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Experimental study on seismic performance of small span-to-depth ratio coupling beams with fiber reinforced concrete

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Abstract: A set of three specimens with different forms of reinforcement are producted, one is with the common concrete, the other two are mixed with the PVA fiber. All have the same span-to-depth ratio of 1.2. Failure modes，ductility performance，bearing capacity and energy dissipation capacity are analyzed. The results show that the mix of PVA fiber postpones the cracking of the specimen, improves the spall state of the coupling beam and increases the ultimate load. Cross diagonal reinforcement can effectively restrict the occurrence and development of the diagonal shear crack, also improve the ductility and energy dissipation capacity.

Keywords: Small span-to-depth ratio coupling beam; Fiber reinforced concrete; Seismic performance; Failure mode

1 Introduction

Coupling beam plays an important role in connecting the wall limbs, transferring force and strengthening shear wall integrity. Restricted by the size of the hole and the shear wall integrity requirements, coupling beams generally have small span-to-depth ratio, high nominal shearing stress and large stiffness, these are all against deformation performance. Many researches[1-6] were made on how to improve the anti-seismic performance. According to Code for Seismic Design of Building (GB50011-2010)[7], reinforcement amount is larger when design common concrete coupling beams, affecting the construction quality and structural performance, so properly reducing the amount of reinforcement, at the same time not affect the seismic performance of the coupling beam is a reasonable research direction.

In order to better understand the failure mechanism, seismic performance and energy dissipation capacity of the fiber reinforced concrete coupling beam, thesis makes three coupling beams with span-to-depth ratio 1.2, completes the quasi-static pushover test, analyze the failure mechanism of the specimens, and discusses the seismic performance of the specimens.

2 General situations of the test

2.1 Specimens design

These full scale specimens are designed with ratio of 1.2, including an ordinary concrete beam(CB-1), a common steel fiber reinforced concrete coupling beam(CB-2) and a cross diagonal steel fiber reinforced concrete coupling beam(CB-3). The concrete strength grade is C30. Fiber volume mixing rate(V_f) for CB-2 and CB-3 is 1.8%.

Specimen CB-1, CB-2, CB-3 have the same longitudinal and stirrup reinforcement, stirrup spacing is 80mm. Take the beam between openings and the connection walls as the prototype, increasing the thickness of the end of specimen to simulate the wall limb with relatively large stiffness on both ends of the beam, The size and the detail of reinforcement is shown in Fig. 1.

2.2 Test equipment

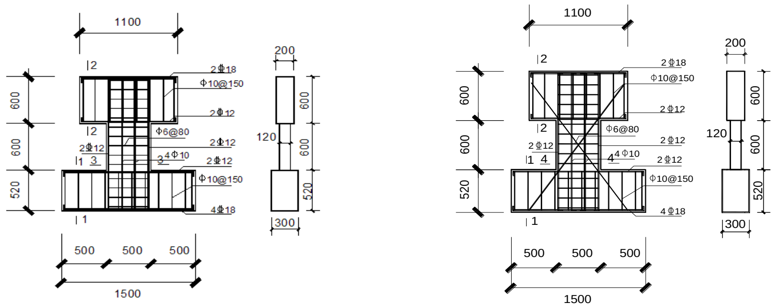
Horizontal load is provided by reciprocating actuator and load point lies in the mid-span of the coupling beam specimens; The bottom of the coupling beam is fixed with tie bar anchored in anchor slots and pressure beam on both sides, the upper end of the coupling beam is fixed with plate whose stiffness is large enough, making the specimen uniformly forced.

2.3 Test load system

According to Code for Test Method of Concrete Structure (GB/T50152-2012)[8], control the loading displacement in the whole process, the displacement increment is 1mm before specimen yield, then change to 2mm after yield, each displacement increment reciprocate two cycles. After achieving the maximum load, continue to load to a certain extent, when one cyclic loading peak of the descent stage of load-displacement hysteresis curve lower than 85% of the maximum load, considering that specimen fails.

2.4 Test measuring content

The main data of the measured results: steel strain, horizontal displacement, yield load, ultimate load and crack development situation. Load is automatically measured by the load sensor on the equipment, lateral displacement is measured by displacement meter, steel bar strain is measured by strain gauge, all the measurement instruments are connected to automatic data acquisition device, all data is collected automatically. Crack width is measured by the crack width gauge.



Details of reinforcement for CB-1, CB-2   Details of reinforcement for CB-3

Fig. 1. Size and reinforcement of the coupling beam specimen

3 Analysis of experiment result

3.1 The failure process of the specimens

Three specimens have experienced initial crack, crack development, yield and ultimate failure stages, their failure mode and crack distribution is shown in figure 2.

CB-1   CB-2   CB-3

Fig. 2 Failure mode and crack distribution of the specimens

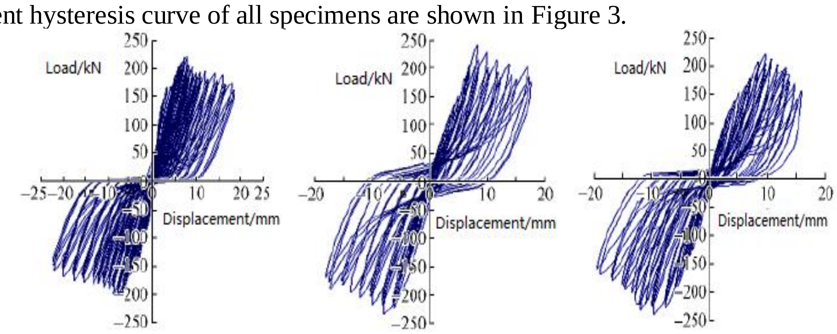
CB-1 first appeared small diagonal crack in the roots of the specimen; When loading displacement reaches 20mm, a few cracks occur along the diagonal direction; Then the specimen dislocate along the shear oblique cracks, losing bearing capacity.

When loading displacement is 4mm, CB-2 appears the first small horizontal crack. As loading displacement reaches 20mm, this specimen is destroyed and cracks develop completely. Unlike CB-1, there is more horizontal crack on CB-2, having the trend to flexural shear failure.

Cracks of CB-3 are relatively uniform, and develop completely when destroyed. In the process of loading, the ultimate bearing capacity of CB-3 increased by 31.9% than that of CB-2. The concrete cover mainly did not fall off when eventually destroyed.

3.2 Load displacement hysteresis characteristics

Load - displacement hysteresis curve of all specimens are shown in Figure 3.



CB-1   CB-2   CB-3

Fig. 3 Load displacement hysteresis loop

Hysteresis curves of the three specimens show as spindle at first, then gradually into an opposite S shape, show varying degrees of pinch gathering phenomenon, CB-1 pinch gathering phenomenon is more apparent, its hysteresis loop is not full and strength declines faster after achieving maximum load, ultimate displacement is small, ductility is weak; The maximum bearing capacity of CB-2 is higher than that of CB-1, pinch gathering phenomenon of hysteresis curve also have been improved, and ductility is good; CB-3 has cross reinforcement, its hysteresis loop is full, and ductility is good.

3.3 Ductility and bearing capacity

According to the equation of [9, 10], the ductility factor μ and the shear compression ratio γ of these specimens are calculated. The results are shown in Table 1.

Table 1. Carrying capacity and displacement ductility coefficient

Model No.	CB-1	CB-2	CB-3
γ	0.259	0.256	0.312
μ	2.57	2.78	2.91

From table 1, shear compression ratio of CB-2 is the minimum, CB-3 is the maximum. Ductility of CB-2 is much better than CB-1, PVA fibers limit the crack width of the specimens and prevent concrete forming serious premature damage in a considerable range of inelastic. The cross diagonal reinforcement improves the ductility performance.

3.4 Dissipation capacity of the coupling beam

According to[9], the energy dissipation coefficient β_i is calculated. The β_i -Δ diagram is shown in Fig. 4.

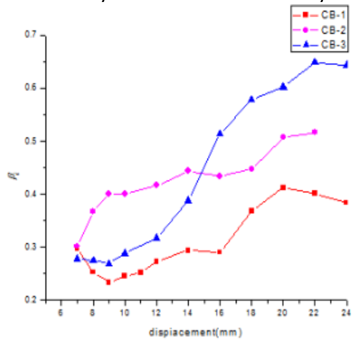


Fig. 4 β_i - Δ diagram

When the loading displacement is 12mm, the energy dissipation coefficient of CB-1, CB-2, CB-3 is 0.2728, 0.4167, 0.3172 respectively; When the loading displacement is 22mm, the energy dissipation coefficient of CB-1, CB-2, CB-3 is 0.4008, 0.5162, 0.6490 respectively. The energy dissipation capacity of the fiber reinforced concrete coupling beam is higher than that of the common concrete coupling beam, this is because PVA fiber restrict the crack development, weaken the stress concentration on the edge of crack; Besides, pulling out the PVA fiber needs to absorb lots of energy, finally improve the energy dissipation capacity. Compared CB-3 with CB-2, the former energy dissipation is slightly better than the latter, this is because diagonal reinforcement works as strut-and-tie, when specimen fails, diagonal reinforcement yield totally; Under repeated load, the plastic strain increases faster, the energy dissipation is also more, thus diagonal reinforcement has great contribution to the improvement of energy dissipation.

4 Conclusion

By low cyclic loading experiments on three small span-to-depth ratio coupling beams, analyzing the experimental phenomena and results obtains the following conclusions:

At the same load level, crack width of small span-to-depth ratio coupling beams with fiber reinforced concrete is smaller than ordinary concrete coupling beams, and with the increasing of load, the phenomenon is more evident; In the destruction process, PVA fiber can improve the overall brittleness of concrete; PVA fiber and diagonal reinforcement can limit the appearance of shear cracks and the development of existing cracks.

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