IOP Conference Series: Earth and Environmental Science

Numerical simulation of the low-cyclic loading of new-type assembled integral beam-column joints

To cite this article: Jiangchuan Wu *et al* 2017 *IOP Conf. Ser.: Earth Environ. Sci.* **61** 012131

IOP Conf. Series: Earth and Environmental Science **61** (2017) 012131 doi:10.1088/1755-1315/61/1/012131

Numerical simulation of the low-cyclic loading of new-type assembled integral beam-column joints

Jiangchuan Wu[1, 2], Jiwen Zhang[2], ,Wanyun Yin[3] and Rencai Jin[3]

[1] School of Civil Engineering, Southeast University, Nanjing 210096, China.
[2] School of Civil and Ocean Engineering, Huaihai Institute of Technology, Lianyungang 222005, China.
[3] MCC17 Group Co., Ltd. , Maanshan 243000, China.
Corresponding author: wujch@sina.com

Abstract. In this paper, the low-cycle cyclic loading test and the elasto-plastic numerical simulation by OpenSEES of assembled integral beam-column joints of the three new prefabricated prestressed concrete beams are carried out. The key technologies such as unit selection, material model selection and prestressing in the numerical simulation of the new assembly-type beam-column joint is studied deeply. The results show that the relative model and parameters of the OpenSEES software can be used to simulate the hysteresis performance of the low-cycle cyclic loading of the new-type assembled integral beam-column joints.

1. Introduction

With the development of construction industrialization and green building in China, precast assembled integral structure has been studied and applied frequently. However, at present, China's the level of construction industrialization is very low and precast assembly technology is relatively backward in China. So it is necessary to carry out in-depth study of the precast assembly structure, to promote the application and development of the precast structure in China. China is a multi-seismic country, and most of the city are in the seismic fortification zone. Therefore, the development of precast assembled integral structure must take into account its seismic capacity.

The Precast Prestressed Assembled Structural System (referred to as PPAS system) studied by Southeast University and other universities and research institutions, is based on the introduction of Japanese prestressed assembled structure, and combines the development of China's national conditions. It is a kind of cost - effective building construction technology. The joint reinforcement diagram and beam end structure details are shown in Figure 1 and Figure 2. PPAS system frame beam is Precast prestressed composite beam. The main beam end is embedded channel steel connector, which can not only be used for rapid bolt connection between beam and column, but also be used as a shear part of old and new concrete joint in joint area. Besides, it can also control the location of the plastic hinge, shift the plastic hinge, improve the stress state of the node area, avoid brittle damage. The secondary beam end use short channel steel for the connection between primary and secondary beam, and weld shear plate to increase the shear section. According to the needs, PPAS system precast prestressed beam end use PVC casing release part prestress of steel strand. PPAS system column using Concrete filled steel tube columns or reinforced concrete composite column node plusing short steel tube .The ribbed floor and the beam and column joints are cast on the site with patent templates.

The full name of OpenSEES is Open System for Earthquake Engineering Simulation (open system for seismic engineering simulation). OpenSEES is funded by the National Natural Science Foundation of the United States (NSF), led by Western University and the Pacific Earthquake Engineering Center (PEER), mainly developed at the university of California, Berkeley. It is a more comprehensive and continuous development of the open program software system for seismic response simulation in structural and geotechnical aspects. Since its introduction in 1999, it has been widely used in the Pacific Earthquake Engineering Research Center and some universities and scientific research projects of research institutions in US. It simulated a large number of practical engineering and shaking table test project, including reinforced concrete structures, bridges, geotechnical engineering, which proved that it has a good nonlinear numerical simulation accuracy.

In the OpenSEES program, the component section can be divided into several kinds of fibers and the user can define the location of each fiber, cross-sectional area and constitutive relationship. The program automatically assumes the strain of each fiber based on the flat section assumption and iteratively computes to ensure that the section is subjected to force balance. The fiber model links the microscopic constitutive relation of the material with the macroscopic component response, taking into account the advantages of macroscopic finite element and micro finite element. At the same time, the so-called flexibility method is used to form the stiffness matrix of the beam-column element based on the fiber model. The iterative solution process includes the iterative solution of the structure level, the component level and the section level. This feature makes the flexibility method have a unique advantage in analyzing the nonlinear response of the component.

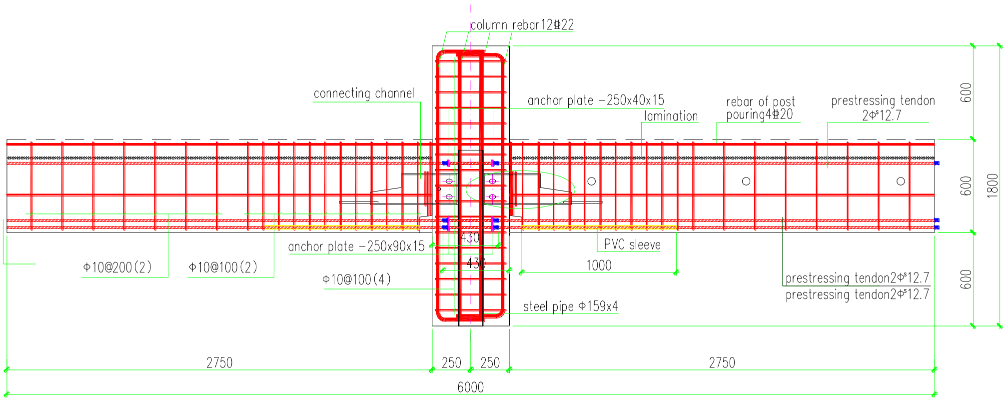

Figure 1. Reinforcement of PPAS joints.

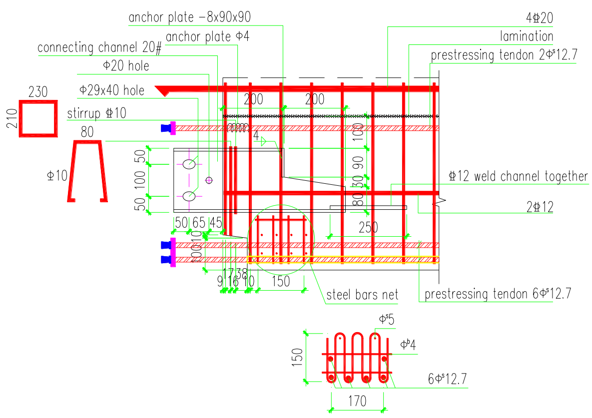

Figure 2. Beam end construction detail.

2. Specimen design

In order to more truly reflect and restore the stress state of the joint, the test use the full test pieces based on the prototype. And according to the design drawings of actual engineering, they are made the appropriate adjustments, combined with the actual size of the laboratory joint frame. The detailed dimensions and reinforcement of the components are shown in Table 1.

Table 1. Size and reinforcement of specimens.

specimen	Section size (mm×mm)	Concrete strength grade	By the beam / column edge extension length	Longitudinal reinforcement	Stirrup
precast beam	250×480	C50	2750mm	Top 2Φ^s12.7 Bottom6Φ^s12.7	Φ10@100/200(2)
Laminated layer	120	C40	2750mm	4Φ22	Φ10@100/200(2)
Cast-in-site column	500×500	C40	600mm	12Φ22	Φ10@100(4)

The precast prestressed beams of the PPAS system are prevented from cracking or crushing due to excessive prestress during the production process. The influence of different prestressed casing release on the joints is considered in the process of making the precast prestressed beams. See Table 2 for specific parameters.

Table 2. The change in parameters of different groups of specimens.

Grouping instruction	Specimens number	Information about Stress release
Cast-in-site comparative joint	RJ0	Ordinary reinforced concrete comparative specimens
Different information about Stress release	PJ1	The out side of the lower row of the two stranded end 1m range of the release
	PJ2	The out side of the lower row of the two stranded end 1m range of the release, and the middle of the low rower of the two stranded end 0.6m range of the of the release and the upper row of two steel wire ends 0.6m range of release

The mechanical propertiy of concrete and steels are shown in Table 3 and Table 4.

Table 3. Mechanical property of concrete(/MPa).

Design strength	fcu	fc	ft	Ec/（$\times 10^4$）
C50	63.6	41.2	3.3	3.636
C40	38.6	25.8	2.6	3.222

Table 4. Mechanical properties of steels.

Reinforcement type	Area/mm^2	fy/MPa	fu/MPa	Es/($\times 10^5$)MPa
Φ^s12.7	98.70	1851.0	2026.0	2.06
Φ22	380.13	524.1	669.6	2.10
Φ10	78.54	296.9	451.8	2.00

The low cycle repeated load test of precast prestressed assembled Structural frame Beam and Column is carried out on the joint testing machine in structure laboratory, the four-storey campus of Southeast University. The loading device is shown in Figure 3, and the joint test chart is shown in Figure 4.

During the test, the column top was loaded with a 320t hydraulic jack, and the axial compression ratio of the control column was 0.2 during the loading process and remained unchanged. In the experiment, the two-point reverse loading method was used. The anti-symmetrical low-cycle cyclic loading with two 50t hydraulic jacks was loaded in left and right beam end distance from the column 2.5m. Before the yield of the specimen, the pressure is controlled by three-stage loading, which is 1/3F, 2/3F and F of the yield load. After the yield, the displacement control is taken, and the maximum displacement of the specimen is 0.5 times, The test is terminated when the load drops to 80% of the maximum load. Before yield, each level of load repeated once; after yield, repeated twice.

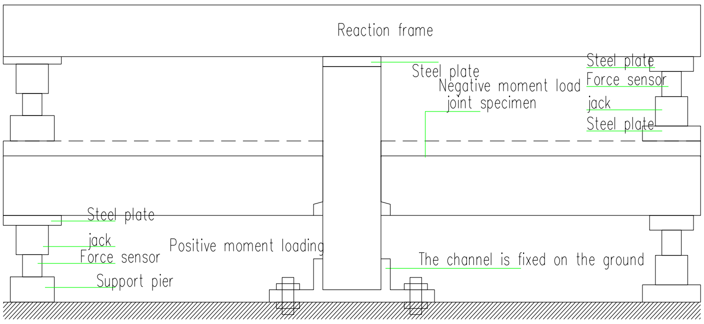

Figure 3. Loading equipment.

Figure 4. Test joints.

3. Result analysis

The nonlinear beam and column model is used as the simulation unit. It is a finite element model and a nonlinear element based on the fiber model method. It allows the stiffness to change along the length of the component. It is a distributed plasticity model. In the solution, the rod end displacement is obtained by the displacement of the node, and then the deformation of the cross section is solved according to the preset displacement interpolation function. Next, the material constitutive model of the section is used to determine the resistance of the section and the tangent stiffness matrix. The resistance of the whole unit and the unit tangent stiffness matrix is calculated according to the Gauss-Legendre integral. The unit model can be widely applied to the static and dynamic nonlinear analysis of the bar structure, and the P-Δ effect can be fully considered. Prestressed tendons are modeled using truss units. Rigid Link units connect truss units for simulating prestressed steel strand wire to reinforced concrete using fiber units for simulating, reflecting the relationship of deformation and coordination between the two. In this study, the steels in beams and columns is made of steel01 model, and the steel01 model is a bilinear follower strengthening model. The elastic modulus of the strengthening section is 0.01ES. ES is the initial elastic modulus of the steel, The effect of softening is not taken into account. Steel stranded Wires in precast beams use steel02 model, which can consider the prestressing effect by setting the initial stress.

Constitutive model of concrete uses the concrete02 model, which is the modified Kent-Park model by Scott et al. The model considers the effect of transverse stirrups by changing the peak stress, peak strain and slope of the softening section of the concrete compression skeleton curve, and it can consider the residual strength of the concrete, and the rising and falling segments of the concrete are all straight, and the initial cracking of concrete can be considered. Concrete02 model keep a good balance between simplification and precision, and the reinforcement nonlinear analysis of concrete structures has good accuracy.

The hysteresis curve of each specimen and calculated by OpenSEES software are shown in Figure 6. The shape of the hysteresis curve of cast-in-place reinforced concrete comparative speciment joint RJ0 and assembled crossed joint specimen PJ1 are similar and relatively full. The hysteresis curves of PJ2 is slightly collapsed showing that the number and range of stress release of the steel strand have a significant effect on hysterestic behavior of the component. The numerical simulation results of the OpenSEES are similar to those of the experimental hysteresis curves. The numerical simulation results can predict the unloading stiffness, reloading stiffness and stiffness degradation of each cycle of prefabricated prestressed beam assembly integral frame joints under the reciprocating load. While the simulation results also reflect the shape and pinching effect of the hysteresis curve of the actual specimen, which can better reflect the hysteresis characteristics of the test specimen.

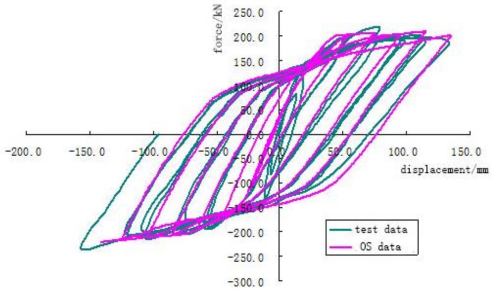

Figure 5. Hysteresis curve of PJO.

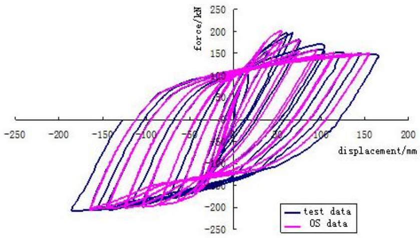

Figure 6. Hysteresis curve of PJ1.

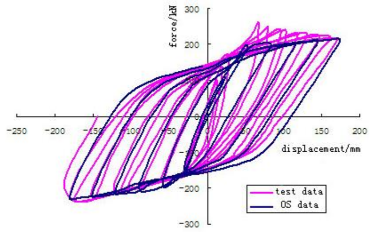

Figure 7. Hysteresis curve of PJ2.

4. Conclusion

In this paper, the finite element software OpenSEES is used as the analysis platform. The Nonlinear BeamColumn model is used as the simulation unit. The steel01 normal steel bar model, the steel02 prestressed steel strand model and the concrete02 concrete model are selected. Rigid Link units connect truss units for simulating prestressed steel strand wire to reinforced concrete using fiber units for simulating, reflecting the relationship of deformation and coordination between the two. OpenSEES software can simulate the unloading stiffness, reloading stiffness and stiffness degradation of each cycle under the action of low cyclic reversed load. The simulation results also reflect the shape and pinching effect of the hysteresis curve of the actual specimen. which better reflects the hysteresis characteristics of the test specimen.

Acknowledgments
MCC "three five" major science and technology special (MCC technology plan [2013]1) funded projects; Lianyungang Civil and Architectural Innovation Research Institute (KH16020); Lianyungang City Science and Technology Project (SH1628); Jiangsu Province Construction System (China) Technology Project (2016ZD34).

References

[1] Cai Jianguo, Feng Jian, Wang Zan, et al. Seismic Behavior of Frame Comprised of Precast Prestressed Concrete Components[J]. ACTA SCIENTIARUM NATURALIUM UNIVERSITAIIS SUNYATSENI . 2009 (2): 136-140.
[2] Cai Xiao-ning, MENG Shao-ping, Sun Wei-wei. Experimental Study on the Force Behavior of Self-resetting Prefabricated Frame Edge Node Components[J]. Engineering Mechanics. 2014 (3): 160-167.
[3] Chen Yaogang, Guo Zhengxing, Dong Niancai, et al. Joint Connection Construction Technology of the New Precast Concrete Shear Wall Structure[J]. CONSTRUCTION TECHNOLOGY. 2011 (11): 3-5.
[4] Cheok G S, Lew H S. Performance of Precast Concrete Beam-to-column Connections Subject to Cyclic Loading [J]. PCI Journal. 1991, 36 (3): 56-67.
[5] Dou Zu-rong, Wang Yi, Xue Wei-chen. Seismic Performance of Precast Monolithic Concrete Frame Exterior Connections Under Low Cyclic Loading[J]. Journal of Architecture and Civil Engineering of Building Science and Engineering. 2010 (2): 61-66.
[6] Liang Peixin, Guo Zhengxing. Experimental Study on New Prefabricated Unsymmetrical Hybrid Subassemblages [J]. Construction Technology. 2010 (3): 63-65.
[7] Li zhongxian, Zhang Xuesong, DingYang,Seismic Behavior of Steel Reinforced Concrete Joints with Beam End Plastic Hinges [J]. Journal of South China University of Technology (Natural Science Edition). 2007 (3): 77-82.
[8] Loo Y C, Yao B Z. Static and Repeated Load Tests on Precast Concrete Beam-to-column Connections [J]. PCI Journal. 1995, 40 (2): 106-115.
[9] Wang Dongyan, Li Zhenbao, Lu Haibo, et al.Strengthing Experimental Research of Unbonded Post-tensioned Precast Concrete Structure[J]. Earthquake Resistant Engineering and Retrofitting. 2007: 333-335.
[10] Wang Lili, Zhang Jiwen. Experimental Vestigation on Flexural Behavior of Novative Concrete Frame Joint Assembled with Precast Prestressed Concrete Beam[J]. Industrial Architecture. 2015(8):73-77.
[11] YU Jian-bing, GUO Zheng-xing, GUAN Dong-zhi. Experimental Study on Seismic Behavior of a New Precast Beam-to-column Connection [J]. Construction Technology. 2014 (22): 26-29.