EXPERIMENTAL STUDY ON SEISMIC BEHAVIOR OF INTERIOR JOINTS OF PRECAST PRESTRESSED CONCRETE FRAMES

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ABSTRACT :

This paper describes a precast concrete framing system, in which the U-shaped reinforcing bar is used to provide the flexural resistance between prestressed beams and columns. The characteristics of this system are firstly described. Then the cyclic loading tests on three beam-column sub-assemblages are reported. The distinct difference among the three specimens is the length of the U-shaped reinforcing bar. The strains of the reinforcement bars are mainly discussed in this paper. The results show that the yield loads of specimens have small relation to the length of the U-shaped reinforcing bar, and the yield loads of the stirrups are larger than longitudinal reinforcement bars. The reinforcement bars of the column are not yield during the test, so the column works well. This meets the requirement of strong column and weak beam. The strains of the U-shaped reinforcing bars indicate the slip of the bar is from the beam-column interface to the end of the service hole, and it corresponds with the theoretical analysis.

KEYWORDS: cyclic loading test, precast concrete structure, joint, service hole

1. INTRODUCTION

Moment resisting frames of the buildings are often designed to provide the required earthquake resistance for the building. In some countries, these frames are often constructed by precast reinforced concrete elements or precast prestressed concrete elements that are connected with cast-in-place concrete joints. The aim of these systems is to emulate the behavior of conventional cast-in-place reinforced concrete structures and save the construction time (Yee 2001, Park 2002, Kim 2003). Connection design is one of the most important considerations for the successful construction of precast reinforced/prestressed concrete structures. The detailing and structural behavior of the connection affect the strength, stability, and constructability as well as the load distribution of building under loads.

This paper discusses a precast prestressed concrete frame is that illustrated in Figure 1. It is a moment frame that is made from precast prestressed beams and precast reinforced columns, in which the components are connected by the U-shaped reinforcing bar. And the service hole at the end of the beam which is used for post-pouring concrete and putting the U-shaped reinforcing bar. Besides the common advantages of precast structure as described in the first paragraph, it also has following outstanding characters such as the adoption of first prestressed easily, the reduction in the height of member section, convenient construction of joints and low amount of steel usage (Zhu 2006).

This system was used widely in Jiangsu Province, China. Despite the growing popularity of using this system, general applications of it in Earthquake- resistant Grade Ⅱ frame structures are still limited. One of the major reasons for this is the lack of research on this system subjected to earthquake loading to support design and construction practices. Herein, the seismic behavior of the beam-to-column connections were investigated according to low reversed cyclic loading test. The test program and strains of the reinforcement bar measured in the test will be mainly discussed in this paper. The other results of the test will be discussed in other literatures.

2. TEST PROGRAM

Three interior beam-to-column joints with different lengths of service hole, called JC40, JC45, and JC50, were designed and constructed for the test. The tests were carried out at Southeast University because of the institution's role in developing the system in China. And the experiments were implemented according with JGJ101-96.

2.1. Test Specimens

The test units modeled the region form contraflexure of the column below the joint to contraflexure point above the joint and contraflexure point of beams on either side of the joint. The structural details of the specimens are given in Figure 1. Figure 2 together with Tables 2 and 3 summarizes the material properties and cross sectional details of the service hole, beams and columns of the models. The construction processes for the precast connections are described in detail in Cai *et al.* (2008).

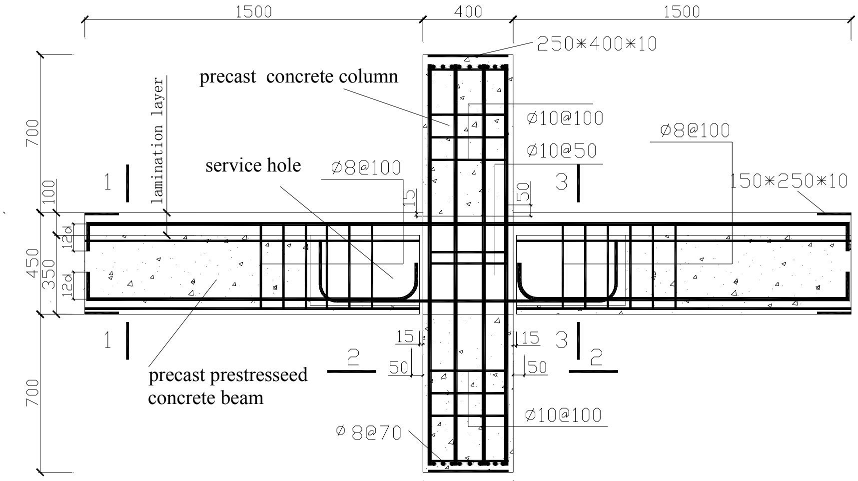


Figure 1 Test units

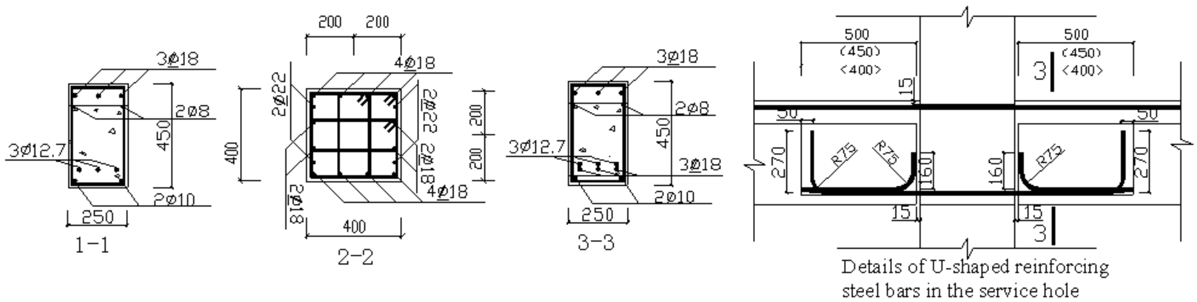


Figure 2 Cross sectional details of test units

Table 1 Material properties of concrete

Concrete	C40(1)	C40(2)	C40(3)	C50
Axial compressive strength f_c [Mpa]	29.1	27.2	29.3	34.0
Elastic modulus [$\times 10^4$ Mpa]	3.35	3.32	3.38	3.45

Table 2 Material properties of reinforcing bar

Reinforcing bar	Specification	HPB235	HPB235	HRB335	HRB335
	Diameter [mm]	8	10	18	22
Yield strength f_c [Mpa]		251.3	242.5	412.8	410.5
Elastic modulus [$\times 10^5$ Mpa]		2.16	2.11	2.08	2.11

2.2. *Test Setup*

The test setup is shown in Figure 3. In the setup, the column remained vertical and each beam was loaded vertically by a servo-controlled hydraulic actuator located at the point of inflection near the beam tip. P-△ effects were thus excluded from the test behavior. For every model test, an axial load was first applied at the top of the column. This load, which was equal to about 30 percent of the design axial strength of the column, was kept constant throughout the test. Then a vertical load was applied to the connecting beam stage by stage until failure of the model occurred. Figure 4 shows the loading history of the reversed cyclic load tests. The first three cycles were load controlled, in which the applied load were 30%, 50% and 100% of yield load. The subsequent cycles were controlled by the magnitude of the vertical deflection, measured at the tip of the beam. All beams were loaded two cycles in every level of displacement. The vertical tip deflection was increased in multiples of $\triangle_y$, where $\triangle_y$ is the deflection at first yield.

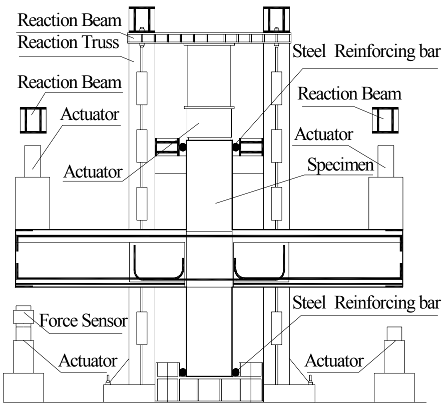


Figure 3 Test setup

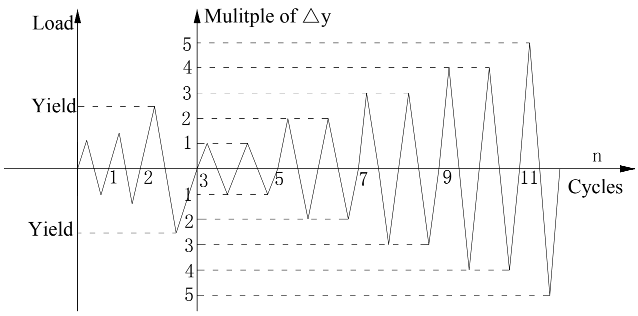


Figure 4 loading history

2.3. *Measurements*

The following are to observed and measured: (a) vertical cyclic loads; (b) deflections at the tip of beams; (c) strains of longitudinal steel bars; (d) strains of U-shaped reinforcing bars; (e) strains of stirrups at the beam end beside the column faces. The distributing of strain gauges on the test models are shown in Figure 5.

3. TEST RESULTS AND ANALYSIS

The electrical resistance strain gauges, which were attached to steel bars, were connected to a data acquisition system to record the data. The strain analysis was mainly discussed in this paper. The stress distribution and growing progress can be obtained from this analysis. And it will support the materials for seismic analysis of this system.

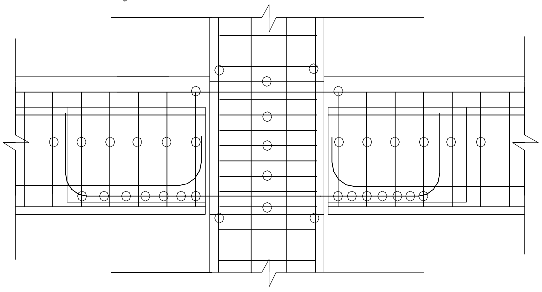
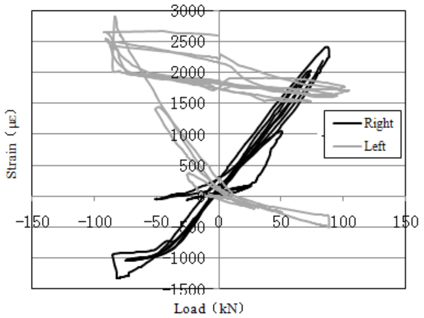


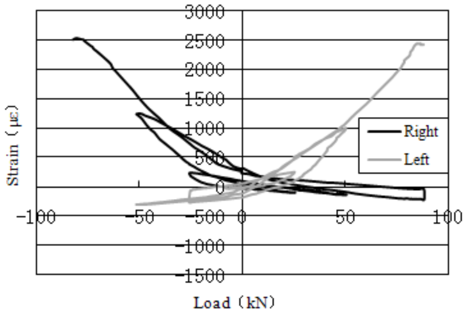
Figure 5 Strain gauges on the test models

3.1. Strains of Longitudinal Steel Bars for Beams

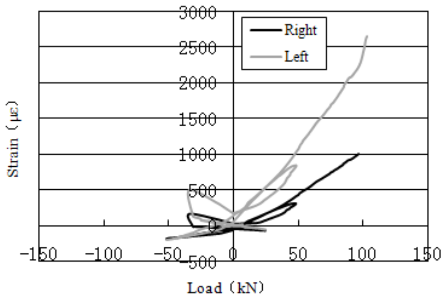
The strains of longitudinal steel bars in the beams at the column face are used to evaluate the yield load of beams. Figure 6 is the strain-load relation for all test models. It can be found that difference of yield load and crack load of the beams among the three models were small, and the yield load and crack load had small relation to the length of the service hole. The yield load and crack load also had good agreement with the ones in Cai *et al.* (2008).



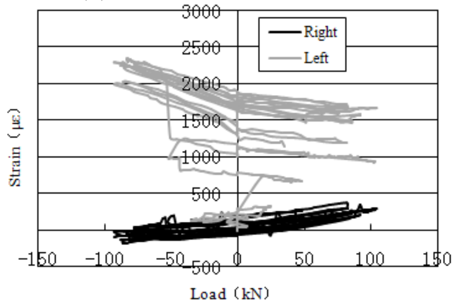
(a) Upper side of beams for JC40



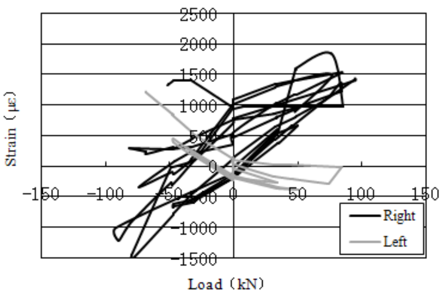
(b) Underside of beams for JC40



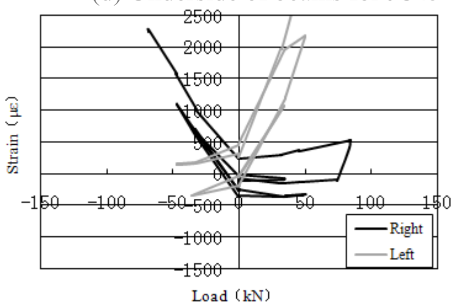
(c) Upper side of beams for JC45



(d) Underside of beams for JC45



(e) Upper side of beams for JC50

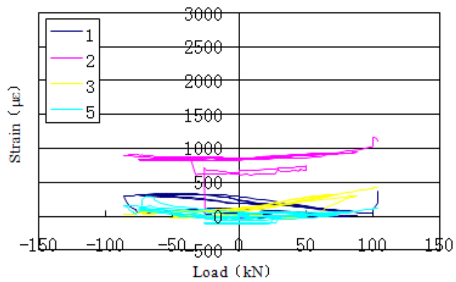


(f) Underside of beams for JC50

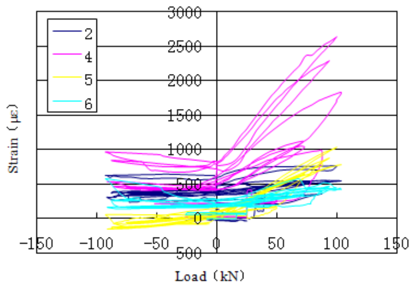
Figure 6 Strains of longitudinal steel bars for beams

3.2. Strains of Stirrups at Beam Ends

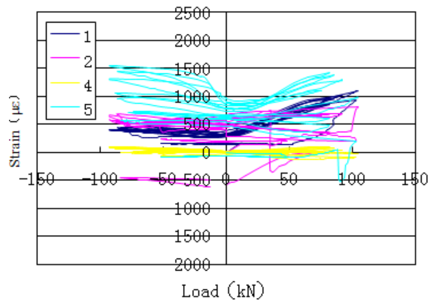
Figure 7 is the strains of stirrups at the beam ends. The service hole at the beam ends were designed as the plastic hinge, so the stress of stirrups in this region is very important. The serial numbers of the strain gauges are from the column face to the end of the service hole.



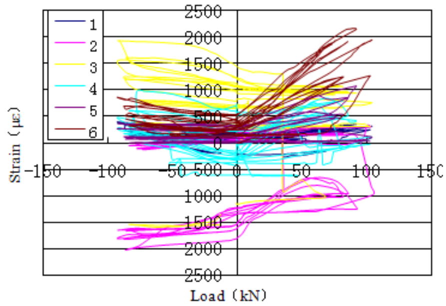
(a) Right side of the column for JC40



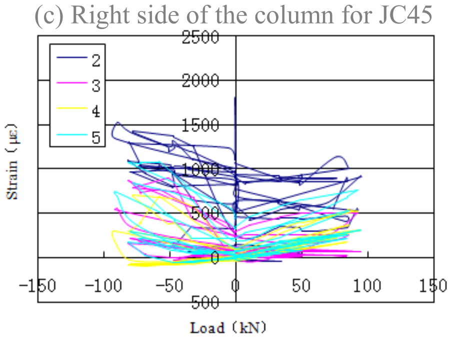
(b) Left side of the column for JC40



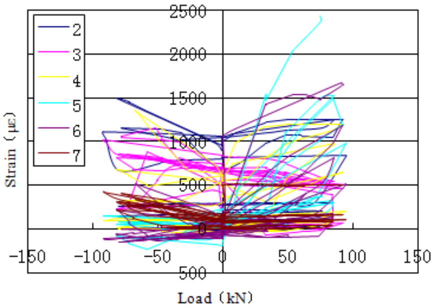
(c) Right side of the column for JC45



(d) Left side of the column for JC45



(e) Right side of the column for JC50



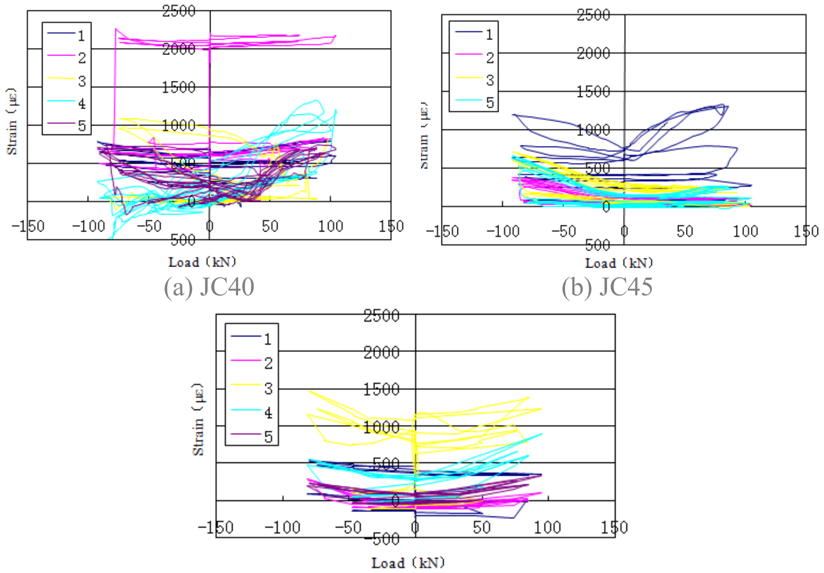
(f) Left side of the column for JC50

Figure 7 The strains of stirrups at the service hole

It is clear that the yield loads of stirrups were irrespective of the length of service hole, and they were larger than the yield load of longitudinal steel bars. It is corresponding to the requirements "strong shear weak bending". And this will leads to from the bending plastic hinge at the beam ends.

3.3. Strains of Stirrups in the Joints

The joint is very important to a moment resisting frame. The mechanism of the joint is very complex when it suffers to an earthquake load. The joint not only receive the axial force, moment and shear force from the columns but also the moment and shear force from the beams. The failure modes of the joint are always shear failure or bond failure. And if the joint is failure, the moment resisting frame will collapse and the ductility of the frame is not perfect. In order to investigate the seismic performance of the joint, the strains of stirrups in the joint were measured in this study. The serial numbers of stirrups are from the top down. And Figure 8 is average stain of two strain gauges on one stirrup versus the applied load at the tip of beams.



(a) JC40 (b) JC45

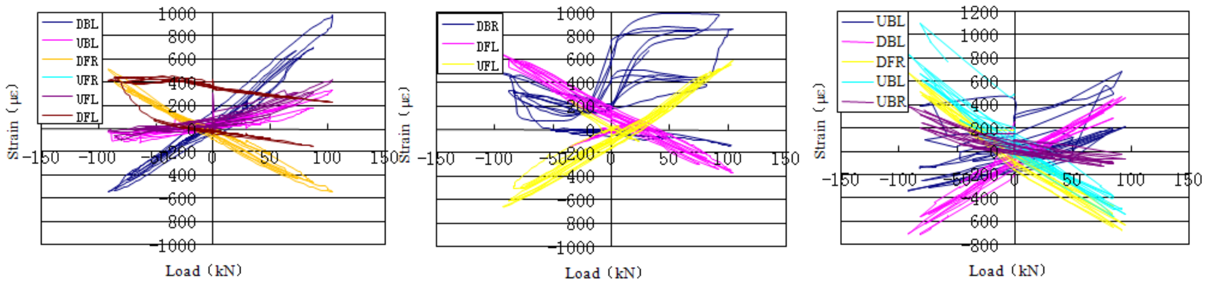
(c) JC50

Figure 8 Strains of stirrups in the joints

Form this figure, it shows us that almost all stirrups in the joints were not yield, and this meets the phenomenon that there are only small cracks in the joints. The core region was not destroyed during the test. This is corresponding to the principle "strong joint weak element".

3.4. Strains of Longitudinal Steel Bars for Columns

The strain gauges were on the corner longitudinal steel bars beside the joint. The strains of longitudinal steel bars for column are shown in Figure 9. In this figure, each cutline was identified by three letters. The first letter, U or D, indicates upside and underside of the joint. The second letter, F or B, represents the strain gauges on the front or back face of the test model. The last letter, L or R, identifies it whether on the left or right face of the column. The longitudinal steel bars were not yield during the test, and there are no any apparent cracks on the column face. It meets the seismic design principle "strong column weak beam".



(a) JC40 (b) JC45 (c) JC50

Figure 9 Strains of longitudinal steel bars for columns

3.5. Strains of U-shaped Reinforcing Bar

The precast prestressed concrete beams and precast concrete columns are connected by U-shaped reinforcing bar and cast-in-place concrete in the service hole. The slip of the U-shaped reinforcing bar is important to the seismic performance of this precast concrete frame system. So the strains of U-shaped reinforcing bar are supposed to investigate the slip of the bars. In order to add the bonding area between the reinforcing bar and concrete, the U-shape reinforcing bar was notched from the face to the center, and the strain gages were in the notch. Figure 10 illustrates the strains of U-shaped reinforcing bar for JC45 versus applied load at the tip of beams. It can be concluded from this figure that the bonder power would be larger when the distance to the column face was smaller. This is corresponding to the theoretical theory.

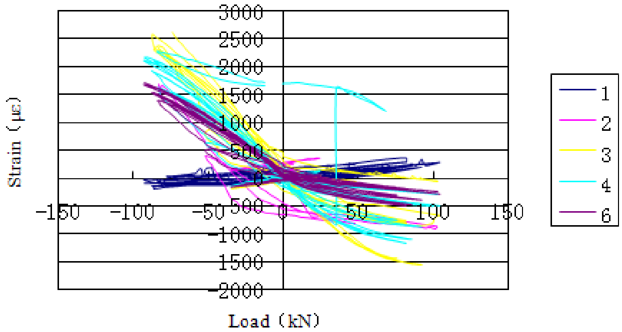


Figure 10 Strains of U-shaped reinforcing bar for JC45

4. CONCLUSION

Three beam-to column connection specimens were designed and tested under reversed cyclic loading in order to investigate the seismic performance of this precast prestressed concrete frame system. On the basis of introductions of the test models, test setup, and test regimes, the strain of the steel bars were analyzed in this paper. Based on the results of this study, the following conclusions can be stated:

1. The yield load and crack load of beams have small relations to the length of U-shaped reinforcing bar (service hole).
2. The yield loads of stirrups of beams are larger than the yield loads of longitudinal reinforcing bars for beams. This is corresponding to the requirement "strong shear weak bending".
3. The longitudinal reinforcing bars for beams are not yield during the whole test. And the column has no apparent crack. It meets the seismic design principle" strong column weak beam".
4. The stirrups in the joint are also not yield, and the joint work very well on the experiment. So the joints of specimens are accord with the principle" strong joint weak element".
5. The strains of the U-shaped reinforcing bars show us that the bond force is larger when the distance to the column face is smaller.

REFERENCES

Cai, J.G., Feng, J., Zhu, H.J., Liu, Y.F., and Huang, L.F. (2008). Experimental Study and FEM Analysis of Seismic Behavior of Joints for Frame Structures Comprised of Precast Prestressed Concrete Components, *Key Engineering Materials*, in press

Kim, J. (2003). Behavior of hybrid frame under seismic loading, *Ph.D. dissertation*, University of Washington

JGJ101-96 (1996). Specification of testing methods for earthquake resistant building ,China Architecture and Building Press, Beijing, China

Park, R. (2002). Seismic design and construction of precast concrete building in New Zealand, *PCI Journal* **15**, 60-75

Yee, A.A. (2001). Structural and Economical Benefits of Precast/Prestressed Concrete Construction, *PCI Journal* **14**, 46-52

Zhu, H.J. (2006). Seismic research by experiment for the joint of framed structures comprised of precast prestressed concrete components, *Master dissertation*, Southeast University.