Experimental Study On The Axial Compression Of GRP-Concrete-PVC Tube Composite Column

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Abstract. GRP-Concrete-PVC composite column is a new type of composite column which is composed of GRP outer tube, PVC inner tube and reinforced concrete filled between them. A composite column with a moderate hollow ratio of 0.367, concrete strength grade C30, and reinforcement ratio of 0.9% is designed to investigate the failure phenomenon and loading capacity under axial pressure by static test. It is found that the appearance of the GRP tube has no obvious damage when the load is less than 30% of the ultimate bearing capacity, although some local cracks are initiated in GRP tube. As the load increases, the cracks propagate continuously. Occasionally the specimen has a crisp sound and a squeaking noise. When the load reaches 96% of the ultimate bearing capacity, the upper part of the GRP tube shows some damage character (tube colour turns to white), the outer parts of the tube are tore off, and the glass fiber bundle is layered off. When the load reaches the ultimate bearing capacity, the cracks developed look like an inclined Z-shaped band. The cracks propagate upto around one third of the specimen height from the bottom. The concrete inside the composite column is crushed. The relationship between the axial load and the strain of the GRP tube in different direction is analyzed.

1. Introduction
As a kind of fibre reinforced polymer (FRP) material, glass fibre reinforced plastics (GRP) refers to a composite material with glass fiber as a reinforcing material, which has the advantages of high strength, light weight, corrosion resistance, and fatigue resistance. The use of GRP in construction is convenient and leads little increase in component geometric size. It has been widely used in civil engineering structures. For example, the tube made of GRP has better acid and alkali resistance and moisture resistance behavior than that of the steel tube. This makes the GRP composite column more useful in the complex coastal environment.

Many scholars have carried out research on FRP or GRP constrained concrete composite structures. In 1981, Fardis and Khalili[1] presented preliminary findings regarding the mechanical behavior of FRP-encased concrete in compression and flexure. Mirmiran and Shahawy et al.[2-3] carried out axial compression tests on FRP shell in concrete columns, considering the factors of shell thickness, concrete strength, shape of cross section, slenderness ratio and interface bond. In 2008[4], experiments
of 3 circular steel tubes and 10 double skin tubular stubs (DSTS) were carried out by Qian and Liu. In 2009, based on experimental and theoretical analysis, Ruan Bingfeng[5] researched the mechanical behavior of short GRP tube confined and reinforced concrete columns under eccentric load. Yu et al.[6] (2014) investigated FRP-confined concrete-filled steel tubular columns under cyclic axial compression. The proposed stress–strain model can be employed in the modelling of confined Concrete-filled (steel) tubes (CCFT) strengthened with FRP under seismic loading.

Recently, an experimental investigation of GRP tubes[7] that were filled with magnetically driven concrete was carried out to study the flexural behavior of specimens under bending. Design methods for the flexural stiffness of test specimens were also discussed in this study.

Inspired by the researches mentioned above, a new type of composite column specimen, GRP-Concrete-PVC tube composite column which is a combined structure based on GRP tube, solid concrete and hollow steel tube is designed in the current investigation. The failure phenomenon and bearing capacity of the new type of composite column under axial pressure are investigated by means of static test. The strain of the GRP tube is measured statically. The response of the composite column under axial pressure is analyzed to provide a useful and reliable experimental reference for the similar structure design.

2. Test specimen and specimen preparation
The hollow ratio defined as outer diameter of PVC tube divide by outer diameter of GRP tube directly affects the mechanical properties of the composite column. In the current experimental design, a moderate hollow ratio value (0.367) is selected. The cube compressive strength \( f_{cu} \) of the concrete is 30 MPa. The thickness of the PVC tube is 3mm. The GRP tube adopted has an outer diameter of the GRP tube \( D_f \), the thickness of the GRP tube \( t \), the length of the specimen \( L \) and the reinforcement ratio \( \rho \). The outer diameter of the PVC tube is \( D_p \) and the corresponding hollow ratio \( k = \frac{D_p}{D_f} \) are given in table 1.

| Specimen | \( D_f \) (mm) | \( D_p \) (mm) | \( L \) (mm) | \( t \) (mm) | \( \rho \) (%) | \( k \) | Section diagram |
|----------|----------------|----------------|-------------|-------------|--------------|------|----------------|
| 1        | 300            | 110            | 600         | 7           | 0.9          | 0.367|                 |

During the specimen casting process, attention was paid to the position controlling of the GRP tube and the PVC tube. It is firstly necessary to determine the two tubes on a concentric circle, and then fix their positions respectively. A square bottom board was made with a side length of 400mm. Two concentric circles according to the size of the two tubes were then drawn on the board. The GRP tube and the PVC tube were put on the circle. The tubes cannot be moved by setting the wooden block between the two tubes and outside the tubes. The process and result for the specimen casting is presented in figure 1.
3. Instrumentation and loading

3.1 Measurement content and measuring point arrangement

The loading capacity and the axial deformation of the specimen were provided by use of the pressure sensor and the displacement sensor embedded in the compression testing machine. The axial and hoop strain of the GRP tube was collected by a static strain measuring instrument. The measuring points for the strain of the GRP tube were arranged at four points symmetrically in the middle section of the specimen. The adjacent points were hence separated by 90 degrees. An axial strain gauge and a hoop strain gauge were installed at each measuring point, as shown in figure 2. A pair of dial indicators with a measuring range no more than 50mm was symmetrically arranged on the bottom of the compression testing machine. The dial indicators arrangement is shown in figure 3. The axial displacement of the specimen was also collected by a computer acquisition system.

3.2 Test loading scheme

A bearing plate is placed in both ends of the specimen, in order to obtain an accurate load-strain curve of the specimen and make the deformation rate of the specimen stable during the loading process. The loading process consists of two stages, preloading and formal loading. Before each formal loading, the specimen is preloaded. The maximum preload value is 10% of the estimated ultimate load capacity of the combined column. The combined column member is fully contacted with the upper and lower bearing plates to ensure geometric alignment accuracy. Check if the readings at each point of the displacement meter and resistance strain gauge are stable. The test machine is loading-controlled.
Before reaching 70% of the estimated ultimate load, the loading increment is 1/12 of the estimated ultimate load in the test machine; When the load reaches 70% of the estimated ultimate load, the loading increment per stage is 1/25 of the estimated ultimate load. The load holding time in each stage is two minutes. When the ultimate load is reached, the loading speed is slow. The corresponding strain values of GRP tubes are recorded at each loading stage until the specimen is destroyed in the test.

4. Failure modes
The intuitive and accurate observation of the whole process from the beginning of loading to the destruction of the specimen is an important basis for theoretical analysis and mechanism study of the failure modes. The specimen before and after test are shown in figure 4.

There is no obvious damage phenomenon when the specimen is preloaded. The first sound of a click occurs when the loading is upto 240KN. As the load increases continuously, the crack continues to develop. Occasionally, the specimen has a crisp sound and a squeaking noise. When the loading reaches 3150KN, the specimen goes into the progressive failure. The colour of the upper part of the GRP tube appears white, the outer parts are tore off, and the glass fiber bundle is layered off. When the load reaches the ultimate bearing capacity, the cracking is an inclined Z-shape. The cracks propagate upto around one third of the specimen height from the bottom. The concrete inside the combined column is crushed. The ultimate bearing capacity is 3280KN. After this loading value, the load-displacement curve declines rapidly and the specimen is destroyed.

5. Test results

5.1 Axial Load-strain response
The strain of the GRP tube was collected by the static strain measuring instrument. The axial load-strain relationships of the GRP tube at different measuring points are shown in figure 5.
As seen from the axial load-strain curves of the specimen, the slope of the hoop strain curve of the GRP tube is very large at the initial stage of loading. That is, the specimen stiffness is large. A straight line in this stage indicates that the GRP tube is in elastic stage. The axial load-axial strain curve has a smaller slope than the axial load-hoop strain curve, indicating that the axial strain increases faster than the hoop strain. That is, the modulus of the GRP tube in the hoop direction is significantly larger than that in the axial direction. The load-strain curve becomes gentle when the load increases to a certain value and the combined column reaches the nonlinear stage. Approaching the loading capacity, the load increment is small and both strains increases significantly.

5.2 Load-displacement response
The axial displacement of the two dial indicators is shown in table 2. The load-displacement curve collected automatically by the computer acquisition system. The load-displacement curve is a straight line at the initial stage. As the load increases, the displacement increases continuously. The increased displacement–loading curve becomes a quasi-parabola. After the load reaches the ultimate load (3280kN), the displacement increases rapidly. Destructive failure occurs finally.

6. Conclusion
(1) When the load is between 7.3% (i.e., 240/3280) to around 30% of the ultimate bearing capacity, small cracks appear locally in the GRP tube, and the squeaking sound is accompanied. The GRP tube has no obvious damage phenomenon. The cracks continue to develop and propagate as the load increases up to nearly 80% of the loading capacity. The specimen has a crisp sound and a squeaking sound occasionally. When the load reaches 96% of the ultimate bearing capacity, the specimen goes into the progressive failure stage. Damage happens in the upper part of the GRP tube, as indicated by colour change (turn to white), the outer parts are tore off, and the glass fiber bundle is layered off. When the load reaches the ultimate bearing capacity, an inclined Z-shape crack band is formed. The cracks propagate to around one third of the specimen height from the bottom. The concrete inside the combined column is crushed and the load-displacement curve drops rapidly.

(2) The axial load-axial strain curve and the axial load-hoop strain curve are analyzed. The results show that the axial strain increases faster than the hoop strain. The modulus of the GRP tube in the hoop direction is significantly larger than that in the axial direction.
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