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Experiment and Analysis on the Flexural Property of Sap Concrete Beam Reinforced With FRP Bars

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Abstract: Designed and made four 6m long SAP concrete beams reinforced with Carbon-Glass fiber tendon, and performed a beam destructive testing by load onto two points. The beams are tested under static flexural loading to investigate the cracking patterns under all levels of load. The modes of failure, characteristic of deformation and load carrying capacities are evaluated in the test. Put forward the calculation formula of the bearing capacity of load carrying limit for SAP concrete beam reinforced with FRP bars.

***Keywords:** FRP bars, SAP concrete beam, Flexural property, Load carrying capacity.*

1. Introduction

Fiber Reinforced Polymoer (FRP) can be used to solve the problem of engineering failure caused by steel-bar corrosion due to its lightweight, high-strength and splendid erosion-resistance [1-3]. Super-Absorbent Polymer Concrete (Hereinafter referred to as SAP concrete) is lightweight porous structural concrete, applying a saturated sphere formed by a high performance water absorbent resin for the adsorption of seawater, take it as coarse aggregate and add sea water to mix it up with ordinary Portland cement and sand in some certain proportion. Research shows that the engineering property of SAP concrete is splendid [4-6]. Based on the engineering advantages of the two materials, the fiber reinforced SAP concrete structure has an optimistic prospect in the structural engineering of the coastal area.

FRP is a linear elastic material, which leads to brittle destruction characteristics of fiber reinforced concrete components and the large crack width and deflection under the conditions of use [7]. Compared with traditional materials, the elastic modulus of FRP bars and SAP concrete is lower, so the stiffness of the flexural components is smaller than that of ordinary concrete, and large deformation occurs at the load bearing. Through destructive experiments with four 6m long SAP concrete beams reinforced with Carbon-Glass fiber, the paper study on the effects of reinforcement ratio and section size on the beam crack, strain, deflection and flexural capacity of the beam section, and the formula of load carrying capacity is proposed, which can be used for reference in practical engineering application.

2 Experiment program

2.1 Materials

The absorption ratio of the water absorbent resin used for mixing SAP concrete is about 20 in the artificial seawater. The density of saturated spherical aggregates form by water absorption is $1072kg/m^3$, the particle diameter is 4~5.5mm; Compound admixture includes Naphthalene Water Reducer and mineral admixture. The volume weight of the fiber used in the experiment is $0.91g/cm^3$, tensile strength is 383MPa, diameter is 51μm, length is 9mm. Fine aggregate is sea sand. Pouring beam specimen while performing compressive strength test of concrete, the mix proportion of SAP concrete and mechanical properties is shown in Table 1.

The FRP bars used in this experiment are Carbon-Glass fibers produced by Weihai Guangwei Carbon Fiber Company, and the diameter is 16mm and 8mm. The main part of the inside of the reinforced bars is Glass Fiber, the outside is Carbon Fiber, and made by using resin bond. In order to increase the bond strength between the steel and concrete, the spiral wound carbon fiber bundle is formed on the outer surface.

***Table 1.** Performance parameters of SAP concrete*

Mass ratio						Compressive strength	Elastic modulus
Cement	**Water**	**Sand**	**Saturated SAP**	**Fiber**	**Admixture**	30.73MPa	17.6GPa
1	0.28	0.96	0.26	0.0027	0.061		

2.2 Description of beams

The span of the test beam is 6m, the net span is 5m, and the pure deflection length is 2m. The longitudinal ribs at the bottom of the beam are Carbon-Glass fiber bars with 16mm diameter, and the Carbon-Glass fiber bars with no rib is set as a frame to ensure the integrity of the rib. In order to ensure that the component does not occur shear destruction, choose Carbon-Glass fiber bar with 8mm diameter as stirrup. The gap is 100mm between encryption areas, and 200mm between non-encryption areas. The section size and reinforcement of the test beam are shown in Table 2 and Figure 1.

Table 2. *Design of test beams*

Number	Sectional dimension	Reinforcement				Reinforcement ratio
		①	②	③	④	
L-1	6000×450	2 ϕ16	2 ϕ16	8@100	8@200	0.45%
L-2	6000×450	2 ϕ16	3 ϕ16	8@100	8@200	0.67%
L-3	6000×600	2 ϕ16	2 ϕ16	8@100	8@200	0.33%
L-4	6000×600	2 ϕ16	3 ϕ16	8@100	8@200	0.50%

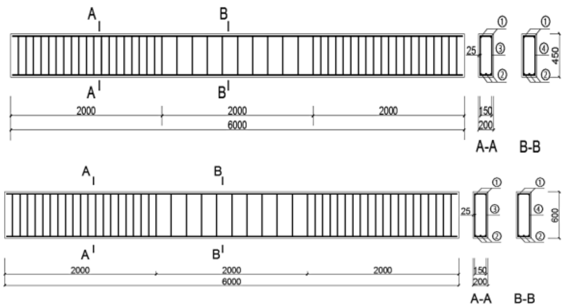


Figure 1. *Details of test beams*

2.3 Experimental equipment

The strain of FRP bars and concrete is measured by the electric resistance strain gauge, and the data is collected by strain collection box. 3 dial indicators are arranged at mid-span and two pedestals, measuring the deformation of the beam span. The test is performed by electro-hydraulic servo press, load by two points loading mode. The loading process adopts the graded loading, the specimen are loaded with 5kN for every grade before cracking and 10kN for every grade after cracking, and holds load for 5 minutes for every grade, observes the development of deflection value and crack during the period of load holding. The main test contents are: cracking load and destructive load of specimens, deflection of specimen under load at all levels, the strain of the longitudinal FRP bars and SAP concrete, crack width and the development, etc. The experimental equipment is shown in Figure 2.

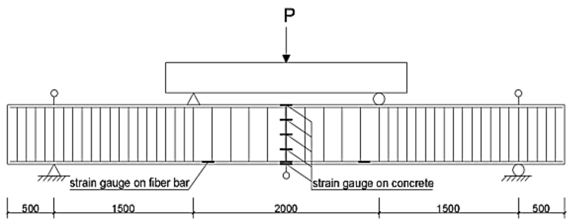
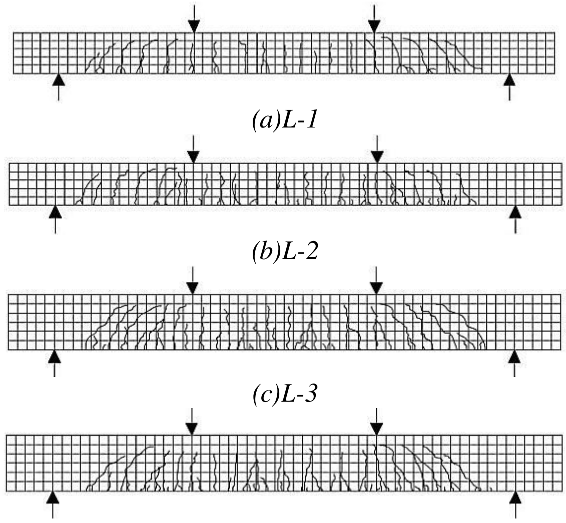


Figure 2. *Testing apparatus*

3 Test results and discussion

3.1 Distribution of cracks

All the destruction patterns are tensile failure, which is FRP bars fractured, the concrete in compression zone is not crushed, and the specimen is broken along the inclined crack. With the incensement of the reinforcement ratio, the stiffness of the specimen increases, the number of cracks increases, the distance between the crack decreases. The initial crack load of specimen L-1 and L-2 is 15kN, when loading to 40kN, the initial crack of specimen L-3 and L-4 appears, the initial crack of all beam specimens appeared at the junction of pure deflection and deflection shear. With the incensement of the load level, more vertical cracks begin to appear in the middle of the span and develop rapidly to the compression zone, and the vertical crack can be developed to the place 90mm apart from the edge of compression zone. When the specimen is damaged, the diagonal cracks connected at the position of 1/3, the fiber bars were pulled off, and the specimen is suddenly broken with a huge sound. The diagonal crack is also the widest crack, and crack width is 1.5mm, it occurs when the load is 220kN. The crack form of the beam specimen is shown in Figure 3.



(a)L-1

(b)L-2

(c)L-3

(d)L-4

Figure 3. *The development of crack*

The development trend of cracks in beams with different section sizes is similar, the height of concrete compression zone is one fifth the height of beam, and many cracks with long length occurred, the width of the crack is 0.7±0.2mm, and it is naturally different from the crack form of the common concrete beams [8-10]. Reinforced concrete beam cracks in a cognizable form, it rarely appeared long wide cracks, and the crack length is short. The cracks of FRP bars reinforced SAP concrete beams are long, and the crack width is almost the same, it is difficult to identify which the key crack is leading to the destruction of the component.

Figure 4 shows the ultimate failure mode of SAP concrete beams reinforced with FRP bars is shown.

Figure 4. *The failure mode of beam*

3.2 The load-deflection relationship

The results show that, the mid-span deflection developed slowly before the section cracking. After the section cracking, the stiffness of the component is reduced. Because of the low elastic modulus of FRP bars and SAP concrete, the stiffness of the beam specimen decreased obviously, and large destruction occurs to specimen. The limited deflection is measured at the 90% of ultimate load carrying capacity. The cracking load and ultimate load of each specimen are shown in Table 3. The load-deflection curve of each specimen is shown in Figure 5, the load-deflection curve of the test piece is double broken line, and the load of the turning point is the cracking load. Before cracking, the specimen is in the elastic state, and the load deflection curve shows a linear development, because of the low stress and the large section rigidity, the deflection of the specimen is of slow growth. After the cracking of the specimens, the concrete is pulled out of the working area, and the deflection of the specimen begins to appear faster and larger, which manifest as the load-deflection curve has a turning point.

Table 3. *The result of loading test*

Number	Cracking load/kN	Ultimate load/kN	Limited deflections/mm
L-1	15.0	150.0	101.11
L-2	15.0	190.0	104.39
L-3	35.0	230.0	64.85
L-4	40.0	290.0	69.64

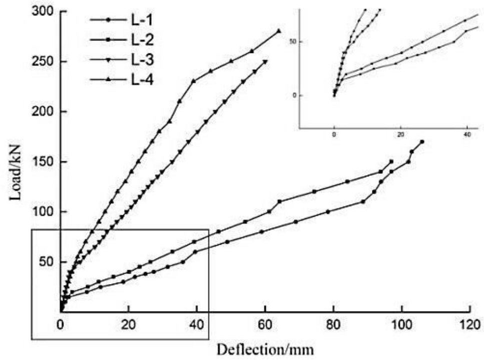


Figure 5. *Load- deflection curve*

As is shown in Figure 5, the deflection of SAP concrete reinforced with FRP bars is significantly affected by the height of the cross section, and the influence of the reinforcement ratio is unobvious, The bottom reinforcement area of L-2 is 201mm^2 more than L-1, and the deflection value is only reduced by 5mm when load to 150kN. In the limit state, the effective height of L-3 is 150mm higher than that of L-1, deflection value decreases 36.26mm, and the deflection of L-4 is 34.75mm lower than that of L-2. In order to improve the deformation capacity and reduce the deflection angle, it is more effective to increase the section height than to increase the reinforcement area.

3.3 Strain

Through the strain gauge on surface of the concrete and the bottom of FRP bar, the strain condition under all levels of load is tested, as well as the strain development trend of concrete and FRP bars in tension zone. The concrete strain of the beam specimen is shown in Figure 6 along the height of the section under different levels of load, as shown, during the whole process of destruction, with the development of cracks, the position of neutral axis is moved upward gradually. Therefore, the section of the test beam is basically in accordance with the assumption of plane cross section [11-13].

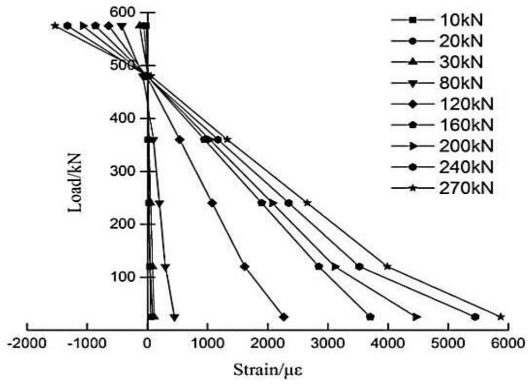


Figure 6. *Strain of the cross section of beam L-4*

The strain development of concrete and fiber tendon in tension zone is shown in Figure 7, the test shows that the bond between FRP bars and SAP concrete is well, and they can cooperate with the force before destruction. However, as the elastic modulus of the two materials is small, when the initial crack appeared in the lower part of the beam, the position is relatively high, the cracking moment of the neutral axis rises near the top. With the load increasing, new cracks is constantly added. The stress is redistributed, and the beam deflection appears obviously like an arc structure. The neutral axis moves down, and when we continue to increase the load, the neutral axis moves slowly up until the beam is destroyed.

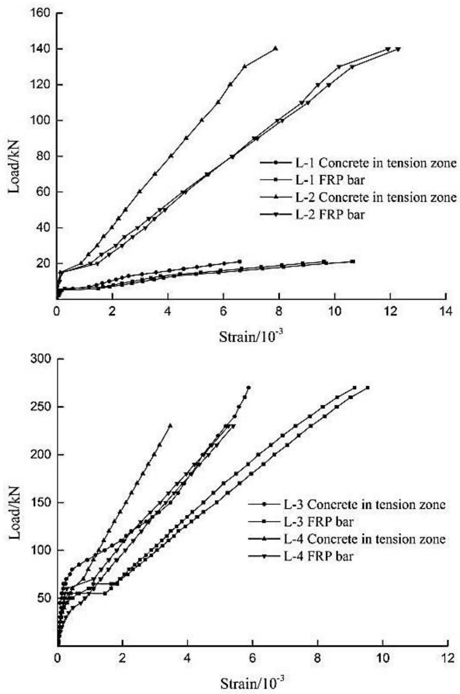


Figure 7. *The load-tensile strain curve*

4 Theory

4.1 Fundamental assumption

The tensile strength of FRP bars is high, when the FRP bar is pulled out, SAP concrete have not been crushed. Failure mode of FRP bars reinforced SAP concrete beam is similar to the failure mode of the over-reinforced beam. So in this paper, structural design and calculation of the load carrying capacity of the beam are mainly based on the following assumptions:

1) Before and after deformation, the deformation of the normal section is satisfied to the assumption of plane cross-section.

2) No consideration of the tensile strength of concrete.

3) Adopt ideal SAP concrete constitutive model.

4) The stress-strain relationship of FRP bar is linear elastic.

5) Well bonding performance between FRP bar and SAP concrete.

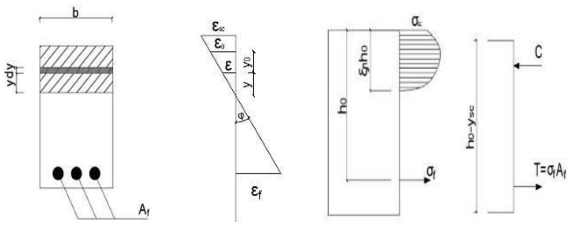
4.2 Theoretical analysis

The limit strain of SAP concrete, $\varepsilon_{sc} = 0.0016$,, Strain of FRP bar, $\varepsilon_f = f_f/E_f$, the f_f and E_f are the compressive strength and elastic modulus of FRP bars. The balanced depth of compression zone ξ_n can be calculated by formula (1), Height of equivalent compression zone of SAP concrete is x_b in the formula, and the β_1 is conversion coefficient of equivalent rectangular stress pattern, and we can set value in accordance with Chinese current code for design of concrete structure[14].

$$\xi_n = \frac{x_b}{h_0} = \beta_1 \frac{0.0016}{0.0016 + (f_f/E_f)} \quad (1)$$

The bending moment of the cross section can be calculated according to the following formula:

$$M_u = A_f f_f \gamma_f h_0 \quad (2)$$



(a)Section *(b) Strain* *(c)Stress* *(d)Internal force*

Figure 8*. Internal force distribution of HFRP-reinforced SAP concrete beams*

Table 4. *Statistical analysis of bearing capacity*

Number	M_c/kN·m	M_t/ kN·m	$\frac{M_c}{M_t}$	Average value	Standard deviation	Variable coefficient
L-1	161.73	150.0	1.08	1.11	0.13	0.12
L-2	242.60	190.0	1.28			
L-3	219.91	230.0	0.96			
L-4	329.87	290.0	1.14			

γ_f is the coefficient of internal force arm. When The failure modes of beams manifest as balanced failure, the γ_f reaches the minimum value.

$$\gamma_f = 1 - 0.5\xi_n \quad (3)$$

In this paper, the ultimate strain of the FRP bars is 0.0167.According to the formula (1) and (3), $\gamma_f \approx 0.965$. At this time, the flexural capacity of the normal section of the SAP concrete beam reinforced with FRP bars can be calculated by formula (4).

$$M_u = 0.965 A_f f_f h_0 \quad (4)$$

The flexural capacity of the normal section of the SAP concrete beams is calculated by using the proposed formula. Comparison of calculated and experimental results is shown in Table 4. Among them, M_c and M_t are the calculation values of the proposed formula and the test values of the flexural capacity of the normal section. As shown in the table:

1) For the testing beams, the average error of the flexural capacity of the normal section and the test value is 11%, and the calculated value of the flexural capacity of the specimens is slightly higher than that of the test values.

2) The average value of M_c/M_t was 0.91, and the standard deviation is 0.11, coefficient of variation is 0.12, showing that the two are in good agreement.

5 Conclusions

1) The failure mode of SAP concrete beams reinforced with FRP bars is tensile failure, and the failure is sudden, almost with no plastic changes. Compared with ordinary reinforced concrete beams, the crack of SAP concrete beams reinforced with FRP bars is distributed uniformly along the beam body, and it is long and wide, and the developed height is relative high.

2) The stiffness of SAP concrete beams reinforced with FRP bars is small, and the components will have large deflection and wide crack in the case of small load, therefore, the destruction of SAP concrete beams reinforced with FRP bars is controlled by deflection and crack width, and the structure design should be controlled by the stiffness.

3) FRP bar with rib on the surface has a well bonding performance with SAP concrete, they can work together before the beam is damaged, and the section is basically in accordance with the assumption of plane cross section.

4) When the tensile failure occurs, the coefficient of internal force arm of the section of the SAP concrete beams reinforced with FRP bars can be approximately 0.965, the ultimate load carrying capacity be calculated by formula (4).

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