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Dynamic testing of prefabricated concrete frame hook-type joints

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Dynamic testing of prefabricated concrete frame hook-type joints

Wei Gu[1,a], Zhongquan Chang[1], Xinxin Zhang[2] and Yannian Zhang[2]

[1]Jiaxing Vocational Technical College, Jiaxing 314036, P. R. China

[2]Shenyang Jianzhu University, Shenyang 110168, P. R. China

[a]Corresponding author: gw@jxvtc.edu.cn

Abstract. A new type of prefabricated concrete beam-column hook-type joint with simple structure and convenient installation was proposed. In order to comprehensively evaluate the dynamic behaviour of a newly hook-type joint, dynamic tests were carried out on five full size model specimens with different strength grade of concrete and steel bar. The seismic behavior parameters such as failure pattern, bearing capacity, and hysteresis loop and ductility coefficient of each specimen were analyzed, and the strain distribution of post-pouring band were studied. Experiment results show that the destruction process of prefabricated concrete hook-type joints has the initial crack, through crack, beam yield, limit, and destroyed stages. The hysteretic loop is plump and has good plastic deformation ability, and the ductility coefficients are above 3.5, which indicate that the hook-type joints have good ductility. The analysis results shows that the steel bar strains in the post-pouring band continue to increase steadily after the joints yield, which means it has good working performance. Therefore, the hook-type joint of the prefabricated concrete frame have good seismic performance and reliability.

1. Introduction

Prefabricated construction refers to the construction of prefabricated parts assembled and connected in the factory industrial production site. These kinds of building structure have the advantages of high production efficiency, fast construction speed, and green environmental protection, following the principle of sustainable development [1]. Many investigators have studied the prefabricated concrete frame. Since the early 1950s and 1960s, the United States, Canada, Japan, Europe and other countries have carried out in-depth and extensive research and application of prefabricated structures. At present, many developed countries have established perfect prefabricated building structure system [2-4]. In China, some research institutes such as China Academy of Architectural Sciences, Dalian University of Technology and Chongqing Jianzhu University have achieved a series of research results in recent years [5-7]. Precast concrete frame structure is a kind of widely used structure system. However, the splicing position of beam and column joints is easy to be destroyed and becomes the weak part under action of earthquake [8].

In this work, a newly type of prefabricated concrete beam-column hook-type joint is proposed. Hook-type joint is mainly composed of concrete column, concrete beam and concrete external beam, its characteristic is that the joints on either side of the beam of ladder type, and external concrete beam as the cross section, longitudinal reinforcement by the shear and truncation, lower beam longitudinal reinforcement and upper beam longitudinal reinforcement through joint core without truncation, when installation will link external beam bottom longitudinal reinforcement of concrete beams and upper beam longitudinal reinforcement hook on top of the longitudinal reinforcement ring at the bottom of the beam and beam longitudinal reinforcement hanging ring, concrete beam down stage settings link of a u-shaped stirrup, and plus a u-shaped stirrup plus u-hook the stirrup, and the connection mode has high bearing capacity, good plasticity and toughness, convenient construction, good economic effect and other advantages.

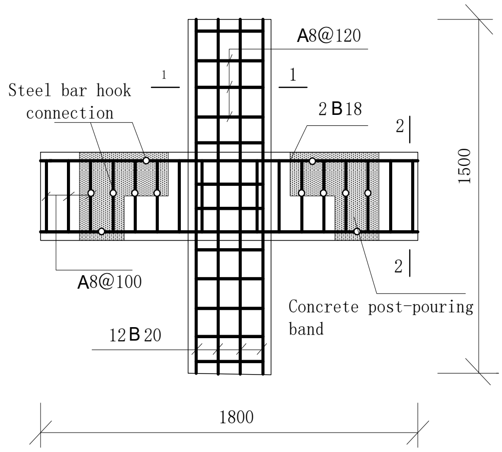
2. Specimens Design

2.1 Sample Design

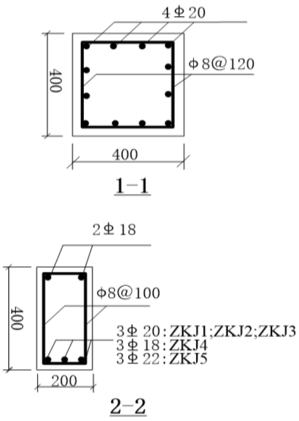
In order to verify that the seismic behaviour of the newly joint, five full-size models were designed by selecting the cross-shaped composite body at the middle joint of the frame structure in this test. Specimen numbers and parameters are shown in Table 1 and Figure 1.

Table 1. Parameters of specimen

Specimen number	Precast member concrete strength	Post-pouring concrete strength	Longitudinal reinforcement of beam bottom
ZKJ - 1	C40	C45	3B20
ZKJ - 2	C30	C35	3B20
ZKJ - 3	C20	C25	3B20
ZKJ - 4	C30	C35	3B18
ZKJ - 5	C30	C35	3B22



(a) Detailed drawing of joint reinforcement



(b) Section plan

Figure 1. Joint size and reinforcement configuration (mm)

2.2 Performance Index of Materials

The mechanical properties and elastic modulus of concrete and steel bar materials are tested according to the relevant standard codes during the process of making model specimens. The measured values are shown in Table 2 and Table 3.

Table 2. Measured performance index of concrete

Concrete grade	Cube compressive strength fcu/MPa	Prism compressive strength fc/MPa	Elastic modulus Ec/MPa
C20	21.8	14.6	26600
C25	27.5	14.8	29400
C30	36.1	24.1	31300
C35	37.1	24.8	31600
C40	42.8	28.6	32100
C45	50.9	34.0	32400

Table 3. Measured performance index of steel bar

Steel bar grade	Steel bar diameter d/mm	Yield strength fy/MPa	Ultimate strength fu/MPa	Elastic modulus Es/GPa
HPB300	8	296	381	2.121
HRB335	18	362	549	1.963
HRB335	20	396	545	2.014
HRB335	22	443	568	2.131

3. Loading Design

3.1 Loading Device and System

The test specimen loading device is shown in Figure 2. The test adopts 5000 kN automatic reaction frame, and the axial force on the top of the column is exerted by 1500 kN jack. Two square clamps at the top and bottom of the beam are used to simulate the seismic wave force at the end of the beam by limiting the up and down displacement of the beam through the upper brace and the lower pressure. 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.

Figure 2. Loading device

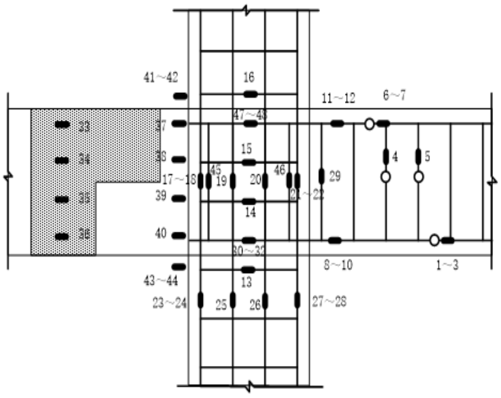


Figure 3. Arrangement of strain gauge

3.2 Strain Gauge Layout

Figure 3 shows that the detailed layouts of strain gauge at the measuring point of joints. In the test, the arrangement of strain gauge is mainly selected in several key parts: the longitudinal reinforcement and stirrups of columns and beams in the core of joints; the concrete and longitudinal reinforcement and stirrups at the roots of outer beams in the core area of joints; the longitudinal reinforcement and stirrups at the concrete and hook joints in the post-pouring area.

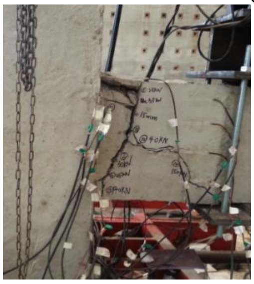
4. Discussion

4.1 Analysis of Test Phenomena

The failure patterns of five specimens under quasi-static loads are shown in Fig. 4. The new type reinforced concrete joints and ordinary concrete joints have a similar failure process, that is, initial crack -- through crack -- beam yield -- limit -- failure 5 stages. When the loading load reaches 25 kN, the first crack appears simultaneously in the five members. The crack is located at the upper root of the joint beam and extends rapidly to the lower part of the beam. When the test is loaded on 116 kN, the longitudinal bars on the upper beams of each specimen are successively yielding. And the loading way changed from load control to displacement control. As the experiment proceeds, the displacement of the beam end, showed a trend of increase and joints of the upper beam crack down, on the adjacent section also began to appear new tiny cracks, position by the upper beam. When the displacement is 20mm, the carrying capacity peak of ZKJ-1 has firstly appeared, which is 156.1 kN. In the later loading process, the cracks on the joint beam increase, the width continues to increase, and extends to the part of the post-pouring band, and the post-pouring band gradually begins to produce cracks, in which the position of the joint between the post-pouring band and the original joint is the weak position, where there are more cracks. With the increase of displacement, the upper and lower longitudinal reinforcement of the joint yield, and the concrete above the root of the joint is crushed. Until the end of loading, the concrete on the upper side of the beam root of the five specimens all suffered great damage with a maximum crack of about 15mm.

At the same time, the experimental results also show that the hysteretic loops of the five specimens are basically the same in the change rule and shape. At the initial loading stage, the hysteretic loop shows a sharp uniform shape, indicating that the initial energy dissipation capacity is basically good. With the continuous cyclic loading, the hysteretic loop shows an S-shape which indicates that the energy dissipation capacity of the specimen decreases gradually.

(a)ZKJ-1



(b) ZKJ2

(c)ZKJ-3

(d) ZKJ-4

(e) ZKJ-5

Figure 4. Failure patterns of specimens

Table 4. Feature value of yield and peak point

Specimen number	Loading direction	Yield point		Peak point	
		P_y/kN	Δ_y/mm	P_m/kN	Δ_m/mm
ZKJ-1	Forward	138.31	13.16	156.17	19.62
	Negative	146.40	12.27	145.42	23.33
ZKJ-2	Forward	133.88	12.47	152.71	32.93
	Negative	143.31	12.07	141.38	26.53
ZKJ-3	Forward	129.80	11.93	148.67	25.73
	Negative	119.09	11.20	133.31	23.21
ZKJ-4	Forward	116.92	13.13	128.49	27.27
	Negative	119.47	13.53	133.31	25.73
ZKJ-5	Forward	148.38	13.40	172.32	23.33
	Negative	156.77	13.26	186.94	26.17

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Table 5. Feature value of failure point and ductility coefficient

Specimen number	Loading direction	Failure point		Ductility coefficient
		P_u/kN	Δ_u/mm	
ZKJ-1	Forward	143.49	42.67	3.540
	Negative	128.66	42.82	
ZKJ-2	Forward	133.11	44.27	3.548
	Negative	113.89	42.81	
ZKJ-3	Forward	125.03	45.53	4.860
	Negative	70.45	43.73	
ZKJ-4	Forward	90.01	51.07	3.878
	Negative	74.49	52.31	
ZKJ-5	Forward	126.19	53.43	4.042
	Negative	161.56	54.33	

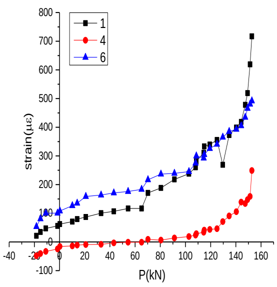
4.2 Bearing Capacity and Ductility Coefficient

Specimens were taken several feature value analyses: the yield load P_y and yield displacement Δ_y; the peak load P_m and peak displacement Δ_m; the failure load P_u and failure displacement Δ_u. The calculated loads and displacements are shown in Table 4 and Table 5. As shown in Table 4and Table 5, the specimen ZKJ-5 bearing capacity is the largest and ZKJ-4 bearing capacity is the smallest. The following conclusions are drawn from the comparison of three specimens ZKJ-1, ZKJ-2 and ZKJ-3, under the same reinforcement ratio, the higher the strength of concrete, the greater the bearing capacity of specimens. By comparing ZKJ-2, ZKJ-4 and ZKJ-5 under the same concrete strength condition, the result shows that, the higher the reinforcement ratio is, the greater the bearing capacity will be.

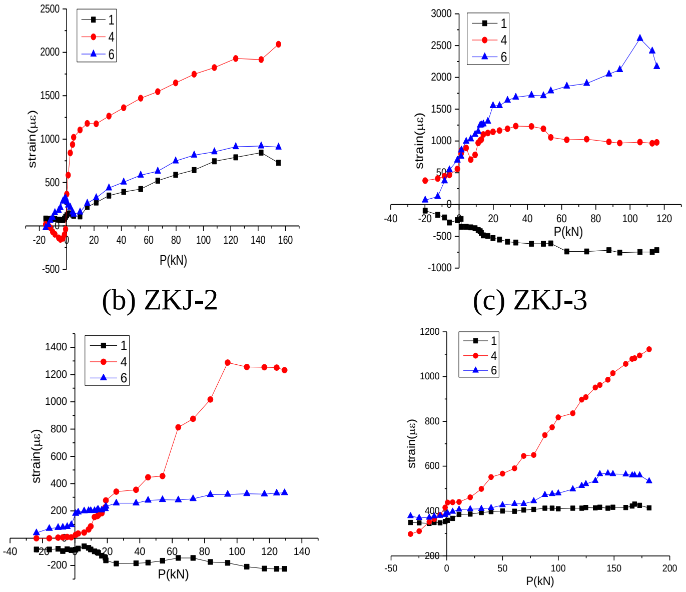
The ductility coefficient of the hooked joint is shown in Table 5. Ductility coefficients are all greater than 3.5, the structure has good ductility; the ductility coefficient of ZKJ-5 specimen is larger, indicates that the higher reinforcement type and the larger reinforcement ratio have a certain effect on the ductility of the structure, and the value is increased.

4.3 Strain Analysis of post-pouring band

Figure 5 shows the strain distribution of the steel bar of the post-pouring band, and 1#, 4#, and 6# respectively represent the strain gauge Nos. at the lower longitudinal steel bar, stirrup, and upper longitudinal steel bar of the post-pouring band. Compared with other strain gauges, the overall strain value of # 4 strain gauge changes more than that of other strain gauges, indicate that its position stress is larger. The strain distribution curves of the three strain gauges are all linear, and the stress change frequency is uniform and the range is close. The stress on the stirrup is greater than that on the longitudinal steel bar. Generally speaking, the variation trend of these strains is basically the same, and the change rate is basically similar. It indicates that the steel bar at the hook is under uniform stress and good working performance.



(a) ZKJ-1



(b) ZKJ-2 (c) ZKJ-3

(d) ZKJ-4 (e) ZKJ-5

Figure 5. Strain distribution of steel bar

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 -- through crack -- beam yield -- limit -- failure 5 stages.

(2) The hook-type joints have full hysteretic loop and good plastic deformation capacity. The ductility coefficients of the joints are all greater than 3.5, which indicate that the hook-type joints have good ductility.

(3) After the hook-type joints reach the yield load, the steel bar strain in the post-pouring band maintains a stable growth, which means it has good working performance.

(4) The hook-type joints of the prefabricated concrete frame have good seismic performance and reliability.

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