Experimental study on bending of local members cut in large precast concrete columns

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Abstract: The static bending test of 5 concrete trabeculas cut from two large prefabricated members is carried out, and the parameters such as reinforcement ratio and deflection of longitudinal reinforcement are studied, and the mechanical characteristics of the members and the bearing capacity of the normal section are analyzed in combination with the current code, cracks and deflection. The results show that: (1) The stress characteristics of cut trabeculae are the same as those of ordinary reinforced concrete beams, and the average strain of concrete keeps plane along the section; (2) The deflection of longitudinal tendons and the reinforcement ratio of upper longitudinal tendons have no significant effect on the bearing capacity of members; (3) The maximum crack width and the average crack spacing are in agreement with the calculated values of the code, which can be calculated according to the current code; (4) The crack width and deflection meet the requirements of the current code.

1. Introduction
Because of its large size, self-weight, high center of gravity and multi-offset, high bearing capacity, large-scale precast concrete members are difficult to test and realize. In our country's current standard "Code for acceptance of Construction quality of concrete structure Engineering" (GB50204-2015) [3], there is a lack of acceptance methods corresponding to the structural performance of large concrete prefabricated members. After cutting large prefabricated members, the axial compression test and bending test are carried out to verify the structural performance of the large prefabricated members. The compression test mainly verifies the quality of concrete, while the flexural test mainly verifies the tensile behavior of steel bar and the compressive performance of concrete. In this paper, the bending test of local members is carried out: (1) under vertical load, the bearing capacity, deflection, crack and failure characteristics are studied; (2) the influence of reinforcement ratio and deflection of longitudinal reinforcement on the flexural load of the members is studied to verify the feasibility of calculating the local members' bearing capacity according to the current standard formula.

2. Pilot scheme
Two large prefabricated concrete specimens, numbered 1-1 #1 and 1-2 #1, were designed. The original members are cut along the axis of symmetry into 8 small columns under axial compression. The section size is 400 mm, the length is 3120 mm, the thickness of the protective layer is 25 mm, the strength grade of concrete is C40, and the longitudinal reinforcement is made of HRB400 steel bar with nominal diameter of 22mm. Stirrups are made of HRB400 bars with nominal diameter of 10mm.

2.1 Design of large scale precast concrete specimen
The 1-1# of large precast concrete specimens is made up of three kinds of reinforcement methods, A,
B and C. The specimen 1-2# is made up of D.

Table 1 Prototype test piece design parameter list

| number | Specimen size (mm) | Concrete strength (MPa) | Reinforcement mode | Quantity and specification of steel bar | Protective layer thickness (mm) |
|--------|------------------|-------------------------|--------------------|----------------------------------------|-------------------------------|
| 1-1#   | 6000*800*800     | C40                     | A                  | 6\#22, \#10@100                        |                               |
|        |                  |                         | B                  | 14\#22, \#10@100                       | 25                            |
|        |                  |                         | C                  | 13\#22, \#10@100                       |                               |
| 1-2#   | 4500*800*800     | C40                     | D                  | 12\#22, \#10@100                       | 25                            |

Fig 1 Prototype member 1-1#, 1-2# rebar layout
2.2 Reinforcement of curved trabeculae after cutting

There are five types of internal reinforcement in the locally curved trabeculae cut from the large precast concrete specimens 1-1# and 1-2#, among which there are four beams with L2PJ40L3PJ40L4PJ40L4PJY40 type reinforced beams and one LCPJ40 type reinforced trabeculae. The bending trabeculae are divided into two types: L2PJ40, L3PJ40, L4PJ40, L4PJY40, L4PJY40, L4PJY40, L4PJ40.

| specimen | Curved | size (mm) | strength (MPa) | steel bar | layer (mm) | Number |
|----------|--------|-----------|----------------|-----------|------------|--------|
| 1-1# L2PJ40 | 3120*400*400 | C40 | 2#22, #10@100 | 25 | 1 |
| 1-1# L3PJ40 | 3120*400*400 | C40 | 3#22, #10@100 | 25 | 1 |
| 1-1# L4PJ40 | 3120*400*400 | C40 | 4#22, #10@100 | 25 | 1 |
| 1-1# L4PJY40 | 3120*400*400 | C40 | 4#22, #10@100 | 25 | 1 |
| 1-2# LCPJ40 | 3120*400*400 | C40 | 3#22, #10@100 | 25 | 4 |
3. General situation of test

Fig. 4 is a loading device used for beam bending performance test. The loading equipment is a Jack. A pure bending section is formed in the middle of the span by two point concentrated force loading. The load is distributed by the Jack and the counterforce beam, and the load value is measured by the pressure sensor. A steel pad with a height of 10mm is installed at the support of the specimen to prevent local damage to the end due to stress concentration. The flexural properties of the beam were tested, and the L=3120mm, a=100mm, b=1040mm, c=1040 mm.

3.1 performance tests of materials

In order to obtain the practical mechanical properties of the specimens, tensile tests were carried out on the strength of the steel bars of the same size and the same batch as the specimens (2 bars of each size, each length of 500mm). Six groups (3 in each group) were set aside for each column to be 100 × 100 × 100mm cubic concrete specimens, which were maintained in the same condition as the test members, and the axial compression tests of the cube test blocks were carried out. The results of wood tests are shown in tables 3 and 4.
Table 3 Mechanical properties of steel bars

| Kind   | Diameter (mm) | Actual sectional area(mm²) | Yield strength(MPa) | Ultimate tensile strength(MPa) |
|--------|---------------|-----------------------------|---------------------|-------------------------------|
| HRB400 | 10            | 82.11                       | 424.06              | 658.51                        |
|        | 22            | 388.45                      | 466.66              | 620.52                        |

Table 4 Mechanical properties of concrete

| Specimen number | $f_{cu}$ (MPa) | $f_c$ (MPa) | $f_t$ (MPa) | $E_c$ (GPa) | Batch     |
|-----------------|----------------|-------------|-------------|-------------|-----------|
| 1-1#、1-2#      | 40.50          | 27.10       | 2.06        | 32.72       | first     |
|                 | 43.60          | 29.14       | 2.59        | 33.40       | second time |
|                 | 44.70          | 29.67       | 2.65        | 33.60       | third time |

3.2 Test measurements
The main contents of the test are as follows: 6 displacements in span, two loading points and two supports, cracking load, ultimate load and longitudinal tension under various loads, strain, crack width and crack distribution of compressive steel bar and concrete.

4. experimental phenomenon

4.1 Cross-section strain-preserving plane

Fig5 Average concrete strain of different height
The basic premise of the calculation theory of reinforced concrete flexural members is the assumption of plane section. The strain of trabecular beam under each stage load is measured by attaching concrete strain gauge on both sides of the trabecular beam. The average strain of concrete. L2PJ40 trabecular beam is calculated. The average strain of concrete along the cross section height direction of the trabecular beam is shown in Fig. 5. From Fig. 5, it can be seen that with the increase of load, the neutral axis of section moves up step by step, and the average strain of concrete exhibits linear distribution under various loads, and the cross-section strain of the trabecular beam remains plane all the time, which accords with the assumption of plane section.

4.2 Load-Rebar strain / deflection Curve
At the beginning of the test, the load is small, the side of the member is not cracked, the member shows elastic deformation, the steel bar is pulled, the growth of the compressive strain and the deflection of the member are approximately straight line. When the load gradually increases to 60KN,
When the load increases to 250KN, the tension begins to yield and the load-strain curve of the steel bar appears a second turning point. At this loading stage, the deflection increases rapidly, the crack lengthens rapidly, and the load-deflection curve shows a second obvious turning point. When the reinforcing bar enters the strengthening stage, the range of load growth is very small, approximately straight line, the deflection further increases until the concrete is crushed, and the members show obvious ductility. The strain-load curve of steel bar in span is shown in Fig. 6, the curve of deflection load in span of specimen is shown in Fig. 7, and the failure of member is shown in Fig. 8.

5. Test results and analysis

5.1 limit load
The experimental results show that the mechanical behavior of concrete trabeculae with different upper longitudinal reinforcement ratio and longitudinal tendons deflection is the same as that of ordinary reinforced concrete beams. When the ultimate state of bearing capacity is reached, the steel bar yields and the member is destroyed with obvious omens, which begins to load to the normal
section of the beam, and the average strain of the section accords with the assumption of the plane section. Table 5 lists the values of the ultimate moment Mu and the ratio of the measured ultimate moment M and Mu/M calculated from the concrete strength and the yield strength of the steel bar calculated by the code formula. Table 5 shows that the calculated limit moment Mu is in good agreement with the measured limit moment M in accordance with the average value of Mu / M ratio. It shows that the formula for calculating the normal section bearing capacity of flexural members in GB50010-2010 (2015 edition) code is still applicable to the cutting reinforced concrete beams.

The thickness of L3PJ40 protective layer is 30 mm LCPJ 40 is 90 mm. Table 5 shows that the difference between the experimental bearing capacity of L3PJ40 and that of LCPJ40 is 2KN, and the effect on the overall bearing capacity of the member is 1.2. It can be seen that the influence of longitudinal tendons deflection on the bearing capacity of the member is not significant. The analysis of L2PJ40,L3PJ40,L4PJW40,L4PJY40, L4PJY40 in Table 5 shows that there is no obvious change in the bearing capacity of the members with different ratio of longitudinal reinforcement, and the range of test value is about 2KN (1.2%), which shows that the upper longitudinal reinforcement has no obvious change. The reinforcement ratio has no effect on the bearing capacity of the members.

| Table 5 Component test results |
|--------------------------------|
| Number | f₀ (N/mm²) | fᵣ (N/mm²) | Theoretical bending moment M₀ (KN·mm) | Test bending moment M (KN·mm) | M₀/M |
|--------|------------|------------|----------------------------------|-----------------|------|
| L2PJ40 | 29.67      | 466.66     | 171.92                           | 172.11          | 0.99 |
| L3PJ40 | 29.67      | 466.66     | 167.61                           | 174.25          | 0.96 |
| LCPJ40 | 29.67      | 466.66     | 165.27                           | 172.18          | 0.96 |
| L4PJW40| 29.67      | 466.66     | 165.45                           | 165.98          | 0.99 |
| L4PJY40| 29.67      | 466.66     | 173.20                           | 174.73          | 0.99 |

5.2 stiffness and deflection

By comparing the measured deflection of span with the calculated value of GB50010-2010 (2015 edition) code in Table 6, we can find that the average value of the calculated value of the code is 10.445, the average value of the test value is 11.106, and the calculated value of the code is less than the experimental value. When the deflection is calculated according to the specification, the stiffness multiplied by the reduction coefficient of 0.85 is adjusted and compared with the experimental value. It was found that the average value of fs/f was 0.947 and the coefficient of variation δ (0.012) was 0.012. The calculated deflection f was in good agreement with the measured deflection f, indicating GB50010-2010 (2015 edition) Code flexural member deflection calculation formula is still applicable to cut reinforced concrete trabeclae.

The specification states that the deflection limit of the flexural member is D / L 1 / 200. It can be seen from Table 6 that the ratio of deflection to span of test beams under long term load is less than 1 / 200, so the deflection limit value of cutting concrete flexural members under long term load can meet the requirements of the code.

| Tab6 | Short-term rigidity and deflection of beam |
|------|-------------------------------------------|
| Member | M₀ (KN·mm) | E₀ (GPa) | B₀ (EPa) | f₀ | f | Δf/f |
| L2PJ40 | 171.92 | 33.60 | 16.38 | 8.51 | 9.21 | 0.94 |
| L3PJ40 | 167.61 | 33.60 | 13.31 | 10.21 | 11.36 | 0.96 |
| LCPJ40 | 165.27 | 33.60 | 12.47 | 10.37 | 11.03 | 0.95 |
| L4PJW40 | 165.45 | 33.60 | 11.17 | 12.02 | 12.11 | 0.96 |
| L4PJY40 | 173.20 | 33.60 | 12.62 | 11.13 | 11.82 | 0.93 |

| μ | 0.947 |
| δ | 0.012 |
5.3 crack spacing and fracture width

When the member is near the ultimate load of 90, the crack has become stable. While describing the fracture shape, the horizontal spacing of each crack in the pure bend section is measured, and the average crack spacing in the pure bend section is taken as the average value, which is compared with the average crack spacing calculated according to the GB50010-2010 (2015 edition) code in Table 7. Table 7 shows that the calculated ratio of mean crack spacing to experimental average crack spacing is 0.958, and the coefficient of variation δ is 0.030. The measured values are in good agreement with the calculated values. Average crack of reinforced concrete flexural members with visible cutting The gap can still be calculated according to the standard formula.

Table 7 Comparison of theory value to tested value of average crack spacing

| Member    | \( L_c \) (cm) | \( L \) (cm) | \( L_c/L \) |
|-----------|----------------|--------------|-------------|
| L2PJ40    | 11.46          | 11.85        | 0.97        |
| L3PJ40    | 11.36          | 11.67        | 0.97        |
| LCPJ40    | 11.9           | 12.68        | 0.94        |
| L4PJW40   | 10.90          | 11.85        | 0.92        |
| L4PJY40   | 12.02          | 12.13        | 0.99        |

\( \mu \) 0.958
\( \delta \) 0.030

When checking the crack width of concrete members, according to the standard combination of loads and considering the effect of load long-term effect. The influence of long-term effect can not be considered in the test. Under the test condition, the short-term load effect under the limit state of normal use is calculated by the design load effect. The normal load effect is about 80% of the design load effect. In the normal service limit state, the maximum crack width formula in the code is used to calculate. If the increase coefficient of crack width is 1.5 under long term load, the maximum crack width under long term load can be inferred according to the measured maximum crack width under short term load. Short-term load The measured maximum crack width \( \omega_0 \) under load and the maximum crack width \( \omega_1 \) calculated by the code are compared with the calculated ones in Table 8, and the calculated maximum crack width \( \omega_c \) is compared with the calculated maximum crack width \( \omega_1 \) under long-term load.

As can be seen from Table 8, The ratio of the maximum crack width \( \omega_1 \) calculated according to the code and the maximum crack width \( \omega \) under the load calculated by the code and the maximum crack width \( \omega_0/\omega \) under the load calculated according to the measured value of the test is 1.037. The coefficient of variation \( \delta \) is 0.073. It can be seen that the current code is concerned with coagulation. The formula for calculating the maximum crack width of soil bending members under long term load is suitable for cutting concrete trabeculae. The maximum crack width of the test beam is less than or equal to 0.30mm. Therefore, according to the specification, the crack width of the cut reinforced concrete flexural members meets the requirements under the normal service limit state.

Table 8 Comparison of theory value to tested value of maximal crack width

| Member    | \( \omega_1 \) (mm) | \( \omega_0 \) (mm) | \( \omega \) (mm) | \( \omega_0/\omega \) |
|-----------|---------------------|---------------------|------------------|---------------------|
| L2PJ40    | 0.33                | 0.21                | 0.32             | 1.03                |
| L3PJ40    | 0.33                | 0.20                | 0.30             | 1.10                |
| LCPJ40    | 0.34                | 0.22                | 0.33             | 1.03                |
| L4PJW40   | 0.32                | 0.19                | 0.29             | 1.10                |
| L4PJY40   | 0.35                | 0.25                | 0.38             | 0.92                |

\( \mu \) 1.037
\( \delta \) 0.073
6. conclusion

(1) The stress characteristics of the cut reinforced concrete trabeculae are basically the same as those of the ordinary reinforced concrete beams. The average strain of concrete keeps a plane along the section and load-deflection. The strain curve of tensile steel bar has two obvious turning points as that of ordinary reinforced concrete beam. One turning point corresponds to concrete cracking and two turning points correspond to the yield of tensile steel bar.

(2) The influence of longitudinal tendons deflection and the ratio of upper longitudinal reinforcement on the bearing capacity of the members is not significant.

(3) The measured values of ultimate bearing capacity test, the maximum crack width and the maximum crack width measured by the average crack spacing test are in good agreement with the theoretical values calculated according to the code, and can be calculated according to the GB50010-2010 (2015 edition) code.

(4) Under normal service condition, component deflection and crack width can meet the specification requirements.

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