Seismic performance of a new type prefabricated concrete frame joint

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Abstract. In view of the problems existing in the beam-column joint of prefabricated concrete frame structure, a new hook-type joint is proposed in this paper. The quasi-static tests were repeatedly performed on full-scale models, using combined joints with different concrete strength and steel bar types. The failure pattern, carrying capacity, hysteresis loop and energy dissipation ability of the new hook-type joints were analyzed. The results show that the failure process of hook-type joint has five stages; they are initial crack, thorough crack, beam yield, limit, and failure. The hook-type joints have good working performance, good recovery characteristics and strong strength and stiffness, but the energy dissipation ability is weak.

1. Introduction
Prefabricated construction refers to the construction of prefabricated components which are produced at factory and assembled and connected on site. This kind of building structure has the advantages of high production efficiency, low labour intensity and less pollution to environment [1]. Frame structure is a commonly used structural system, but the column-to-beam joint is a weak part which will affect seismic performance because of its complicated force[2]. Therefore, the joint connection is key to researching prefabricated concrete frame structure. Experts and scholars in China and all over world have proposed various types of connection plans in construction. For example, both Cheok and Lew have carried out experimental researches on the pre-stressed joint, the result shows that this post-tensioning pre-stressed joint connection can enhance the rigidity of the core area of the joint, so as to improve resilience[3]. Ertas and others also have proposed the joint of bolted connection and done experimental researches. Their results show that the joint has good working performance, which is equal to the mechanical performance of cast-in-place integral structure[4]. Song and Gao have done structural dynamic test research to the bolt connections joint; their analysis shows that the hysteretic loop of this kind of connection joint is fuller, and the joint has higher deformation and energy dissipation ability[5,6]. Ersoy and Zhang have experimented on the joint of welded steel plate. Their results show that the joint is safe, reliable, has good weight capacity and energy dissipation capacity[7-8].

However, there are still some defects to be improved, for example, the manufacturing process of pre-stressed joints is complex, the bolt connection joints require accurate specimen fabrication and installation, and welded steel plate joints will increase the consumption of steel in the construction of structure. Therefore, in this paper, the authors have proposed a new connection form of frame joints solution, performed quasi-static tests repeatedly with full-scale models, analyzed the seismic performance, and will provide references for further study in prefabricated concrete frame joints.
2. Brief introduction to new joint
The new frame joint is connected by the hook-ring steel bar, then concrete is poured to form an integrated frame at the connecting area. The construction of the joint is shown in Figure 1. The end of the side beam near the core area of the joint is specifically selected to ensure the continuity and integrity of the precast of the core area. The end of the side beam is prefabricated into a step shape, which increases the contact areas for the secondary pouring concrete; improves the bond strength and shears resistance of the joint cross-section. The beam in the middle of the joint adopts integrated prefabricated beam, which can reduce the large areas of casting in the composite beam. The hook-ring connection proposed by our research group is applied on the connection of steel bar; the upper and lower longitudinal reinforcement and U-shaped stirrups at end of the side beam of precast joint core area are made into hanging ring; the position of the longitudinal reinforcement hanging ring is set to the middle point of the stirrup spacing, and the hanging ring position of the stirrups is set in the middle of the beam height. The longitudinal reinforcement and the stirrups at end of the prefabricated intermediate beams are made into hooks. When the joint is installed and spliced, the steel hooks of the intermediate beams are hung on the corresponding rings of the side beams of the joints. This steel bar connection has the advantages of low connection cost, pretty high quality assurance, and convenient installation and easy operation.

3. Specimens design and loading design
In this test, five full-size models with cross-shape were designed in the middle joint of the frame structure, to verify the seismic behavior of the new joint in different concrete strength and steel bar types. Specimen numbers and parameters are shown in Table 1 and Figure 2.

Table 1. Parameters of specimen

| Specimen number | Precast member concrete strength | Post-pouring concrete strength | Longitudinal reinforcement of beam top | Longitudinal reinforcement of beam bottom | Longitudinal reinforcement of column | Stirrups of beam and column |
|-----------------|----------------------------------|---------------------------------|---------------------------------------|-----------------------------------------|-------------------------------------|----------------------------|
| ZKJ - 1         | C40                              | C45                             | 2B18                                  | 3B20                                    | 12B20                               | A8@100                     |
| ZKJ - 2         | C30                              | C35                             | 2B18                                  | 3B20                                    | 12B20                               | A8@100                     |
| ZKJ - 3         | C20                              | C25                             | 2B18                                  | 3B20                                    | 12B20                               | A8@100                     |
| ZKJ - 4         | C30                              | C35                             | 2B18                                  | 3B18                                    | 12B20                               | A8@100                     |
| ZKJ - 5         | C30                              | C35                             | 2B18                                  | 3B22                                    | 12B20                               | A8@100                     |
The test specimen loading device is shown in Figure 3. The test adopts automatic reaction frame, and the axial force on the top of the column is exerted by 1500 kN jack. Two square clamps between the top and bottom of the beam are used to simulate the seismic wave force at the end of the beam. During the test, the horizontal reciprocating load shall be applied to the beam end through the MTS servo loading test system.

In the loading process of quasi-static test, the load-displacement dual control test method should be adopted, that is, load control and graded loading should be adopted before yielding of the specimen, and displacement control should be adopted after yielding of the specimen.

**4. Discussion**

**4.1. Analysis of test phenomena**

The failure patterns of five specimens under quasi-static loads are shown in Figure 4. The new type reinforced concrete joints and ordinary concrete joints have similar failure process-5 stages, that is, initial crack--thorough crack--beam yield--limit--failure. When the loading load reached 25 kN, the first crack appeared simultaneously. The crack appeared in the upper root of the joint beam and extended rapidly to the lower part of the beam. When the test was loaded to 116 kN, the longitudinal bars on the upper beams of each specimen were successively yielded and the loading way was changed from load control to displacement control. As the experiment proceeded, the displacement of the beam end, showed a trend of increase and joints of the upper beam cracked, on the adjacent area new tiny cracks also began to appear. When the displacement was 20mm, the carrying capacity peak of ZKJ-1 had firstly appeared, which was 156.1kN. In the later loading process, the cracks on the joint beam increased, and expanded to the post-pouring areas, and the post-pouring areas started to show cracks, in which the position of the joint between the post-pouring areas and the original joint was the weak position, where there were more cracks. With the increase of displacement, the upper and lower longitudinal reinforcement of the joint yielded, and the concrete above the root of the joint was crushed. By the time the loading ended, the concrete on the upper side of the beam root of the five specimens was all seriously damaged with a maximum crack of about 15mm.
4.2. Hysteretic loop

Figure 5 shows the hysteretic loop, which mainly presents the following characteristics:

1) The shape of hysteretic loop, at the beginning of both cycles, presented a sharp fusiform, indicating that it had a good energy dissipation capacity. In the following several cycles, due to the asymmetry of the reinforcement area of the upper and lower rebar of the beam, the figure presented an obvious S shape with incomplete symmetry, indicating that the energy dissipation capacity of the specimen decreased.

2) Comparison tests were chosen with same reinforcement and different concrete strength in specimens ZKJ-1, ZKJ-2 and ZKJ-3. When the concrete strength gradually reduced, more obviously the hysteresis loop pinched, which showed that the energy dissipation capacity is smaller. Specimens ZKJ-2, ZKJ-4 and ZKJ-5 are the same concrete strength with different reinforcement ratio in comparative tests. When steel model reduced, the hysteresis loop pinched more he more obviously; showing that the energy dissipation capacity is smaller.

3) The slope of the hysteretic loop of the last loading under the same displacement is close to that of the previous loading, which indicates that the hook-type joints have good working performance, good recovery characteristics and strong strength and stiffness. After that, the slope decreases step by step, indicating that the stiffness of the component changes after repeated loading.
4.3. Energy Consumption

In this paper, the influence of energy dissipation capacity of specimens is analyzed through two indexes of energy dissipation coefficient and equivalent viscous damping coefficient. The calculation results of energy dissipation coefficient $E$ and equivalent viscous damping coefficient $H_e$ are shown in Table 2.

| Component displacement | 18  | 20  | 24  | 26  | 30  | 34  | 36  | 38  | 42  |
|------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| ZKJ-1                  | E   | 0.56| 0.56| 0.58| 0.58| 0.59| 0.61| 0.60| 0.51| 0.59|
|                        | He  | 0.18| 0.18| 0.19| 0.19| 0.19| 0.20| 0.19| 0.16| 0.19|
| ZKJ-2                  | E   | 0.43| 0.44| 0.47| 0.508|0.53 | 0.55| 0.39| 0.41| 0.61|
|                        | He  | 0.14| 0.14| 0.15| 0.16 |0.17 | 0.18| 0.12| 0.13| 0.20|
| ZKJ-3                  | E   | 0.36| 0.39| 0.45| 0.47 |0.49 | 0.50| 0.44| 0.38| 0.32|
|                        | He  | 0.12| 0.12| 0.15| 0.15 |0.16 | 0.16| 0.14| 0.12| 0.10|
| ZKJ-4                  | E   | 0.373|0.38 |0.39 |0.44 |0.51 |0.53 |0.46| 0.43| 0.53|
|                        | He  | 0.12| 0.12| 0.12| 0.14 |0.16 | 0.17| 0.15| 0.14| 0.17|
| ZKJ-5                  | E   | 0.36| 0.37| 0.39| 0.43 |0.43 | 0.45| 0.45| 0.41| 0.41|
|                        | He  | 0.11| 0.12| 0.12| 0.14 |0.14 | 0.14| 0.14| 0.13| 0.13|

The energy dissipation coefficient of the component is not much different, only about 0.6 at the limit displacement, but the equivalent viscous damping coefficient is only about 0.15, and the dissipation ability is weak. From the comparison of the five components, it is found that the characteristics of the energy dissipation coefficient is increased with the increase of displacement and load, the energy dissipation coefficient of ZKJ-1 and ZKJ-2 is slightly larger than the other three specimens, indicating that the higher the concrete strength, the stronger the energy dissipation capacity. The comparison between ZKJ-3 and ZKJ-5 shows that the energy dissipation capacity of components increases with the increase of reinforcement ratio.

5. Conclusion

The main work and conclusions are as follows:
(1) The prefabricated concrete hook-type joints and ordinary reinforced concrete joints have a similar failure process, that is, initial crack—thorough crack—beam yield—limit—failure 5 stages.

(2) The hook-type joints have good working performance, good recovery characteristics and strong strength and stiffness.

(3) The energy dissipation ability of the new type joints is weak.

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