Experimental Study on Seismic Behaviour of Angle Steel Connections with Concealed Corbel of Fully Assembled Frame Beam and Column

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Abstract. A method of “concealed corbel angle steel and bolt” is proposed to connect beams and columns of assembled frame. To study the seismic performance of the connection is designed an ordinary concrete beam specimen and three in the form of assembly connection specimens. The hysteretic curve, skeleton curve and ductility coefficient of cast-in-place specimen and angle steel connection specimen with concealed corbel are analysed by low cycle repeated load test. The influence of the angle steel thickness and the additional rib on the specimen in the assembly connection scheme is discussed. The test results show that: compared with ordinary cast-in-place concrete specimens, the assembly connection specimens have higher bearing capacity under the action of low-cycle reciprocating load. The hysteretic curves of the assembly and connection specimens were relatively full, and the displacement ductility coefficient was greater than 3.0, indicating that the assembly and connection specimens had good ductility. Increasing the thickness of the Angle steel and the additional ribs can improve the bearing capacity of the specimens. In particular, increasing the thickness of the Angle steel can significantly improve the bearing capacity of the specimens assembled and connected and reduce the damage of dark corbel before loading.

Keywords. Full assembly, concealed corbel, angle steel, bolt connection, seismic performance.

1. Introduction
Prefabricated structure [1-3] is a new type of structure developed by our country, and it is the only way for construction industrialization. In recent years, due to the needs of China’s economic development, all walks of life are actively changing to the production mode of flow. The construction industry is also slowly changing from the traditional cast-in-place mode to the industrial production mode, and the concept of industrial production of construction is gradually recognized by everyone, so that the component design and production has become more standardized, streamlined construction process and the organization and management of more clearly. Compared with the cast-in-place frame structure, prefabricated structure has the advantages of high production efficiency, short construction period, small environmental impact and less personnel demand. However, the prefabricated concrete frame structure also has some shortcomings, such as poor integrity, difficult design and high construction precision. Compared with steel structure, concrete structure has irreplaceable advantages in structural stability and durability. However, the prefabricated Production and rapid construction speed of steel structure can not be achieved by concrete structure. At present, cast-in-place concrete structure is still the dominant position in China. Therefore, in order to realize the production mode, it is necessary to start from the structural design and create new structural systems, such as prefabricated
structural system [4-9] and steel structure connection system [10-11], etc. most of the building components become finished or semi-finished products in the factory, thus forming an industrialized production mode. It is particularly urgent to establish the system.

At present, scholars at home and abroad have carried out a lot of experimental research on the connection form of prefabricated concrete frame beams and columns. Huang Xianghai [12] designed the steel plate welded concealed corbel form. The test results show that the connection has good deformation performance and the bearing capacity is similar to that of cast-in-place joint. Cai Xiaoning [13] proposed a dry-type connection based on the energy consumption of angle steel and the self reset capacity provided by prestressed reinforcement The results show that the connection has good energy dissipation capacity and self reset capacity; Vidjeapriya [14] designed the beam column connection with open corbel and angle steel, its bearing capacity has decreased, but it is better than cast-in-place joint in displacement ductility and energy consumption; Zhao Bin [15] proposed a fully assembled high-strength concrete beam column joint, through low cycle repeated load test. The results show that under the same ultimate displacement, the bearing capacity of the joint is higher than that of cast-in-place and post-cast integral beam column joints, but its energy dissipation capacity is less than that of cast-in-place and post-cast integral beam-column joints.

On the basis of summarizing the existing prefabricated beam column dry connection, this paper puts forward a connection form of using concealed corbel angle bolt of assembled frame beam column, carries out experimental research on it, analyzes the influence of different angle steel thickness and angle steel rib on the connection performance, and puts forward suggestions for the subsequent design improvement of the specimen connection.

2. Test Overview

2.1. Specimen Design and Fabrication

This test mainly studies the failure characteristics and seismic performance of the prefabricated frame beam column concealed corbel angle steel connection. One ordinary cast-in-place concrete specimen and three assembled frame beam column connection specimens are designed. The dimensions of the ordinary cast-in-place concrete specimen and the fabricated frame beam column connection specimen are the same, the beam length is 1200 mm, the beam section size is 250 mm × 450 mm, the column height is 1500 mm, and the column section size is 400 mm × 400 mm. Prefabricated members were used in all the beams and columns. Four bolt holes with embedded steel sleeve are reserved in the concealed corbel of the column, and four high-strength bolts required for subsequent connection of the notch beam are embedded in the upper part of the column; the beam is a concrete notch beam, and four bolt holes with embedded steel sleeve corresponding to the concealed bracket are reserved at the notch beam Four high-strength bolts are embedded at the bottom of the beam to connect the bottom of the beam with the concealed corbel. During the fabrication of the specimen, the local bearing steel plate is embedded in the notch beam and the concealed corbel to prevent the local crushing of the concealed corbel. The notched beam and precast column are connected as a whole by high-strength bolts through the top angle steel and the bottom steel plate. The specific size of the specimen is shown in figure 1, and the parameters of the specimen are shown in table 1.

Concrete with strength grade of C45 is used for beam and column members of the specimen, M22 high-strength bolt with strength of 10.9 is used for bolt, HRB400 reinforcement is used for beam column reinforcement, and HRB300 reinforcement is used for stirrup. The strength grade of angle steel, connecting cover plate and embedded steel plate is Q235. When assembling frame beam column specimens (SJ-2, SJ-3, SJ-4) for connection, the beam column joint surface is poured with high-strength mortar with a thickness of 10 mm. The standard value of concrete cube compressive strength measured by universal testing machine is 63.23 N/mm². The material properties of steel bar and steel plate are shown in table 2.
Figure 1. Detailed size of specimen and angle steel details (Note: The size unit is mm).

Table 1. Specimen design parameters.

| Specimen number | Column section (b×h)/mm | Beam section (b×h)/mm | Connection type | Angle section (mm) |
|-----------------|--------------------------|-----------------------|-----------------|-------------------|
| SJ-1            | 400×400                  | 250×450               | Cast-in-place   | -                 |
| SJ-2            | 400×400                  | 250×450               | Assembly connection | 180×180×10(1#) |
| SJ-3            | 400×400                  | 250×450               | Assembly connection | 180×180×10(2#) |
| SJ-4            | 400×400                  | 250×450               | Assembly connection | 180×180×12(3#) |

Table 2. Test results of mechanical properties of steel bars.

| Type             | Grade | \( f_y \) (Pa) | \( f_u \) (MPa) |
|------------------|-------|----------------|-----------------|
| Steel plate (10mm) | Q235  | 333.33         | 498.33          |
| Steel plate (12mm) | Q235  | 425.00         | 565.00          |
| HRB400           | 12    | 415.33         | 568.43          |
| HRB400           | 14    | 435.08         | 587.08          |
| HRB400           | 16    | 453.10         | 625.39          |
| HRB400           | 18    | 390.04         | 619.25          |
2.2. Test Loading Device and Loading Scheme
The schematic diagram of loading device for assembling frame beam column concealed corbel angle steel connection is shown in figure 2. During the test, 850kN axial force was applied to the upper end of the column by Jack, and the axial compression ratio was 0.2. Then the compression beam was strengthened and the low cycle repeated load was applied at the end of the beam. In the initial stage of loading, the test piece is pre-loaded and debugged to ensure the machine and instrument can collect data normally. The displacement controlled loading method is adopted. Before the specimen yields, it is loaded once with the displacement of 1 mm at each stage. After the specimen yields, the specimen is repeatedly loaded under the same displacement for 3 times until the horizontal bearing capacity of the specimen decreases to 85% of the specimen is obviously damaged and cannot stop bearing the predetermined force. The loading system is shown in figure 3.

![Figure 2. Schematic diagram of test loading device.](image)

![Figure 3. Loading system.](image)

3. Test Phenomena and Failure Modes
At the initial stage of loading, the cast-in-place specimen SJ-1 is in elastic working state, and there is no visible crack. At this time, the load displacement skeleton curve is almost linear. When the displacement is loaded to 3.0 mm, the first visible horizontal crack appears at the bottom of the west side of the specimen, and the horizontal crack successively appears in the East and west side of the specimen and extends to the South and north side. When the displacement is loaded to 5.0 mm, a new through crack appears in the middle and lower part of the East, and several small inclined cracks appear in the north and south of the specimen. When the displacement is loaded to 10.0 mm, the crack in the lower part of the north side is obviously widened by about 1 mm, and the crack at the root of the East and west side is widened by about 1.5 mm. When the displacement is loaded to 12 mm, new inclined cracks appear in the core area of the beam column connection root, and the original cracks continue to extend and form new inclined cracks. At the same time, the intersection oblique cracks appear in the north and south sides. When the displacement is loaded to 20 mm, the concrete at the root of the West and north sides will fall off less. The cracks at the bottom of the north are widened to 4mm, and the concrete at the bottom of the East has obvious cracks about 5 mm. When the displacement load reaches 29 mm, the concrete at the root of the specimen falls off in varying degrees, and the crack continues to widen, and there is concrete tearing sound from time to time. When the displacement load reaches 36 mm, the concrete at the root of the core area of the specimen is crushed by a large block and the reinforcement is exposed, and the loading stops when the specimen is damaged. The crack distribution of the specimen is shown in figure 4.

![Figure 4. Crack distribution of the specimen.](image)

The failure process of the assembled frame beam column concealed corbel angle steel connection specimen is approximately the same. Taking the specimen SJ-4 as an example, the failure process of the assembled specimen is illustrated. At the initial stage of loading, the specimens show good strength and stiffness, and the specimens are in the elastic stage. When the displacement is loaded to 2
mm, the first oblique crack appears in the middle and lower part of the north part of the specimen, and there is a horizontal crack at the upper part of the steel cover plate in the south. When the displacement is loaded to 3 mm, there is an inclined crack in the middle and lower part and middle part of the corbel in the north, and has the trend of penetrating development. At the same time, inclined cracks were found in the middle and lower part of the South corbel. When the displacement is loaded to 7 mm, the first crack in the west is obviously widened by about 0.5 mm, horizontal cracks appear at the bottom of the North notch, and the crack in the middle and lower part of the notch in the South extends about 6 cm. When the displacement is loaded to 10 mm, the specimen enters the yield stage, horizontal cracks appear in the upper part of the North bracket, extension of horizontal and oblique fractures in the middle and lower part of the South, and the first initial inclined crack in the north side continues to extend to the horizontal crack about 9 cm long. When the displacement is loaded to 18 mm, the bottom of the notched beam in the South and the north side is obviously pulled up, there are many inclined cracks at the North corbel. When loading to 24 mm, the first initial crack in the North continues to widen by about 3.5 mm, the crack at the bottom of the gap in the north is widened by about 2 mm, the middle and lower parts of the bracket continue to produce cross fracture, and the upper part of the bracket produces horizontal cracks. When the displacement is loaded to 28 mm, the concrete at the first initial crack in the north is divided into many small blocks of different shapes, and the concrete at the bracket bulges. When the load reaches 36 mm, the small blocks in the middle and lower parts of the notched beams in the South and North are pulled up by about 6 mm, and the reinforcement is exposed. At this time, it is considered that the specimen is damaged and stops loading. The crack distribution of the specimen is shown in figure 4.

4. Test Results and Analysis

4.1. Hysteresis Curve
The hysteretic curve of each specimen is shown in figure 5. It can be seen from the figure that the hysteretic curve of SJ-1 is full and has good seismic performance. As for the specimen with assembly connection, the upper and lower connection modes of the beam are different, the upper part of beam section is connected with precast column by angle steel, and the lower part is connected with steel cover plate, which is the main reason for the push-pull asymmetry of hysteretic curve. However, the asymmetry of hysteretic curve of cast-in-place specimens is due to the reasons of specimen fabrication and pouring. The hysteretic curves of the three assembled specimens are basically the same, and there is obvious pinch shuttle phenomenon in the hysteretic curves. SJ-4 is used to explain the hysteretic characteristics of the assembled connection specimens. At the beginning of the test loading, the load displacement curve of the specimen is in the elastic working stage. With the further increase of displacement loading, the joint of precast beam and column is pulled up and the initial crack develops, the area surrounded by the hysteresis loop gradually increases, which indicates that the energy
consumption of the specimen increases gradually, and the specimen is in a non-linear elastic state. When the specimens yield, the peak load of the last two loads is lower than that of the first one under the same displacement, which indicates that the specimen has strength degradation. Compared with the cast-in-place specimens, the strength degradation of the assembled specimens is greater, the joint gap between precast columns and notched beams is gradually widened, and the cracks in the beam body continue to develop, and the stiffness of the specimens further decreases and tends to be stable. With the increase of displacement to the peak load, the deformation of the specimen is accelerated. The hysteresis curve has obvious slip phenomenon due to the large cracks in the concrete at the joint of angle steel and bottom steel plate, and the residual deformation of the specimen is obvious. When the specimen continues to be loaded to the peak load, the load of the specimen begins to decrease. When the specimen tends to be damaged, the concrete at the joint of the angle steel and the steel cover plate is crushed and falls off. At this time, the specimen basically fails and stops loading. Comparing the assembled specimen with the cast-in-place specimen, it can be found that the load of the cast-in-place specimen basically does not decrease after the peak load is loaded. The main reason is that the initial loading level is too small, so that the concrete at the root of the specimen is completely crushed at the later stage of loading, and the reinforcement does not yield. Only the reinforcement moves during the push-pull loading in the later stage of the test, so the cast-in-place specimen has no obvious descending section in the later stage. There are different degrees of pinch shuttle phenomenon in the hysteretic curve of each specimen. The hysteretic curve of the cast-in-place joint is fuller than that of the integral assembled joint, and the bearing capacity of the fabricated joint is slightly lower than that of the cast-in-place joint.

Figure 5. Nodal hysteretic curve.
4.2. Skeleton Curve

The skeleton curve of each specimen is shown in figure 6. The change trend of skeleton curve of cast-in-place specimen and assembled specimen in the test is consistent. At the beginning of the test, the load displacement relationship curve changes linearly, and the skeleton curve of the specimen basically coincides. With the further increase of displacement, the cracks at the joints of prefabricated beams and columns are widened and the cracks in the beam body develop, and the slope of skeleton curve of the specimens decreases, which indicates that the specimens have entered the inelastic stage. When the load reaches the peak load, the skeleton curve begins to decline.

![Skeleton Curve](image)

Figure 6. Skeleton curve of specimen.

It can be seen from figure 6 that the positive peak load of the cast-in-place specimen SJ-1 is 164.67kN, and the positive peak load of the three assembled specimens are 126.08kN for SJ-2, 122.36kN for SJ-3, and 120.48kN for SJ-4. Compared with the cast-in-place specimens, the positive bearing capacity of the assembled specimens decreased. The negative peak load of cast-in-place specimen is 127.17kN, and the negative peak load of SJ-2, SJ-3 and SJ-4 is 113.95, 123.23 and 154.63kN respectively. The negative bearing capacity of assembled specimen SJ-2 is lower than that of cast-in-place specimen SJ-1, and the negative bearing capacity of assembled specimen SJ-3 and SJ-4 is significantly higher than that of cast-in-place specimen SJ-1, which indicates that the bearing capacity of the specimen can be significantly improved by the thickness of additional rib and thickened angle steel.

4.3. Ductility

Ductility refers to the deformation capacity from the moment of yielding to the maximum bearing capacity or after reaching the maximum bearing capacity without obvious reduction of bearing capacity. Ductility reflects the deformation capacity of the structure and is also one of the important indexes to measure the seismic performance of the structure. The displacement ductility coefficient refers to the ratio of failure displacement to yield displacement of the specimen [16]: \( \mu = \Delta u / \Delta y \). The yield displacement is calculated by the skeleton curve value using the equal energy method, and the failure displacement is the maximum displacement when the load drops to 85% of the peak load. The ductility coefficient of the specimen is shown in table 3. It can be seen from the table that the displacement ductility coefficients of the specimens with assembly connection are all greater than 3.0, which indicates that the assembled connection specimens have good ductility.
Table 3. Displacement ductility coefficient of specimen.

| Specimen number | Load direction | Yield displacement $\Delta y$/mm | Yield load $P_y$/kN | Peak Value displacement $\Delta max$/mm | Peak value load $P_{max}$/kN | Destruction displacement $\Delta u$/mm | Destruction load $P_{u}$/kN | Ductility coefficient $\mu = \Delta u/\Delta y$ |
|-----------------|----------------|----------------------------------|---------------------|----------------------------------------|----------------------------|----------------------------------------|-----------------------------|---------------------------------------------|
| SJ-1            | +              | 8.47                             | 147.05              | 31.57                                  | 164.67                    | 38.83                                  | 161.35                      | 4.35                                        |
|                 | -              | 9.38                             | 109.40              | 28.15                                  | 127.17                    | 38.83                                  | 119.90                      |                                             |
| SJ-2            | +              | 5.74                             | 113.15              | 16.92                                  | 126.08                    | 32.84                                  | 120.12                      | 4.86                                        |
|                 | -              | 9.07                             | 93.37               | 29.00                                  | 113.95                    | 36.16                                  | 106.87                      |                                             |
| SJ-3            | +              | 6.66                             | 108.17              | 19.54                                  | 122.36                    | 31.81                                  | 105.25                      | 3.90                                        |
|                 | -              | 10.42                            | 95.46               | 23.86                                  | 123.23                    | 31.60                                  | 104.75                      |                                             |
| SJ-4            | +              | 7.22                             | 99.78               | 16.00                                  | 120.48                    | 30.96                                  | 102.40                      | 4.29                                        |
|                 | -              | 9.28                             | 92.88               | 31.81                                  | 154.63                    | 39.76                                  | 135.58                      |                                             |

5. Conclusion

One cast-in-place frame beam column specimen and three assembled frame beam column concealed corbel angle steel connection specimens were tested under low cycle cyclic loading. The load displacement hysteretic curve, skeleton curve, ductility and other seismic performance indexes of the assembled joint were obtained, through the analysis of its seismic performance, the following conclusions are obtained:

1. Compared with the ordinary cast-in-place concrete specimen and the assembled frame beam column concealed corbel angle steel connection specimen, the assembly connection specimen has a higher bearing capacity under the low cycle reciprocating load. The bearing capacity of the connection angle steel can basically reach the cast-in-place bearing capacity with the change of angle steel additional rib and angle steel thickening, while the bearing capacity of the side with steel cover plate connection is lower than that of the cast-in-place specimen.

2. The hysteretic curves of the assembled connection specimens are full, and the displacement ductility coefficients are greater than 3.0, which indicates that the assembled connection specimens have good ductility.

3. Increasing the thickness of angle steel and additional ribs can improve the bearing capacity of the specimen. Especially, increasing the thickness of the angle steel can significantly improve the bearing capacity of the assembly connection specimen and reduce the bearing capacity of the bracket.

4. It is suggested that increasing the thickness of angle steel and adding additional ribs can improve the seismic performance of the assembled specimens and make them equal to cast-in-place.

References

[1] Gu T C 2014 Development status of prefabricated buildings at home and abroad Engineering Construction Standardization (8) 48-51.

[2] Jiang Q J 2010 Summary of the development of prefabricated concrete building at home and abroad Construction Technology 41(12) 1074-1077.

[3] Liu Q, Li X M and Xu Q F 2014 Research and application status of prefabricated concrete structure Construction Technology (22) 9-14.

[4] Wu B H, Gao Z, Yang X P, Dong J Y and Wei W H 2016 Experimental study and finite element analysis on seismic behavior of dry-type notched beam column joints Journal of Wuhan University of Technology 38(10) 74-79.

[5] Song Y P, Wang J, Fan G X and Cheng W P 2014 Experimental study on mechanical properties of beam column joints of prefabricated frame structure Journal of Dalian University of Technology 54(04) 438-444.

[6] Zeng Z P, Hu Z M and Li B 2018 Design and finite element analysis of rigid dry-type beam column connections for prefabricated buildings Chinese Standardization (12) 63-64.

[7] Shi C H 2017 Experimental Study on Prefabricated Concrete Beam Column Joints with Steel Plate Bolt Connections (Beijing University of Architecture).
[8] Guan D, Guo Z and Xiao Q 2016 Experimental study of a new beam-to-column connection for precast concrete frames under reversal cyclic loading Advances in Structural Engineering 19(3) 529-545.

[9] Liao X D, Hu X and Ma R Q 2016 Experimental study on seismic behavior of joints in prefabricated monolithic prestressed concrete frames with high axial compression ratio Journal of Building Structures 37(10) 82-89.

[10] Yang J F, Chen L, Cheng J P, Zhan Y H and Yan X F 2017 Experimental study on seismic behavior of a new type of prefabricated beam column joint Engineering Mechanics 34(12) 75-86.

[11] Zhou T H, Wu H H, Bai L, Guan Y, Li W C and Wang S W 2014 Experimental study on seismic performance of steel frame steel reinforced concrete lateral wall fabricated structure Journal of Building Structure 35(07) 131-137.

[12] Huang X H 2006 Research on New Type of Precast Concrete Frame Joints Southeast University.

[13] Cai X N and Meng S P 2018 Research on restoring force model of prestressed self-restoring concrete frame joints Engineering Mechanics 35(01) 182-190 + 200.

[14] Vidjeapriya R and Jaya K P 2013 Experimental study on two simple mechanical precast beam-column connections under reverse cyclic loading Journal of Performance of Constructed Facilities 27(4) 402-414.

[15] Zhao B, Lv X L and Liu L Z 2005 Experimental study on seismic behavior of precast concrete beam column assemblies Earthquake Engineering and Engineering Vibration (01) 81-87.

[16] JGB50011-2010 2010 Code for Seismic Design of Buildings (Beijing: China Construction Industry Press).