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To cite this article: Zhe Li *et al* 2020 *J. Phys.: Conf. Ser.* **1626** 012172

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Research on Force Performance of Assembled Frame Beam

Zhe Li^{1,*}, Yandong Hu¹, Chuanzhi Zhao^{1,2} and Chengyuan Qiao¹

¹ College of Civil Engineering and Architecture, Xi'an University of Technology, Xi'an 710048, China

² Tongyuan design group, Ji'nan, 250021, China

*Corresponding author email: lizhe009@163.com

Abstract. Three full-scale specimens of prefabricated frame tongue-and-groove beams connected by high-strength bolts were tested under low-cycle reciprocating loads. The failure patterns, hysteresis characteristics, skeleton curves, ductility of specimens, stiffness degradation and energy dissipation capacity of the assembled specimens were studied and compared with the full-scale ordinary concrete specimens. The test results show that the new form of connection is basically in line with the mechanical behavior of the ordinary concrete specimen, and it is feasible to apply it to the prefabricated frame structure. The test explores the influence of the thickness of the connecting steel plates on the mechanical performances of the prefabricated specimens, and find that the both sides connecting steel plate are more beneficial to the underside plates. In addition, in the design, reasonable selection of bolt and aperture size, the control of the machining error of the specimens, the effective connection of the steel bars jointed of laminated layer can further improve the installation efficiency and seismic performance.

Keywords: Prefabricated frame tongue-and-groove beams; Hidden bracket; High-strength bolts; Connecting steel plates.

1. Introduction

In the process of the rapid development of prefabricated constructions, the frame structure is undoubtedly the most cost-effective structural form, and the prefabricated frame beam, due to its relatively simple structure, is also the main energy dissipation component in the seismic structure, it plays a pivotal role in the process of promoting the prefabricated constructions. Currently, the commonly used fabricated frame structure has the disadvantages of complex construction, weak integrity and poor reliability in earthquake ^[1-2]. The tongue-and-groove connection in this paper is different from the ordinary assembled frame beam-column connection. In order to realize the plastic hinge shift of the frame joints and make full use of the energy dissipation capacity of the frame beam, the traditional frame beam column is moved from the joint to a distance away from the column edge. The hidden bracket is a short cantilever beam extending from the beam node in the lower part of the bracket, known as R part, cantilever beam part known as F part; The R part on the notched beam corresponds to the R part of the cow leg, which is extended from the upper part of the beam, and the rest is called the F part. The two parts are connected by the connection cover plate fixed with high strength bolts and the post-cast composite concrete.

In 2000, Feng Jian of southeast university in China studied the tongue-and-groove connection of prefabricated members earlier, designed a number of different tongue-and-groove lengths, reinforcement forms and specimens of prestressed plain and oblique tongue-and-groove simply supported beams, studied the shear performance of simply supported beams under static load, and



proposed an appropriate design method^[3]. In 2005, Xiang-hai HUANG proposed the tongue-and-groove connection form of assembled frame beam and conducted finite element simulation on it. The simulation results show that the bearing capacity of this dry connection form is close to that of cast-in-place beam-column joints^[4]. Meanwhile, in 2008, the shear friction theory and the pull rod model method were applied to analyze the dark cow leg, and the bearing capacity formula was derived and the corresponding design Suggestions were put forward^[5]. In 2009, Nian WU of southeast university applied the connection form into a single frame and conducted experimental research. The test showed that the structure met the design requirements of bearing capacity^[6], but no specific design parameters were given. Then, in 2011, Xiao-jun WU applied the theory of shear friction to analyze and deduce the bearing capacity formula for the assembled frame beam with oblique tongue-and-groove, and found that the formula was more accurate by comparing with the existing test data^[7]. In 2015, Wen-bin SUN studied the flexural bearing capacity and deformation performance of the precast tongue-and-groove frame beam and found that it was basically the same as the integral casting part. According to the test data, the suitable length of the precast beam was qualitatively given^[8]. In foreign countries, more research on the connection form of the cow cow-leg pillar in industrial buildings is taken as the research object. Based on the above scholars' research on tongue-and-groove frame beam, it can be found that: 1. Finite element analysis and theoretical derivation, lack of experimental data support; 2. Most of the existing tests are static load tests, so it is difficult to explain the performance of this form under the action of earthquake. Based on the above problems, this paper studied the mechanical behavior of the tongue-and-groove frame beam after the improvement of previous tongue-and-groove frame beam and the application of low cyclic load on the specimen. Specific improvement contents: 1. Use high-strength bolts to connect components instead of welding; 2. Considering the actual situation of site construction, post-cast composite layer concrete is set to simulate the influence of the slab and improve the integrity of the component. The design consists of four full-size specimens, including a whole pouring standard part. The influence of the thickness of the side and bottom connection plates on the members is explored and the design Suggestions are given.

2. Test

2.1. Specimen Design

In this experiment, a total of 4 specimens were designed, including 1 whole cast specimen (TGA-NB1) and 3 assembly specimens (TGA-B2, TGA-B3, TGA-B4). The specimens were designed in full scale. The column section size of all specimens is 400mm×400mm. The section of the whole pouring beam is 600mm×300mm. The section of the precast beam section of the assembly specimen (TGA-B2~TGA-B4) is the same as the whole cast specimen, in which the concrete height of the upper post-cast composite layer is 150mm. After the expiration of the curing period, the dark ox leg and notched beam are connected through the side and bottom connection plates with high-strength bolts (10.9 grade M24), and the laminated concrete is finally poured. See figure 1 for detailed reinforcement. The assembly specimens have the same structure except the thickness of the joint cover. The specimen size is shown in table 1.

Table 1. Specimen size.

Specimen	column(mm)	beam(mm)	side connection cove(mm)	bottom connection cover(mm)
TGA-NB1	400×400	300×600	—	—
TGA-B2	400×400	300×600	10	10
TGA-B3	400×400	300×600	10	12
TGA-B4	400×400	300×600	12	10

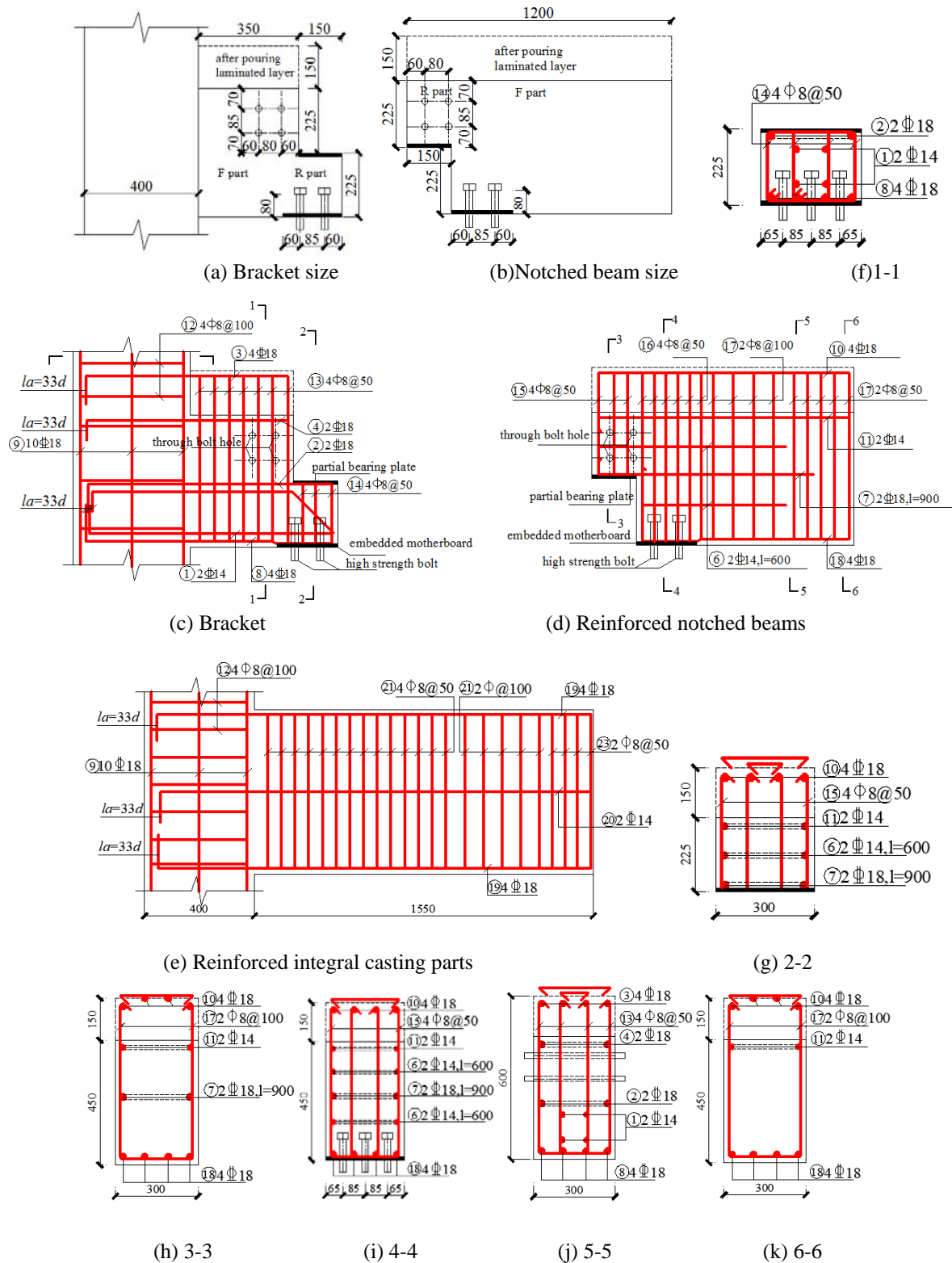


Figure 1. Size and reinforcement of specimen.

2.2. Test Materials

C45 grade commercial concrete was used in all the specimens except the post-pouring composite layer. The compressive strength of concrete cube measured by the universal testing machine was 48.08N/mm^2 . The compressive strength of post-cast concrete (C50S) 53.13N/mm^2 is HRB400 grade, and the steel plate is Q235 grade. The material properties of steel bar and steel plate are shown in table 2.

Table 2. Properties of materials.

Type	grade	Yield strength/MPa	ultimate strength/MPa
Steel plate (10mm)	Q235b	333.33	498.33
Steel plate (12mm)	Q235b	425.00	565.00
Rebar (diameter12mm)	HRB400	415.33	568.43
Rebar (diameter14mm)	HRB400	435.08	587.08
Rebar (diameter16mm)	HRB400	453.10	625.39
Rebar (diameter18mm)	HRB400	390.04	619.25

2.3. Loading System and Loading Device

The test pieces in this paper are all placed in an inverted T shape. The test adopts the method of full displacement loading step by step, with each stage of load cycling once before the yield and three times after the yield. 1. When the specimen is seriously damaged and seriously deformed; 2. The load value is reduced to 85% of the peak load; 3. The high-strength bolt or connecting cover plate produces excessive deformation or is pulled^[9]. Stop loading, end of test. In this experiment, the push is positive and the pull is negative, while in reality, the push is east and the pull is west. The loading regime is shown in figure 2.

An electro-hydraulic servo control system was used to load the test pieces. One end of the actuator was fixed at the beam end, and the other end relied on the reaction wall to provide the supporting reaction. The upper end of the column is provided with a jack. To prevent the specimen from overturning under the action of the actuator, a reaction beam is set at the upper and lower ends of the column. The loading device is shown in figure 3. The contents of this test mainly include: the load on the loading end of the beam, the loading end of the beam, the displacement of the beam, the development and width of cracks in the concrete and the failure of the specimen during the test.

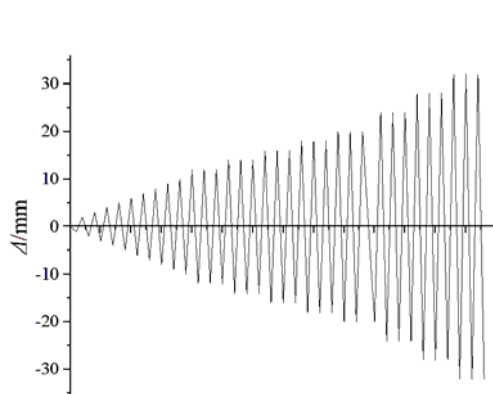


Figure 2. Loading scheme.

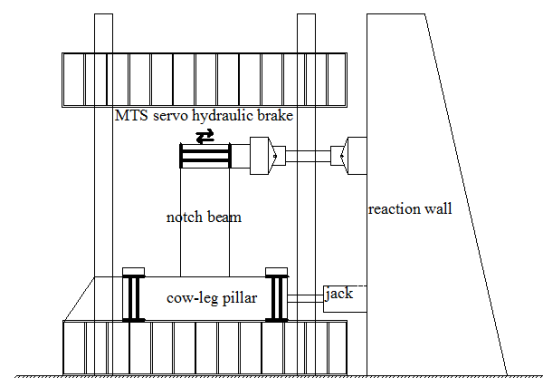


Figure 3. Loading diagram.

3. Damage

Since the failure of TGA-B2~TGA-B4 is similar, the failure process of specimens in the test is described by taking TGA-B2 as an example. The final failure of the specimen is shown in figure 4 . The test process includes four stages: initial crack, through crack, limit and failure.

3.1. Initial Crack

When the displacement (pull) is loaded to 3mm, the first crack appears at the tongue-and-groove joint of the rear casting layer on the east side of the beam and extends horizontally for 3cm to the south and north side of the beam. No cracks appear in other positions, which is the initial crack of the node. The observation that the load-displacement curve is still a straight line indicates that the node is basically in the elastic stress stage.

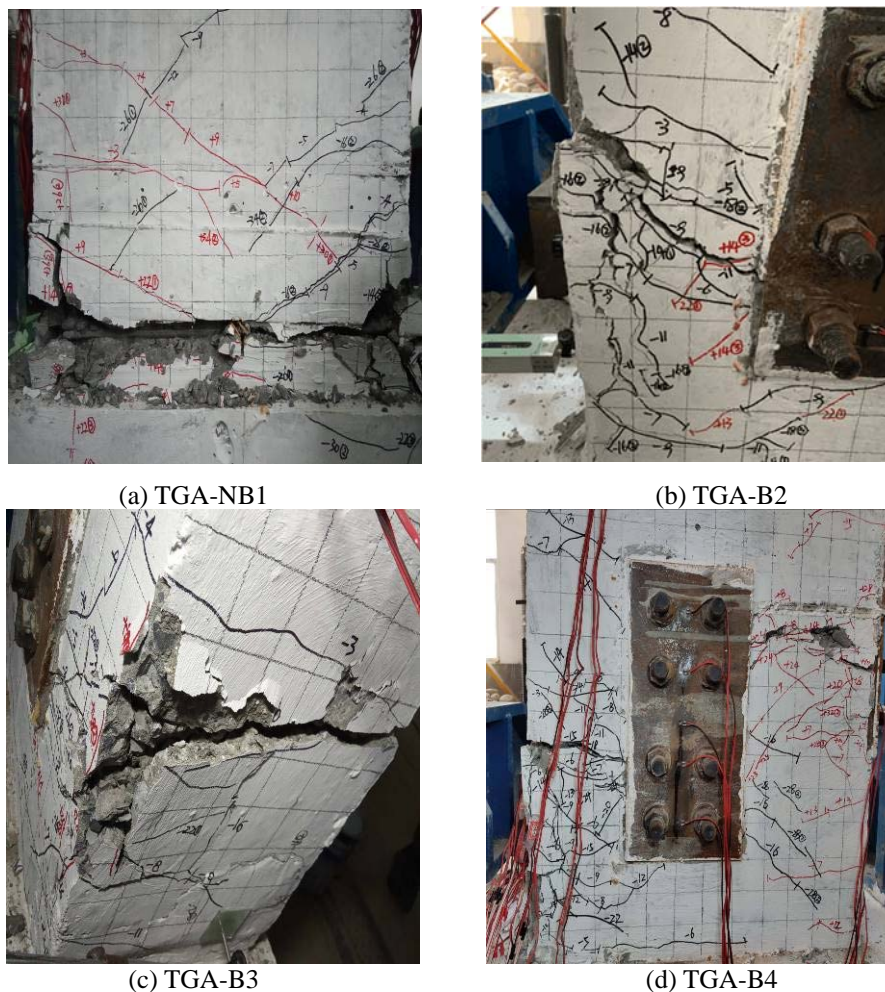


Figure 4. Damage pattern of specimen.

3.2. Lead to Crack

With the increase of load displacement, Liang Shen around tongue-and-groove flat-fell seam place appeared more inclined cracks, the rule is: Liang Na, north of connection plate at the bottom of the top and bottom edges appear cracks of oblique Angle brackets, with initial crack occurs when the first crack for ceiling he have more under lateral horizontal crack and Liang Na, north to extension, until the lateral connection plate parts. The cracks at the junction of beams and columns on the east and west sides continue to widen, while few cracks appear at the junction of beams and columns on the south and north sides. The development of fractures on the south and north sides of the beam is highly symmetrical. When the load reached 11mm, the load no longer increased significantly with the

displacement load. It was judged that the specimen basically reached the yield at this time, and the load was 193.6kN.

3.3. Limit

The displacement continues to increase. When the displacement is loaded to 15mm, the width of the initial crack on the east side of the beam increases to 1mm and develops inward. At 24mm, the specimen reached the limit state. The connecting crack from the bottom of the beam to the side plate appeared in the lower part of the joint on the south and north sides of the beam. The width of the initial crack on the east side reached 3.5mm and debris dropped with abnormal sound. After pouring concrete began to collapse and concrete blocks fell.

3.4. Destruction

With the increasing number of displacement cycles, the distance between the upper and lower edges of the bottom connection cover plate is getting larger and larger, and the damage of the nearby concrete is also getting more and more serious. Under the joint position of post-pouring composite layer, the concrete gradually loses its anchoring effect on longitudinal reinforcement under the repeated load, and the reinforcement is exposed and the specimen is destroyed. Refer to figure. 4(d) for the failure of the specimen.

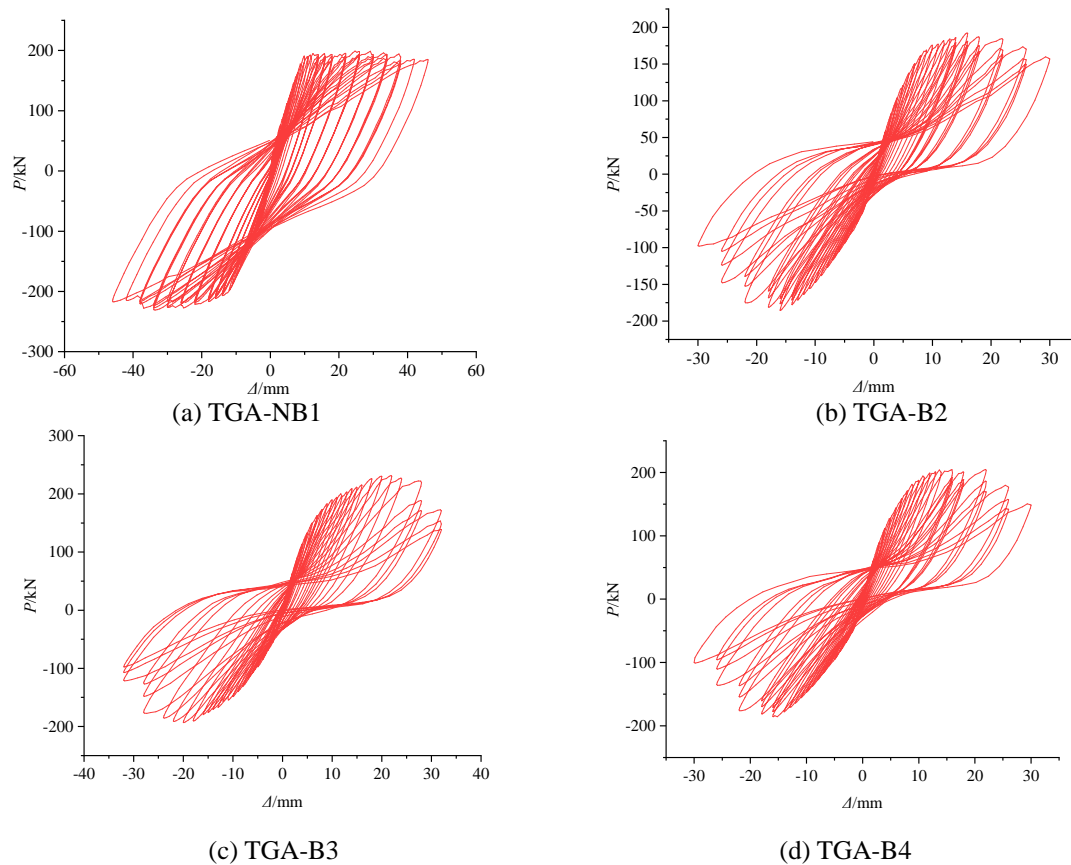


Figure 5. Load-displacement curve.

4. Analysis of Test Results

4.1. Load-displacement Hysteretic Curve

During the test, the load-displacement hysteretic curve of the beam end was measured as shown in figure 5. When the specimen entered the yield stage, the curve began to become full, and the repeated cyclic load did not cause too much stiffness degradation of the pouring specimen. After the peak load of specimens, the bearing capacity of specimens fluctuates but remains basically unchanged under the continuous increase of displacement.

The hysteretic curves of specimens TGA-B2 and TGA-B4 were similar. At the initial stage of displacement loading, the load and displacement presented a linear change. At the yield stage, with the increase of the displacement loading stage, the load growth slows down, and the load-displacement curve presents an inverse s-shape. The reason is that the post-cast composite layer at the tongue-and-groove joint loses its good anchoring function due to the collapse of concrete, so it slips a lot. Under the action of repeated cycles of loads, the concrete continued to peel off, especially after pouring the composite layer of concrete, the stiffness of the specimens in this direction degradation is obvious, at the same time, the bearing capacity of the specimens decreased rapidly.

At the early stage of displacement loading, the specimen TGA-B3 showed a large stiffness. The reason is that the gap beam and the gap between the dark bracket of the steel plate connected at the tongue-and-groove joint are small, and the load can be transferred to the column through the beam end more quickly. Observation specimen peak load displacement increases with the load reduction, compared the influence of load direction on the curve, found that the tension bearing capacity of the specimen is falling even faster, with the other two specimens similar assembly, casting composite layer after crushing the anchorage zone of steel bar slip, and finally to the east end of reinforced concrete exposed test specimens.

4.2. Skeleton Curve

The envelope of the hysteretic curve formed by the node test can be used to draw the corresponding skeleton curve, according to which the bearing capacity and ductility performance of the specimen can be reflected^[10]. The skeleton curve of the node is shown in figure 6.

Except that the skeleton curve of the whole pouring specimen TGA-NB1 has no obvious descending section, the skeleton curves of the assembled specimens all show good consistency, that is, there are three stages: elastic stage, yield stage and limit stage. Concrete specimen skeleton curve is not significantly lower section: the analysis of the reasons of the due to the conservative displacement loading level, specimen after the surrender, reinforced by stretching long beam root causes the concrete crush specimen horizontal shear load borne by the steel bar, basic in the process of loading, the stress due to the high ductility of the reinforced area not spreading around but the beam integral translation.

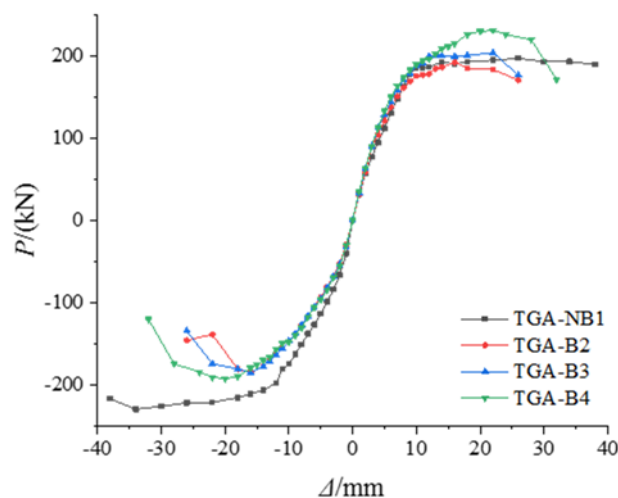


Figure 6. Skeleton curve.

Compared with specimen TGA - B3, specimen TGA - B2 and TGA - B4 the load deformation period is longer than the other, shows the late deformation ability, strong positive loads, mainly because the connection plate at the bottom of the specimen after the overall performance of the casting composite layer is better, at the same time in the displacement loading fittings and without any damage affecting its mechanical performance. For the specimen TGA - B3, due to the premature crushing of the post-cast composite layer (considering the reasons such as incorrect post-cast concrete placement), the stiffness of the specimen deteriorated significantly during the negative displacement loading, the load-holding capacity decreased rapidly, and the bearing capacity decreased significantly under the same displacement. When the load is reduced to 85%, the concrete part of the post-cast composite layer of the specimen is stripped off and the internal longitudinal bars are exposed. At this point, the bearing capacity of the specimen in the negative displacement loading decreases significantly and the steel bar slippage is obvious.

4.3. Ductility

The greater the ductility of the specimen, the more energy it consumes and absorbs from the earthquake, and the stronger the seismic resistance of the specimen itself. The displacement ductility coefficient refers to the displacement ductility coefficient corresponding to the failure of the specimen, that is, the ratio of the displacement to the yield displacement at failure ($\mu = \Delta_u / \Delta_y$). Considering the incomplete symmetry of the hysteresis curve of the specimen, the mean value of the displacement ductility coefficient in the positive and negative directions on the hysteresis skeleton curve is taken^[11]. Definition of ultimate displacement the displacement or end-of-test displacement when the load of the specimen is reduced to 85% of the peak load. The yield displacement is calculated by equal energy method.

Table 3 shows ductility of specimens. It can be seen from table 3 that the displacement ductility coefficient of the assembled tone-and-groove frame beam concrete specimens are all greater than 2.0, which meets the requirement that the displacement ductility coefficient of reinforced concrete structures is greater than 2.0, indicating that the joint specimens have good ductility. At the same time, it can be seen that the ductility of the specimen is slightly improved with the strengthening of the side connection cover and the bottom connection cover. The ductility of the specimen was improved by the strengthening of the lateral joint cover slightly better than that of the bottom joint cover, but not obviously.

Table 3. Specimen ductility.

specimen	direction	nominal yield		peak		limit		ductility coefficient
		displacement (mm)	load (kN)	displacement (mm)	load (kN)	displacement (mm)	load (kN)	
TGA-NB1	+	10.77	184.68	26.00	196.80	38.00	189.10	3.17
	-	-13.56	-204.70	-34.00	-229.80	-38.00	-217.10	
TGA-B2	+	9.00	168.85	16.00	192.00	26.00	170.40	2.33
	-	-11.45	-159.04	-16.00	-185.10	-20.25	-157.34	
TGA-B3	+	9.39	182.37	22.00	203.70	26.00	176.50	2.42
	-	-11.39	-158.97	-16.00	-185.20	-23.71	-157.42	
TGA-B4	+	11.36	194.43	22.00	230.80	29.93	196.18	2.46
	-	-12.55	-162.30	-20.00	-192.50	-28.80	-163.63	

5. Conclusion

1. By comparing with the reinforced concrete specimens, it can be seen that the assembled tongue-and-groove frame beam specimens have a high bearing capacity under the action of low cyclic reciprocating load at the beam end, which can basically reach the same goal as cast-in-place.
2. The test results show that the hysteretic curves of the test joints of the assembly tongue-and-groove frame beam under high-strength bolt connection are relatively full. Meanwhile, the ductility coefficients of the specimens are all greater than 2.0, showing a strong ductility capacity but still lower than that of the whole cast.
3. Changing the bottom connection cover and side connection cover can improve the bearing capacity and ductility of the specimen to a certain extent, which can more significantly improve the mechanical performance of the specimen.
4. Design Suggestions: in actual engineering design, the longitudinal stressed steel bar can be considered according to the load design value, the bottom connecting cover plate and high-strength bolt can be designed according to the maximum bearing capacity provided by the longitudinal bar, and the side connecting cover plate can be designed according to the shear design value of the specimen and moved up as far as possible.

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