SEISMIC PERFORMANCE OF PRECAST PRESTRESSED BEAM-COLUMN CONCRETE CONNECTIONS

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ABSTRACT:

This test researches one monolithic connection and 4 precast prestressed unbonded post-tensioned concrete connections under reversed cyclic loading. Such parameters as PT initial post-tensioning force, PT eccentric position and PT anchor length are discussed. Results of experiment indicate that these elements have desirable seismic characteristics, restoring characteristics and have an ability to undergo large nonlinear displacements with little damage. In this paper a detailed analysis as resilience, ductility, energy dissipation etc are carried out. The objective of this test is to develop guidelines for precast structure in regions of earthquake zone.

KEYWORDS： precast concrete connections, unbonded post-tensioned, reversed cyclic loading, seismic behavior

1. INTRODUCTION

Our preliminary study is about seismic performance of 11 precast prestressed intermediate connections [1] [2] [4], and the result shows that the ductility, strength and seismic performance of connections are perfectly. The post tensioned tendons still maintain elasticity so the specimens have a strong self-centering capability and the residual deformation of specimens is very small.

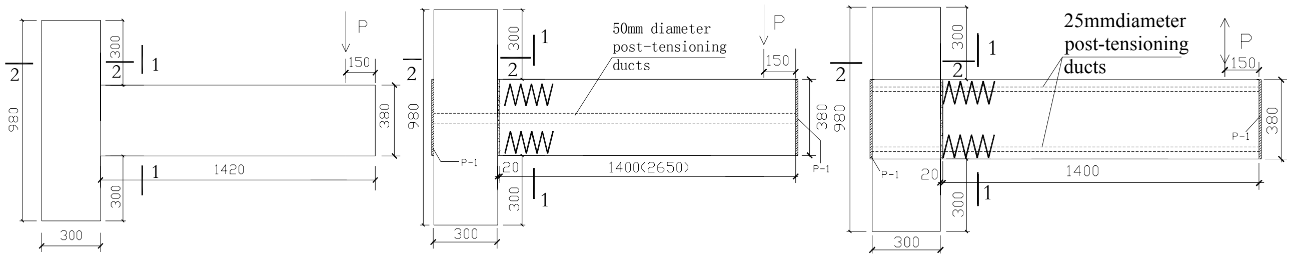
To improve the performance of precast structure, the authors use high strength strand through the precast concrete beams and columns to link them as a whole in the site. Some inner joints of frame are experimented under the low cyclic loading [1] [2] [4]. It is shown that the unbonded precast prestressed structure has a good seismic performance, the failure mode is different from tradition concrete structure and damage was only concentrated in the end of the beam. To further explore the performance of this precast prestressed beam end, a cast-in-place concrete beam and four unbonded precast prestressed beams were tested under low cyclic loading according to the cantilever beam-loading methods. The paper analyzed the prestressed tendons position, anchoring length of tendons and initial prestress value on the impact of specimen displacement ductility, energy consumption and residual deformation.

Precast prestressed structure used standardized components which can provide high quality production and rapid erection. We believed precast concrete structure has the potential of being wildely used in high seismic areas in the future.

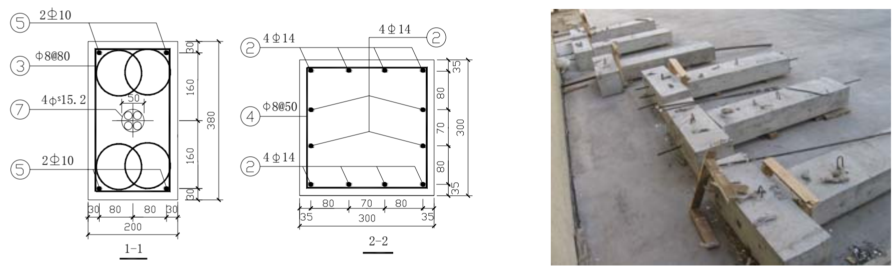
2. EXPERIMENTAL PROGRAMS

2.1. Precast prestressed specimens

A total of four one-second specimens and one monolithic specimen were tested under low cyclic loading. Each specimen is consisted of a precast beam and a precast column. The monolithic member used as contrast. The specimens used variations design parameters as followed: (1) initial stress of post-tensioning steel; (2) tendons position; and (3) anchoring length of tendons. These beams with details were shown in Figure 1 and Table 1.



（a）MCB （b）PCB1、3、4 （c）PCB2



(d) Cross-section 1-1 and 2-2 (e) Photo of specimens

Figure 1 Details of specimen

Table 1 General description of specimens

Specimen	section (mm×mm)	length（mm）	Average initial PT stress f_{pi}/f_{ptk}	PT strands (mm^2)	Location of PT
MCB	300×300 (Column) 200×380 (Beam)	1420（Beam）	——	——	——
PCB2		1400（Beam）	0. 47		eccentric
PCB1		1400（Beam）	0. 494	$4\Phi^s 15.2$	centre
PCB3		2650（Beam）	0.5		
PCB4		1400（Beam）	0.316		

Note：PCB-x

x → Specimen number
B → Beam
C → Concrete
P → M: monolithic
P: precast prestressed

The test beams have a depth of h=380mm, a calculate length of L=1250mm, and the columns have a depth of h=300mm.Each test specimen includes mild steel reinforcements as follows: (1) HPB235 (Q235) nominal transverse [8mm diameter closed hoops at 80mm spacing for beams and 50mm spacing for columns]; (2) HRP335 (20MnSi) longitudinal reinforcement [two Φ10 (10mm diameter) bars top and bottom for beams, 4 Φ14 (14mm diameter) bars for columns];and (3) HPB235 (Q235) spiral wire concrete confinement reinforcement [100mm outside diameter, spirals at 25mm pitch for beams].

Each unbonded post-tensioning tendon is comprised of seven low relaxation strands with a cross-sectional area of A_p=139mm^2 and a design maximum strength of f_{ptk} =1860MPa. The post-tensioning strands are placed inside 50mm nominal diameter PVC ducts located at the beam centerline (i.e., with zero eccentricity), strands of PCB2 placed in 25 mm nominal diameter PVC ducts top and bottom for specimens located at the eccentric section (show in Figure 1c), and run the length of the test beam and the depth of the column (see Figure 1). In order to prevent bond between the strands and the concrete, the post-tensioning ducts are not filled with grout. In practice the post-tensioning strands are typically left unbonded over the entire length of the outer ends of the exterior joints. So in this experiment the length of the post-tensioning steel between the anchors was left unbonded in the test specimens.

High strength fiber-reinforced grout (non-shrink, non-metallic, high early strength New Vision CGM High Performance Grout with polypropylene fibers) was used at the beam-to-column interface to provide good matching surfaces between the precast beam and the column. Ordinary cement grout was used in the ducts of special mild steels.

2.2. Material properties

The design yield strength for the longitudinal and transverse bars is f_y =300MPa and f_y =210MPa respectively. The actual average yield strength is f_y =389.2MPa and f_y =361.2MPa respectively. The design compressive strength for the concrete is f_c =25.3MPa.

The concrete compressive strengths were measured from standard 150×150×300mm prisms tests. Three concrete prisms were tested for the precast beams and columns. The prisms were kept under the same conditions as the precast specimens until testing. The prisms were tested on the same day as the first test. The average (from three prisms) measured concrete compressive strength for specimens is f_c =45MPa. The average (from three prisms) measured concrete elastic modulus is 3.75×10^4MPa.

2.3. Experimental setup

The experimental setup is consists of a precast concrete test beam oriented in a horizontal configuration, and a precast column and reacting wall (shown in Figure 3). The location of the lateral loading actuator represents the midspan of the beam. Note that the beam gravity loads are not modeled in the experimental setup.

Test beam and column are joined using unbonded post tensioning strands and JM anchors (made by Beijing Building Construction Research Institute).

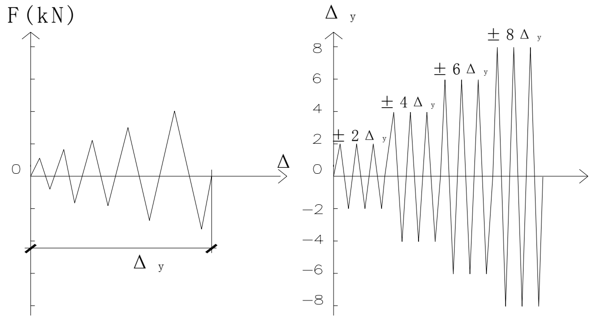


Figure 2 Photo of test setup

Figure 3 Loading history

2.4. Loading sequence

This experiment use force and displacement control reversed cyclic loading. In the first stage use the lateral force of beam end to control the step of loading until the specimen yield, while the displacement in the moment named as yield displacement. This yield displacement used as the next stage (displacement control) control base. In the second stage used the multiples of yield displacement to control loading. The loading history was shown in Figure 3. In each loading step there are three fully cycles.

A 500kN capacity hydraulic actuator was located at the beam height and using a 1000kN capacity hydraulic actuator on the top of the column to keep axial compressive ratio as a constant 0.3. Through sensors we can gain the change values of actuators in beam, column and tendons. Linear displacement and indicating gauge were used to measure the relative displacements and deformations of the precast beams and columns.

In addition, strain gauges were used to measure the strains of concrete, longitudinal steel and special mild steel in beam and column. For each test, all sensors, instrumentation and data acquisition were initialized that any data recorded was right due to the application of the post-tensioning forces and lateral loads.

3. TEST RESULT FROM EXPERIMENT

3.1. Failure mode

The failure modes for the five sets of specimens tested were different. The cast-in-place MCB specimen failed predominantly in shear in the beam near the column connection region as show in Figure 4a. This failure mode was most likely a result of insufficient confinement provided by the transverse reinforcement. The only damage observed in the beam of this specimen was some flexural and shear cracking.

As expected, the failure mode of the monolithic MCB specimen was hinging in the beam. There were also some prominent shear cracks in the hinge region. These shear cracks appear at $2\Delta_y$ and widened in the subsequent cycles. The column of specimens was basically undamaged as show in Figure 4a.

The precast concrete specimens (PCB1、2、3、4) failed as a result of their inability to sustain higher loads due to localized yielding of the grouted special mild steel bars. This yielding allowed for an opening of approximately 14mm between the beam and column at failure and crushing of concrete in the beams see Figure 4a. But there were no such cracks as the monolithic MCB specimen in the beams. After the load removed the post-tensioning forces the specimens to return to its undeformed position and the gap between beam and column closed. There was only plastic crushed deformed (beam concrete cover spalling) can be seen (see Figure 4b, c, d, e).

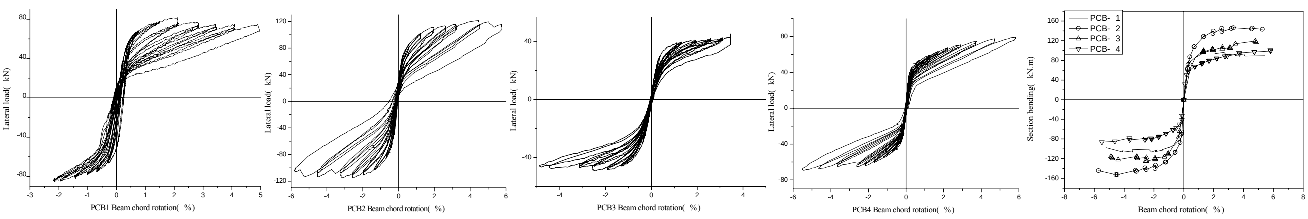
(a) MCB (b) PCB1 (c) PCB2 (d) PCB3 (e) PCB4

Figure 4 Representative failure modes of specimens

3.2. Hysteresis Plots

The hysteresis curves for the PCB specimens are given in Figure 5. In order to eliminate the different displacement between specimens we used beam chord rotation as abscissa. Beam chord rotation θ is calculated as the lateral displacement of the beam at the actuator level, divide by the length of the actuator-to-column face. The beam chord rotation represents the relative chord rotation between a beam member and a column member.

It is show that the ability of energy dissipation is poor but the precast specimens have a desirable self-centering capability and can undergo large nonlinear displacements with little damage. The limited strength and yield strength of PCB2 specimen are higher than other speciments. It is shown that reduces the initial stress of PT can reduce the bearing capability of PCB4 specimen. Increase the length of PT tendon (PCB3) can also reduce the initial stiffness and capability of bearing load.



(a) PCB1 (b) PCB2 (c) PCB3 (d) PCB4 (e) Framework curves

Figure 5 Load—beam chord rotation hysteresis curves and framework curves for specimens

3.3. Energy Dissipation

Based on Jacobson the paper used equivalent viscous damp to evaluate the ability of energy dissipation for specimens under the inelastic large displacement. The sketch map of calculation of h_e is shown in figure 6. The calculated viscous damp factor was in the Table 2. The MCB specimen damping stiffness is 2.78%, greater than others. It is shown that the equivalent viscosity factor of PCB1, 2 is similar, while PCB3, 4 is similar. In the energy dissipated the two are identical that increase the PT anchor length and reduce the initial post-tensioning stress.

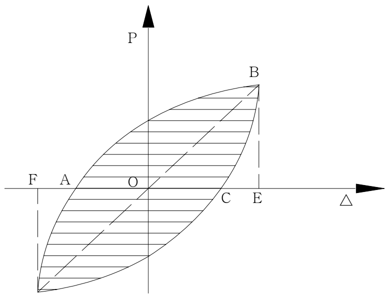
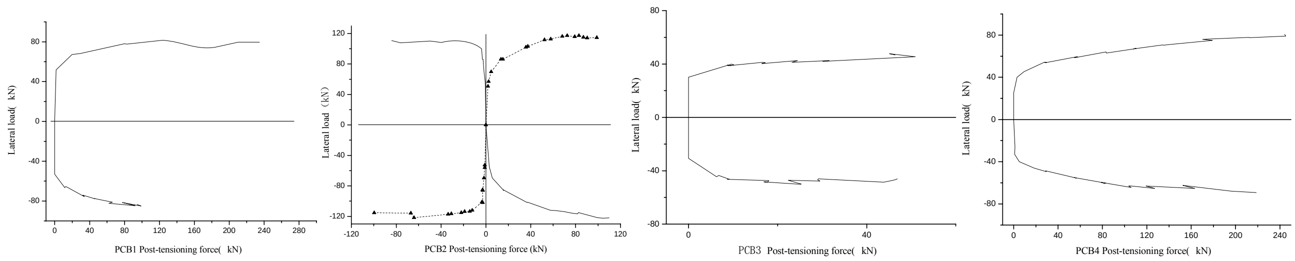


Figure 6 Sketch map of calculation of h_e

Table 2 Energy dissipation factor of specimens

Specimen	S_{ABCD} (kN.m)	$S_{OBE+ODF}$ (kN.m)	h_e
MCB	15.2	8. 7	0.278
PCB-1	2.78	3.642	0.122
PCB-2	8.04	6.91	0.185
PCB-3	2.94	5.784	0.081
PCB-4	2.9	5.3	0.087

3.4. Post-Tensioning Force



(a) PCB1 (b) PCB2 (c) PCB3 (d) PCB4

Figure 7 Framework of beam post-tensioning force vs. beam load

There are differences in the average initial post-tensioning steel stress between the three tests, as show in table 1.The first observation from Figure 7 is that as the initial post-tensioning force is also increased the beam maximum moment. The second is that after the beam maximum moment the post-tensioning force increased quickly not in proportion with beam moment. The beam moment is nearly a constant value.

There are several factors contributing to these results, including: (1) the post-tensioning force provides only a part of the beam end moment resistance; (2) the beam sustains additional “damage” during the displacement cycles to beam chord rotation; (3) the neutral axis depth increase; and (4) there are differences in the initial stresses of the post-tensioning steel affecting the maximum beam end moment reached.

4. CONCLUSIONS

The tests showed that a precast prestressed concrete system is feasible and shows considerable promise. The purpose of the experiment was to evaluate a number of concepts and to identify the most promising one. The key issues are that, given the appropriate details, the PT steel remains elastic and the system loses little strength up to very large drifts. The following conclusions can be drawn from the research:

1 Although the energy dissipated is low the ductility of PCB specimen is better than MCB specimen, the residual deformation of PCB specimen is little, the damage degree of PCB specimens is light than MCB specimen. In PCB specimens there is only a main crack between beam and column and there is little shear cracks in beam. It is mean that on the aspects of reducing shear cracks the PT tendon is more effective than horizontal reinforcements in beam.

2 Initial stress of PT tendon impact on the early stage of bearing capability of specimens largely but which is weakened with the load. For the point of energy dissipated, the larger the initial prestress the more increase the capacity of energy dissipated of overall specimen.

3 Increasing the anchorage length of PT tendon (PCB3 specimen), it will reduce the initial stiffness, the cracked load, the load yield and capacity of consuming energy.

4 Comparing to the centre layout of PT tendon of PCB1, 3, 4 specimens the eccentric layout of PT tendon of PCB2 specimen has an ideal capability of cumulative consuming energy and bearing load.

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