STUDY ON STRUCTURAL PERFORMANCE OF PRECAST CONCRETE BALCONY WITH HPFRCC

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ABSTRACT

In this study, the construction method of precast concrete balconies with High Performance Fiber- Reinforced Cementitious Composite (HPFRCC), in which only the head of the cantilever slab is replaced by the precast members, is introduced. The test parameters are type of concrete and thickness of lateral groove part. The static cyclic loading for test specimens is carried out. The specimen with HPFRCC failed at the lateral groove part avoiding reinforcing bars. The test result shows that thickness of lateral groove part affects ultimate load. The results of section analysis suppose the reduction of tensile strength of HPFRCC due to cyclic loading. All specimens show enough load capacity to the horizontal force by structural design.

KEYWORDS: HPFRCC, precast, balcony, structural performance

1.INTRODUCTION

Recently, in reinforced concrete apartment housing construction, an industrialization method of construction has been required to reduce the cost and to be improved of process control and the quality control. The construction method of precast concrete balconies, in which only the head of the cantilever slab is replaced by the precast members, has been adopted. By using this method, it is possible to work without heavy industrial machine such as a big drane. In this study, High Performance Fiber-Reinforced Cementitious Composites, called HPFRCC, is used in the precast part. HPFRCC is made by mixing with organic fibers of the polyvinyl alcohol (PVA) in cement materials and make performance as high ductility in tension. Due to the tensile capacity of HPFRCC, reinforcing bars are not arranged in the precast part. That causes the reduction of manufacturing process of members and cover thickness. In addition, the reduction of cover thickness at the precast part make possible to reduce the whole floor slab thickness and total weight of balcony. If the weight of slab is lighter, the weight of whole building can be lighter as leading the improvement of earthquake resistance.

In order to investigate structural performance of specimens manufactured by this method, the static cyclic loading test which is assumed as an earthquake response to the balcony had been carried out by authors [1]. The results of this experiment show the proper method of connecting between the precast concrete member in case of ordinary concrete and floor slab. Based on the results of the experiment, the un-reinforced precast member with HPFRCC is manufactured and static loading test is carried out in this study. The purposes of this study are to investigate the possibility of employing HPFRCC for the un-reinforced precast member and to develop the construction knowledge.

2.OUTOLINE OF LOADING TEST

2.1. Specimen

An example of specimen and arrangement of reinforcement is shown in Figure 1, details of the precast member are shown in Figure 2 and list of specimen is shown in Table 1. Each specimen has a different thickness of floor slab part and lateral groove part. The shape of specimen and arrangement of reinforcement are same. The construction of specimen is same as actual construction of buildings. The precast concrete member of the head of the cantilever slab is manufactured then floor slab part and guardrail part of the balcony is cast in-situ. The test part of specimen is from the connection between the precast member and guardrail to the anchored floor slab part. In the loading test, the floor slab is fixed to loading bed with channels-using steel bars. The width of specimen is 1,500mm. The main parameters are type of concrete of the precast member (ordinary concrete or HPFRCC) and thickness of lateral groove part. The connection method between the precast member and guardrail are same in all specimens. Y-insert is set up in the precast member and is connected by joint reinforcing bars, D13. Shear cotters which size is 80x40mm and depth is about 20mm are set at the Y-insert part.

For PCD-2and PCD-3, the precast member is connected to floor slab by anchors, and has no ordinary reinforcing bars inside. The anchoring bar is D10. To keep cover depth of lateral groove part, the anchor has cross shape and shear cotters are set at the slab connection in order to have better connection between the precast member and the part of concrete casted in-situ. For PCS-4, the arrangement of reinforcing bars of the precast member is the same as a ordinary RC balcony and reinforcing bar also has a role of anchors at slab connection. All specimens are same arrangement of reinforcing bars at guardrail part and floor slab. In addition, the precast members are casted from the downside.

Because the guardrail connections of each specimen would be yield first as expected, the loading process is divided into two parts for the specimen PCD-3 and PCS-4. As the first part, the basic performance of the guardrail connection is investigated. After that, carbon fiber sheets are attached on the guardrail connection to prevent the failure of that part so that the performance of precast part and the slab connection is investigated as the second part of the loading test. The specimens to investigate the guardrail connection are called PCD-3P and PCS-4P.

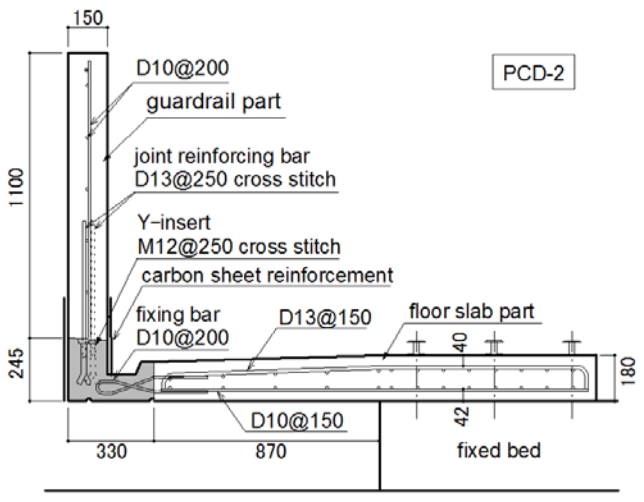

Figure 1 Specimen and layout of reinforcement

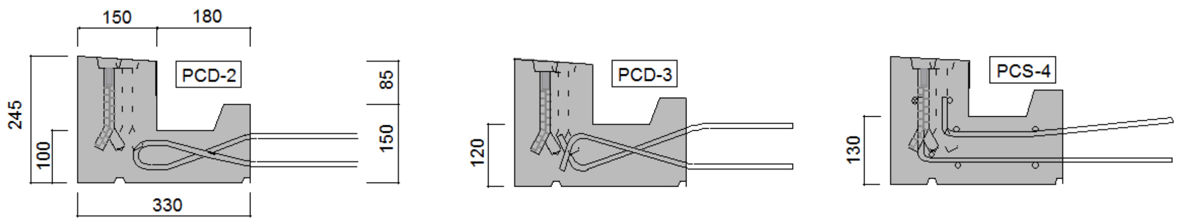

Figure 2 Detail of the precast members

Table 1 List of specimen

Specimen name	the precast member					Reinforcement of floor slab	Reinforcement of guardrail
	Inside reinforcing bar	Floor slab anchor	Guardrail connection Joint reinforcing bar	Y-insert	Thickness at groove		
PCD-2	nothing	D10@200	D13@250	M12	100	Main bar D13@150 D10@150	D10@200
PCD-3 (PCD-3P)	nothing	D10@200			120		
PCS-4 (PCS-4P)	6-D10 1-D13	D10@150			130		

2.2.Material properties

Deformed reinforcing bar, HPFRCC with PVA fiber, ordinary concrete and carbon fiber sheet are used for the specimens. The sizes of deformed reinforcing bars are D10 and D13 (SD295). Mix property of HPFRCC is shown in Table 2. Mechanical properties of HPFRCC and concrete are shown in Table3. Fiber volume fraction of PVA in HPFRCC is 1.5% and PVA fiber properties are shown in Table 4. Carbon fiber sheets are attached with epoxy resin after grinding surface of concrete and flattening with putty type resin.

Table 2 Mix Property of HPFRCC

Type	Water / cement ratio	Fiber volume fraction	Unit quantity (kg/m^3)			
			Cement	Water	Fine aggregate	Fly ash
HPFRCC	60%	1.5%	576	380	484	291

Table 3 Mechanical properties of HPFRCC and natural concrete

Type		Compressive strength (MPa)	1/3 secant modulus (GPa)	Tensile strength (MPa)	Tensile ultimate strain (%)
HPFRCC		40.5	15.1	3.93^{*1}	0.959^{*1}
Concrete	Precast part	47.1	33.3	3.74^{*2}	-
	In-situ casting part	29.0	26.6	2.52^{*2}	-

*1 JCI-S-003-2007 *2 Splitting tensile test

Table 4 PVA fiber properties

Material	Fiber length (mm)	Diameter (mm)	Tensile strength (MPa)	Elastic modulus (GPa)
PVA fiver	12	0.04	1600	40

2.3. Method of loading and measurement

The position of loading and LVDTs are shown in Figure 3. The horizontal displacement of the top of the guardrail part (δ_{top}: the guardrail-top displacement, average of D1 and D2) is monitored and the static loading tests are performed by the monitoring displacement control using actuator which is fixed at the guardrail part. The actuator is kept holding by chains to prevent own weight acting to specimens. The loading direction that the specimen is pushed by actuator is defined as plus loading. And opposite direction is defined as minus loading. Slips and opening width at the guardrail connection and the slab connection are measured. The displacement in test result of each measured item is the average value of displacements on both sides.

The loading history is shown in Figure 4. The loading has 15cycles. The loading cycles for 1mm and 2mm are twice and from 3mm to 90mm, every one cycle loading is carried out. In PCD-3P and PCS-4P, loading history has 8 cycles that are from 0.5mm to 10mm as peak displacement in order to avoid much failure at the guardrail connection.

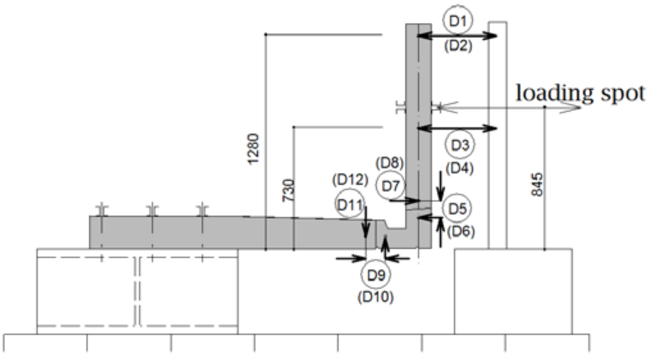

Figure 3 Position of loading and LVDTs

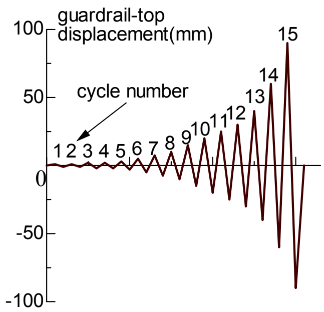

Figure 4 Loading history

3.TEST RESULT AND ANALYSIS

3.1. Failure Process

The final crack patterns of the precast part of each specimen in a side view are shown in Figure 5.

For PCD-3P, the guardrail connection is opened and the slab connection showed slip. The guardrail connection showed slip and lateral groove part was cracked later. Finally, the loading finished without more cracking. PCS-4P had similar behavior as PCD-3P. The guardrail connection showed slip and opened. The slab connection opened more keeping constant load and the loading finished. Only the connection part had cracks.

For PCD-2 reinforced with carbon fiber sheet at guardrail connection, the slab connection opened and showed slip firstly. Opening at the slab connection became clearly and multiple cracks were observed at the under surface of the lateral groove part in minus loading. Then, a crack between downside groove and bottom of guardrail part became clearly and collapsed avoiding inside reinforcing bars of the precast member at this crack.

For PCD-3, similar behavior was observed as PCD-2. The slab connection opened and showed slip. The lateral groove part had multiple cracks. After that, cracks were observed from the part of shear cotter to the slab connection. These cracks were almost perpendicular to the slab connection. PCD-3 failed due to a crack between downside groove and bottom of guardrail part. Final collapse section in PCD-3 is shown in Figure 6

For PCS-4, opening at the slab connection, which had already opened in the loading for PCS-4P, became wide at the early loading stage. After that the lateral groove part and bottom of guardrail part were cracked and these cracks grew to the guardrail part. Vertical cracks along the Y-insert of the guardrail connection were observed. In addition, it is confirmed that the opening of the slab connection became smaller with increases of crack width at bottom of guardrail part. Finally, vertical cracks opened and loading finished with increase of the opening around guardrail part.

Relationship between the load and the guardrail-top displacement is shown in Figure 7 and its envelope curve is shown in Figure 8. For PCD-3P, load becomes small due to slippage at the slab connection. The relationship of PCD-4P is similar to PCS-3P. For PCS-4P, load decrement is observed due to cracks at guardrail connection. As shown in Figure 8, the envelope curves of load-guardrail top displacement relationships of PCD-2 and PCD-3 are almost same shape although the load is difference. Both of these specimens show the slip type curve. And the load becomes small when a crack of a final collapse opens at the lateral groove part. It is assumed that thickness of the lateral groove part affect the load capacity. For PCS-4, the load becomes smaller because cracks at bottom of the guardrail part are opened in minus loading. It is considered that the load in plus loading is bigger than in minus loading because a crack occurs along the Y-insert of the joint reinforcing bar at the guardrail connection in minus loading.

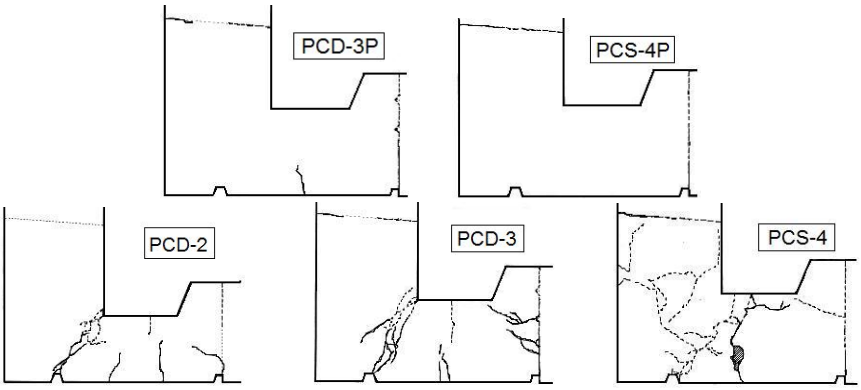

Figure 5 Final crack pattern


Figure 6 Final collapse section in PCD-3

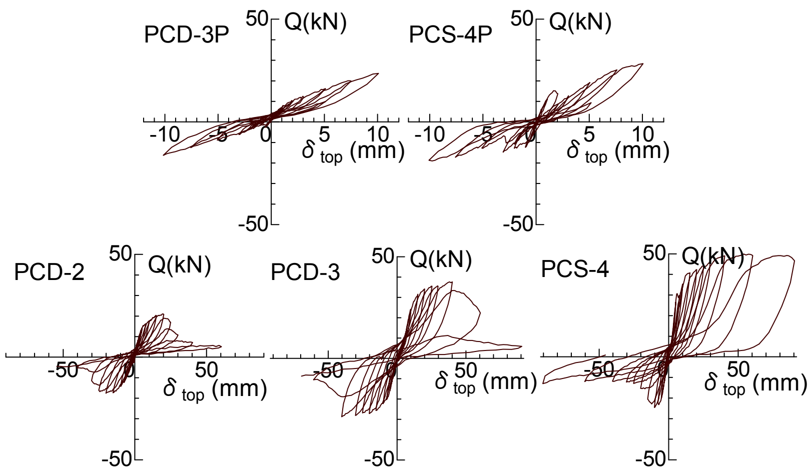

Figure 7 Relationship between load and the guardrail-top displacement

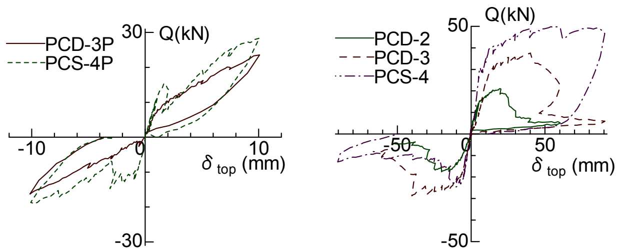

Figure 8 Envelope curve

3.2. *Analysis of maximum load*

The maximum load of the loading test is compared with the calculated value of bending ultimate strength by section analysis. The section analysis is conducted in three focused sections, which are the guardrail connection (section A), the lateral groove part (section B) and the slab connection (section C). For PCD-3P and PCS-4P, section A is dangerous section. For PCD-2, PCD-3 and PCS-4, section B and C are dangerous sections. The bending moment calculated for dangerous sections is converted to the force at loading point of the guardrail part. Concrete strength for connection part is to be same as that of the concrete in-situ part. The concrete strength of the precast member is used for section B. The stress-strain model of HPFRCC is shown in Figure 9. The tensile stress of HPFRCC is assumed to be uniformly distributed all over tensile side of section. The maximum loads of experiment and analytical values are shown in Table 5.

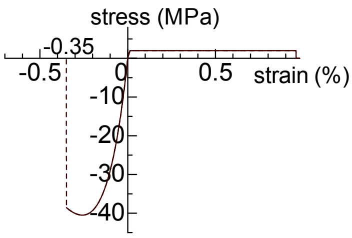

Figure 9 Stress –strain model of HPFRCC

Table 5 Comparing maximum load and calculation value

Specimen name	Loading direction	Maximum load of experiment (kN)	Calculated section	Maximum load of analysis (kN)	Experiment / Analysis
PCD-3P	Plus	23.6	A	19.1	1.24
	Minus	16.3	A	20.5	0.80
PCS-4P	Plus	28.4	A	19.1	1.49
	Minus	19.0	A	20.5	0.93
PCD-2	Plus	21.1	B	41.7	0.51
			C	54.1	0.39
	Minus	17.6	B	23.2	0.76
			C	51.4	0.34
PCD-3	Plus	37.6	B	47.6	0.79
			C	71.6	0.53
	Minus	28.7	B	27.5	1.04
			C	71.6	0.40
PCS-4	Plus	49.9	B	67.7	0.74
			C	36.8	1.36
	Minus	24.6	B	32.0	0.77
			C	39.0	0.63

In addition, the operating load acts as axial force on the calculated section B and C. The convergence calculation is carried out to have same value between the load and axial force. Calculation for section B of PCD-2 and PCD-3 is done for the section where the reinforcing bars are crossed as the weak section.

Calculated strength is determined as the smallest value of each section. For PCD-2 and PCD-3, in which HPFRCC is used, failed at the lateral groove part in experiment. However as shown in Table 5, calculation result shows that the weakest point of these specimen is the slab connection. Therefore, because collapse surface of these specimens avoided reinforcing bars, the existing of reinforcing bar is omitted. In addition, the tensile strength is reduced to be half value in the precast member. Calculation result is shown in Table 6.

In this result, the maximum loads of experiment and analysis become closer. Therefore, it is assumed that the actual tensile strength of HPFRCC is the half value of tensile strength evaluated by material test. It is considered that tensile strength of HPFRCC becomes smaller because PVA fibers pullout from matrix or rupture at collapse section. However it is necessary to investigate the effects of cyclic loading on HPFRCC.

For PCS-4, the maximum load of experiment and analysis dose not fit in minus loading because of cracks along Y-insert of the joint bars. The average ratio of experimental load to analytical one is 1.36 in plus loading. So, it is confirmed that section analysis can be adopted to evaluate experimental maximum load in safe side in case of PCS-4.

Table 6 Calculation result

Specimen name	Loading direction	Maximum load of experiment (kN)	Maximum load of analysis (kN)	Experiment / Analysis
PCD-2	Plus	21.1	18.7	1.13
	Minus	17.6	16.8	1.05
PCD-3	Plus	37.6	27.3	1.38
	Minus	28.7	23.9	1.20

3.3.Design force for earthquake and wind

The design force is calculated as the 15-story buildings (the height of buildings is 45 meters) at three dangerous sections which are same as the case of section analysis. The design seismic force is calculated using Eq. (3.1) and the design wind force is calculated using Eq. (3.2). Calculation result of the design force is shown in Table 7. By comparing calculated and experiment load, it is confirmed that all specimens have enough strength against the design force.

$$P_e = k \times W \tag{3.1}$$

$$P_w = C \times q \times A \tag{3.2}$$

P_e: designing seismic force

P_w: designing wind force

where,

k : horizontal seismic coefficient (=1.5)

W: weight

C: wind factor (=1.2)

q: velocity pressure (N/m^2) ($=120\sqrt[4]{h} \times 9.81$)

A: area receiving wind pressure (m^2)

h: height (m)

Table 7 Calculation result of design force

Section	Design seismic force (kN)	Design wind force (kN)
A	8.9	6.0
B	10.9	7.4
C	12.3	7.4

4. CONCLUSIONS

In this study, the balcony specimen using the precast concrete member is manufactured and static loading is carried out. The parameters are type of concrete and thickness of lateral groove part. From the test results, the followings are summarized.

1. The specimen with HPFRCC showed multiple cracks at lateral groove part and collapse took place at the surface avoiding reinforcing bars. Thickness of lateral groove part affects the maximum load.

2. The maximum load of experiment is compared with that of calculation by section analysis. The result shows that for PCD-2 and PCD-3 with HPFRCC, the tensile strength of HPFRCC is considered as about half value of the strength examined by material test. It is assumed that the cyclic loading influences the strength of HPFRCC.

3. All specimens show enough load capacity to the earthquake and wind design.

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