EXPERIMENTAL STUDY AND ACTUAL STRUCTURE DESIGNING OF LOOP JOINT USED FOR SEGMENTED PRECAST CONCRETE BRIDGE PIER AND CAISSON.

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Abstract

Generally, the pre-cast (abbreviated to PCa) member is manufactured at the factory and is transported to the site. But there is the Road Law which prescribes the load limitation of weight, length and so on. Due to that limitation, the PCa member has to be divided into several blocks. As a result, these blocks can be transported to the site by trailer and are jointed at the site. This paper reports the vertical joint method of the PCa blocks which are used for substructures (bridge pier and caisson). The PCa member has a hollow section and is divided into two blocks vertically. These two blocks are jointed by loop joint. The loop joint is prescribed in DIN1045. In Japan the loop joint is mostly used as PCa slub. The slub is designed only for out-plane section force. But vertical joint of segmented PCa members have to be designed for in-plane section force as well. Two kinds of experiment were performed, one is a seismic experiment, and the other is bending and shearing experiment.

- PCa.members jointed by loop joint had the similar seismic performance, which were the load-displacement relationship and ductility ratio.
- PCa.members jointed by loop joint had the similar bending and shearing strength, compared with non joint member.

As the horizontal joint method of PCa member has been presented at the 16th and 18th US-Japan Bridge Engineering Workshop, the explanation of horizontal joint method was not repeated in this paper. Finally, the outline of the segmental PCa bridge pier and caisson on Niigata prefecture, which was planned and designed by Hokuriku Regional Development Bureau of Ministry of Land, Infrastructure and Transport, is presented.

Introduction

The PCa segmental method has been mainly applied to prestressed concrete bridge .The PCa segmental method were the shorten of the construction period, the improvement of concrete quality, the reduction of cost and consideration of environment. Recently the PCa segmental method has been applied to substructures such as bridge pier and caisson. PC-Well method is one of the effective PCa segmental method of caisson.

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The PCa member has a circular hollow section which outer diameter range from 1.6 to 3.8m. The PCa member with 3.8m in diameter is the upper limit of size prescribed by Japanese Road Law. As a result, short span bridge comparatively applies to PC-Well method. Photo.1 and Photo.2 show bidge pier and caisson of PCa segmental method. This structure was constructed on Gunma prefecture in Japan by Kanto Regional Development Bureau of Ministry of Land, Infrastructure and Transport. And the cross section of pier is oval with 4.6m in larger side and 2.6 m in shorter side. These members can be transported form the factory to the site by trailer. In order to apply the PCa segmental method to long span bridge, the cross section of a PCa member has to be make larger than 3.8 m. But the weight of PCa member will exceeds the limitation of the Road Law. So the division of PCa member was suggested, the joint method of PCa blocks was investigated. There are many joint methods such as lap joint, mechanical joint, mortar sleeve joint, loop joint, prestressed joint, and so on. Based on the lower cost and easier assembling, the loop joint prescribed in DIN 1045 was selected among these joint methods. The loop joint is a kind of the lap joint, and the required lap length can be shorten. In this paper, experimental results of seismic performance, bending and shearing strength are reported.

Photo.1 Bridge pier and caisson of the PCa segmental method

Photo.2 Transport form the factory to the site by trailer

Experiments

(1) Seismic performance

1) Specimens

The cross section of the pier is decided as rectangular and hollow section in order to reduce the weight of PCa block. The size of the specimen is 1/7.5 of a real structure.

Specimen No. 1 is PCa concrete column, which is divided into blocks both in horizontal and vertical directions. Specimen No. 2 is a conventional reinforced concrete (abbreviated to RC) column as a reference column. Details of the PCa block are shown in Fig.1. The process of making a Specimen No. 1 is shown in Fig.2. Prototype of Specimen No.1 is shown in Photo.3 and Photo.4. Prototype of Specimen No.2 is shown in Photo.5 and Photo.6. Specimens are shown in Photo.7 and Photo.8.

At first, two blocks are jointed horizontally by filling mortar into space between blocks to form lapped loop jointing. Secondly, these hollow blocks are piled up on the footing by bonding together with epoxy resin. Longitudinal reinforcing bars are inserted into the sheath after mortar grout pored into the sheath.

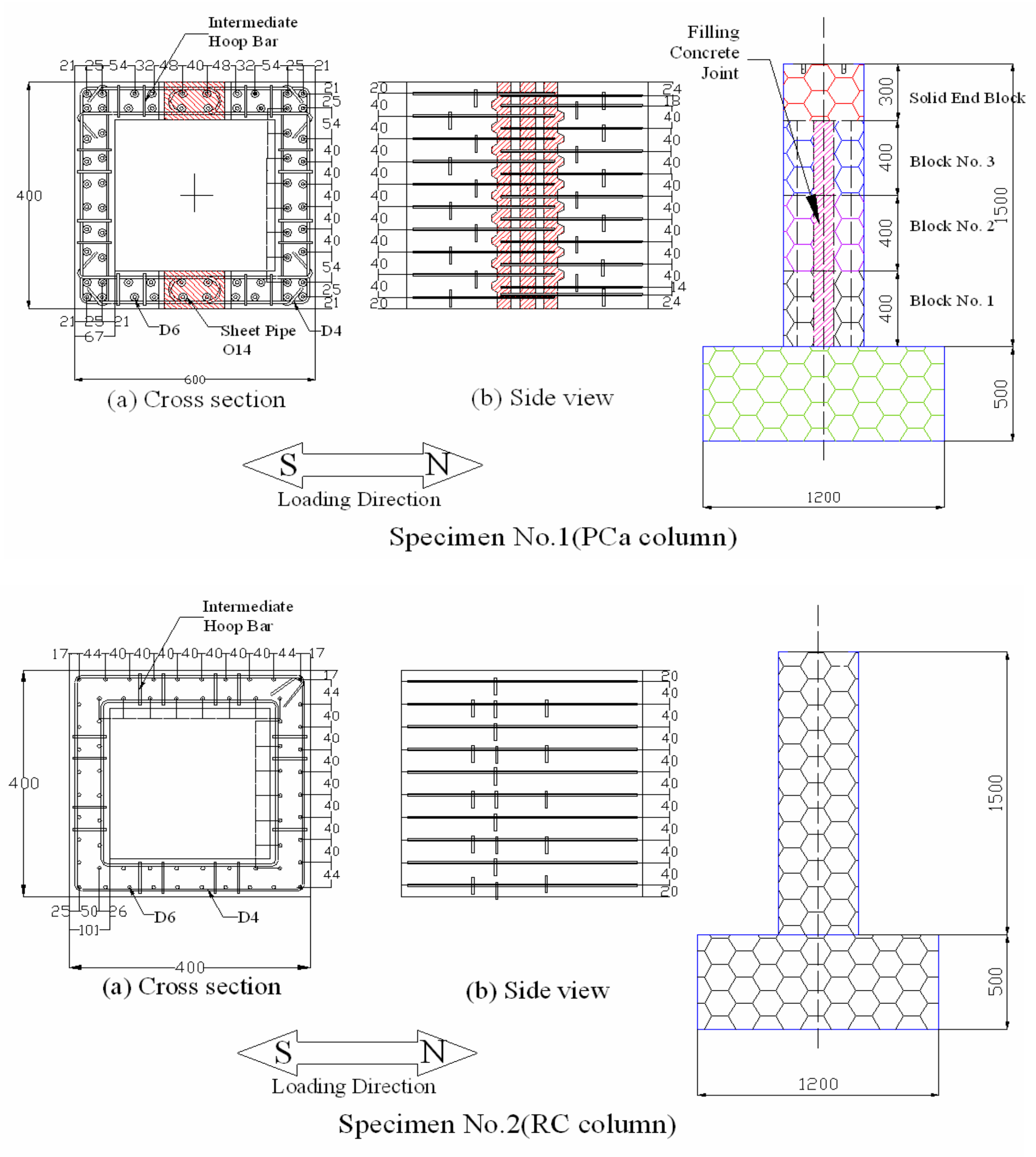

Fig.1 Details of the PCa block

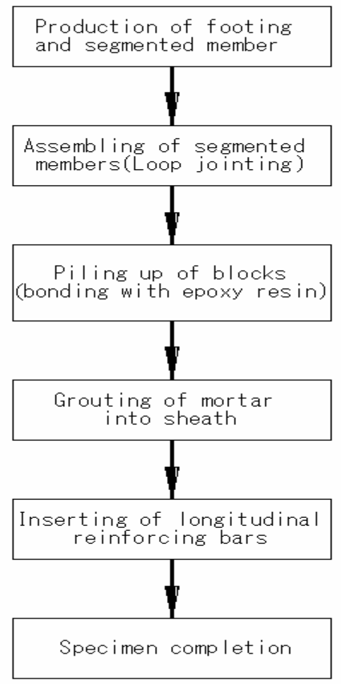

Fig.2 Process of making Specimen No. 1

Photo.3 Loop joint (No.1)

Photo.4 Assembling of loop joint

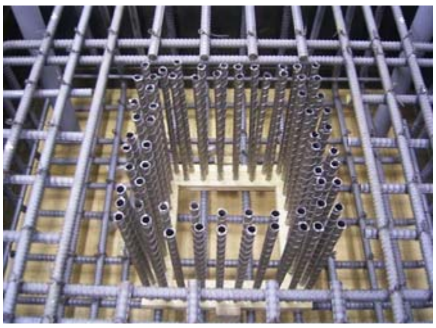

Photo.5 Arranged sheaths in footing

Photo.6 Arranged reinforcing bars

Photo.7 Specimen No.1

Photo.8 Specimen No.2

2) Loop joint

The lap length shall be calculated by the following equation (DIN 1045).

Required lap length $La = f \cdot ao \cdot (Ase/Asv) \cdot k \geqq 1.5dB$

f	:	A coefficient by anchoraging shape of a reinforcing bar It is 0.5 for a reinforcing bar with a hook or a loop
ao	:	Basic anchoraging length $ao = (\sigma sa/4\tau oa) \cdot \phi$
σsa	:	βs (Yield stress of a reinforcing bar) /νSafety rate $=311/1.75=178N/mm^2(1744kgf/cm^2)$
τoa	:	It is oa=$2.4N/mm^2$ ($24kgf/cm^2$) forσck=$40N/mm^2$
φ	:	A nominal diameter of a reinforcing bar
Ase /Asv	:	Necessary reinforcing bar cross sectional area / Placement reinforcing bar cross sectional area≧1/3 It is assume it 1.0.
k	:	A coefficient in consideration of influence of quantity to move a jointing reinforcing bar When a lap joint position concentrates on the same section, it is 2.2
dB	:	A bending diameter of a reinforcing bar

$La = 0.5\times1744/(4\times24)\times0.4\times1.0\times2.2 = 8.0(cm) \geqq 1.5\times4.8 = 7.2$

Therefore, a lap length of a specimen is 8.8cm satisfied required lap length (8.0cm).

Specimen No.1

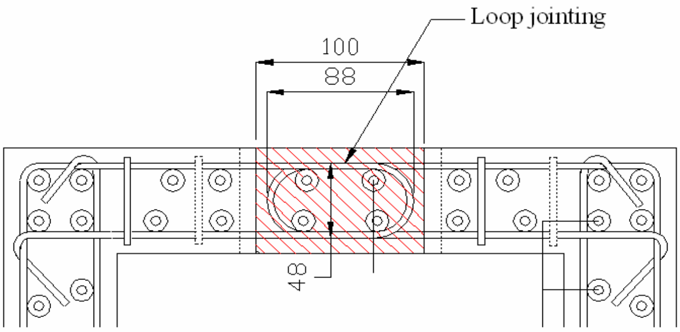

Fig.3 Designed loop jointing

2) Material properties

・Reinforcing bar

The yielding strength of all reinforcing bars used in this experiment are shown in Table 1.

・Mortar

Mortar is used in this experiment. The mortar with self-compacting ability is desirable. The mix design process follows the self-compacting concrete concept. Lime stone powder is used in addition to sand and cement in order to obtain the self-compacting ability. The compressive strengths of
Mortar at tested date are shown in Table 2.

・Grout mortar

The premixed mortar is used for grouting. The w/c ratio is 0.40 in consideration of flowability and additional retarder is used to keep fluidity for a long time. The compressive strengths of mortar grout at tested date are shown in Table 2.

Table 1 Properties for all reinforcement

Bar No.	Yielding Strength N/mm^2	Yielding Strain $\times 10^{-6}$	Young Modulus N/mm^2	Ultimate Strength N/mm^2
D4	311	2200	1.9×10^3	526
D6	342	2150	2.1×10^3	568

Table 2 Compressive strengths of mortar

Specimen No.	Footing N/mm^2	PCa member		
		Mortar N/mm^2	Joint N/mm^2	Mortar Grout ※) N/mm^2
1	91.8	41.2	42.1	55.0
2	91.3	37.7	—	—

※) This is used for anchorage a reinforcing bar

3) Measurement

・Displacement Transducer Installation

The positions of horizontal displacement transducer are shown in Fig.4. To measure splitting of concrete cover at column base, the displacement transducers are installed at column 50 mm separated from footing. The displacement transducers are installed in a top part of column to control displacement by load.

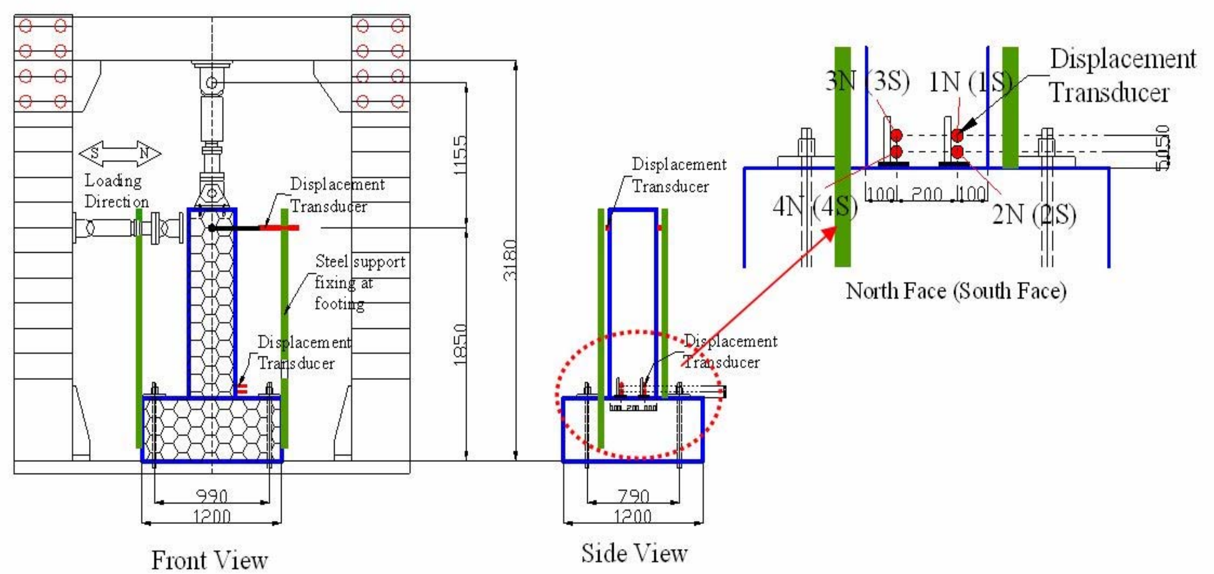

Fig.4 Positions of horizontal displacement transducer

・Strain Gauge Installation

To measure buckling of main reinforcing bars, the stain gauges were installed at the positions A through D in Fig.5.

For specimen No. 1, to measure shear force at joint part, the strain gauges are installed. The strain gauge position and numbering are shown in Fig.6.

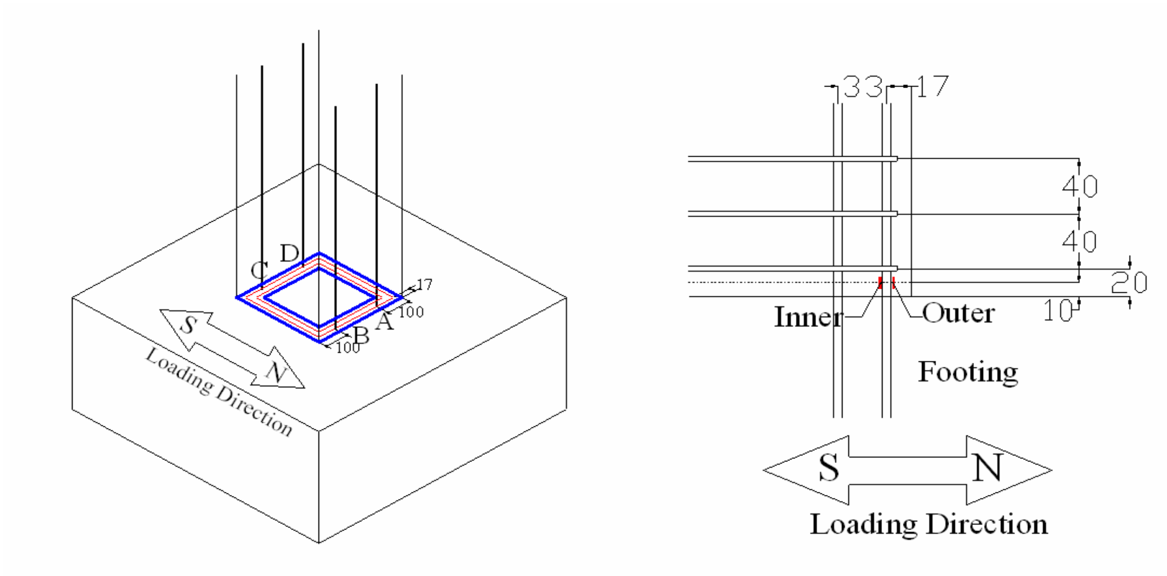

Fig.5 Strain gauge position and numbering (Specimen No1,2)

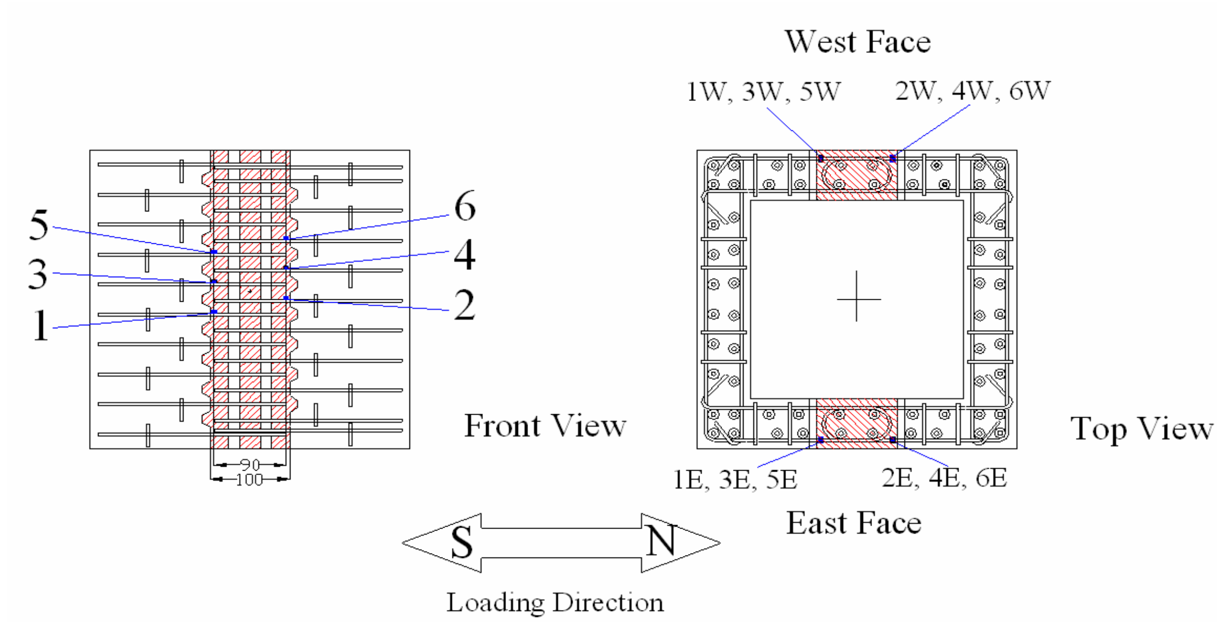

Fig.6 Strain gauge position and numbering (Specimen No1)

4) Experimental program

Overview of the experiment is shown in Fig.7. Loading steps are shown in Fig.8. The photo of the set up of the experiment is shown in photo.9.

Experimental works under alternated cyclic lateral loading with axial load were carried out. The loading direction for Specimen No. 1 was parallel to concrete joint of which aim investigate shear resistance at the joint.

The applied axial load was 120 kN. In the first step, the maximum horizontal load of ±50kN is applied. In the second step, when increasing the load, the maximum displacement is controlled to equal with yield displacement, which is δ_y (6.0mm). From next, the maximum displacement in each steps was controlled to be multiples of the yield displacement such as $\pm 2\delta_y$, $\pm 3\delta_y$, $\pm 4\delta_y$, ….

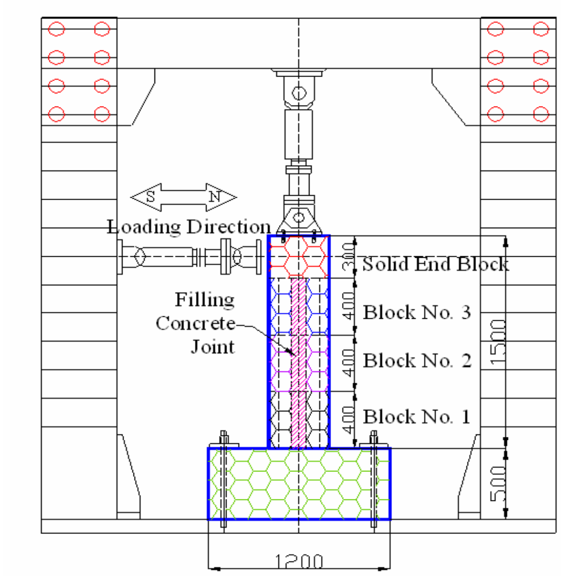

Fig.7 Overview of experiment

Loading speed is about 0.05mm/s. The figure of the yield displacement of main reinforcing bars based on a past experiment result[2]. In addition, the yield displacement was about the same figure when calculated by finite limited element program.

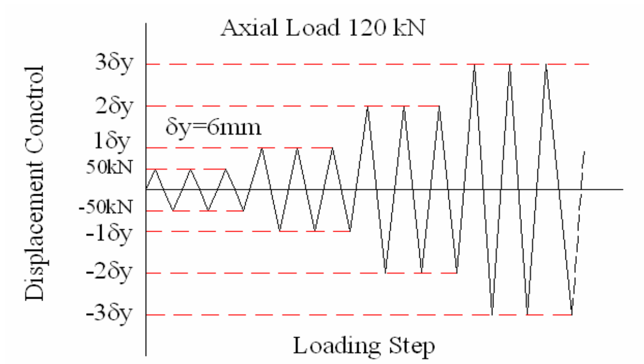

Fig.8 Loading pattern


Photo.9 Set up of the experiment

(2) Bending and shearing tests

1) Specimen

Dimension of specimen is as follows.

Outer diameter : ϕ 3500mm

Thickness of a member : 350mm

The segmented PCa members are joined by loop joints. The concrete design strength of PCa member and the joint are the same 40N/mm^2, which is joint parts of PCa member, are rough finishing. The type of

Table 3 Specimens designation

Specimen No.	hight (mm)	Loop jointing	Experiment
1	500	Not use	Bending test
2	500	Use	Bending test
3	1000	Not use	Shearing test
4	1000	Use	Shearing test

specimen is shown in Table 3 and the cross section, side view and arrangement of reinforcement are shown in Fig.9.

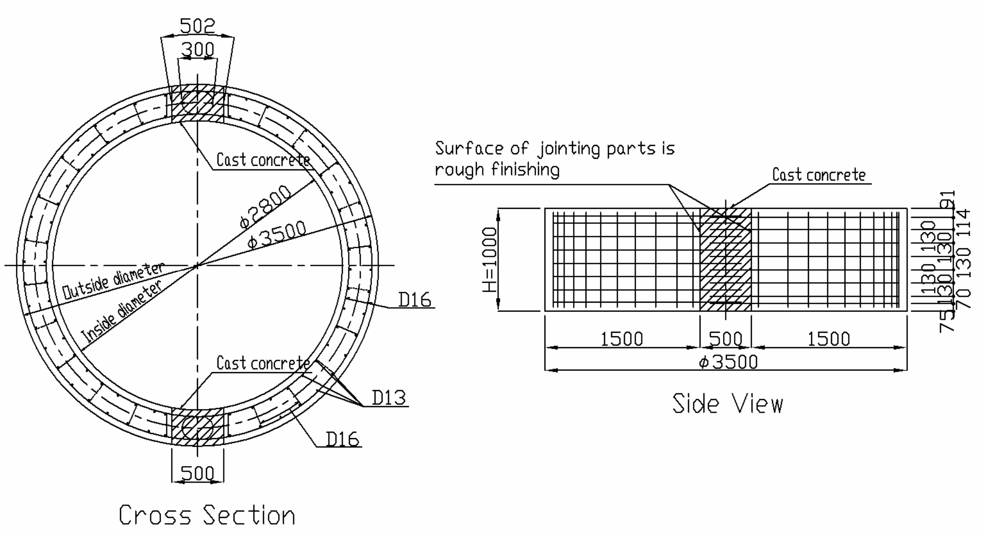

Fig.9 Specimen drawing

2) Loop jointing

Required lap length La = f・ao・(Ase/Asv)・k ≧1.5dB

f	:	0.5
ao	:	ao = (1600/(4・24)・1.6
σsa	:	1600kgf/cm^2
τoa	:	24kgf/cm^2
φ	:	1.6cm
Asek/Asv	:	1.0.
k	:	2.2
dB	:	20cm

Photo.10 Specimen member is set up

La = 0.5×1600/(4×24)×1.6×1.0×2.2 = 29.3 (cm) ≧1.5×20 = 30(cm)

Therefore, a lap length of loop joint is 30.0cm. The drawing of the loop jointing is shown in Fig.10.

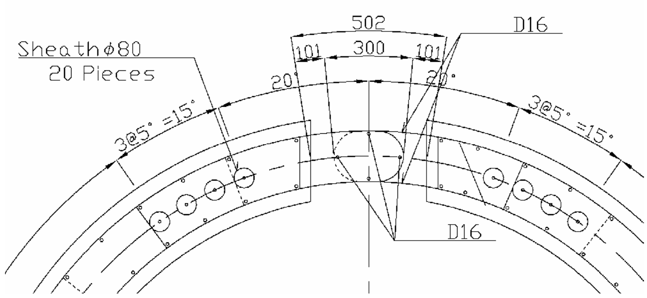

Fig.10 Drawing of the loop joint

3) Bending and shearing test

The bending and shearing test are performed. The loading set up is shown in Fig.11. Specimens are cantilever arm. Specimens of bending test are one point loading. The shear span ratio is 3. Specimens for shearing test are two points loading. The shear span ratio is 1. The loading is performed with prestressing steel bar and the center hall jack. The load is increased gradually.

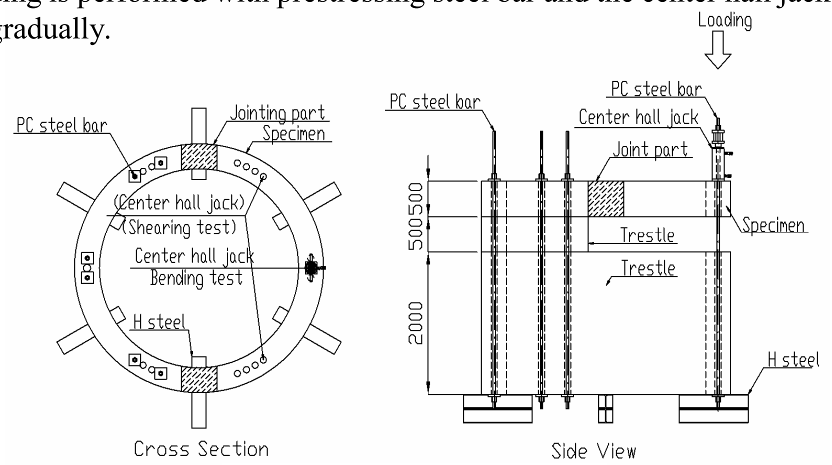

Fig.11 Loading method

Experimental results

(1) Seismic performance

1) Shearing behavior of loop joint

In this figure, most loop joint bars dose not yield until breaking load is applied. But three Strain gauges showed the yielding among totally 12. However, crack pattern at the jointing area is the same as conventional RC specimen until ultimate state is reached and shear damage was not observed at all joints. Cracks of specimens are indicated in photo.11 and photo.12. One of lateral load-strain relationship of loop reinforcing bar is shown in Fig.12.

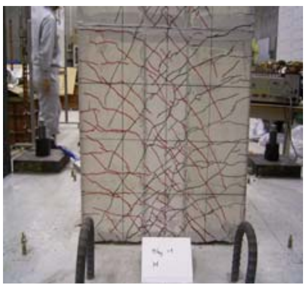
Photo.11 Cracks(No.1)


Photo.12 Cracks(No.2)

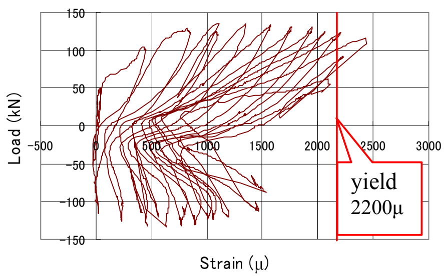

Fig.12 Strain gauges positions

2) Failure mode

In RC column (Specimen No.2), the covering splits off with buckling of longitudinal reinforcing bar at the displacement ($9\delta_y$) of 9 times of yield deflection. The buckling of longitudinal reinforcing bar is detected by displacement transducer near column base and visual check. When longitudinal reinforcing bar begins buckling, the bars push out the covering. Hence the displacement of the covering suddenly increased.

In PCa column (Specimen No.1), the crack width increased at the same time when the longitudinal reinforcing bar occurred at displacement ($10\delta_y$) of 10 times of yield deflection. There was no buckling at all for specimen No.1.

Photo.13 Failure (No.2)

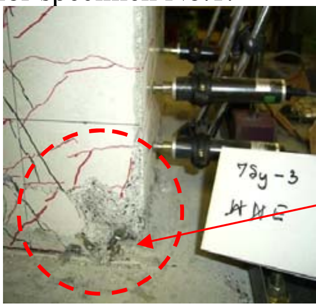

Photo.14 Failure (No.1)

Photo.15 Failure (No.1)

3) Load-deflection

History charts and enveloped curves of load-deflection curve are shown in Fig.13 through Fig.15.Maximum load of PCa column (Specimen No.1) is higher than that of RC column (Specimen No.2). This reason is supposed that strength of mortar grout in sheath of PCa column is higher than that of mortar in RC column.

The load dropped remarkablly from deflection of $9\delta_y$ to $10\delta_y$ in both specimens. From this result, the ultimate displacement of both specimens can be said to be 9 times of yield deflection and the ductility of the PCa column is almost the same as that of the conventional RC column.

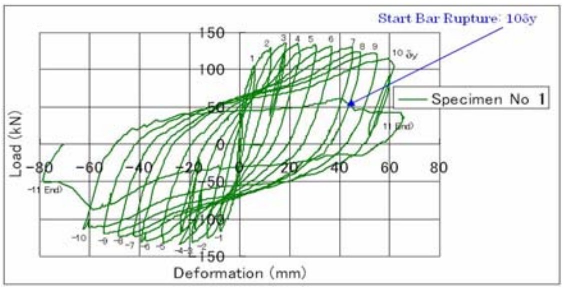

Fig.13 Load-deformation (No 1)

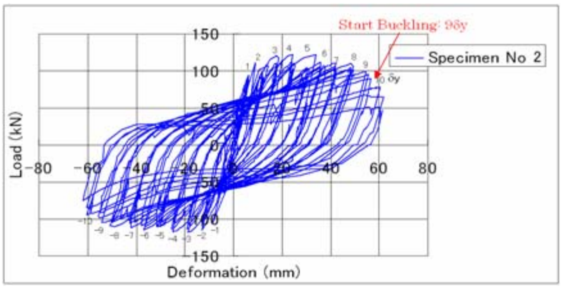

Fig.14 Load-deformation (No 2)

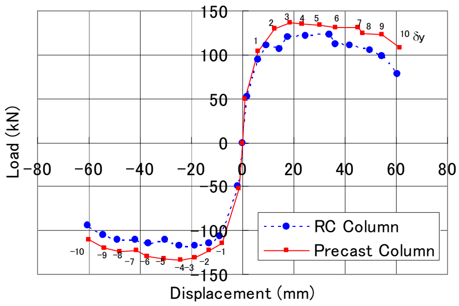

Fig.15 Load-displacement

(2) Bending and shearing test

1) Bending test

Table.5 and Fig.16 show the comparison of breaking load and load-displacement relationship for Specimen No.1 and Specimen No.2. The breaking load of Specimen No.1 is almost the same as Specimen No.2. Both specimens are destructed by compressed force from bending. It is understood that the breaking load of specimen No.1 and No.2 are almost the same displacement in Fig.17. Moreover, the breaking load is also almost equal. It is thought that member with the loop joint has almost the same bending strength as the non joint member.

2) Shearing test

Table 5 and Fig.17 show the comparison of breaking load and load-displacement relationship for Specimen No.3 and Specimen No.4. The breaking load of Specimen No.3 is almost the same as Specimen No.4. There was no influence to the maximum shearing stress by the loop joint. When Specimen No.3 and Specimen No.4 are compared the envelope curves of the load-displacement, the histories to breaking point are almost the same. Moreover, the breaking load is also almost equal. It is thought that member with the loop joint has almost the same shearing strength as the non joint member.

Table 5 Breaking load

Specimen No.	Loop jointing	Breaking load (kN)	Failure mode
1	Not use	159	Bending
2	Use	160	Bending
3	Not use	937	Shearing
4	Use	943	Shearing

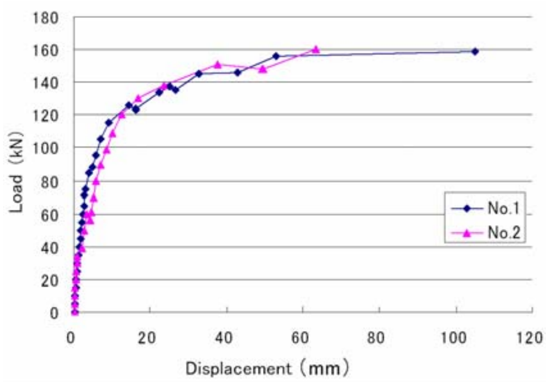

Fig.16 Load-displacement (Bending test)

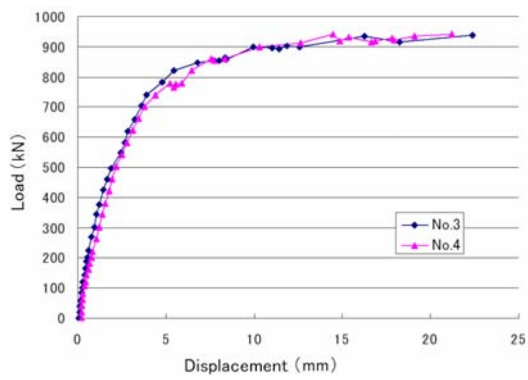

Fig.17 Load-displacement (Shearing test)

Conclusions

(1) Seismic performance
1) Maximum load of PCa specimen is higher than that of conventional RC specimen
2) The loop jointing in the PCa specimen had enough higher shear force under seismic loading, compared the RC specimen.
3) The ductility of the post arranging reinforcement PCa specimen with the loop jointing was almost the same as that of conventional RC specimen.

(2) Bending and shearing test
A Member connected with a loop jointing has bending strength and shearing strength almost the same as non joint member.

The loop joint is economical and widely used. The loop joint method has the high seismic performance and has almost the same as bending strength and shearing strength in the experimental result for PCa bridge pier and caisson.

Real Construction

The segmental PCa bridge pier and caisson is now planned and designed on Niigata prefecture by Hokuriku Regional Development Bureau of Ministry of Land, Infrastructure and Transport.

The huge earthquake occurred in Niigata Prefecture in 2004. The new Ugachi bridge is planned and designed for recovery from seismic disaster damage. Then, the PCa segmental method (loop joint) is used for it's pier and caisson, because of shorter construction period, lower cost and environmental consideration.

The production of the PCa member is shown Photo.17 and Photo.18, and the drawing of the segmental PCa bridge pier and caisson with loop joint is shown in Fig.18.

Photo.17 Assembling of the form

Photo.18 Manufactured PCa member

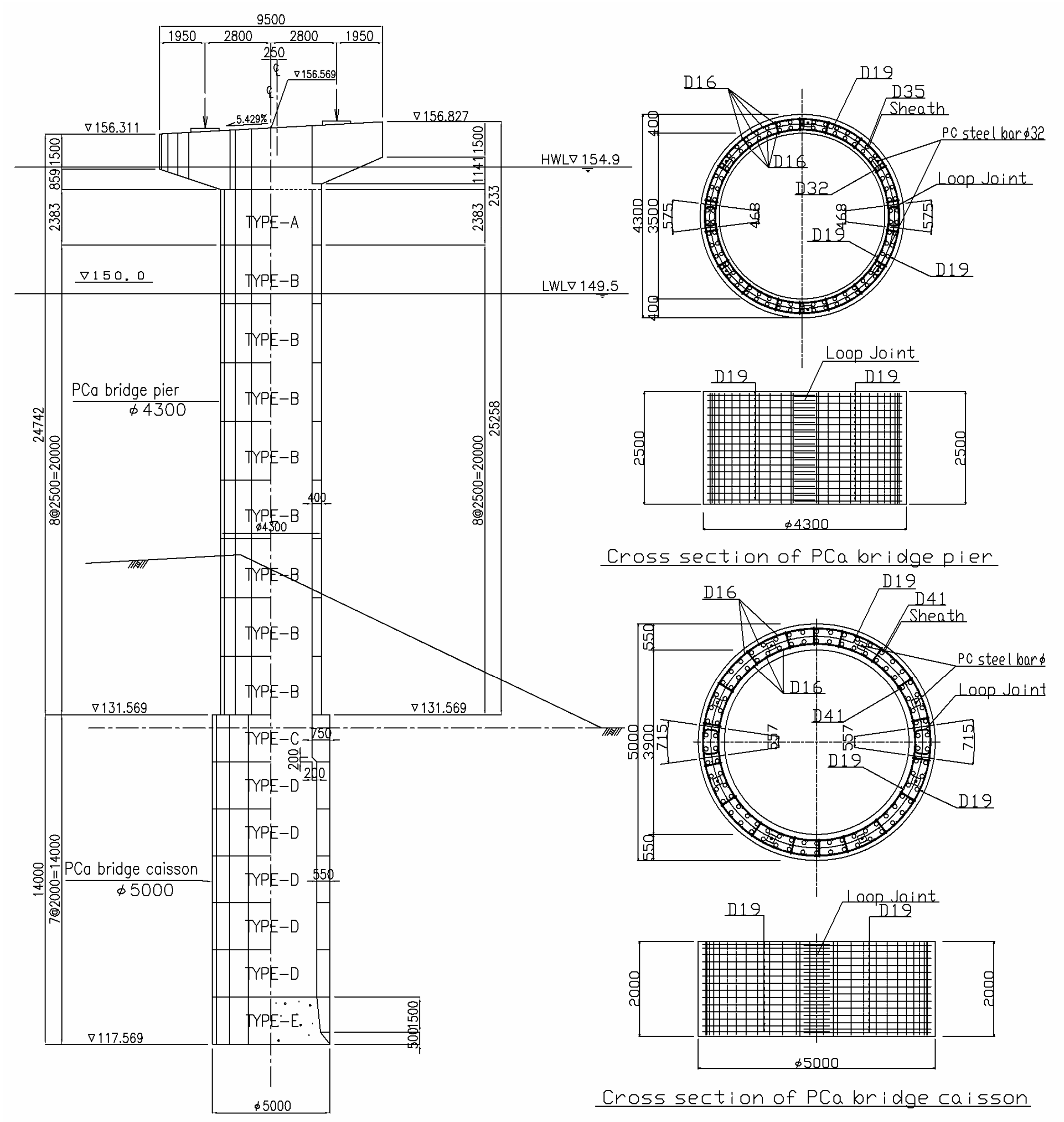

Fig.18 The segmental PCa bridge pier and caisson with loop joint

The construction of PCa pier and caisson with loop joint will be realized in the near future.

Referrence

[1] Japan prestressed concrete contractors association: a RC loop joining from the design / execution manual (a plan) for PCa PC bed, 1999 (in Japanese)

[2] Shioi,Y.,Nakai,M.,etc.: Seismic performance test of joining method of precast prestressd concrete members, JCI,Vol.38,No.8,2002.8 (in Japanese)