

Experimental study on seismic performance of precast reinforced-concrete shear walls

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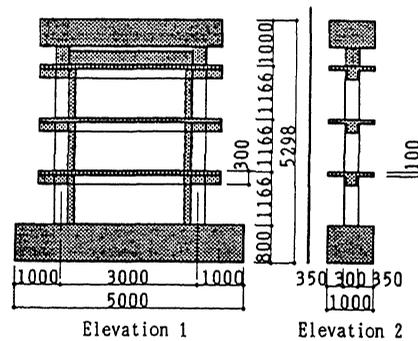
ABSTRACT: A Japan-U.S. cooperative research program, Precast Seismic Structural Systems (PRESSS), has been carried out. We made an experimental study on seismic performance of two precast reinforced concrete three-storied shear walls in order to establish a design guidelines for precast reinforced concrete structures. Seismic performance of shear walls puts the important effect on seismic performance of frame building. Therefore, the seismic performance of shear walls should be made clear. The objective of this study is an investigation about the seismic performance, especially about the vertical joint between a column and a shear wall supposed to effect on strengths of buildings.

1. DESIGN of TEST SPECIMENS

The specimens are two shear walls, that is three-storied, one-third scale, 3 meters span, 1.17 meters height on each floor. The specimens are made of columns, beams, shear walls, slabs, a foundation, and a loading-beam (Fig. 1). The precast members of the specimen are columns and shear walls with beam (Fig.1, white parts), and the cast-in-place members of it are slabs, a part of beams, vertical joints, and so on (Fig.1, gray parts). The size of members is shown in Table 1.

The specimen has vertical joints and horizontal joints. The vertical joints are reinforced concrete 150mm wide, 230 or 100mm thick, between cast-in-place column and beam, or precast column and shear wall, respectively. They include shear-cotters (100x100mm section, 20mm thick, 45 degrees) and maybe cotter-bars. The horizontal joints have two types; one is splice- sleeves-and- mortar-type which is 10mm thick between shear wall and slab, or column and slab, and the other is cotter-bars-type between beam and slab. In order to discuss why vertical joints fail, we decide the parameters of test specimens as the existence of cotter-bars and vertical-bars area of shear wall in the horizontal joint on the first floor.

The specimen PCWALL1 has no cotter-bars and all vertical-bars of shear wall in the horizontal joints on the first floor, and the specimen PCWALL2 has cotter-bars and three vertical-bars in each side of shear wall on the first floor. We show the detail of vertical



notes) □:Precast, ▣:Cast-in-place

Fig.1 Test Specimen (unit:mm)

Table 1. Member Size of Specimen (unit:mm)

Member	Member Size	
Column (PCa)	Section:	300x300
	Main bar:	12-D13 Main bar ratio: 1.69%
	Hoop:	D6-@40 Hoop ratio: 1.07%
Beam (PCa)	Section:	230x300
	Main bar:	12-D13 Main bar ratio: 2.21%
	Stirrup:	D6-@40 Stirrup ratio: 0.348%
Wall (PCa)	Length:	2400
	Height:	856 Wall bar: D10-@100
	Thickness:	100 Wall bar ratio: 0.71%
Slab (Cast-in-place)	Length:	4000
	Width:	1000 Slab bar: 6φ-@50 mesh
	Hoop:	D6-@40 Slab bar ratio: 0.560%

joint in Fig.2, and the results of material test in Table 2.

2. TEST SETUP and LOADING HISTORY

Test set-up equipment is in Building Research Institute. We put the specimen on reaction floor, four actuators upon the specimen for axial force loading, two actuators on reaction wall for horizontal force loading. This test setup is called a cantilever loading. The specimens are subjected to cyclic load history.

During cyclic loading, the specimen PCWALL1 is subject to the axial force (210ton) and the top moment which keeps the inflection point 7-meters high. The specimen PCWALL2 is subject to the axial force (100ton). The inflection point of PCWALL2 is 4.2-meters high.

The cyclic load history is as follows; one positive-negative cycle at lateral force (=20 ton which is below bending crack strength), one cycle at joint translation angle ($R= 1/2000, 1/1600$ rad.), two cycles at $R=1/800, 1/400, 1/200, 1/100, 1/67, \text{ or } 1/50$ (rad.), generally and the deflection for failure.

During loading, we sample the data of deformation in column and shear wall, and joint slip and opening displacement at horizontal and vertical joints on each floor.

3. RESULTS

The crack configuration in Fig.3 and lateral load - horizontal displacement on the fourth floor relationship in Fig.4 are shown. About specimen PCWALL1, bending-crack is found at $R= 1/1600$ (rad.), bending yield happens at about $R=1/250$, and specimen strength decrease largely at $R=1/50$ because of shear-slip- failure at precast shear wall on the first floor. The bending yield is caused by tensile-yielding of column-main-bars in tensile-side-column on the first floor and wall-vertical - bars in quarter- tensile-side - wall from first to third floor. It is unexpected that there is no failure in vertical joints in spite of no cotter bars.

About specimen PCWALL2, bending-crack is found at $R=1/1600$ (rad.), bending yield happens at about $R=1/270$, and specimen strength decrease largely at $R=1/67$ because of vertical- joints-failure on the first floor. The bending yield is caused by tensile-yielding of column-main-bars in tensile-side-column on the first floor. The result is that the vertical-joints-failure is cause by the decrease of axial force, the inflection point height, and the wall-horizontal-bar area on the first floor.

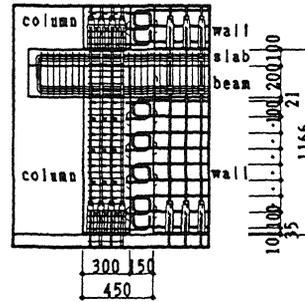


Fig.2 Detail of Vertical Joint

Table 2. Results of Material Test (unit:kg/cm²)

a) Tensile Strength of Bar				
Type	Diameter	Yield Strength	Rupture Strength	
PCa	D 6	3560	5060	
	D10	3950	5810	
	D13	4030	5950	
Cast-in-place	D 6	3690	5260	
	D13	3650	5140	

b) Compressive Strength of Concrete				
Type	first Story	second Story	third Story	
PCWALL1 (PCa)	505	515	507	
PCWALL2 (PCa)	526	522	526	
Cast-in-place	555	505	617	
Mortar	646	680	691	
Grout	691	691	691	

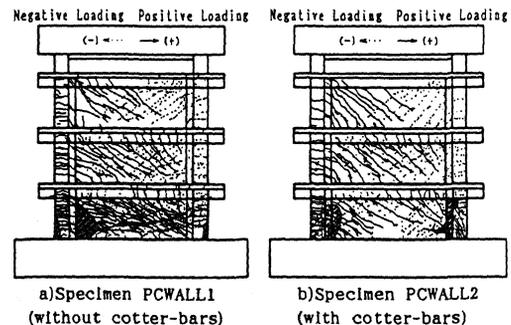


Fig.3 Crack Configuration

3.1 COMPARISON of TEST RESULTS with CALCULATED RESULTS about STRENGTHS.

Table 3 is the comparison of test with calculated results about bending-crack, bending-yield, and maximum strength of specimens. The equations for calculations are below Table 3. About bending-yield and maximum strength, calculated results follow test results perfectly, but about bending-crack strength, calculated result is greater than test. It is because we decide the bending-crack-happening as the time when we can see a crack at precast members ignoring horizontal joints.

3.2 OVERALL DISPLACEMENT

Fig.6 shows the overall displacement of specimens at $R=1/400$, $1/200$, $1/100$, $1/50$ or $1/67$ (rad.), and maximum R (joint translation angle). We describe the displacements by ten times multiplying. In Fig.6, we can find that the overall displacements follow the bending - displacement-type from first to third floor until smaller displacement, and the horizontal displacement concentrates on the first floor at maximum R while the story drift displacements on the second and third floor decrease.

Fig.5 shows rotation angle - story drift angle relationship. It is clear that the relationship of each floor is linear until $R= 1/50$ or $1/67$ (rad.), and the displacement concentration on the first floor is caused by a rapid increase of the story drift angle on the first floor and decrease of rotation angle.

3.3 DISCUSSION about DISPLACEMENT CONCENTRATION

Fig.8 shows the lateral load - opening or slip of vertical and horizontal joints relationship. Fig.7 shows the sampling place of these data. Both of joint opening displacement and slip is tend to increase at positive loading (column tensile). In specimen PCWALL1, the joint slip is about 7-millimeters at $R= 1/50$ (rad.), and in specimen PCWALL2, it is about 14 millimeters at $R=1/67$ (rad.). After that, in PCWALL1 the precast wall on the first floor is mainly deformed while negative loading (column compressive), and in PCWALL2 the vertical joints failure is caused by rupture of wall-vertical-bars, increase of joint-slip displacement at the first floor wall, and compressive failure of columns while positive loading (column tensile).

4. CONCLUSIONS

1. The horizontal displacement concentrates on the first floor because of shear failure or horizontal joint slip displacement of the first floor wall while the rotation angle and story drift angle from second to third floor decrease.

2. The vertical joint failure on the first floor is caused by the increase of horizontal joint slip of shear wall.

3. The equations for calculated results properly follow the test results even if precast concrete shear wall.

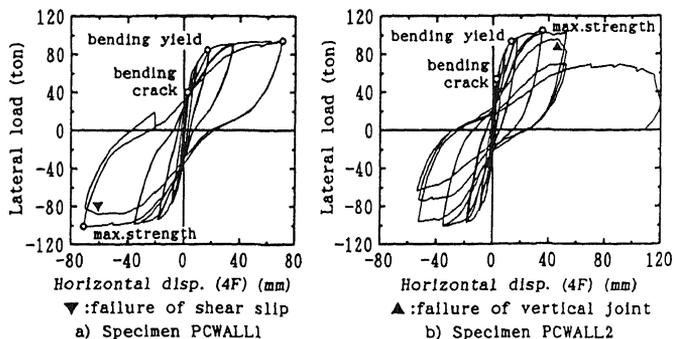


Fig.4 Lateral Load - Horizontal Displacement on the Fourth Floor (4F) Relationship

Table 3. Comparison of the Test Results with Calculated Results

a) Specimen PCWALL1				
Shear Strength	Bending Crack	Yield	Ultimate	
	Qc	Qy	Qu	
Test Results (ton)	40.2	84.8	100.8	
Calculated Results (ton)	30.3	79.8	88.2	
Test Results/Calculated Results	1.33	1.06	1.14	

b) Specimen PCWALL2				
Shear Strength	Bending Crack	Yield	Ultimate	
	Qc	Qy	Qu	
Test Results (ton)	53.5	93.4	104.3	
Calculated Results (ton)	38.0	84.5	85.4	
Test Results/Calculated Results	1.41	1.11	1.22	

notes) [Ref.1,2]

1-1. Bending Crack Moment : $M_c = (1.8 \cdot \sqrt{F_c + N/A_e}) \cdot Z_e$ [ton·m]

1-2. Shear Strength : $Q_c = M_c/h$ [ton]

2-1. Yield Moment : $M_y = 0.8 \cdot a_1 \cdot s \sigma_y \cdot D + 0.2 \cdot a_w \cdot s \sigma_{wy} \cdot D + 0.5 \cdot N \cdot D \cdot (1 - N/b \cdot D \cdot F_c)$ [ton·m]

2-2. Shear Strength : $Q_y = M_y/h$ [ton]

3-1. Ultimate Moment : $M_u = (a_1 \cdot s \sigma_y + 0.5 \cdot a_w \cdot s \sigma_{wy} + 0.5 \cdot N) \cdot l_w$ [ton·m]

3-2. Shear Strength : $Q_u = M_u/h$ [ton]

4-1. Values in calculation : $s \sigma_y = 4000$ [kg/cm²],

$s \sigma_{wy} = 3900$ [kg/cm²],

4-2. Values in PCWALL1 : $F_c = 502$ [kg/cm²], $N = 226.0$ [ton],

$h = 700.0$ [cm],

4-3. Values in PCWALL2 : $F_c = 533$ [kg/cm²], $N = 115.8$ [ton],

$h = 424.7$ [cm].

notation)

F_c : Compressive Strength of Concrete [kg/cm²]

A_e : Equivalent Section Area of Concrete with Steel [cm²]

Z_e : Section Modulus [cm³]

h : Height from Inflection Point to Slab on the First Floor [cm]

a_1 : Section Area of Column Main Bar [cm]

$s \sigma_y$: Tensile Strength of Column Main Bar [kg/cm²]

a_w : Section Area of Horizontal Bar in Wall [cm]

D : Width of Specimen [cm]

$s \sigma_{wy}$: Tensile Strength of Horizontal Bar in Wall [kg/cm²]

N : Axial Force [ton]

b : Thickness of Wall [cm]

l_w : Length of Specimen [cm]

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