

Research Article

Seismic Resistance Properties of Improved Dry-Type Beam-Column Joint: An Experimental Research

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Dry-type joints are an advanced type of sustainable beam-column connection mode used in the prefabricated concrete frame structural system. This paper proposed an improvement scheme for high-strength bolt dry-type joints and designed a new type of common bolt dry-type joints. A pseudo test involving low-cycle repeated loading is conducted to assess the seismic resistance properties of new joints including damage mode, hysteretic curve, skeleton curve, and ductility factor. Numerical simulation is applied to validate the rationality of experimental results. It is found that when the bending capacity of the end block of the beam is consistent with that of the bolt, the deformation of the bolt will no longer increase greatly after a period of large deformation; at this period, the bolt does not fully enter the plastic stage, but at this time, the end block of the beam begins to appear large cracks and enter the plastic deformation and has good energy dissipation performance.

1. Introduction

Prefabrication is considered as the best way to realize building industrialization and sustainable construction because of its socio-economic and environmental advantages such as higher construction efficiency, better controlled quality, and less waste and pollution compared with the traditional cast-in-place method [1, 2]. Joints, as the most vulnerable part of the whole prefabricated structural system, usually determine the capacity of whole structure [3, 4]. The failure of joints sometimes results in the failure of the whole building. Therefore, the design of joints is the key link in prefabricated structure design. The construction of cast-inplace joints requires a lot of wet work on-site, which will produce more waste and pollution.

Currently, the most common types of beam-column joints for prefabricated concrete frame structures are castin-place joints and welded joints. The construction of castin-place joints requires a lot of wet work on-site, which will generate much waste and pollution. Because of the need for high temperature, welded joints need to consume a large amount of energy and emit carbon dioxide. Both of them are not sustainable enough [5–11]. Dry-type joints are the latest development. All structural components fastenings are all prefabricated in factories, and connection between beam and column members is realized by bolt on-site. These advanced joints can not only reduce negative environmental impacts caused by construction activities but also have good mechanical properties and structural performance [12, 13].

Our project group has designed a new dry-type joint using high-strength bolts to achieve good antiseismic behavior [14, 15]. Experimental results show that this new drytype joint can have good ductility and energy dissipation capacity. However, the design still has many disadvantages. First and foremost, the displacement of high-strength bolts is very small in the process of experiment. This means they cannot dissipate energy efficiently. In addition, the size of reserved holes is not big enough, which caused that reserved holes are likely to be blocked when grouting in the gap.

Based on identified disadvantages of previous design, this paper aims to (1) improve the design of dry-type joint; (2) test the seismic resistance properties of improved joint through a pseudo-static experiment approach; and (3) validate the feasibility and mechanism of the proposed improved design scheme through numerical simulation. Research results can not only enrich the structural systems of prefabricated buildings but also contribute to the knowledge body of sustainable construction in general.

2. Materials and Methods

2.1. Specimen Design. In order to better understand and compare the seismic resistance properties of the improved dry-type joints, the new test specimen is the same in size as the specimen before the improvement. The beams and columns in the test specimen are both prefabricated components, in which the strength grade of longitudinal bars and stirrups is both HRB400. The pressure plates and bolts are made of Q345 steel. The column is made of concrete with strength grade C80 and section size of 750 × 750 mm. Eight bolt holes with the diameter of 40 mm are reserved in symmetrical position on the upper part of the bracket on the column. The beam is made of concrete with strength grade C40. The section size of the "T" expanded end of the beam is 750×750 mm, and the section size of the beam body is 400×750 mm. Eight bolt holes with the diameter of 50 mm are reserved for the "T" expanded end of the beam. After the beam and column are placed in the corresponding position, they are connected and fixed with a steel long bolt with a diameter of 28 mm through reserved holes. The 20 mm gap at the junction the "T" expanded end of the beam and column was filled by sleeve grout, and a 40 KN pretightening force was applied to each bolt by electric torque wrench. The three-dimensional diagram of the new improved common bolt dry-type beam-column joint is shown in Figure 1, and the size and reinforcement of specimen are shown in Figure 2.

It is necessary to point that we have tested high-strength bolt in previous experiment, where some shortcomings had been found; thus, a new beam was assembled by a new kind of joint, which had no difference with previous joint except bolt strength. To address the shortcomings existing in the previous high-strength bolt dry-type beam-column joints, the following improvements were made in terms of test specimen design and installation:

- High-strength bolts are replaced with common bolts, and the bolt size is reduced from 30 mm to 28 mm.
- (2) The reserved bolt holes at "T" expanded end of the beam are expanded from 40 mm to 50 mm. This makes the installation process more convenient without the need for later adjustment and repair.
- (3) The reserved holes were perforated by PC tubes so that the mortar in the gap is not likely to flow into the holes. This can help to prevent reserved holes from bee blocked when grouting.

The material property test was conducted before the experiment according to the standard of the mechanical properties test method of ordinary concrete (GB/T50152-2012) [16]. The measured compressive strength of concrete is

shown in Table 1. The measured diameter, yield strength, ultimate strength, and elongation of steel bars and bolts are shown in Table 2.

Figure 3 displays the stress position of bolt, which provides support for predicting the strength of bolt.

$$M_0 = (F_1L_1 + F_2L_2 + F_3L_3) \times 2. \tag{1}$$

From geometric relations,

$$F_{3} = \frac{1}{3}F_{1},$$

$$F_{2} = \frac{2}{3}F_{1},$$
(2)
(2)

 $F_1 = f_y S = 374 \times 3.14 \times \left(\frac{20}{2}\right) = 230.17KN, \quad (3)$

where f_y refers to the yield strength of bolt and S refers to the cross sectional area of bolt.

According to (2), $F_2 = 153.45$ KN and $F_3 = 76.72$ KN. According to (1), $M_0 = 388$ KN• $m = 0.85 \times 456$ KN•m. The design is reasonable.

2.2. Test Loading Device and Loading System. This experiment was completed in the Key Laboratory of Structure and Underground Engineering of Anhui Jianzhu University. The test loading equipment was the 500 KN electro-hydraulic servo loading system with the displacement stroke of the actuator produced by Beijing Foli Company. The test loading device is shown in Figure 4.

A pseudo-static test of low-cycle repeated loading is adopted in this experiment [17, 18]. The free end of the beam is subjected to a low-cycle repeated load by the actuator. The force-displacement controlled combined loading system (Figure 5) is applied. The full loading process is divided into two stages. Initially, the force controlled loading is used before the specimen yields. Each grade was loaded 5 KN and cycled once. Then, displacement controlled loading was used when the specimen yields. Each grade was 20 mm and cycled three times until the specimen failed. At the same time, a constant axial pressure of 1080 KN was applied to the column top by hydraulic jack during the test, and the corresponding design axial pressure ratio was 0.05.

2.3. Arrangement and Selection of Test Points. In order to collect relevant test data, the strain of concrete and reinforcement was measured on the precast members, respectively. The main location of the strain is shown in Figure 6 where LS represents the bolt strain, Z represents the reinforcement strain on column, L represents the reinforcement strain on beam, and H represents the concrete strain. Two displacement sensors were installed at the bottom of the beam to measure the displacement deformation of the precast beam under low cyclic reciprocating load, which are shown in Figure 7.

Shock and Vibration



FIGURE 1: Specimen design drawing: (a) elevation plan; (b) a three-dimensional joint diagram; (c) top view.



FIGURE 2: Reinforcement drawing of specimen: (a) A-A sectional drawing; (b) B-B sectional drawing; (c) C-C sectional drawing.

Concrete strength	3 days	7 days	28 days
C40	26.53	38.31	50.31
C40	27.28	37.52	47.52
C40	26.45	38.63	49.34
C80	27.30	77.30	84.36
C80	28.20	78.22	87.12
C80	27.90	77.91	85.46

TABLE 1: Performance parameters of concrete (unit: N/mm).

TABLE 2: Performance parameters of steel bars and bolts (unit: N/mm²).

Туре	Rebar/bolt diameter d (mm)	Yield strength, f_{yk}	Ultimate strength, $f_{\rm stk}$	Elongation
HRB400	12	465.2	577.3	21.6%
HRB400	14	447.4	567.6	23.2%
HRB400	16	437.6	620.4	23.2%
HRB400	18	456.4	589.6	22.6%
HRB400	22	421.3	571.9	19.6%
HRB400	25	456.6	605.7	20.2%
Q345 bolt	28	380.2	516.8	17.9%
Grade-8.8 bolt	30	618.7	785.2	11.4%



FIGURE 3: Stress position of bolt.



FIGURE 4: Loading diagram: (a) field photo; (b) design diagram.



FIGURE 5: Load regime diagram.



FIGURE 6: Location map of main strain gauge: (a) beam top steel strain gauge position; (b) position of concrete strain gauge on top of beam.



FIGURE 7: External displacement meter layout.

3. Results and Discussion

3.1. Experimental Phenomenon. The test loading direction stipulates that pushing down refers to positive direction (+), pulling up refers to the negative direction (-), and the loading order is positive before negative. At the initial stage of the force controlled loading, the deformation and strain of the specimen did not change significantly, and no cracks occurred. When loaded to +25 KN, the first crack of 0.06 mm width occurred at the junction of beam "T" expanded end and beam body, and a crack of 0.09 mm appeared on the grouted gap surface. When reversely loaded to -55 KN, symmetric cracks occur on the bottom surface and the upper surface of the beam. With the increase in the loaded force, the beam continues to crack and the crack width develops. The strain of the longitudinal reinforcement and the bolt of the beam increases gradually. When loaded to -80 KN, a large displacement deformation was observed on the beam. The crack width at the grouted gaps increased to 2.76 mm, and the reinforcement strain at the "T" expanded end of the beam changed suddenly. This indicates that longitudinal reinforcement yields.

Then, displacement controlled loading was applied to replace force controlled loading. When the loaded to +30 mm, the crack width at the grouted gaps reached 3.84 mm. When loaded to +70 mm, a crack appeared at the top with a width of 0.2 mm and a crack width of 5.3 mm, and the crack width at the grouted gaps reached 5.3 mm. When loaded to -90 mm, there were deep penetrating cracks formed at the bottom of the beam and the crack width at the grouted gaps reached 10 mm. When loaded to +110 mm, the concrete at the "T" expanded end of the beam is partially crushed and the test specimen failed.

The final failure mode and crack trend of the beam are shown in Figures 8 and 9.

By comparing the test phenomena of different specimens, we can see that the load borne by the first crack in P1 (assembled by common bolt) is less than that of the first crack in P2 (assembled by high-strength bolt). The common bolts in P1 deform during the whole loading process while the high-strength bolts in P2 do not deform and the stress value does not reach the yield strength. The generation and development trend of the cracks in the two specimens gradually developed from the t-shaped end of the precast beam to the end of the beam with the continuous increase in the load. Besides, the width of the crack kept increasing as well. At last, both of them were damaged due to crushing of the concrete at the t-shaped end of the precast beam.

3.2. Comparative Analysis. In this section, the improvement of seismic resistance properties of normal bolt dry-type joint (P1) is evaluated by comparing the failure characteristics, hysteretic curve, skeleton curve, and ductility coefficient with the figure for previous high-strength bolt dry-type joint (P2) tested under the same experimental conditions. It is necessary to note that the only difference between the two specimens is the type of the bolt; others including reinforcement, strength of concrete, and size of beam are all the same.

3.2.1. Failure Characteristics. P1 and P2 have many similarities in failure characteristics. There were no cracks appearing on the column or the bracket during the whole test process. The initial cracks firstly appeared at the "T" expanded end of the beam. With the increase in load, the number of cracks gradually increased and the cracks developed from the "T" expanded end to the tail of the beam body. The concrete at the "T" expanded end of the beam is finally crushed, and the whole specimen failed. However, the failure of P1 is more ductile than that of P2. In addition, the common bolt in P1 has a large deformation, while the high-strength bolt in P2 has no significant deformation.

3.2.2. Hysteretic Curve. The hysteretic curves of the two specimens are shown in Figure 10. It can be seen from the figure that the variation trends of hysteretic curve of the two specimens are similar. In the initial stage of loading, the load and displacement of the two specimens both show a linear relationship, indicating that both are in the elastic stage.



Common Bolt



Grade-8.8 Bolt (b)

FIGURE 8: Specimen failure local diagram: (a) common bolt; (b) Grade-8.8 bolt.



FIGURE 9: Continued.



FIGURE 9: Crack diagram of specimen. (a) Distribution diagram of crack diagram on bottom of beam. (b) Distribution diagram of crack diagram on side of beam. (d) Distribution diagram of cracks on top of beam. (e) Distribution diagram of cracks on side of beam.



FIGURE 10: Load-displacement control hysteresis curve.

With the increase in load, the longitudinal reinforcement at the "T" expanded end of the beam yields. The slope of hysteretic curve gradually increases and the area of the hysteretic ring also increases, indicating that the plastic deformation of the two specimens gradually increases, and both specimens have good energy dissipation capacity.

However, the comparison shows that the hysteresis ring of P1 is plumper than that of P2, indicating that P1 has stronger energy dissipation capacity and better seismic resistance properties. The displacement of P1 is obviously larger than that of P2 in the elastic phase, indicating that P1 has better deformation capacity. The "pinching" effect of specimen P2 is more obvious than that of P1, indicating that there is a serious slip of reinforcement in P2. 3.2.3. Skeleton Curves. The skeleton curves of the two specimens are shown in Figure 11. It can be learned that the skeleton curves of the two specimens have similar change trends with obvious descending segments, indicating that both the two specimens have good ductility. However, the descending section of P1 is more gentle compared with that of P2. This indicates that P1 has better ductility.

3.2.4. Ductility Coefficients. The ductility coefficients of the two specimens are shown in Table 3. Compared with P2, the ductility coefficient of P1 increased from 2.17 to 3.05 with an improvement of 40.5%, which proved that the ductility of P1 performance was better once again.

4. Numerical Simulation

4.1. Transformation between Parameters of Concrete Plastic Damage Model. For the concrete plastic damage model provided in ABAQUS, the stress-strain curve of compression and tension beyond the elastic part shall be in the form of $\sigma_c - \tilde{\varepsilon}_c^{\text{in}}$, and $\sigma_t - \tilde{\varepsilon}_t^{\text{in}}$ must be input with positive value; otherwise, the operation will be interrupted automatically with an error. The stress-strain curve of compression and tension for the concrete plastic damage model is shown in Figure 12. And the calculation formula is as follows:

Compression stage:

$$\begin{cases} \tilde{\varepsilon}_{c}^{in} = \varepsilon_{c} - \varepsilon_{oc}^{el}, \\ \\ \varepsilon_{oc}^{el} = \frac{\sigma_{c}}{E_{0}}. \end{cases}$$

$$\tag{4}$$



FIGURE 11: Load-displacement control skeleton curve.

TABLE 3: Analysis table of ductility fact	tor (unit: mm).
TABLE 5: Analysis table of ductility fact	tor (unit: mm).

Туре	Direction of action	Yield displacement	Limit displacement	Ductility factor	
P1	Pull	24.48	78.47	3.21	2.05
	Press	29.07	83.68	2.88	5.05
P2	Pull	48.20	95.30	1.97	2.17
	Press	46.90	110.90	2.36	2.17



FIGURE 12: Curve of the concrete damage plasticity model: (a) compression stage; (b) tensile stage.

Tensile stage:

$$\begin{cases} \tilde{\varepsilon}_{t}^{ck} = \varepsilon_{t} - \varepsilon_{0t}^{el}, \\ \\ \tilde{\varepsilon}_{0t}^{el} = \frac{\sigma_{t}}{E_{0}}. \end{cases}$$
(5)

When the compression and tension damage data are input into ABAQUS, the inelastic strain will be

automatically converted into plastic strain through the following formula. If the plastic strain is less than 0, ABAQUS will report an error and cannot conduct operation.

Compression stage:
$$\tilde{\varepsilon}_{c}^{pl} = \tilde{\varepsilon}_{c}^{\text{in}} - \frac{d_{c}}{(1-d_{c})} \cdot \frac{\sigma_{c}}{E_{0}},$$
 (6)

Tensile stage:
$$\tilde{\varepsilon}_t^{pl} = \tilde{\varepsilon}_t^{ck} - \frac{d_t}{(1-d_t)} \cdot \frac{\sigma_t}{E_0}$$
. (7)

In equations (6) and (7), E_0 is the initial elastic modulus of concrete; $\tilde{\epsilon}_c^{pl}$ and $\tilde{\epsilon}_c^{in}$ are compression plastic strain and



FIGURE 13: Finite element model: (a) grid plot of specimen; (b) local grid.

compression inelastic strain of concrete, respectively; $\tilde{\varepsilon}_t^{pl}$ and $\tilde{\varepsilon}_t^{ck}$ are tensile plastic strain and tensile inelastic strain of concrete, respectively; $\tilde{\varepsilon}_{0c}^{el}$ and $\tilde{\varepsilon}_c^{el}$ are, respectively, the compressive elastic strain when concrete is not damaged and the compressive elastic strain considering damage; and $\tilde{\varepsilon}_{0t}^{el}$, respectively, are the tensile elastic strain when the concrete is not damaged and the campage and the elastic strain considering the elastic strain the tensile elastic strain the tensile elastic strain the tensile elastic strain the concrete is not damaged and the elastic strain considering the damage;

4.2. Finite Element Modelling. Finite element analysis software ABAQUS [19-22] is used to simulate the seismic resistance properties of the new dry-type joints assembled by the common bolt in this paper. The reinforcement adopts the three-dimensional two-node T3D2 element, and its properties are set with the double-fold model; concrete adopts three-dimensional solid reduction integral C3D8R element, and its properties are set with the concrete plastic damage model. Embedded technology is applied to realize the coupling between concrete and reinforcements. The established finite element model is shown in Figure 13(a). Due to the existence of bolt holes, the mesh quality has a great influence on the model convergence during numerical simulation. Therefore, it is necessary to carry out fine mesh cutting and division of bolt holes. The mesh of irregular parts around bolt holes is shown in Figure 13(b).

4.3. Failure Mode. Figure 14 shows the equivalent plastic strain cloud diagram, which is used in numerical simulation to represent the plastic damage degree of concrete, of the specimen with common bolt dry-type joint. And Figure 15 shows the failure of precast beam in experiment. It can be seen from the simulation results that except the severe damage to the "T" expanded end end of the beam, there is basically no damage to other parts. In the real test, the ultimate failure model of the specimen was concrete in the middle part of the "T" expanded end of the beam crushing, while other parts were basically intact. Therefore, the simulation results are consistent with the test results, indicating that the test results are not accidental.

4.4. Analysis of Bolt Deformation. The bolt stress-strain cloud diagrams of the two specimens are shown in Figure 16. It can be found that during the whole test process, the highstrength bolt was not damaged and there was even no obvious deformation leading to a limited unloading capacity. The main reason was that the high-strength bolt had high yield strength. The plastic failure of concrete occurs prior to bolt yield failure. After the improvement, the maximum strain of common bolt increases by about 120% compared with high-strength bolt. The energy can be dissipated through the deformation of bolt, thus improving the dynamic property of the dry-type joint and the capacity of the whole structure. At the same time, using common bolts instead of high-strength bolts can also help to save engineering costs.

In addition, the numerical simulation results show that the common bolt does not yield completely. Therefore, the capacity of structure can be further improved by increasing the ratio of reinforcement at the "T" expanded end of the beam.

4.5. Comparative Analysis of Hysteresis Curve. The comparison of hysteresis curves between simulation and test, both of which were assembled with common bolt, is shown in Figure 17. These results show the two have good energy dissipation capacity and seismic performance. Because of ignoring the sliding effect of reinforcement in the finite element simulation, the finite element simulation result is plumper than the experiment. At the beginning of the test loading, the two are in the linear state, which indicates that the test is in the elastic stage. With the increase in the loading displacement, the hysteresis loop area also increases. It indicates that the test enters the nonlinear stage. During the loading process, the setting of boundary conditions cannot reach the ideal fixed state and then the loading of the force may cause slight looseness to the boundary constraints of the specimen. As a result of it, the positive and negative hysteretic curves obtained by the test are not completely symmetric. Therefore, the simulation results are in good agreement with the experimental results.



FIGURE 14: Equivalent plastic strain nephogram of concrete.



FIGURE 15: Failure diagram of precast beam.



FIGURE 16: Stress-strain nephogram of bolt.

5. Conclusions and Recommendations

5.1. Conclusions. The previous high-strength bolt dry joint has some shortcomings. This paper puts forward an improvement scheme and designs a new common bolt dry-type joint in order to solve this problem. A series of pseudo-static tests are carried out to assess the improvement of seismic resistance properties of new joints. The failure mode, hysteretic curve, skeleton curve, and ductility coefficient of the two specimens with high-strength bolt and common bolt are compared. The rationality of the test results is verified by numerical simulation. The main conclusions are as follows:

 Compared with high-strength bolt dry-type joints, the hysteretic curve of the improved common bolt dry-type joints is plumper, the descending section of



FIGURE 17: Comparison between numerical simulation and experiment skeleton curves.

the skeleton curve is more stable, and the ductility coefficient is higher. This means improved common bolt dry-type joints have better seismic resistance properties.

- (2) The improved common bolt dry-type joint is more convenient to install. The bolt hole is not easily blocked. It is more environmental and cost-effective. Therefore, new joints have good practicability.
- (3) Compared with high-strength bolts, common bolts can generate larger deformation, which makes the linked beam and column components have better rotation ability. Therefore, common bolts can improve the ductility and capacity of the whole prefabricated concrete frame structure.

The improved common bolt dry-type joint has better seismic resistance properties and practicability, which proves the feasibility of the improved scheme. The results of this paper can be applied to enrich the prefabricated structural systems and the knowledge of sustainable construction. In addition, the new dry joint proposed in this paper can be applied to various prefabricated concrete frame structures due to its good economic and environmental benefits.

5.2. Recommendations.

(1) During the test, the bolt still did not reach the yield strength although the common bolt had a large deformation compared with the high-strength bolt. Finally, the concrete of the beam was crushed before the bolt was damaged. This failure mode is not expected. In the later research, the seismic resistance properties of the joints can be further improved by optimizing the reinforcement ratio of the "T" expanded end of the beam. (2) In this paper, finite element software ABAQUS is used to effectively simulate the seismic resistance properties of the new dry-type joints. More attention can be paid to how to apply numerical simulation to further optimize the design of this advanced joint, thus saving the time and economic cost brought by experimental research.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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References

- Y. F. Wang and Z. J. Yang, "On the development of prefabricated building," *Chinese & Overseas Architecture*, vol. 2017, no. 1, pp. 57–59, 2017, in Chinese.
- [2] X. K. Huang and C. Y. Tian, "Research on prefabricated concrete structure," *Housing Industry*, vol. 2010, no. 9, pp. 27–32, 2010.
- [3] M. N. S. Hadi and T. M. Tran, "Seismic rehabilitation of reinforced concrete beam-column joints by bonding with concrete covers and wrapping with FRP composites," *Materials and Structures*, vol. 49, no. 1-2, pp. 467–485, 2016.
- [4] N. Shajil, S. M. Srinivasan, and M. Santhanam, "An experimental study on self-centering and ductility of pseudo-elastic shape memory alloy (PESMA) fiber reinforced beam and beam-column joint specimens," *Materials and Structures*, vol. 49, no. 3, pp. 783–793, 2015.
- [5] G. W. Yang, C. J. Che, S. N. Xiao, B. Yang, T. Zhu, and S. Jiang, "Experimental study and life prediction of bolt loosening life under variable amplitude vibration," *Shock and Vibration*, vol. 2019, Article ID 2036509, 8 pages, 2019.
- [6] C. X. Wu, Y. F. Zhang, C. Zhang, X. S. Deng, and Y. Zhou, "Study on seismic behavior of precast concrete beam column joints," *Earthquake resistant engineering and Retrofitting*, vol. 37, no. 1, pp. 83–90, 2015.
- [7] X. L. Gao, L. B. Xu, J. Li, and Y. Cao, "Experimental analysis on mechanical behavior of precast concrete beam column joints," *Journal of Huazhong University of Science and Technology(Natural Science Edition)*, vol. 44, no. 10, pp. 47–52, 2016.
- [8] J. H. Zhao, Y. Hu, D. F. Zhang, and C. Chen, "Experimental study on seismic behavior of prefabricated composite CFST column steel beam frame," *Journal of Building Structures*, vol. 41, no. 8, pp. 88–96, 2020.

- [9] D. Chen, L. Ding, and C. Y. Shao, "Finite element simulation of FRP connectors for prefabricated sandwich panel," *Journal* of Anhui Jianzhu University, vol. 25, no. 6, pp. 8–14, 2017.
- [10] W. Ma, Y. Li, and K. W. Ding, "Mechanical properties of new dry-type beam-column bolt connection joint," *Sustainability*, vol. 11, pp. 1–14, 2019.
- [11] Y. Li, Comparative Study on Mechanical Properties of New Fabricated concrete Beam-Column Dry Joints, Anhui Jianzhu University, Hefei, China, 2020.
- [12] Y. Chen, Q. Gao, and Z. Q. Guan, "Self-loosening failure analysis of bolt joints under vibration considering the tightening process," *Shock and Vibration*, vol. 2017, Article ID 2038421, 15 pages, 2017.
- [13] X. W. Li, "Load transfer characteristics of a cable bolt in DEPT," *Shock and Vibration*, vol. 2019, Article ID 2106741, 10 pages, 2019.
- [14] China Architecture & Building Press, Code For design of concrete structures (GB50010-2010), China Architecture & Building Press, Beijing, China, 2011.
- [15] China Architecture & Building Press, Technical Specification for Precast concrete Structures(JGJ 1-2014), China Architecture & Building Press, Beijing, China, 2014.
- [16] China Architecture & Building Press, Standard for Test Methods of concrete structures(GB/T50152-2012), China Architecture & Building Press, Beijing, China, 1978.
- [17] China Architecture & Building Press, Code Of Seismic Test For Buildings (JGJ/T101-2015), China Architecture & Building Press, Beijing, China, 2015.
- [18] C. Fang, Y. Ping, and Y. Chen, "Loading protocols for experimental seismic qualification of members in conventional and emerging steel frames," *Earthquake Engineering & Structural Dynamics*, vol. 49, no. 2, pp. 155–174, 2019.
- [19] Y. Z. Wang and C. G. Fu, Examples And Detailed Explanation of Structural Engineering Analysis of ABAQUS, China Architecture & Building Press, Beijing, China, 2010.
- [20] Z. Zhuang, X. C. You, and J. H. Liao, *Finite Element Analysis and Application Based on ABAQUS*, Tsinghua university press, Beijing, China, 2009.
- [21] Y. Q. Long, *Introduction of Finite Element Method*, People's Education Press, Beijing, China, 1978.
- [22] L. S. Chu, G. J. Li, D. D. Li, and J. Zhao, "Study on progressive collapse behavior of SRC column-steel beam hybrid frame based on pushdown analysis," *Shock and Vibration*, vol. 2017, Article ID 3075786, 12 pages, 2017.