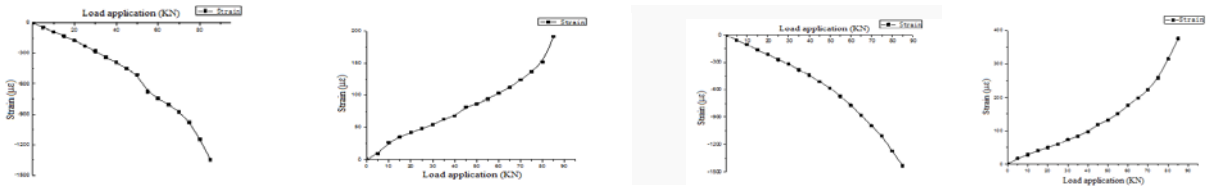
The research finds that the axial bearing capacity of concrete columns will increase along with the increasement of the other two direction stress when the concrete column is in triaxial compression state. For ordinary spiral stirrups reinforced concrete columns, when cracks inside concrete column continue to develop and cause the volume expansion to extrude spiral reinforcement, spiral reinforcement will play a role in restricting the expansion of concrete columns to prevent the continued development of cracks. The spiral reinforcement in the concrete column will not work together with concrete until near failure, and therefore it cannot fully play the role of concrete columns. Reinforcement effect is not ideal. And if using SMA will produce a good effect, according to the shape memory effect of SMA, to apply hoop compressive stress on the concrete column which makes the column in the ideal state of triaxial compression.

SMA has three kinds of recoverable ways. If SMA is completely in a state of freedom, it will be shrinked. Deformation disappears and recovers to the original state. If SMA is restricted when recoverable contraction occurs, preventing the restore to the original shape, SMA will produce relatively large recoverable stress acting on the structure which prevents its recovery. At room temperature, SMA is stretched, wrapped around the concrete column and shaped， and then make the

temperature reach the phase transition point by connecting DC power at this time SMA will recover to its original shape. It not only restores the original linear shape, but also recovers the length before being stretched in the recoverable process. By restraining it back to the straight line shape, on the premise of anchoring concrete columns prevent SMA to restore the initial length before stretched. So the shape memory alloy will have a great effect on the surface of the column which achieves the application of hoop stress on the column. Make the axial compressive concrete column under the ideal working conditions of triaxial compression which can improve the stress state of the concrete column, constrain the lateral deformation of columns, improve the axial compressive capacity of concrete columns and delay the destruction of the column.

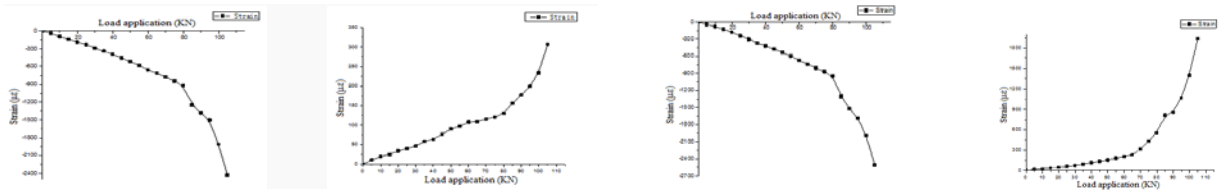
Comparison of predictions and experimental results

This experiment measured the corresponding strain of various loads of concrete column under three different conditions, and obtained the load and ultimate bearing capacity of concrete columns when the cracks occured. Strain 1, strain 2, strain 3 and strain 4 showed the vertical and transverse strains measured by two groups of strain gauges respectively. The corresponding strain of the loads of all levels under three different conditions are shown in the following diagrams. The curve diagram of the strain of the plain concrete column under load is in Fig.9. The curve diagram of the strain of the winding SMA undriven concrete column under load is in Fig.10. The curve diagram of the strain of the winding SMA driven concrete column under load is in Fig.11. The corresponding load was 78kN when cracks appeared on the plain concrete column, and the ultimate load was 87kN. The corresponding load was 83kN when cracks appeared on the winding SMA undriven concrete column, and the ultimate load was 106kN. The corresponding load was 90kN when cracks appeared on the winding SMA driven concrete column, and the ultimate load was 114kN.



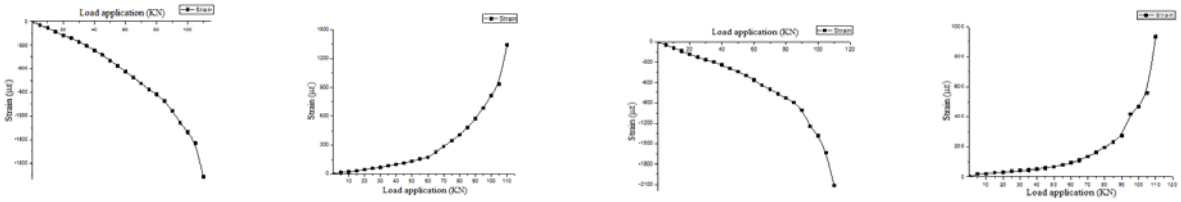
(a) (b) (c) (d)

Fig 9. (a) The curve diagram of the strain 1 of the plain concrete column under load
(b) The curve diagram of the strain 2 of the plain concrete column under load
(c) The curve diagram of the strain 3 of the plain concrete column under load
(d) The curve diagram of the strain 4 of the plain concrete column under load



(e) (f) (g) (h)

Fig10. (e) The curve diagram of the strain 1 of the winding SMA undriven concrete column under load
(f) The curve diagram of the strain 2 of the winding SMA undriven concrete column under load
(g) The curve diagram of the strain 3 of the winding SMA undriven concrete column under load
(h) The curve diagram of the strain 4 of the winding SMA undriven concrete column under load



(i) (j) (k) (l)

Fig11. (i) The curve diagram of the strain 1 of the winding SMA driven concrete column under load
(j) The curve diagram of the strain 2 of the winding SMA driven concrete column under load
(k) The curve diagram of the strain 3 of the winding SMA driven concrete column under load
(l) The curve diagram of the strain 4 of the winding SMA driven concrete column under load

For the plain concrete column under axial compression, minor cracks began to appear on the concrete column in vertical direction when the load was close to the ultimate load, and the cracks developed constantly with the load increasing. The concrete column will suddenly be destroyed when the load reached the ultimate load. Chipping appeared on concrete column which lost bearing capacity eventually. A significant vertical crack could be observed. The failure phenomenon is shown in Figure.12(1)

For the winding SMA undriven concrete column, when the load reached the ultimate load of concrete, the lateral deformation of the concrete column would increase quickly, and the concrete fractured. When the load continued to increase, the middle part of the column would arch and dilate due to the compression of the concrete. When the load was close to the ultimate load, concrete column expanded outward and extended up and down which led to the failure of the column and the loss of bearing capacity. The failure phenomenon is shown in Figure.12(2).

For the winding SMA driven concrete column, heated SMA to produce the restoring force on the column, and closing phenomenon occured on some slight cracks. The speed of the development of the cracks was slower than the above two kinds of circumstances. With the load increasing, creases phenomenon appeared on the surface of the columns and expanded outward. When the load was close to the ultimate load of the column, the concrete in the middle of the column expanded rapidly which led to the failure of concrete columns. The failure phenomenon is shown in Figure.12(3).

The experiment results coincide with the analysis of the reinforcement mechanism.

(1) (2) (3)

Fig 12. (1) The failure phenomenon of plain concrete column
(2) The failure phenomenon of winding SMA undriven concrete column
(3) The failure phenomenon of winding SMA driven concrete column

Conclusions

For the winding SMA undriven concrete column, the SMA did not immediately enter the working state. When concrete produced a certain deformation to extrude the SMA, it would constrain the deformation of concrete, that was SMA would not play a role until the concrete was close to failure. So the concrete column could not play its due role because of the existence of cracks and other damage. But when using the driven SMA reinforced concrete column, heating could make the restricted recover of SMA occur immediately and produce a large recovery force applied on the concrete column which could significantly inhibit the development of the cracks even promoted micro crack closure. At this time the concrete column was under the state of triaxial compression. The axial compression bearing capacity would increase with the increase of the remaining two direction stress which restrained the development of cracks commendably and improved the bearing capacity and crack resistance of concrete column greatly.

Acknowledgments

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