ACI/JCI – 6th Joint Seminar
- Advancing the Design of Concrete Structures -
Component Design Advancements, Part 1 of 4

ACI Concrete Convention in San Francisco
Hilton San Francisco Union Square
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Design Concept for Precast and Prestressed Concrete Structural Components

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aci CONCRETE CONVENTION

Background

Needs to accelerated on-site bride construction
Accelerated Bridge Construction (ABC)

- New bridges
- Replacement due to deterioration
- Replacement due to seismic damage

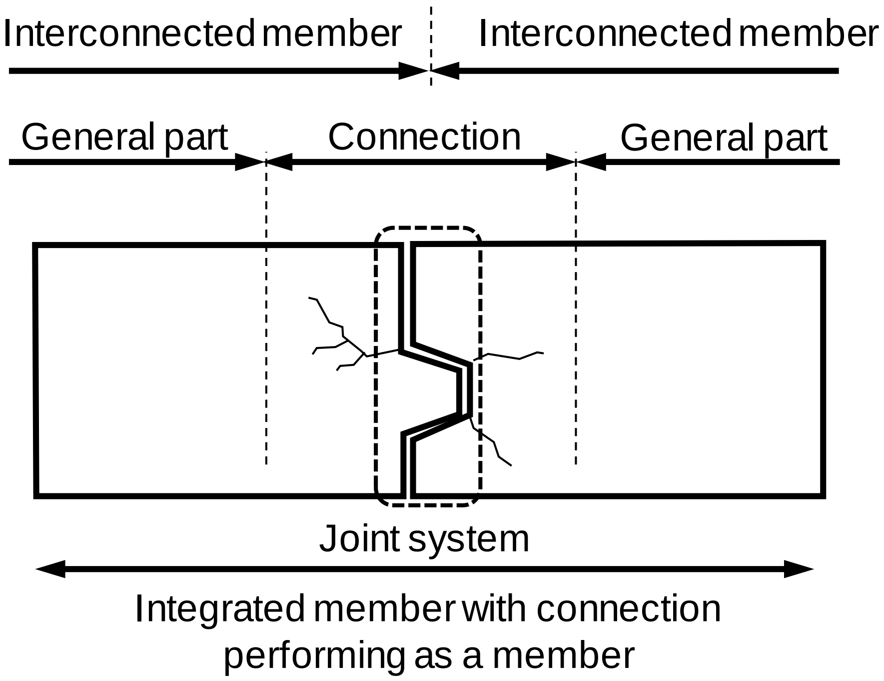
Use a precast concrete components
Details of connections between

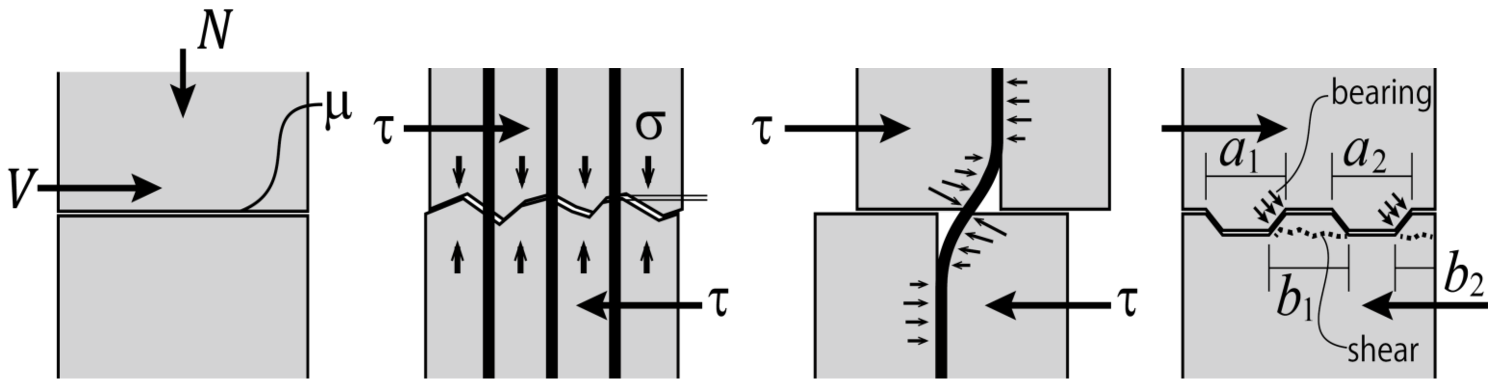
- precast concrete member and cast-in-place concrete member
- precast and precast concrete members

Technical Committee in JCI, TC183A (2018/2019)

- The committee in JCI, TC183A "Technical Committee on Design Concept for Precast and Prestressed Concrete Structural Components including Connections" chair Dr. Tomohiro Miki, Kobe University was established at 2018 and worked for two years.
- This committee has investigated domestic and international design codes and standards and summarized their design concepts. In addition, the evaluation equations and the application for the connections in PCa and non-prestressed reinforced concrete (PCaRC) members, PCa-prestressed concrete (PCaPC) members, and connected PCa members as seismic reinforcements were surveyed.
- Development of the structural components and new materials which are expected to be applied in the future practice were also discussed. Furthermore, examples of the application of PCa members in the buildings and bridges were investigated and conducted several case studies for a process of the application of PCa components and a trend in the practice of design and construction in Japan.

Example of Connection Region Proposed

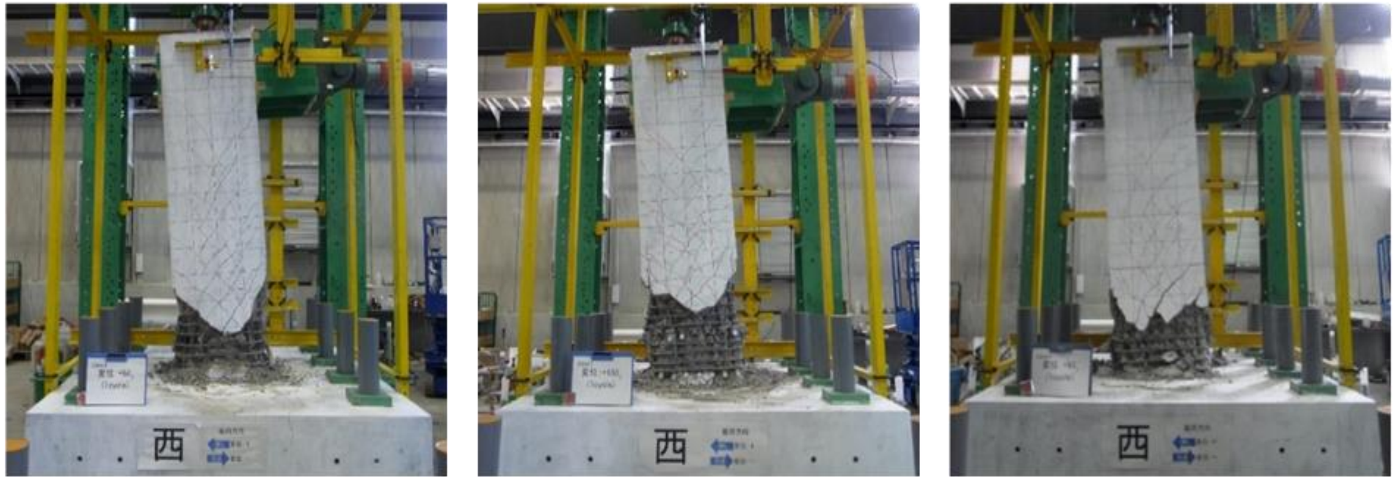


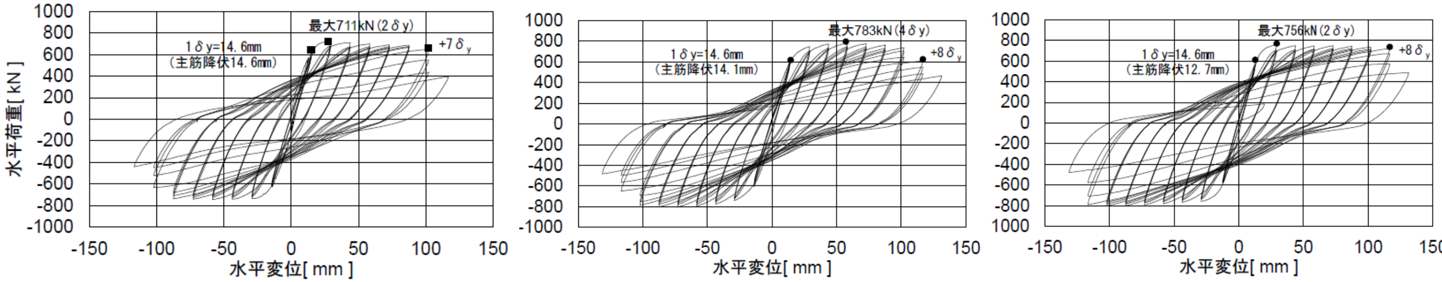


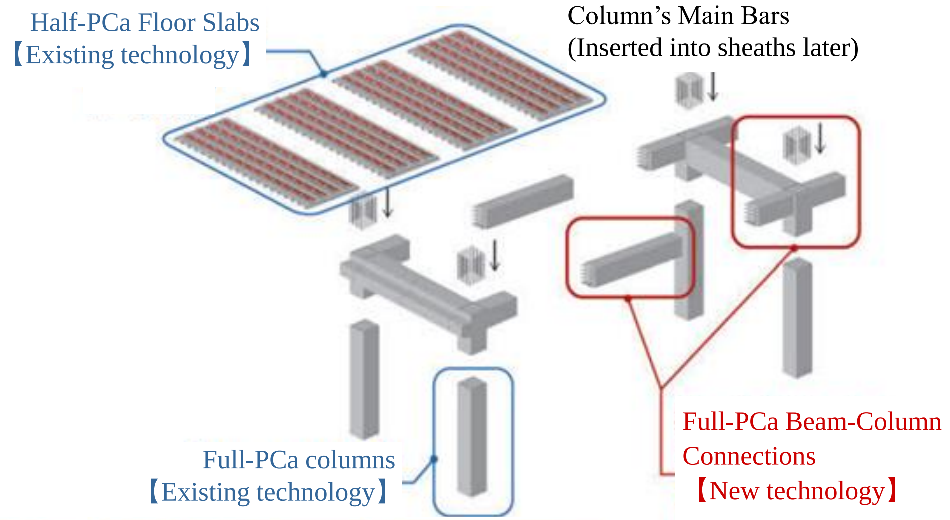
(a) Friction (b) Shear friction (c) Dowel action (d) Shear key

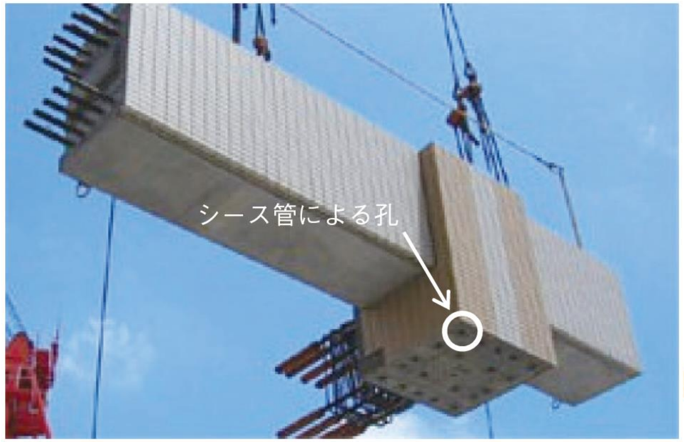
Stress Transfer Mechanisms in Connection Elements

Example for railway viaducts - Seismic evaluation









Reasons for Adoption of PCa Construction (Buildings)

Building use	Reasons for adaption / Status of the PCa methods									
	Shortening of a construction period	Labor saving	Reducing costs	Improvement in quality	Improving performance				Harmonization of the surrounding environment	The others
					Service-ability	Safety	Durability	Conservation performance		
Residential bldg.1	○	○		○						
Residential bldg.2	○	○	○	○					○	
Residential bldg.3	○			○					○	
Residential bldg.4	○		○							
Stadium 1	○	○	○							New materials
Stadium 2	○	○	○	○						Design, Workability
Mixed-use bldg.1	○	○	○	○						
Mixed-use bldg.2					○	○	○			Weight reduction, New technologies
Mixed-use bldg.3		○		○						
Logistics warehouse	○	○	○	○						
Office bldg.1		○		○	○	○	○	○	○	Energy conservation, Design
Office bldg.2					○	○	○			New materials and technologies
Hospital	○	○		○		○				New materials and technologies
Educational facility										
Total amount (14 cases)	9	9	6	9	3	4	3	1	3	6

Reasons for Adoption of PCa Construction (Civil Engineering)

Civil enginering	Reasons for adaption / Status of the PCa methods									
	Shortening of a construction period	Labor saving	Reducing costs	Improvement in quality	Improving performance				Harmonization of the surrounding environment	The others
					Service-ability	Safety	Durability	Conservation performance		
Railway viaduct 1	○	○		○			○			
Railway viaduct 2	○	○		○			○			
Railway viaduct 3	○	○		○			○			
Railway viaduct 4	○			○			○		○	
Railway viaduct 5	○	○		○			○			
Highway girder 1	○	○	○	○			○			
Highway girder 2	○	○		○			○	○		Weight reduction
Highway girder 3	○	○								
Highway girder 4	○	○		○		○	○	○		Limitation of girder height
Floor slab 1	○	○		○			○			
Floor slab 2	○						○	○		Restriction of passage
Floor slab 3	○	○	○	○			○	○		
Floor slab 4	○	○		○			○			
Floor slab 5	○	○		○			○			Weight reduction
Concrete guard fence 1	○	○		○						
Concrete guard fence 2	○	○		○			○	○		
Bridge pier 1	○	○		○						Safety of field-work
Bridge pier 2	○	○		○						Safety of field-work
Box culvert	○	○								
Shield tunnel		○				○	○			Improvement in water cut-off performance
LNG storage tank	○	○		○						Safety of field-work
Total amount (21 cases)	20	19	2	17	0	2	15	5	1	8

Case studies

- The PCa method was adopted in high-rise residential buildings in many cases in which a reduction of costs through the shortened construction periods was realized. There are cases of stadiums that adopted PCa members in the foundations and large structural members. In the mixed-use office buildings, super-high-strength concrete and steel members were applied in several cases.
- However, in the architectural area, especially in urban areas, the situations to use the PCa construction method have not been generalized due to the peculiarities inherent of the method, in which there are restrictions of the transportation and lifting-up of PCa members.
- The PCa components are adopted for most members if structural types, cross-sectional dimensions, and details are unified, such as railway rigid frame viaducts, shield tunnels, and LNG tanks. There are many cases in road bridges adopting the PCa members as a construction process becomes short in limited and narrow space of constrictions, a weight reduction of superstructures.
- Case studies based on these practical examples of design and construction reveal that a lesson to promote PCa conversion is to understand the merits of PCa construction in the process and costs benefits and consider the construction processes from the beginning of the design stage.

Summary and future prospects from JCI-TC183A

- Significant advantages in the construction using PCa members are recognized in the design and construction. Standardization of PCa members and PCa construction will realize the automation of structural design and deployment in artificial intelligence (AI) utilization.
- In an era when workers and specialist engineers are completely insufficient, labor savings, work assistance and/or automation by robots are required. The utilization of PCa members is one of the countermeasures in this issue.
- The platforms such as building/construction information modeling (BIM/CIM) are frameworks for information transmission.
- Moreover, carbon-neutral, reduction of CO2 and other greenhouse gases emissions are also keen issues. The advantages of multi-faceted PC structural components in the concrete structure can provide design improvement, a reduction of environmental impact, and quality assurance.
- To integrate the PCa connections, an application of post-tensioned (PT) prestressing is promising. Criteria controlling the behavior of the connections and an energy-absorbing performance in the structural design is needed to be established.
- Public support systems for application development of PCa and/or PCaPC constructions, such as education for engineering designers to improve comprehension of PC structures and ordering/dealing operation systems are also required.

Precast Concrete Bridge Columns

Hewes, J.T. and Priestley, J. N. (2001) Seismic Design and Performance of Precast Concrete Segmental Bridge Columns, Caltrans, UCSD / SSRP-2001/25

Seismic issues

- Seismic resistance
- Energy dissipation capacity

Detail in the practical design

- PC tendons (sometimes unbonded) are used to control an energy dissipation capacity of the PC column.
- Simple connection may be realized by reducing the number of reinforcing bars at the connection portion.

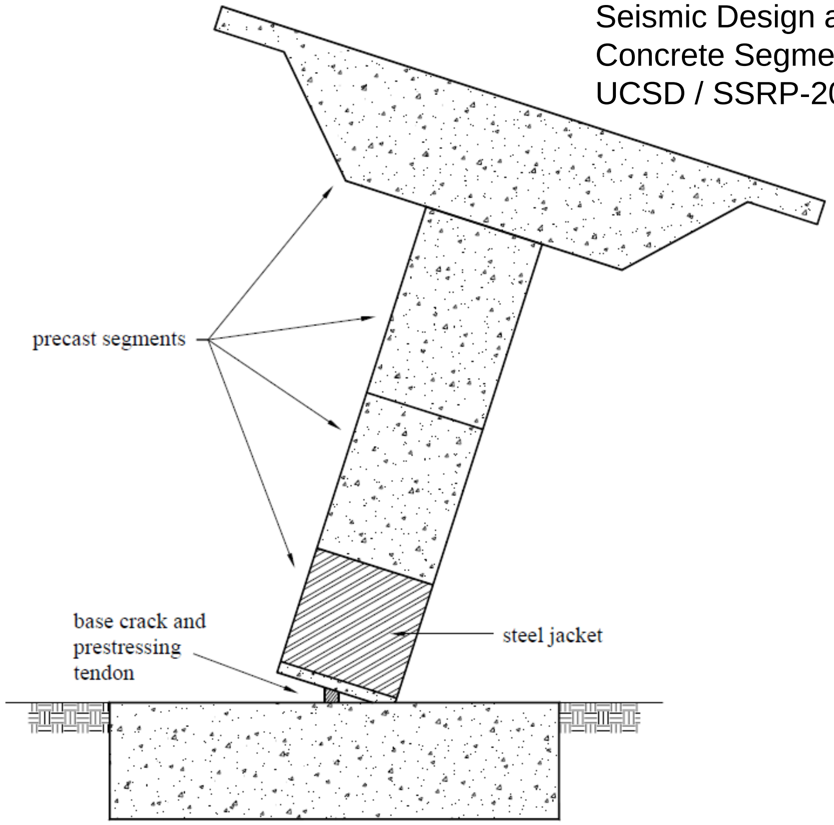


Figure 1.1 Idealized Transverse Column Response

Background

◎new build and rebuild for damaged or aging structures

⇒quick construction

Prefabricated components

◎restoring just after the earthquake disaster

⇒ self-centering and small residual displacement

Prestressed concrete

Precast Prestressed Concrete (PCaPC) bridge piers

Objectives

Comparison: Monolithic PC column v.s. Precast PC column

Energy dissipation capacity

- To confirm **the energy dissipation** of the PCa-PC columns during reversed cyclic loading

Residual displacement

- To confirm **the re-centering performance** the PCa-PC columns during reversed cyclic loading

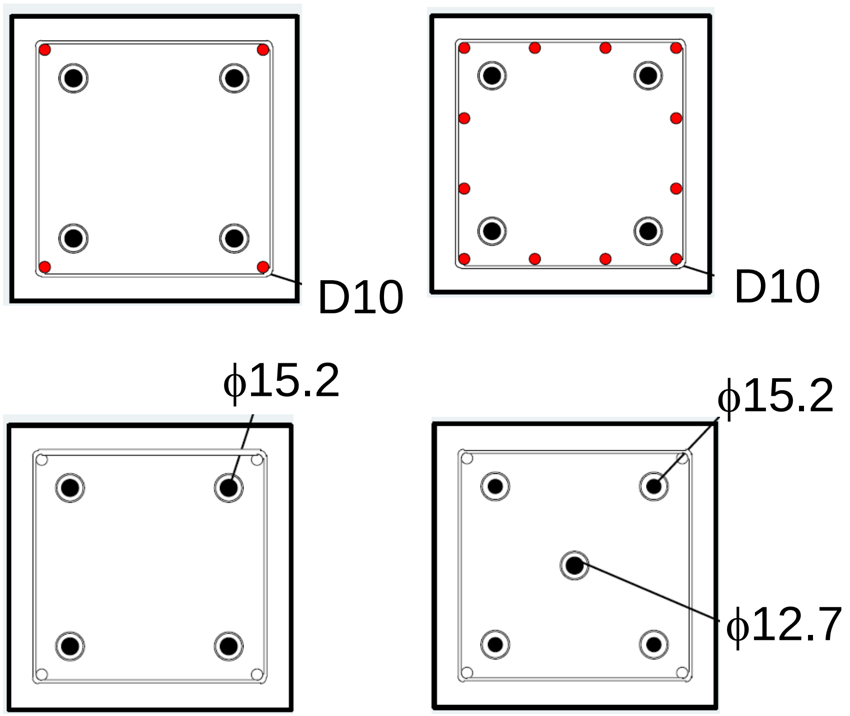
Damage evaluation based on visualization

- In order to evaluate the damage in the PCa-PC columns during earthquake, **image analysis** was conducted in the loading tests.

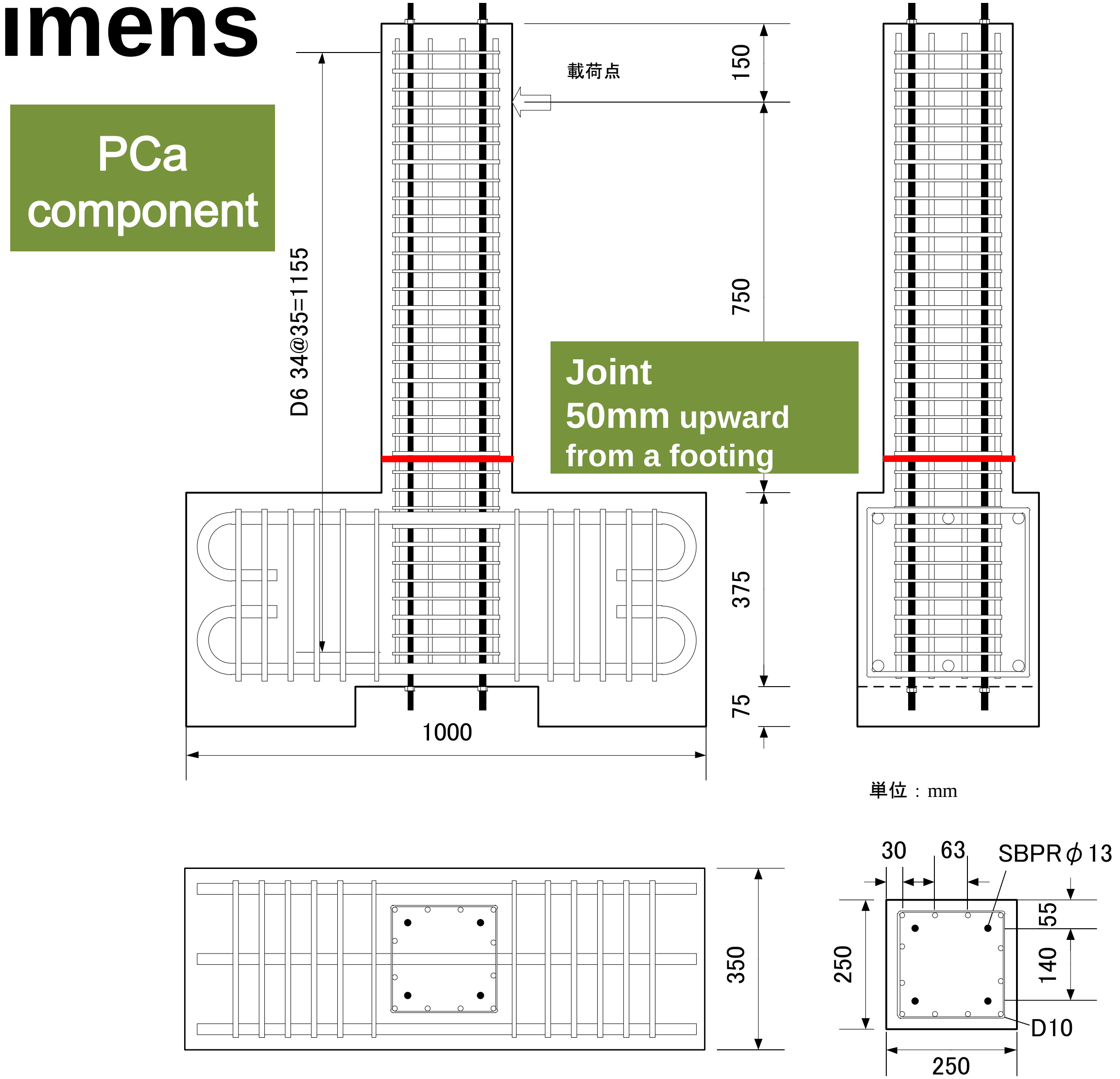
Specimens

Rebar: D10

	Concrete condition	Rebars at the joint	PC strand (bar)	Height of the joint
M-C4-S4	Continued (monolithic)	#4 Continued	#4 SWPR7B Φ15.2	50mm
M-C12-S4	Continued (monolithic)	#12 Continued	#4 SWPR7B Φ15.2	50mm
M-C12-B4	Continued (monolithic)	#12 Continued	#4 SBPR Φ13	50mm
J-C4-S4	Discontinued (with a joint)	#4 Continued	#4 SWPR7B Φ15.2	50mm
J-C12-S4	Discontinued (with a joint)	#12 Continued	#4 SWPR7B Φ15.2	50mm
J-DC-S4	Discontinued (with a joint)	Discontinued	#4 SWPR7B Φ15.2	50mm
J-DC-B4	Discontinued (with a joint)	Discontinued	#4 SBPR Φ13	50mm
J-C4-S5	Discontinued (with a joint)	#4 Continued	#5 SWPR7B Φ15.2	50mm
J-C4-S1:4	Discontinued (with a joint)	#4 Continued	#1 SWPR7B Φ15.2 #4 SWPR7B Φ12.7	50mm
J-C4-S4-125	Discontinued (with a joint)	#4 Continued	#4 SWPR7B Φ15.2	125mm



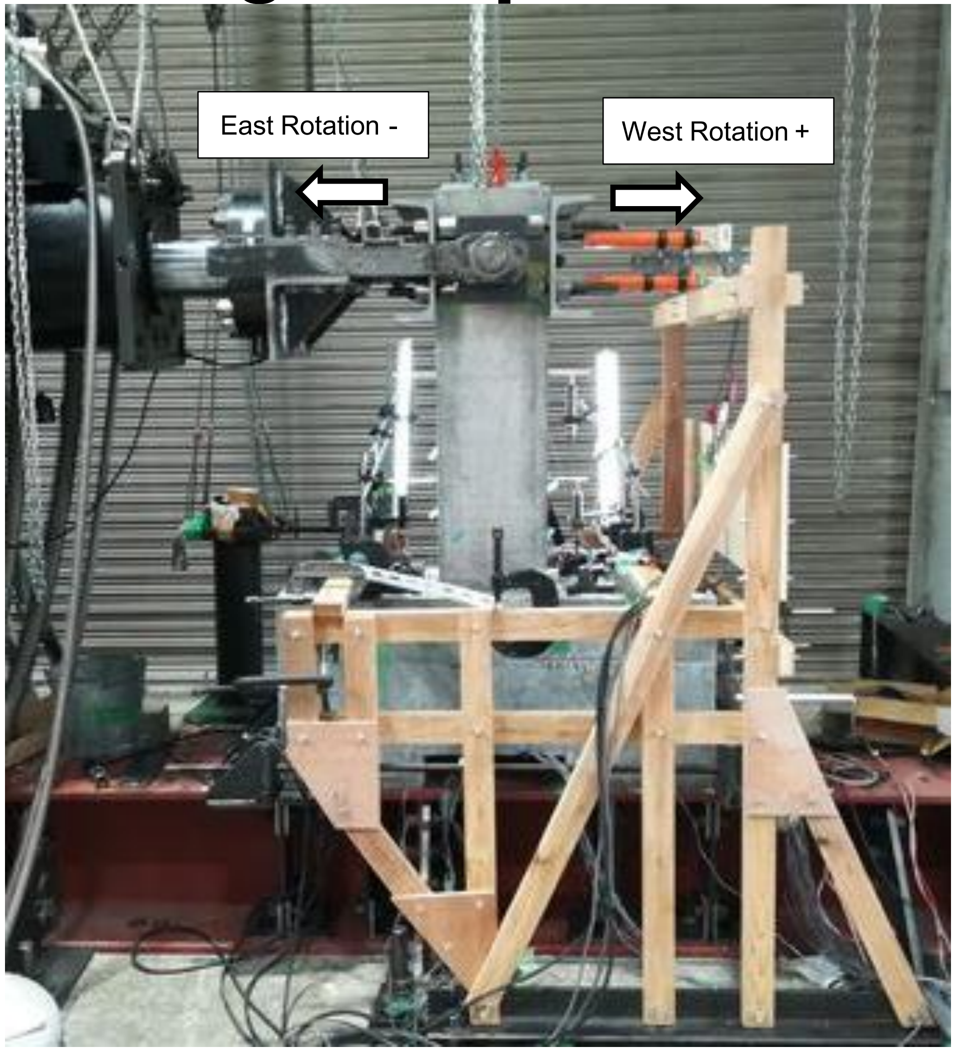
Specimens



- **PC bars**
  - SBPR(930/1180) 4×15.2mm
- **Longitudinal rebars**
  - SD345 12 or 4 × D10
- **Hoops**
  - SD295 D6@35
- **Prestressing**
  - 4MPa
- **Concrete Strength**
  - 35N/mm²

Specimen preparations

Loading setup and measurements



- 300 kN Capacity Actuators
- Set member angles for loading sequence

$$\text{Member angles} = \frac{\text{lateral displacement}}{\text{height of the column}}$$

2 cycles for each displacement

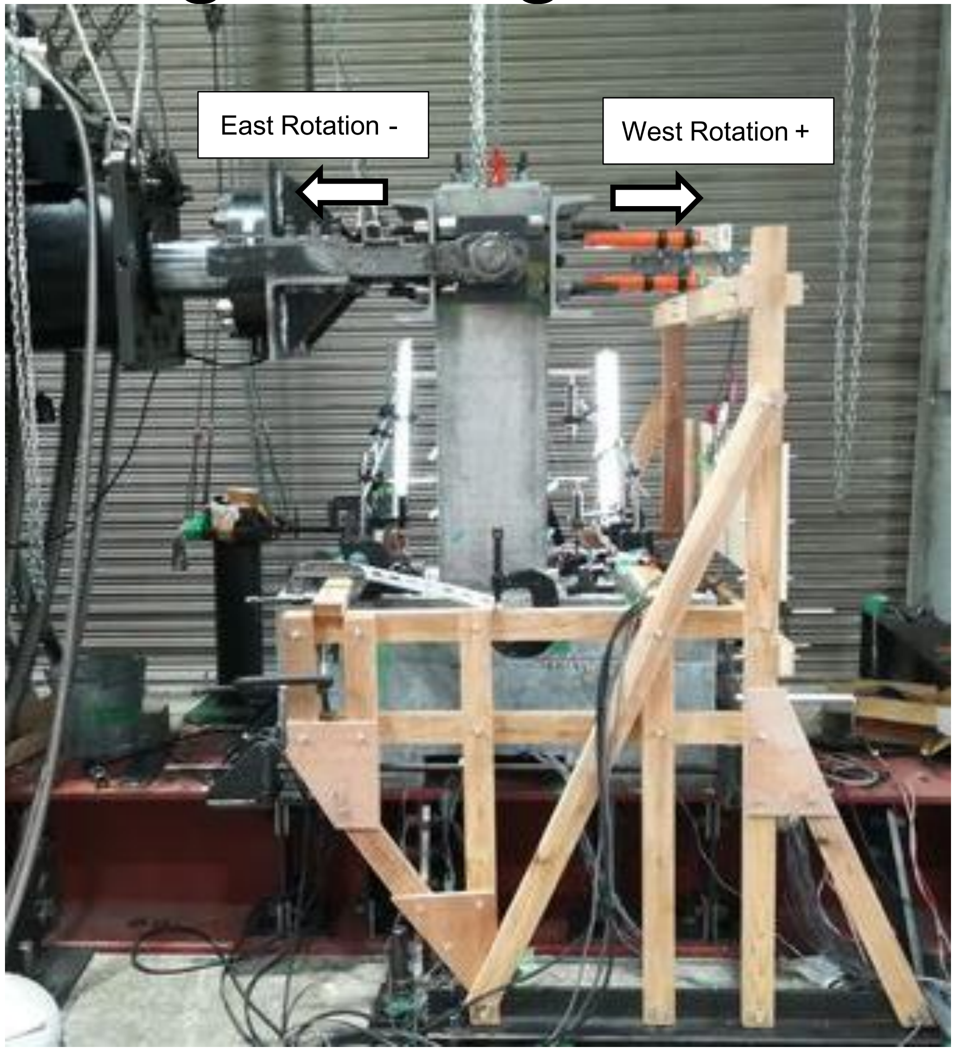
0.25, 0.50 , 0.75, 1.0, 1.5, 2.0, 2.5, and 3.0%rad

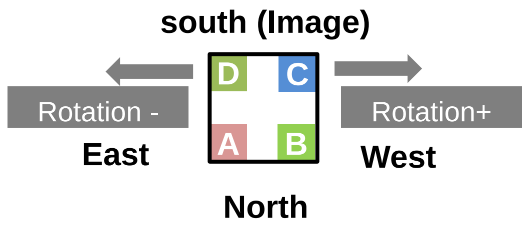
1 cycle for each displacement

3.5, 4.0, 5.0, 6.0, 7.0, 8.0%rad, (9.0, 10.0%rad)

- Strain measurements for PC bars and reinforcing bars

During loading test

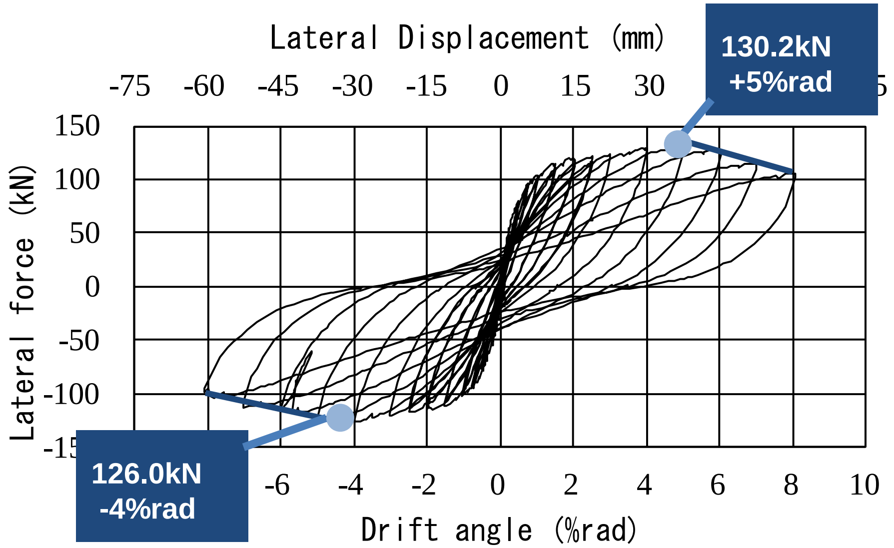




- South (CD plane)
  Digital image captures to use image analysis
- North (AB plane)
  Crack width measurement by using crack scaling
- East (AD plane) for jointed specimen
  Crack opening displacement
- Others
  Deformation measurement using displacement transducers

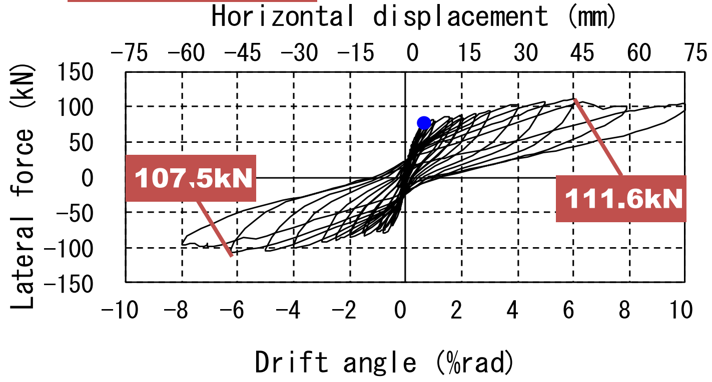
Lateral force – drift angle relations

Monolithic

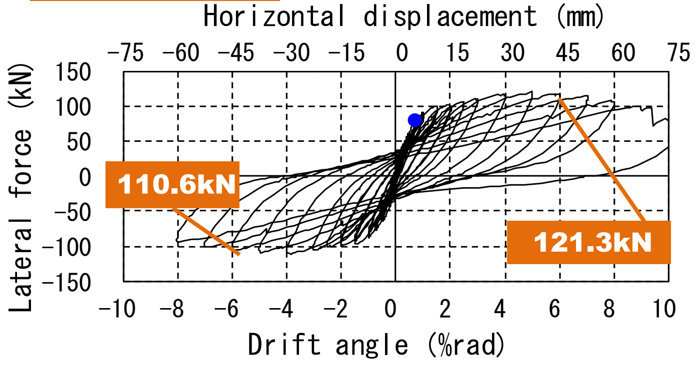


● Yielding of Longitudinal rebars

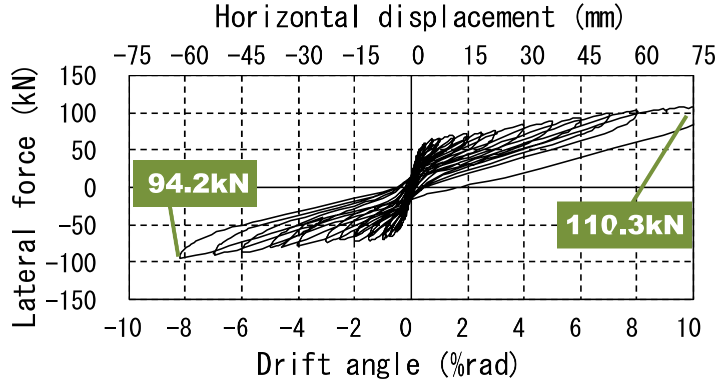
J-C4-S4



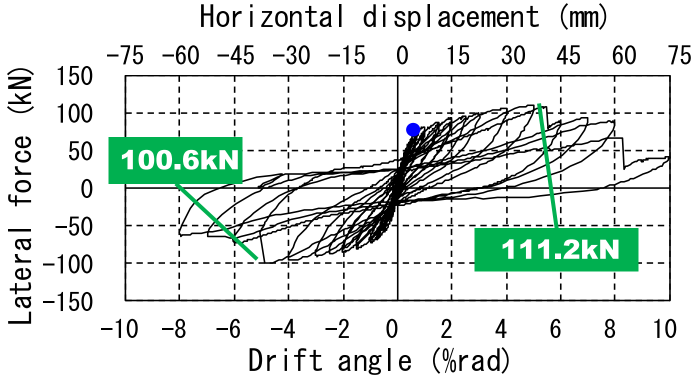
J-C12-S4



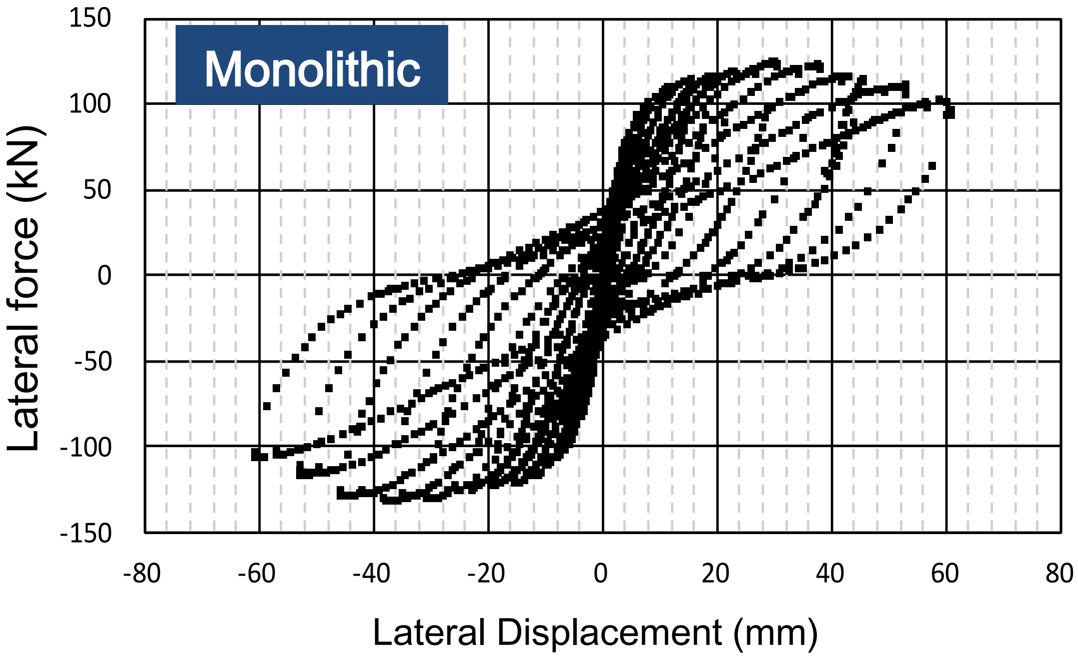
J-DC-S4

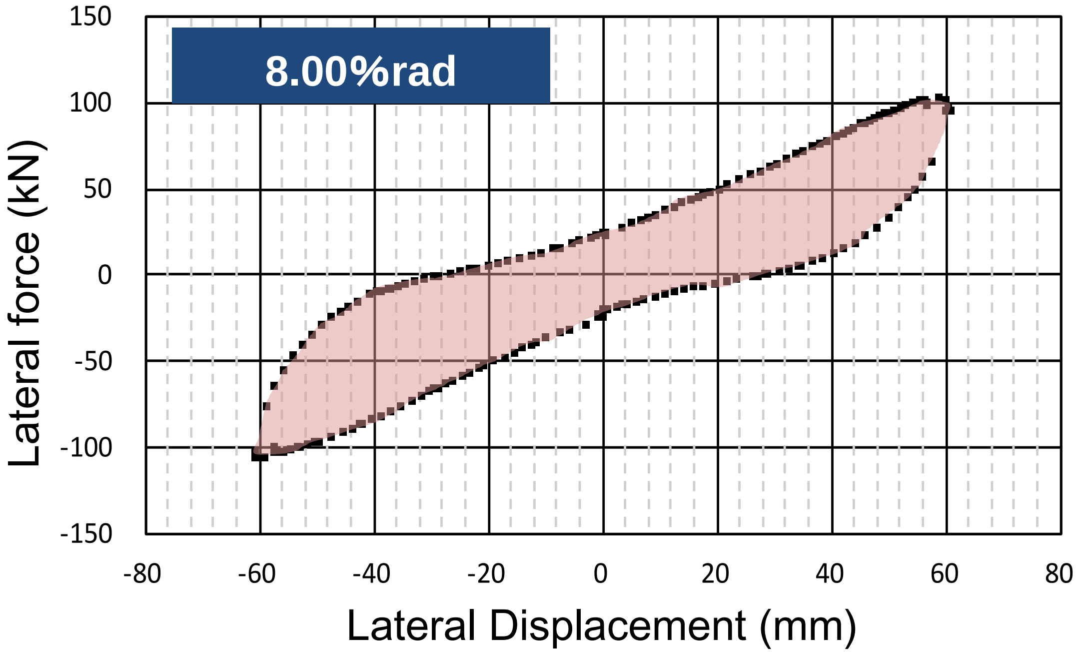


J-C4-S5

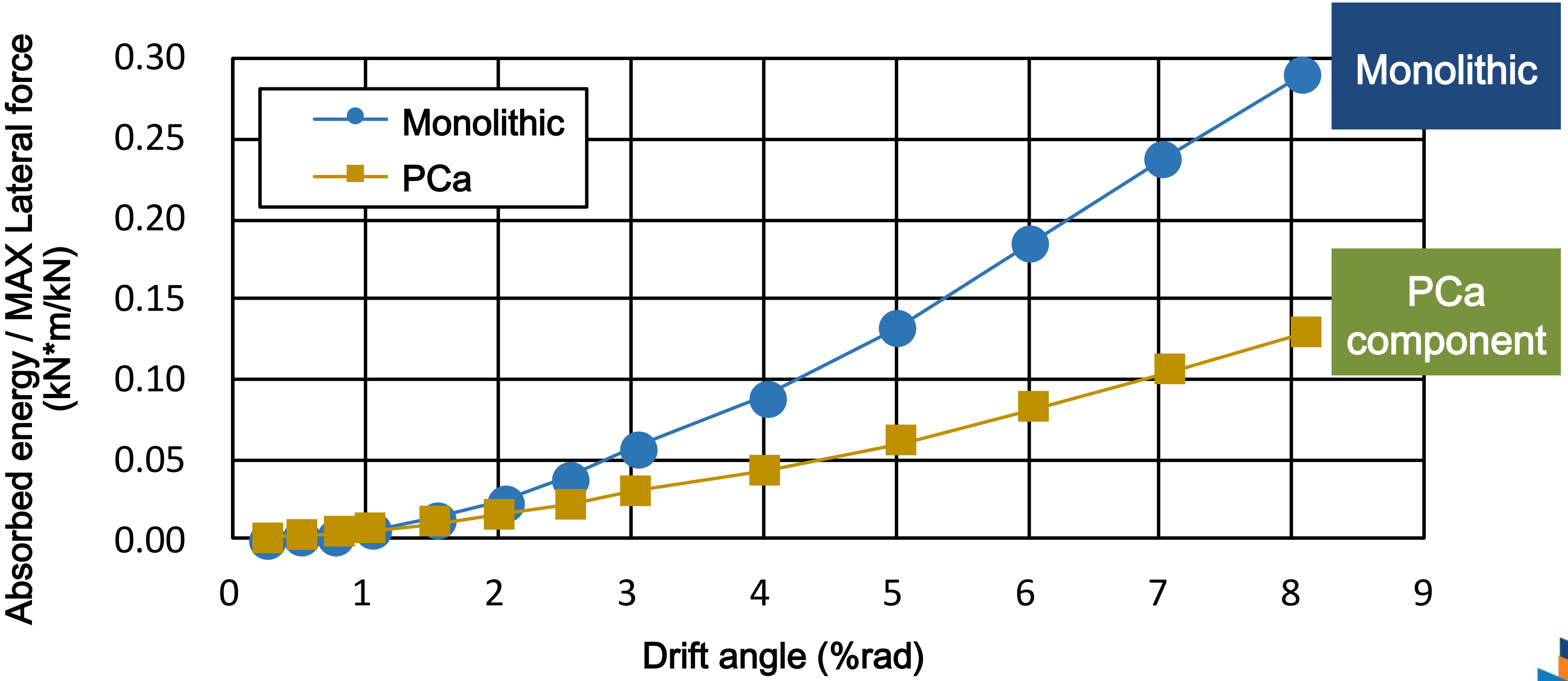


Energy absorption calculation

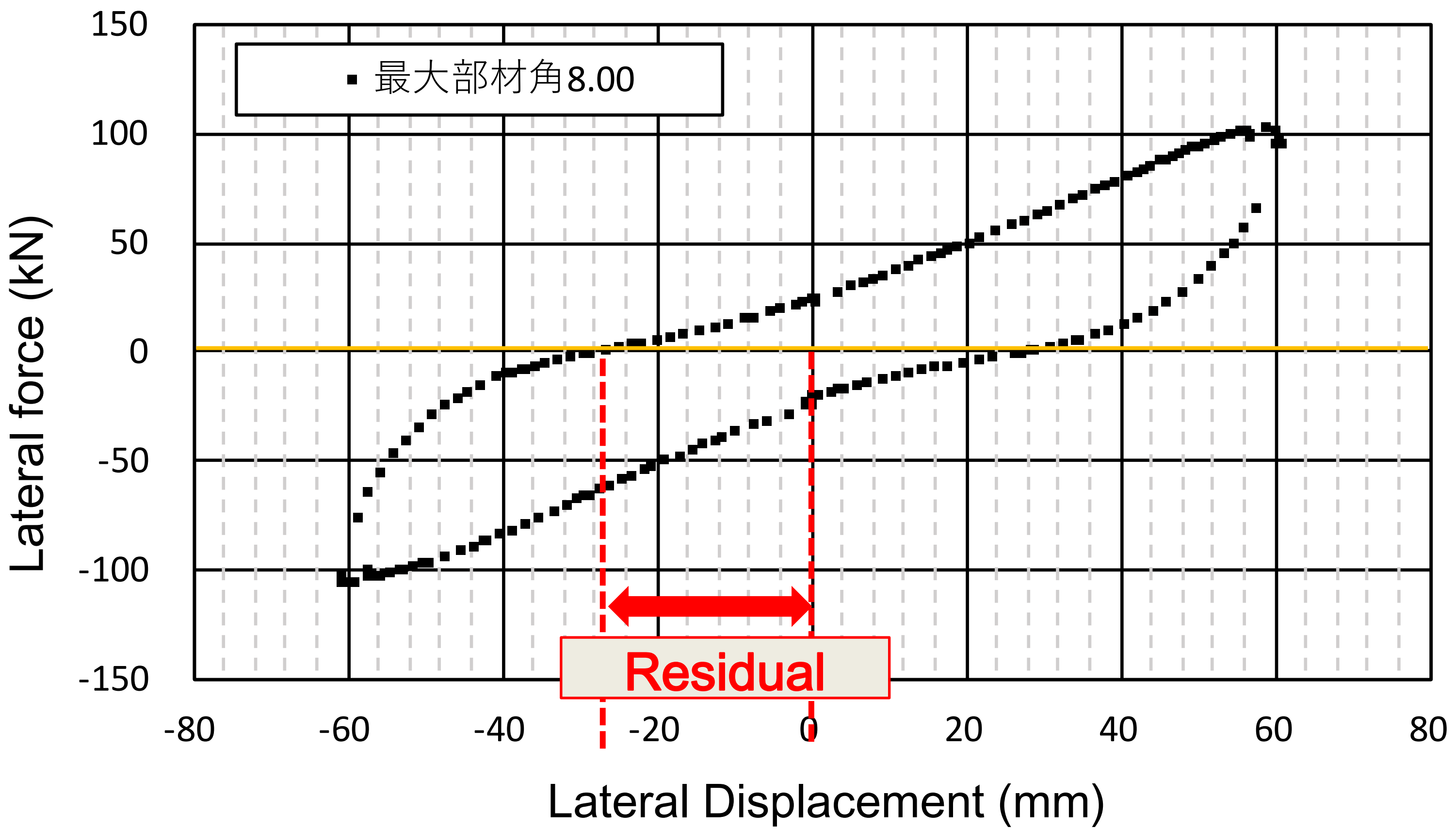




Accumulated energy absorption



Residual displacement calculation



Residual lateral displacement at loading point

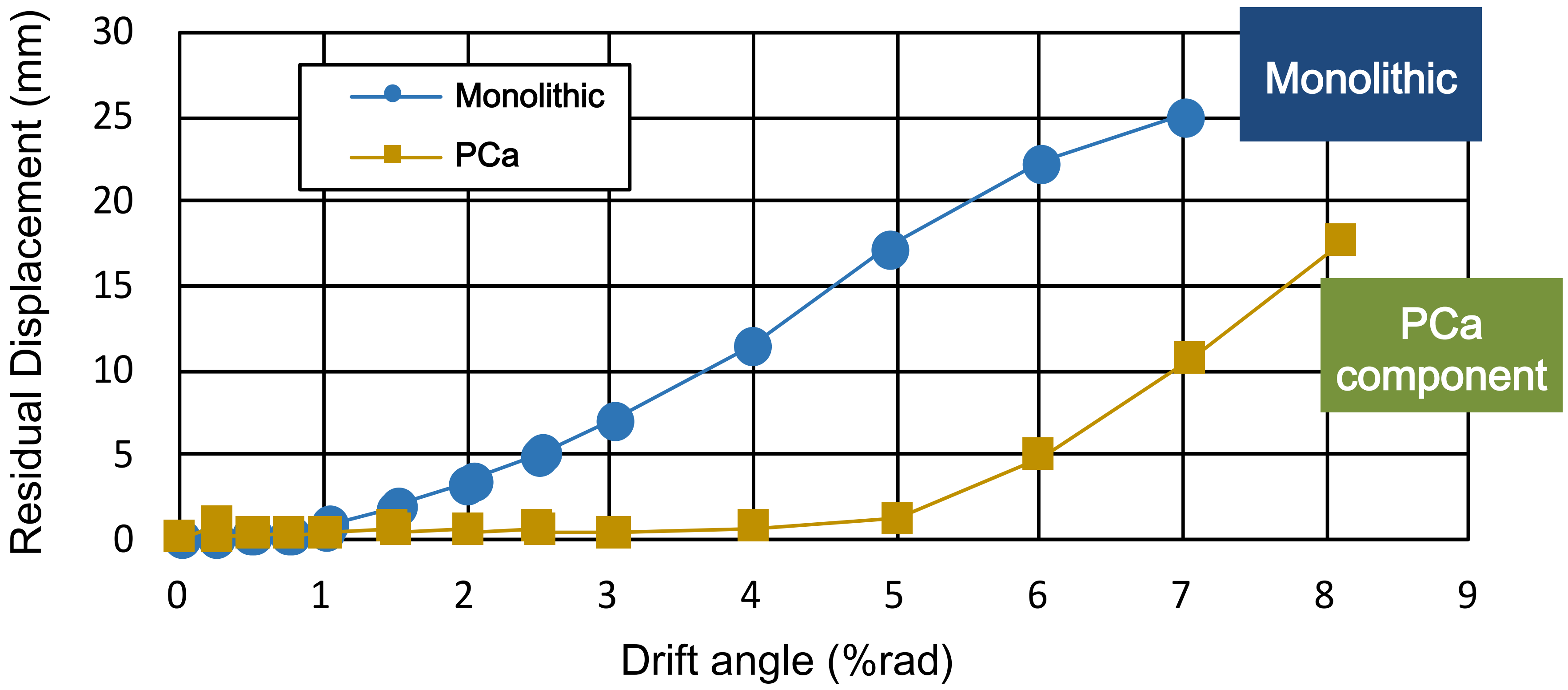
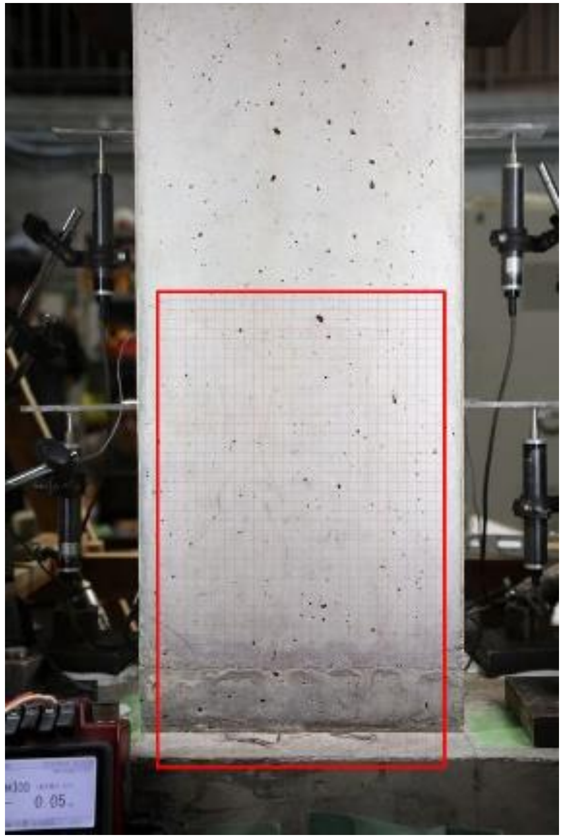
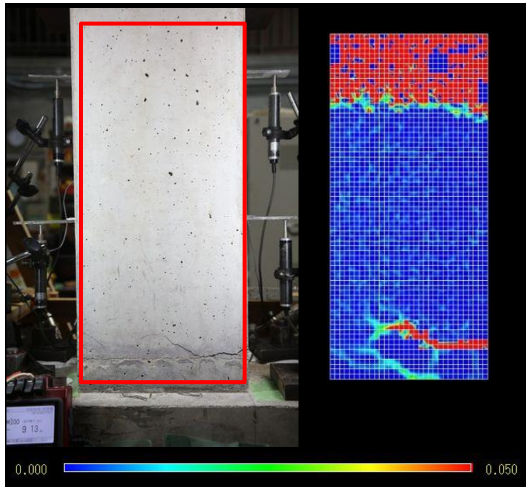


Image analysis by DIC

Setup of image capture



Target of DIC



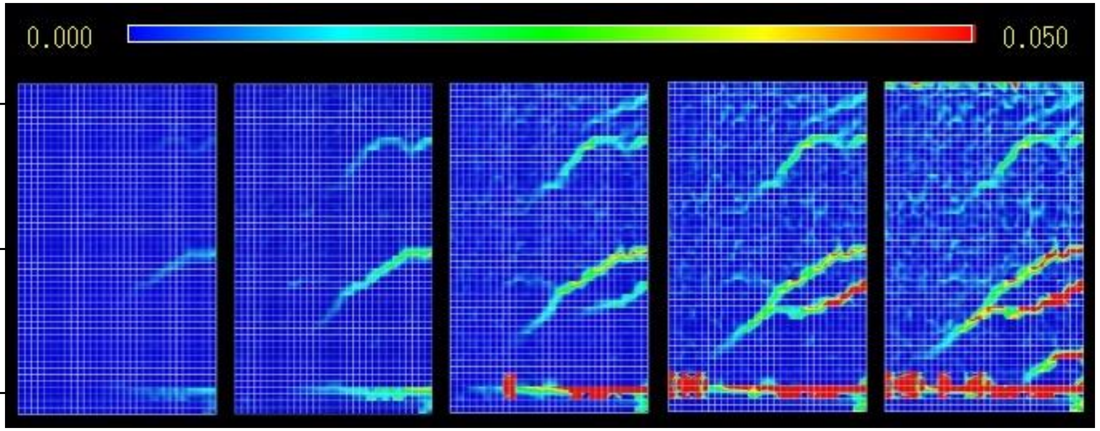
Results example

Tensile strain distribution

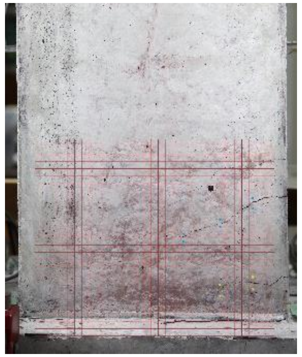
Height from the base

Monolithic

300mm
150mm
0mm



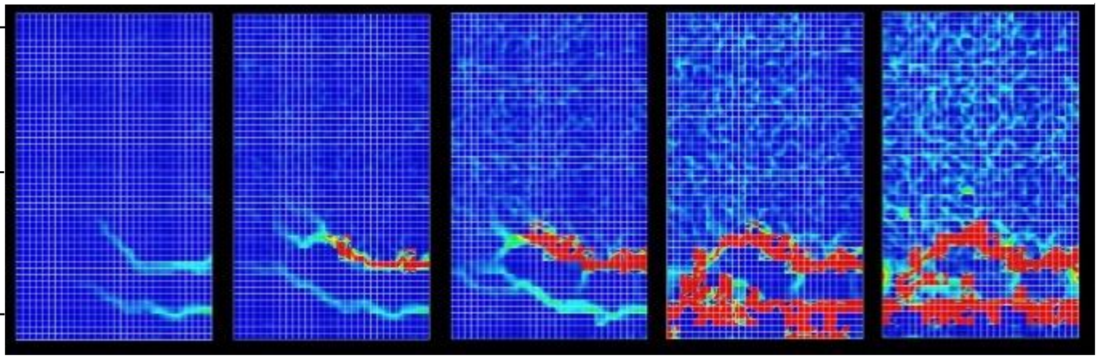
0. 25 0. 50 1. 00 1. 50 2. 00 (%rad)



2. 00%rad

PCa component

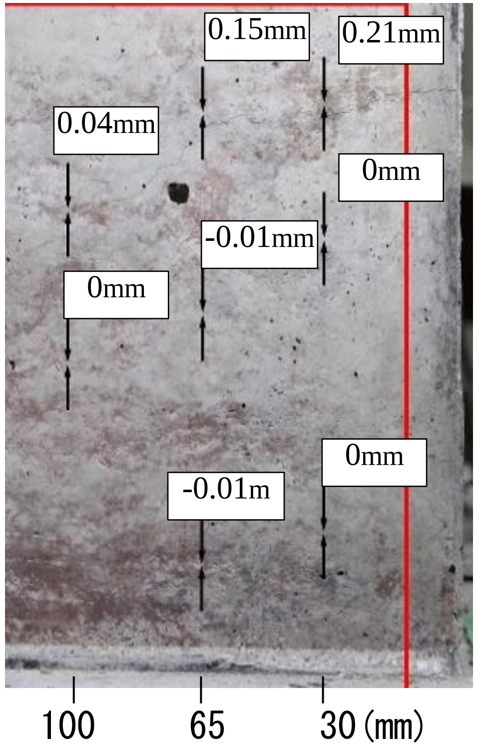
300mm
150mm
0mm



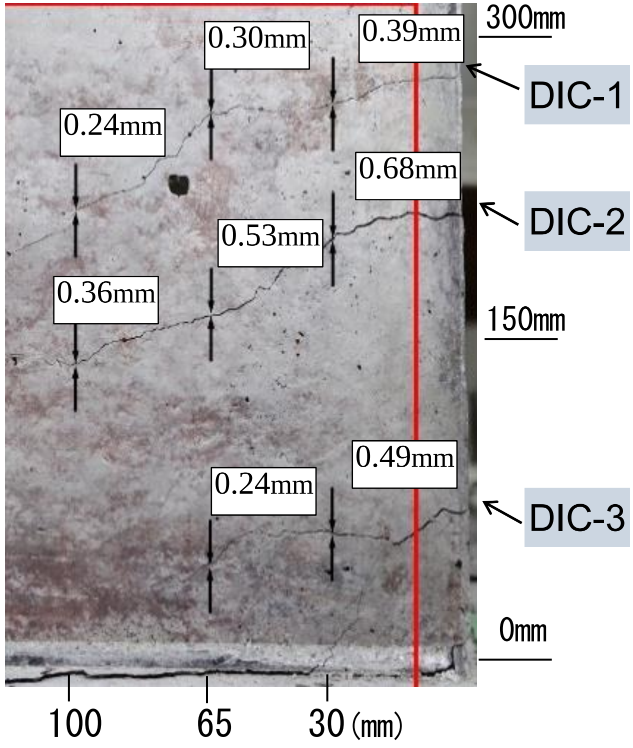
0. 25 0. 50 1. 00 1. 50 2. 00 (%rad)

2. 00%rad

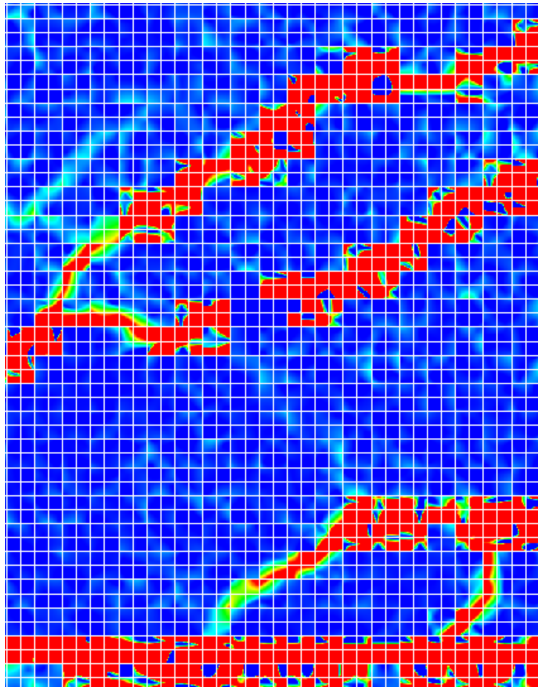
Crack widths in monolithic column



0.50%rad



2.00%rad

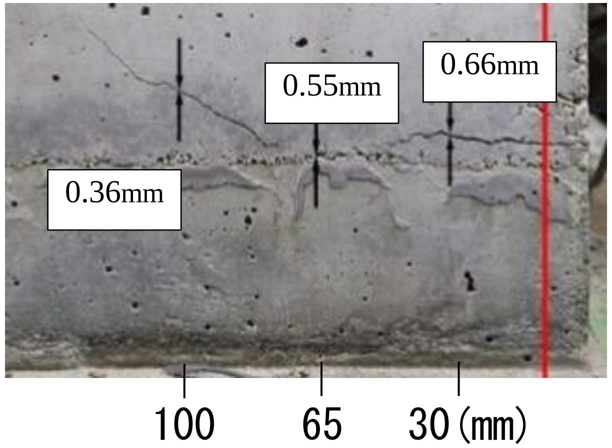


2.00%rad

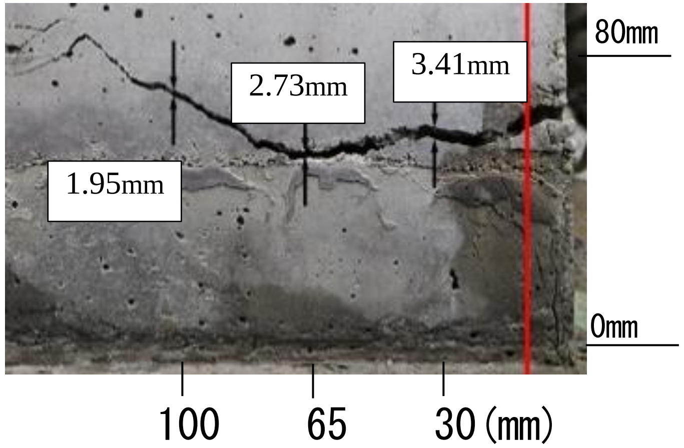
Crack widths in PCa column

Close-up view at bottom the column

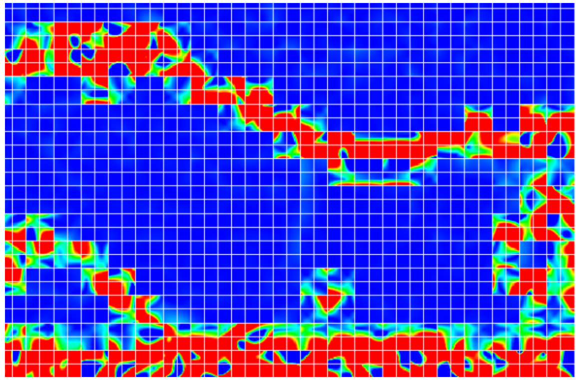
0.50%rad



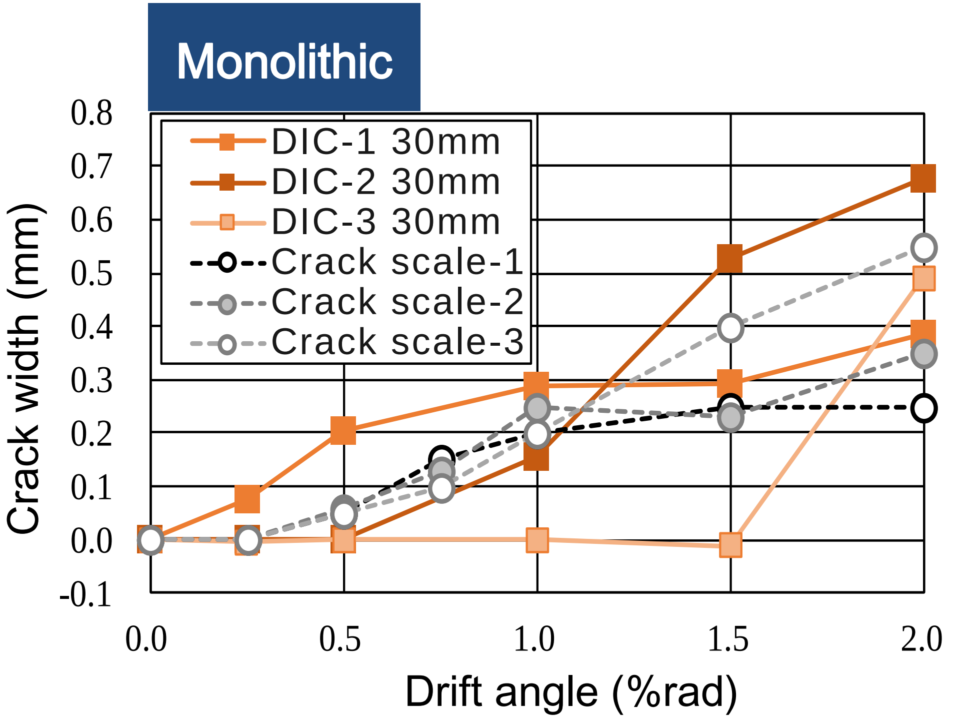
2.00%rad

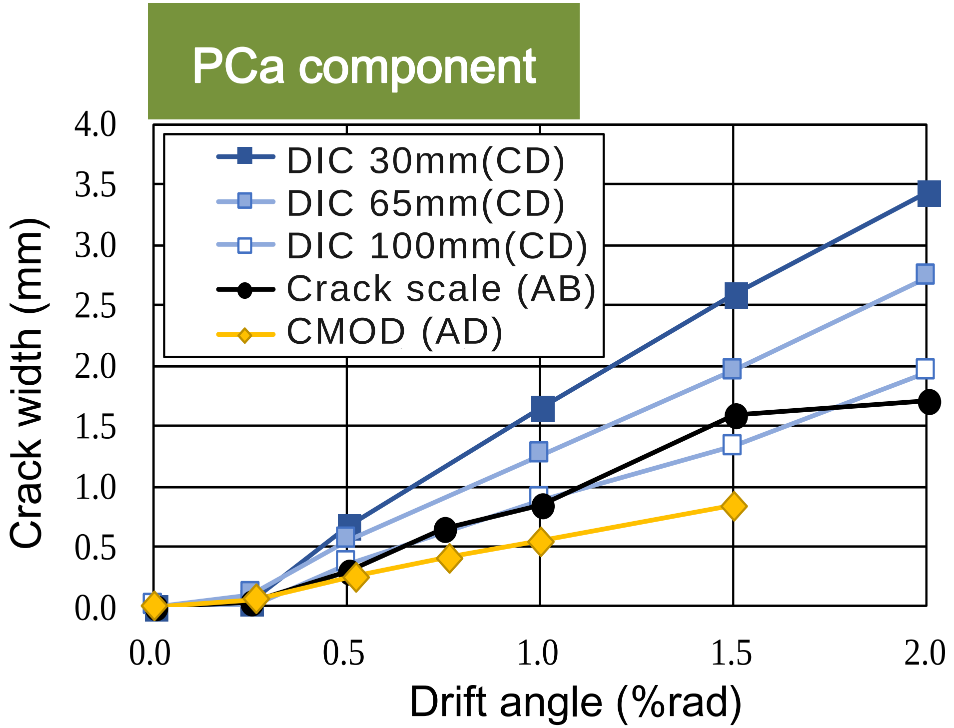


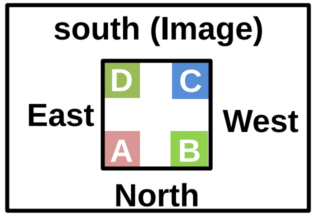
2.00%rad



Crack width measured at each drift angle



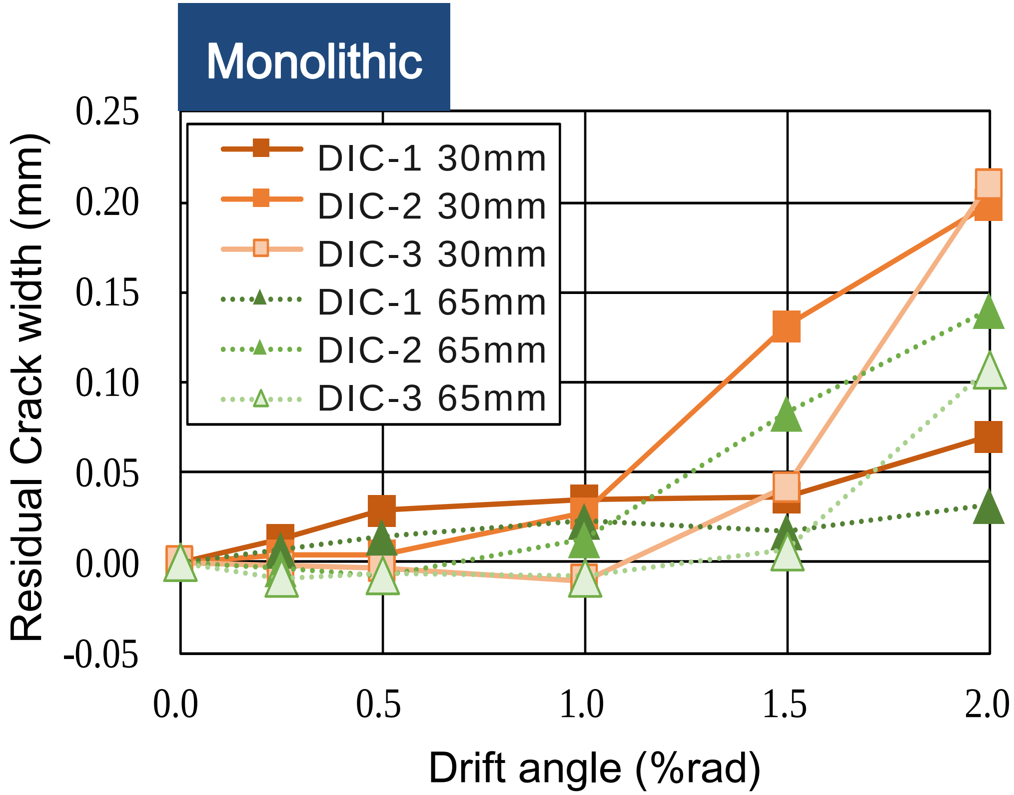


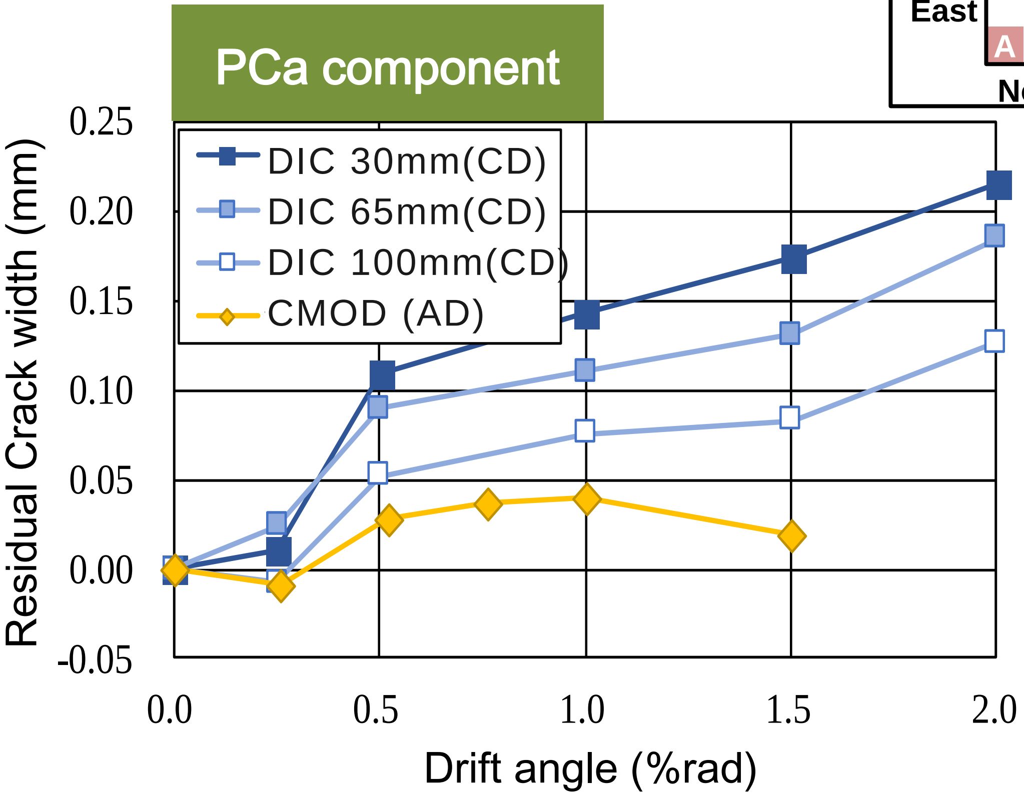


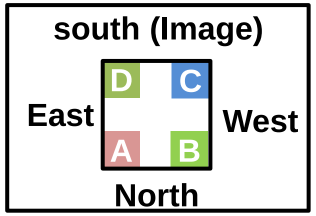
- **Crack width increases as increasing the lateral displacement.**
- **Crack width at same displacement is… Monolithic < PCa**

→ Damage was concentrated at the joint portion.

“Residual” crack width at 0 kN loads







Concluding remarks

- JCI-TC183A has investigated Japanese and international design codes, also the evaluation equations for the connections in PCaRC and PCaPC members, and its seismic reinforcements were surveyed. Several case studies for the application process of PCa components and a trend in the practice of design and construction in Japan were summarized here.
- The cumulative energy absorption of the PC specimen with a joint was half of that of the PC monolithic specimen at the member angle of 8% rad.
- The residual lateral displacement of the PC specimen with a joint was smaller than that of the PC monolithic specimen through the loading.
- Image analysis using a digital image correlation method can capture the strain distribution during the loading test. The results clearly show that the damage was localized at the joint portion of the bottom of the column.

Acknowledgements

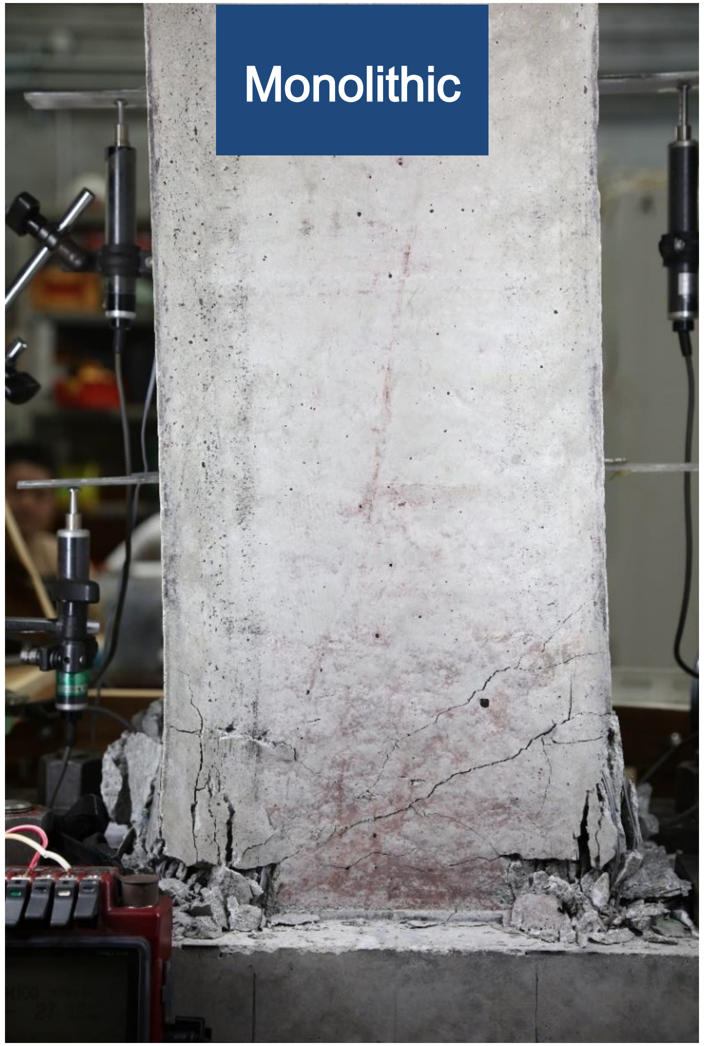
- **<u>Technical committee in JCI TC183A</u>**
  Technical Committee on Design Concept for Precast and Prestressed Concrete Structural Components including Connections
- **<u>JSPS (Japan Society for the Promotion of Science)</u>**
  R2904: Globalization of Research on Urban Resilience against Multiple Natural Hazards
- **<u>JSPS (Japan Society for the Promotion of Science)</u>**
  JP15KK0208, 25709040: Sensitivity of Volumatic Heterogeneity in Concrete Materia on Shear Resisting Mechanism of Reinforced Concrete Beams
- **<u>Hanshin Expressway Foundation</u>**
  Study on Resilient Concrete Structures in terms of Precast and Prestressed Concrete Bridge Columns

Thank you for your attention.

Design Concept for Precast and Prestressed Concrete Structural Components

- Presented By: Tomohiro Miki
- Affiliation: Kobe University
- Description: In Japan Concrete Institute, Technical Committee on “Design Concept for Precast and Prestressed Concrete Structural Components including Connections” was organized with a chair of Dr. Miki, in 2019/2020. This technical committee conducts a literature survey for the domestic and international design codes and discusses the performance-based design for precast and prestressed/non-prestressed concrete structural components including connections. Issues in the application of these precast concrete components are analyzed based on a case study of practical examples including bridges, buildings, football stadiums, and transportation warehouses. The presentation includes the practical investigations and discussion on the future direction of structural application for the precast prestressed concrete components to the buildings and bridges.

Damage of the columns at 6%rad

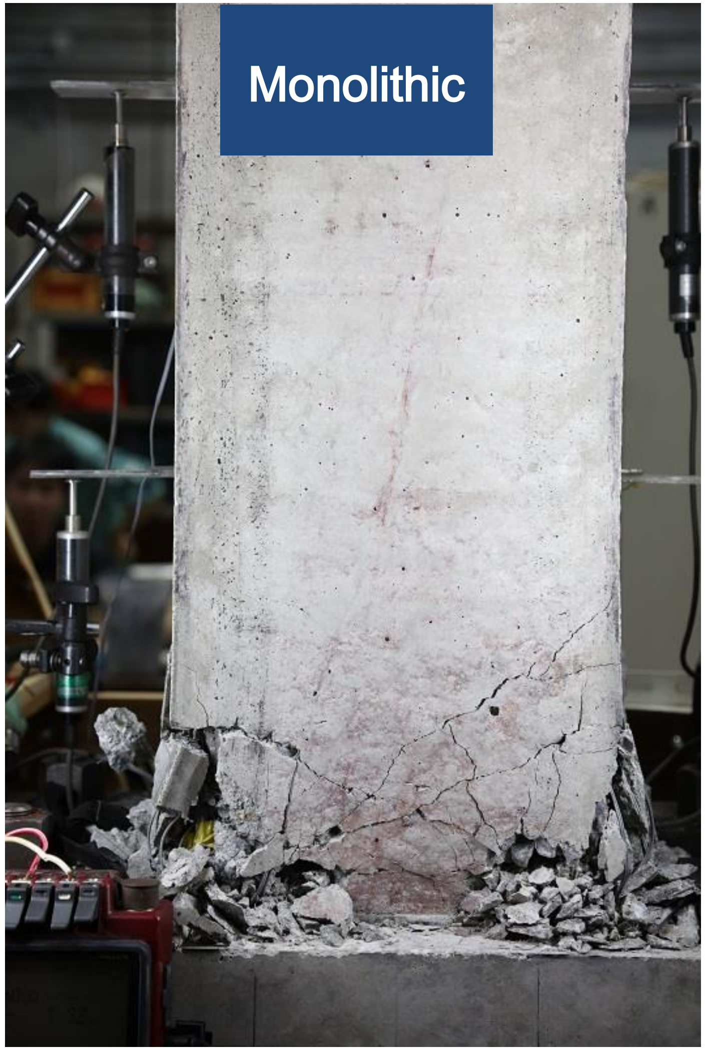


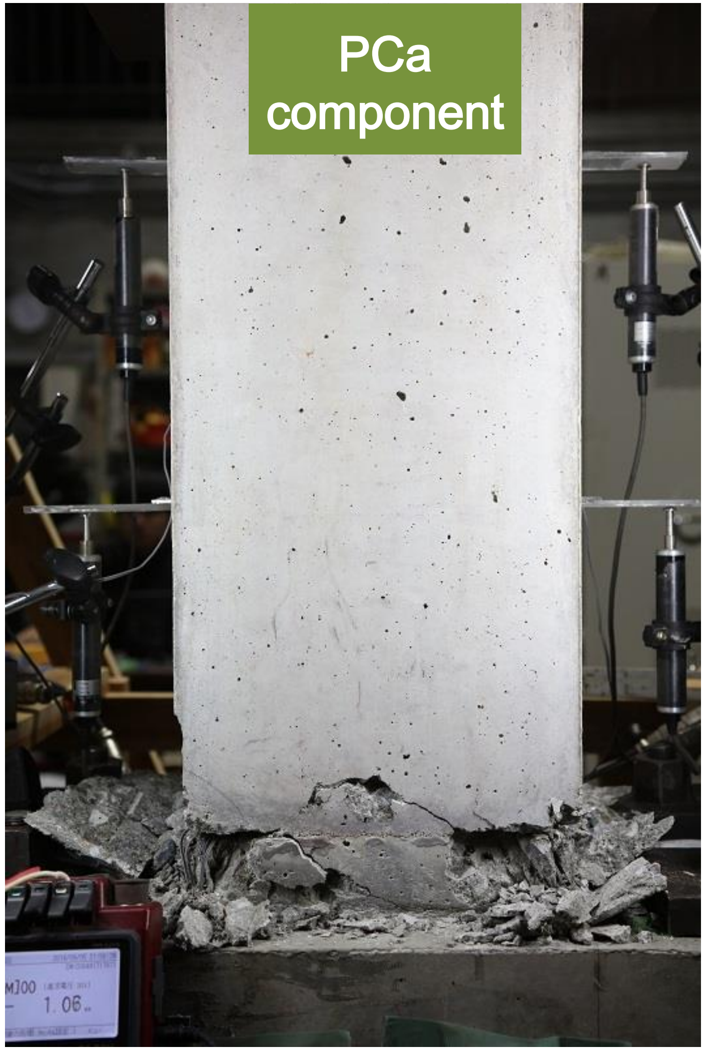
Damage of the columns at 6%rad

Monolithic

PCa component

Damage of the columns at 8%rad





Damage of columns at 8%rad

Monolithic

PCa component

Comparison of damages of columns

6%Rad

8%Rad