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Study on construction system using PCa composite members for large scale structures

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ABSTRACT: This paper propose how to apply PCa composite construction method to large scale structures such as Nuclear power plants, and we investigate the structural characteristics, comparing the monolithic specimen, by the following two loading tests, "Direct Shear Test Series" and "Earthquake Resistant Wall Series". By the former series, we confirm that the shear keys on the edges in the PCa panels are serviceable to transfer the shear force in plane. And by the latter series, the PCa composite walls have the almost same structural characteristics as the monolithic wall. Consequently the PCa composite construction method, we confirm, is useful for large scale structures.

1. Research Background and Objectives

We propose the construction method using the half PCa *1 panels, which serves the forms, for the earthquake resistant elements, such as thick walls and thick slabs in the large-scale reinforced construction structures, for example power plants, sewage disposal plants and nuclear power plants etc.

And we investigate the half PCa structure characteristcs comparing the Monolithic structures by the test results.

*1) PCa:Precast concrete

We study two test series, "Direct Shear Test Series", which investigates the characteristics of shear transfer by shear keys on the edge of the half-PCa panels, and "Earthquake Resistant Wall Series", that investigates the characteristics of earthquake resistant walls with PCa panels comparing of the Monolithic wall.

2. Outline of Construction Methods and placement of two test series

Fig.1 shows the image of the PCa composite construction method and an example of PCa composite earthquake resistant wall. Fig.2 shows the detail of PCa panel and in-situ placed concrete. Fig.3 shows the image of the stress transfer on the edges in the PCa panels.

The proposed PCa composite construction method is, showed in Fig.1, that the PCa panels are basically used as the forms and the concrete is placed into or on them in situ.

Especially in the case of the wall,

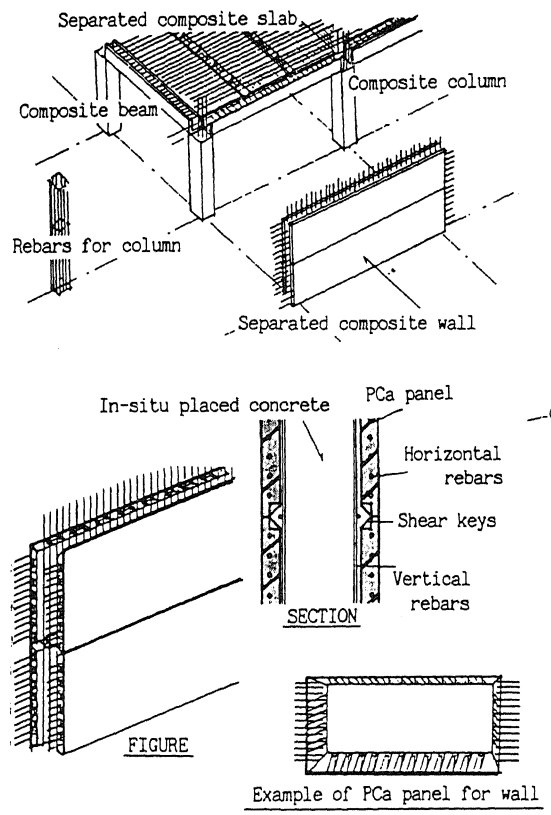


Fig.1 The image of the PCa composite construction and an example of PCa composite earthquake resistant wall

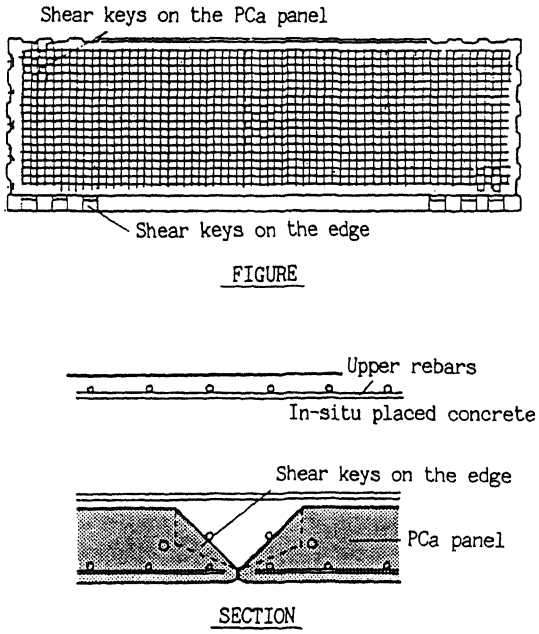


Fig.2 Details of PCa panel and In-situ placed concrete

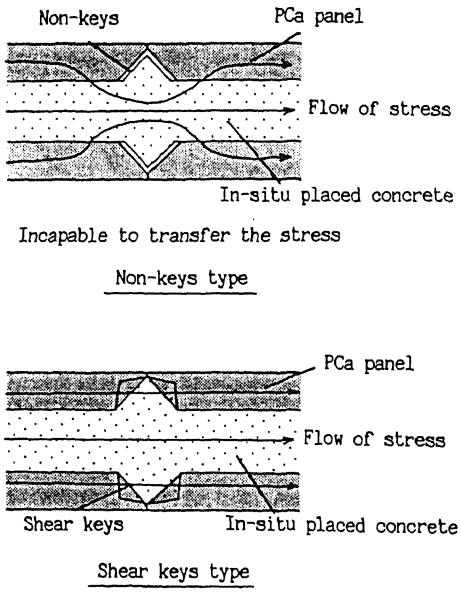


Fig.3 The image of the stress transfer on the edges in the PCa panels

utilizing the wide width, the concrete is placed in situ between the PCa panels into both faces of walls.

However, when the PCa composite construction method is utilized for RC structures, the construction joints are appeared between the PCa panels and the parts of in-situ placed concrete. So there are some cases that the stress transfer between them disrupted.

Especially discontinuity of the shear transfer on the edges in the PCa panels lowers the rigidity in plane.

By the way, in the large scale structures, comparing the ordinary strctures, the level of shear force in plane is too high. Therefore the PCa panels and the in-situ placed concrete with the joint bars must resist it in a body.

Accordingly, showed in Fig.2, the shear keys are set on the edges of the PCa panels in order to transfer the shear force in plane. The stress between the PCa panels transfers through the in-situ placed concrete.

In other words, by the shear keys on the edges in the PCa panels, we image the mechanism of a stress transfer shown in Fig. 3.

"Direct Shear Test Series" is to understand the structural characteristics of the joint with the above shear keys for the direct shear force and to compare the PCa composite boards and the Monolithic one.

"Earthquake Resistant Wall Series" is to confirm the following items by the performance of the PCa composite walls, adjusting the shear keys which are grasped in "Direct Shear Test Series", under horizontal load (earthquake force).

(1) Elasticity rigidity of the PCa composite walls is equal to that of the Monolithic wall.

Specifically, when shear force is given, cracks on the edge of the PCa panels must not appear before the diagonal shear cracks extend in the wall, and there is no sudden decrease in strength.

(2) The shear force is smoothly transferred by the shear keys on the edges and on the surface of PCa panels.

Specifically, the shear transfer by the shear keys is adequate throughout till the ultimate, and there is no sudden decrease in ultimate strength.

(3) Strength of stability is not noticeably different from that of a Monolithic wall.

Specifically, there is little difference in the condition of destructibility.

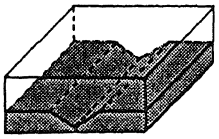
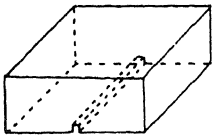
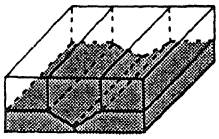
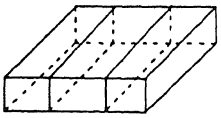
3. Direct Shear Test Series

3.1 Test Overview

Table 1 shows a list of the specimens and Fig.4 shows the specimen's figure and loading method.

Specimens are assumed to be 1/3 scale. The

Table I The list of the specimens

Specimen Figure	 Composite slab			 Monolithic slab			 Composite slab(Slit in situ-placed concrete)	 Only in situ-placed concrete of S-7
Name	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8
Bar ratio(%)	0.44	0.79	0.62	0.44	0.62	0.69	0.44	0.69
Panel's thick-ness(PCa/All)	90/250		90/180	0/250	0/180	0/160	90/250	0/160

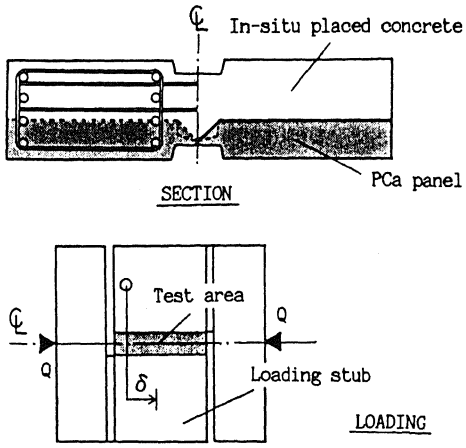


Fig.4 The specimen's figure and loading method

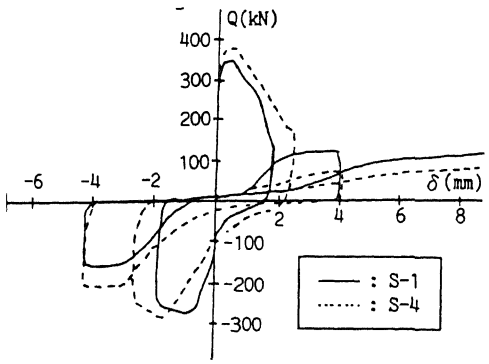


Fig.5 An example of the shear force(Q) - relative slip(δ) relationship (S-1 and S-4)

size is 512mm long and 160mm wide of the test area. The number of the specimens are planned in 8 bodies.

The primary parameters are following:

(1) the PCa panel thickness ratio (PCa panel thickness/overall thickness)

(2) the joint rebars ratio.

In order to investigate the efficacy of the shear keys, specimen with a slit in the in-situ-placed concrete have been prepared.

And the shear keys are coated with grease to negate the bonds of the concrete.

The loading method is following:

(1)Loading:

The loading method applied is alternative direct shear force loading, using the improved S-shape loading.

(2)Loading cycle:

The loading cycle was confirmed at ±1st cycle as the approved load level, and the ultimate strength at + 2nd cycle.

In the cycles after 2nd cycle loading is not Load-control, but control by the amount of relative slip, and to a basic total of 5 cycles.

(3)Measurement:

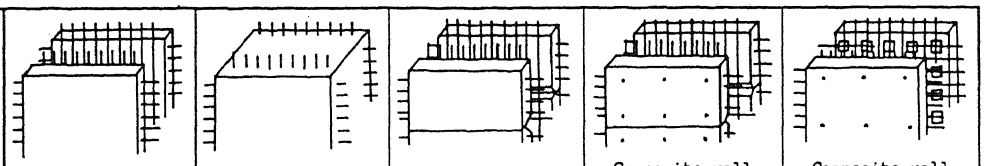
Load by the load cell, relative slip of the panel by the deformation gauges, and strain of the joint rebars by foil strain gauges.

3.2 Test Result and Investigation

3.2.1 Destructibility and Strength of stability

In the destruction process in S-1 ~ S-6, the cracks first appear along the boundary line between the loading stubs and the test area, then the shear cracks appear diagonally in the center of the test area, and specimens have the ultimate strength when these cracks extend to both boundary

Table 2 The list of the specimens

Specimen Figure						
		Composite wall	Monolithic wall	Composite wall	Composite wall with Tie bar	Composite wall with Tie bar
Name		W-1	W-2	W-3	W-4	W-5
Rebars	Horizon.	in full-PCa panel	in-situ placed con	in separated PCa panel		in full-PCa panel with shear keys on the panel
	Vertical	in-situ placed concrete				

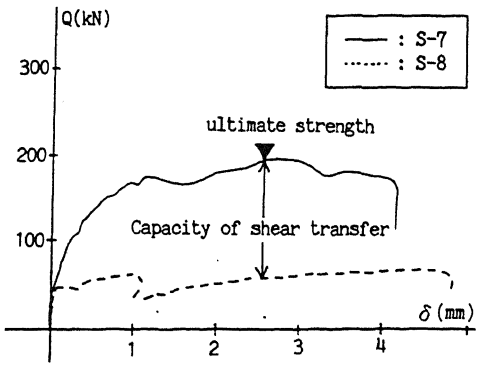
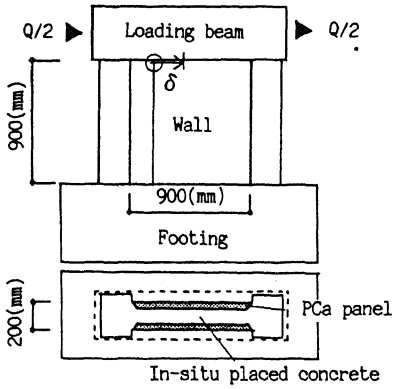


Fig.6 The estimation of the shear keys in the Q-δ relationship (S-7,S-8)



- Scale approx. 1/4
- Wall size 900(mm) ×900(mm)
  thickness 200(mm)
- PCa board thickness 40(mm)
- Rebars for Wall D 6(SD345) ps=0.62%
  (Horizon and Vertical)
- Rebars for Column D22(SD390) pg=5.61%

Fig.7 The specimen's figure and the loading method

lines between stubs. And the destruction process were almost same in all of the specimens.

Fig.5 shows an example of the shear force(Q)- relative slip(δ) relationship (S-1 and S-4). In both specimens, the elasiticity rigidity was quite high before the first crack appeared.

On the strength when cracks appeared, the strength in S-1 was 70% in S-4.

The ultimate strength and the amount of the slip at the point were essentially the same for both S-1 and S-4.

After the ultimate strength, the large slip suddenly appeared and the strength lowered.

In the next cycle, in the small amount of slip, the strength basically did not rise. But as the amount of slip was increasing, the strength gradually recovered slightly. However, that strength was considerably less than peak strength. Strength of stability showed a reverse S shaped curve and the characteristics are slip destructibility pattern.

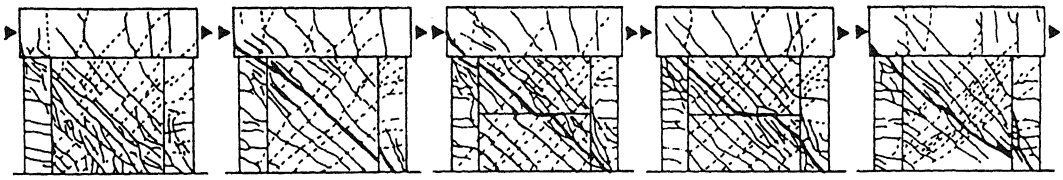
3.2.2 The Estimation of the Shear keys

Fig.6 shows the estimation of the shear keys in the Q-δ relationship(S-7,S-8).

This shows that the strength gap between S-7 and S-8 at the ultimate point was 129.4 kN.

This is estimated, we consider, as the shear transfer capacity of the shear keys.

Consequently the shear keys on the edges in the PCa panels are effective against direct shear force, and they can be said to transfer the shear stress on the whole section.



W-1 W-2 W-3 W-4 W-5

Fig.8 The ultimate destruction

4. Earthquake Resistant Wall Series

4.1 Test Overview

Table 2 shows the list of the specimens, and Fig.7 shows the specimen's figure and the loading method. The specimens are assumed to be 1/4 scale and following are consistent for all.

Wall size(internal) : 900 mm ×900 mm,
Wall thickness : 200 mm,
PCa panel thickness : 40 mm,
Wall reinforcement ratio :
both vertical and horizontal=0.62 %

And the prime parameters are

(1) The figure of the PCa panel (Full-size or Separated)
(2) The reinforcements arrangement
(3) Whether tie bars are used.

The specimens are ;

1)W-2 :
W-2 is a monolithic earthquake resistant wall and assumes the usual wall.

2)W-1 :
W-1 is the full-size PCa panels wall. On the wall reinforcements, horizontal are in the PCa panels and the vertical are in the in-situ placed concrete, and they are mutually separate. The horizontal and the vertical reinforcements are fixed in the surrounding framework.

3)W-3 :
In W-3, to lighten the weight of PCa panels, PCa panels are horizontally separated. Otherwise factors duplicate those in W-1.

4)W-4 :
W-4 adds the tie bars to W-3. The tie bars are inserted in the direction of the wall thickness. They are to restrict buckling of the PCa panels caused by high axial loading and high shear force.

5)W-5 :
In W-5, differing from the other PCa specimens, both vertical and horizontal reinforcements are arranged in the PCa panels.

The PCa panels and the in-situ placed concrete are connected by the shear keys arranged in the PCa panels and the anchored reiforcement from the surrounding framework.

Loading method is shown in Fig.8.

Shear force Q is given evenly in the specimen by loading Q/2 horizontally to the right and left of the loading beam in the specimen. Axial force is not loaded in this test.

Loading cycles are followed; specimens are alternatively loaded by load-control till ±3rd cycle and by deformation-control after ±4th ~±9th cycle. And at + 10th cycle, the ultimate strength were confirmed.

Measurement were load for load cell, deformation for deformation gauges, and strain of column' main reinforcements, wall' reinforcements and tie bars for foil strain gauges.

4.2 Test Results and Investigation

4.2.1 Destructibity

Fig.8 shows the ultimate destruction figures. All of the specimens showed the following destruction process:

Bending cracks appeared at the column base in tension.

⇩

Bending cracks appeared at the column in tension.

⇩

Cracks by bending and shearing appeared in the wall.

⇩

Shearing cracks appeared in the wall.

The ultiamte destruction are following;

(1)W-2 (Monolithic)

First the column base in compression were crushed by pressure. At the same time one shearing crack pierced diagonally in the wall's strut. And by the crack opening the strength was lost.

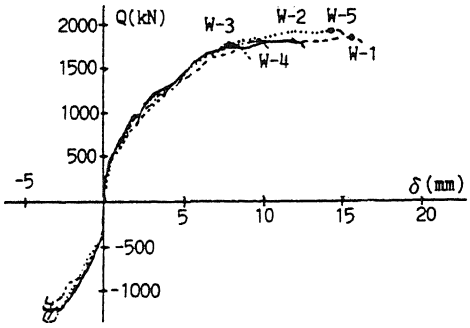


Fig.9 The shear force(Q)-Top level deformation(δ) relationship curve envelope

(2)W-1 (Full-sized PCa):

The shearing cracks were broken up in the strut in the PCa panels. Finally the strength was lost when several of the shear cracks opened, differing W-2.

(3)W-5 (Full-sized PCa):

The destruction process of W-5 was the same as that of W-1.

The shearing cracks were broken up in the strut in the PCa panels, differing in W-2. But finally the strength was lost when one of the shear cracks pierced diagonally in the strut of the wall and opened as in W-2.

The effect of the tie bars could not confirmed clearly.

(4)W-3 and W-4 (Separated PCa):

In W-3 and W-4, the tendency was to follow the same process as W-1 and W-5.

The ulimate strength was lost when the shearing cracks at the strut of the wall sheared off the shear keys between the PCa panels. And the PCa panels slipped at the parts.

The tie bars used in W-4 did not aid the ultimate strength.

4.2.2 Defomation Ability

Fig.9 shows the shear force (Q) - top level deformation (δ) envelope.

All of the PCa specimens(W-1,W-3~W-5) showed the same tendency towards W-2 in the elasticity rigidity and the second stage rigidity (the zone that cracks appear in the PCa panels and they diminish the rigidity of the wall.)

However, on the deformation at the ultimate strength we can group, with W-2 as a boundary, of the separated PCa walls (W-3 and W-4) and the full-sized PCa walls (W-1 and W-5), where their relationship is (W-3,W-4) < (W-2) < (W-1,W-5).

Consequently on the earthquake resistant walls, the full-sized PCa walls has a slightly greater, and the separated PCa walls is slightly less capable of deforming than the Monolithic wall.

This occurs because, when a PCa composite walls are constructed, a minute gap is left between the PCa panels and the surrounding framework.

That is to say, in low force levels, the PCa panels does not affect the wall's rigidity, and it is subject to the rigidity of the in-situ placed concrete.

But In a heavy load, the PCa panels touches the surrounding framework and the PCa panels and the in-situ placed concrete is responsible for the entire wall's shear force. As a result, this scarce deformation at the ultimate strength occures because the shear keys between the separate PCa panels are not able to resist the shear force that are affected in the wall.

5. Conclusion

The following points have been confirmed by this study.

(1) By using PCa panels that have shear keys set on the edges in the panels, the PCa composite structure shows approximately the same performance as a monolithic structure in rigidity and strength because the shear keys transfers the shear force even if the transfer is not continuous in the connecting sections.

(2) These PCa composite walls have the same characteristics, for example the ultimate strength, the rigidity and the deformation, as a monolithic wall in the face of either positive or negative loads, and can be evaluated at thickness of the PCa panels.