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TRI-DIRECTIONAL LOADING TESTS ON REINFORCED CONCRETE SHEAR WALLS

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TRI-DIRECTIONAL LOADING TESTS ON REINFORCED CONCRETE SHEAR WALLS

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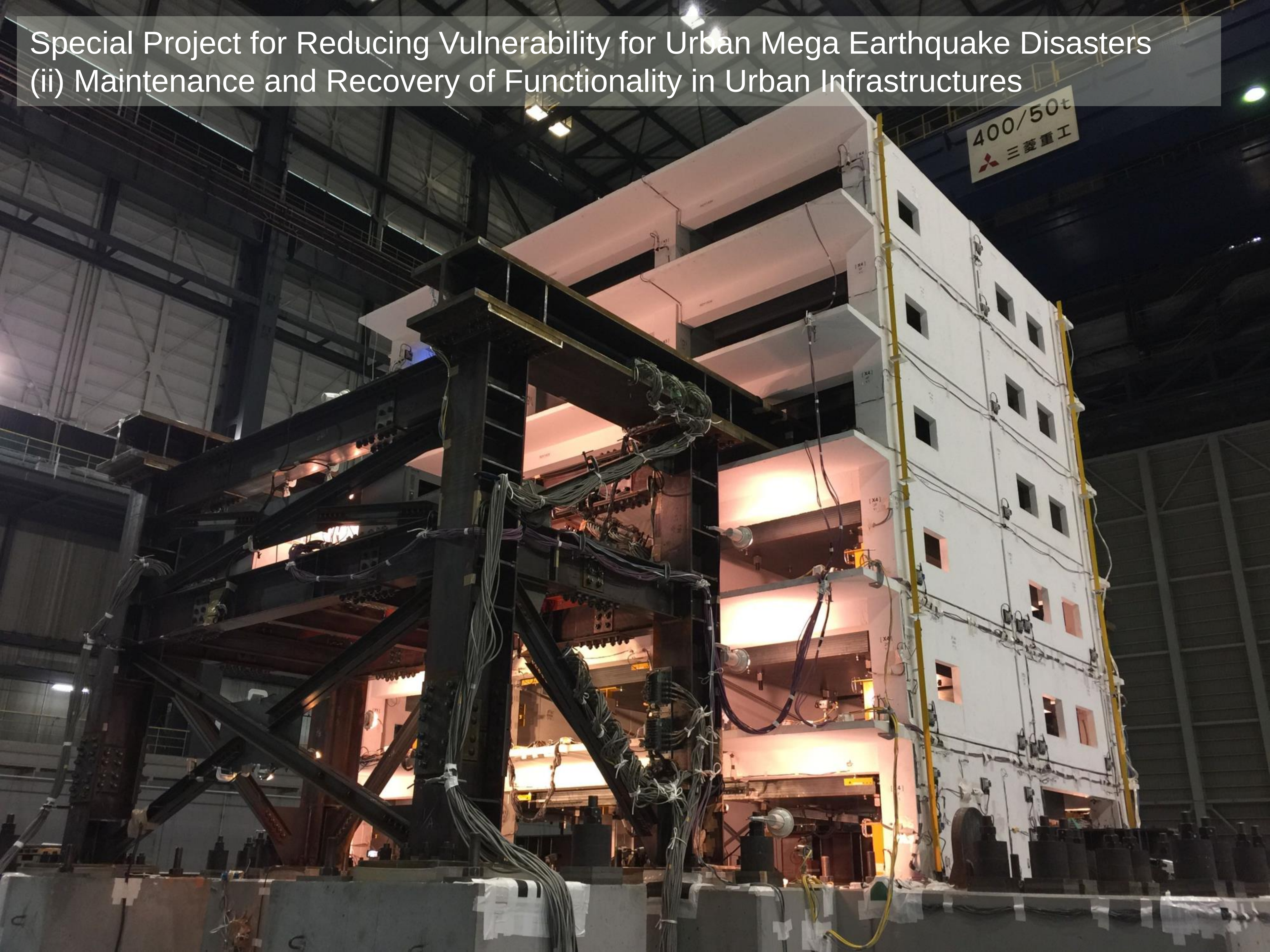
Special Project for Reducing Vulnerability for Urban Mega Earthquake Disasters
(ii) Maintenance and Recovery of Functionality in Urban Infrastructures

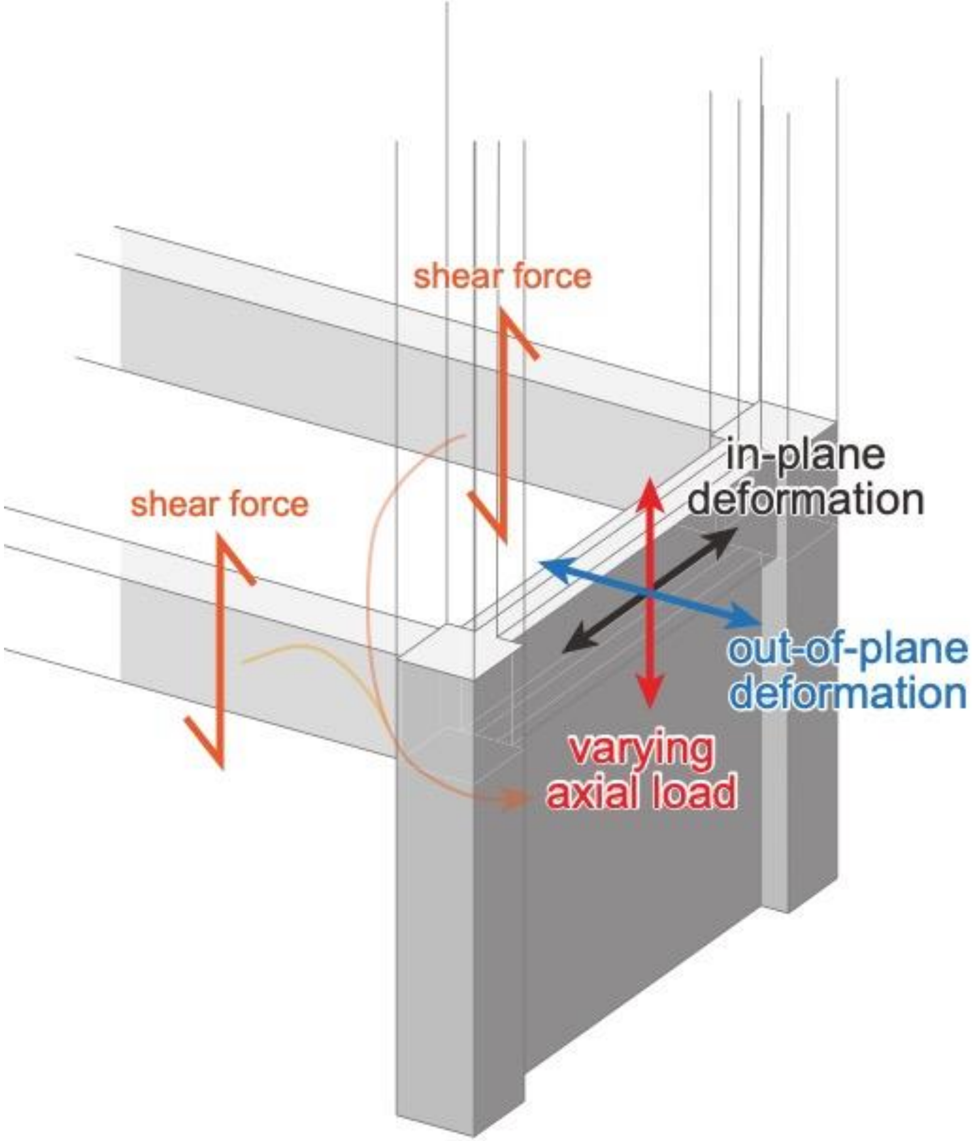


Special Project for Reducing Vulnerability for Urban Mega Earthquake Disasters
(ii) Maintenance and Recovery of Functionality in Urban Infrastructures

#3-5(JMA Kobe 140%-1) 1/2

#3-5(JMA Kobe 140%-1)   1/2

wall in X-2 frame on the 2nd floor


shear force
shear force
in-plane deformation
out-of-plane deformation
varying axial load

Introduction

Background

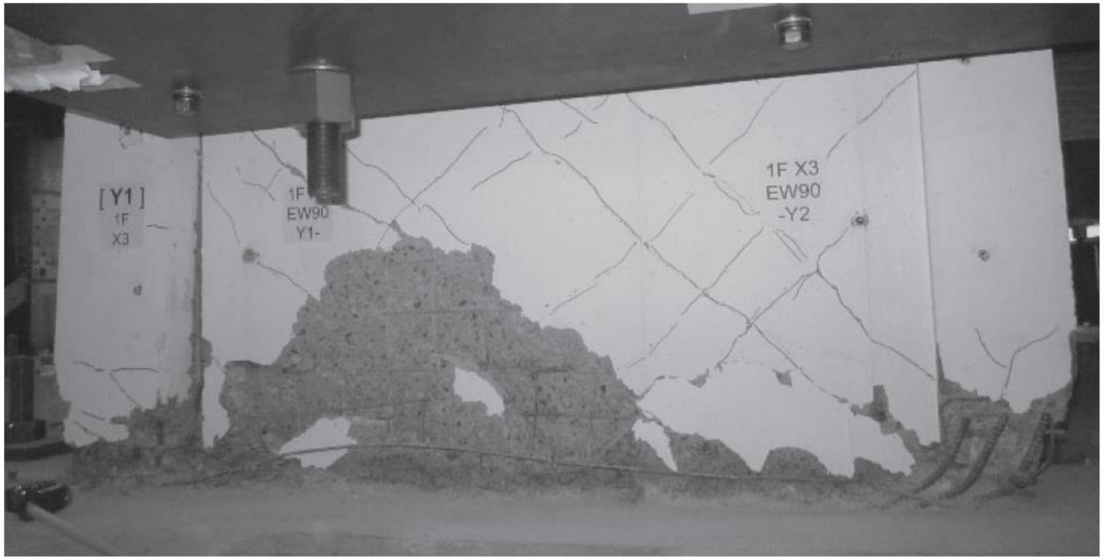
- At present, structural performance evaluation method of RC members considering tri-directional forces in earthquakes has yet to be established.

$$Q_w = \left\{ \frac{0.068 p_{te}^{0.23} \left(F_c + 18 \right)}{\sqrt{\frac{M}{QD} + 0.12}} + 0.85 \sqrt{p_{wh} \sigma_{wh}} + 0.1 \sigma_o \right\} t_e j$$

$$\sigma_o = \frac{N}{A_g}$$

axial load

total area



Shaking table tests in E-Defense

Ref) Yonezawa et al.: Nonlinear Analysis for Shaking Table Test of RC 6 Story Building – Research and development for quantification of collapse margin of RC buildings

Introduction

Objectives

- investigating effects of axial load condition and lateral bi-directional loading path on the shear capacity of shear walls

Methodology

- conducting loading tests on shear wall specimens subjected to bi-directional loading under various axial load

TRI-DIRECTIONAL LOADING TESTS ON REINFORCED CONCRETE SHEAR WALLS

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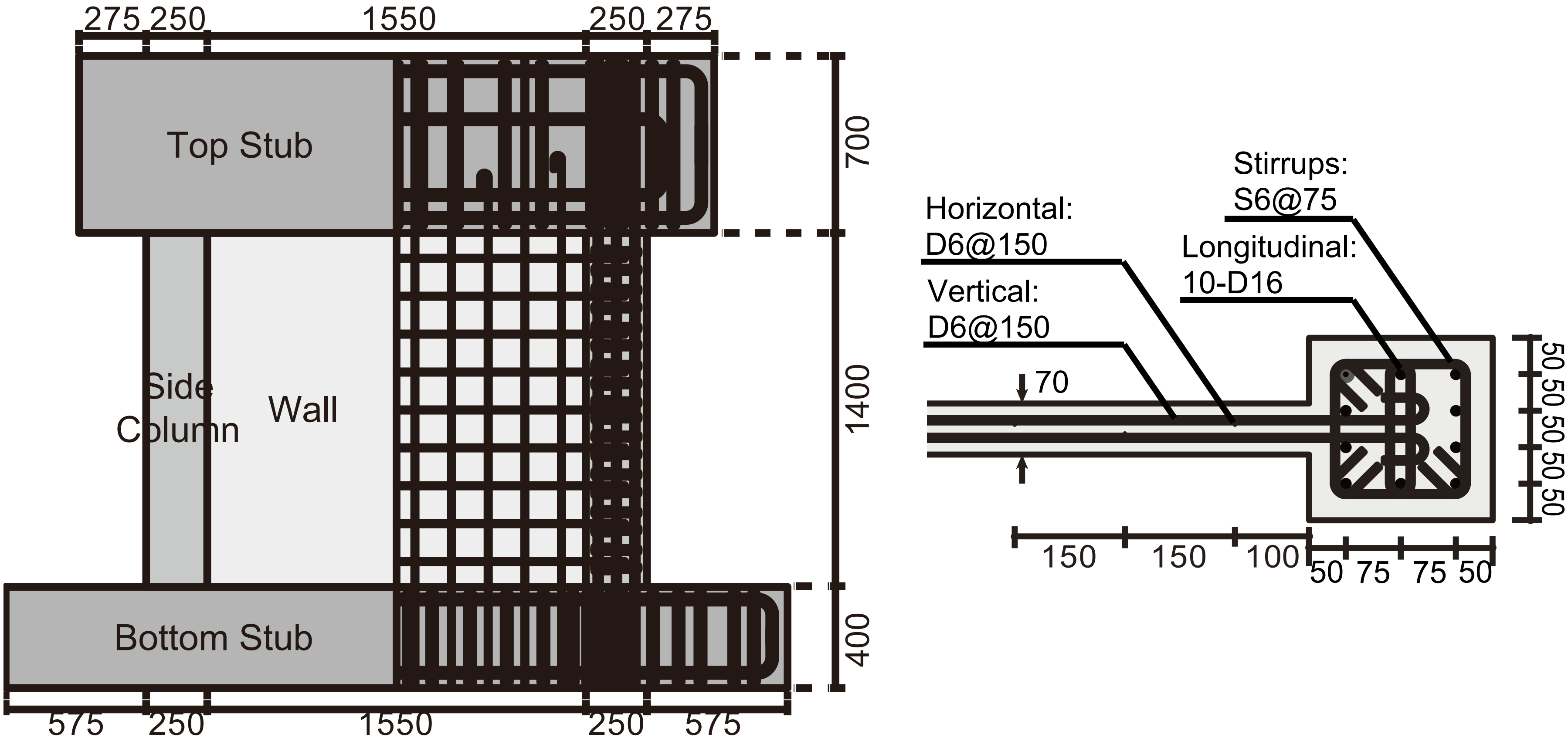
Outline of Loading Tests

Outline of specimen

- Specimens: 30%-scale shear walls with identical dimensions and reinforcement arrangements.



Outline of Loading Tests

Experimental parameters

- Parameters: Axial load condition, O/I drift ratio

(O/I drift ratio = out-of-plane drift angle / in-plane drift angle)

Axial load O/I drift ratio	constant		varying	
	$0.12A_gf'_c$	$0.20A_gf'_c$	$0 \sim 0.20A_gf'_c$	$-0.33a_{cg}f_y \sim 0.20A_gf'_c$
0	**WB00-C12** 1)			
1.5	**WB15-C12** 1)	**WB15-C20**	**WB15-C20T00**	**WB15-C20T33**
3.0	**WB30-C12** 1)		**WB30-C20T00**	

A_g	gross sectional area of concrete
f'_c	compressive strength of concrete
a_{cg}	gross sectional area of long. rebars
f_y	yield strength of long. rebars

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1) Idosako et al.: Bi-directional Lateral Loading Tests on RC Shear-dominant Walls, Journal of Structural and Construction Engineering (Transaction of AIJ)

Outline of Loading Tests

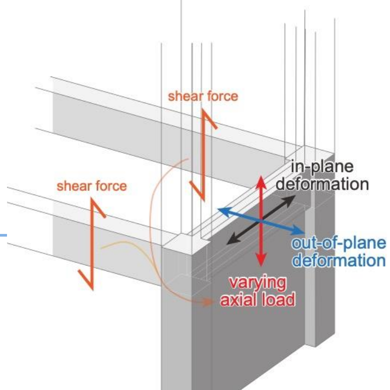
Material

- There was a difference in the compressive strength of concrete.

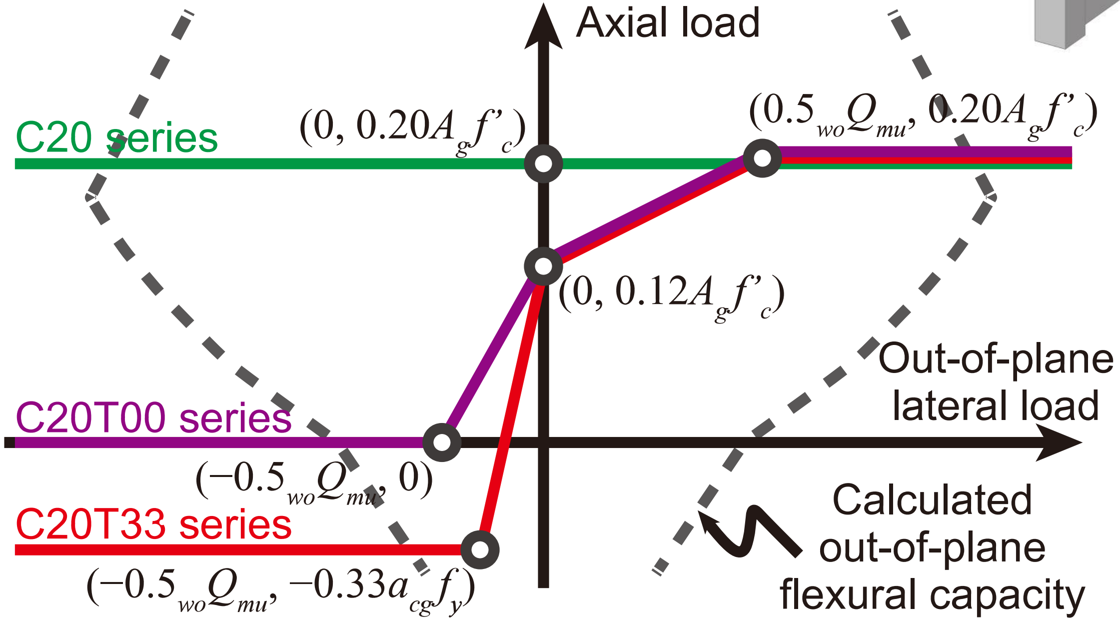
Axial load / O/I drift ratio	constant		varying	
	$0.12A_g f'_c$	$0.20A_g f'_c$	$0 \sim 0.20A_g f'_c$	$-0.33a_{cg}f_y \sim 0.20A_g f'_c$
0	**28.9**			
1.5	**28.9**	**21.9**	**23.0**	**26.9**
3.0	**28.9**		**24.5**	

unit: MPa

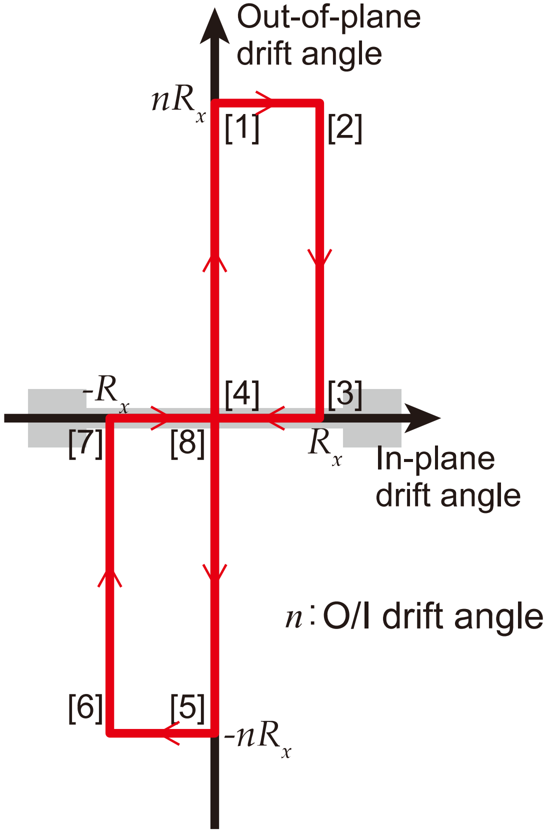
Loading protocol



- Axial load



- Lateral loading path



- Out-of-plane flexural capacity is calculated as two columns ignoring the effect of wall panel.
- R_x = 0.05, 0.10, 0.25, 0.50, 0.75, 1.0, 2.0%

Outline of Loading Tests

Calculation of capacity

- Flexural and shear ultimate capacity under the maximum axial load was calculated according to the equations of practical design in Japan.

Axial load O/I drift ratio	constant	varying	
	$0.20A_gf'_c$	$0 \sim 0.20A_gf'_c$	$-0.33a_{cg}f_y \sim 0.20A_gf'_c$
1.5	**WB15-C20**	**WB15-C20T00**	**WB15-C20T33**
3.0		**WB30-C20T00**	

Outline of Loading Tests

Capacity calculation – in-plane

- It is estimated that shear failure precedes in the in-plane direction.

Axial load O/I drift ratio	constant	varying	
	$0.20A_gf'_c$	$0 \sim 0.20A_gf'_c$	$-0.33a_{cg}f_y \sim 0.20A_gf'_c$
1.5	676 $\wedge$ 1422	692 $\wedge$ 1449	750 $\wedge$ 1546
3.0		714 $\wedge$ 1486	

In-plane $\frac{\text{shear}}{\text{flexural}}$

unit: kN

Outline of Loading Tests

Capacity calculation – out-of-plane

- It is estimated that flexural failure precedes in the out-of-plane direction.

Axial load O/I drift ratio	constant	varying	
	$0.20A_g f'_c$	$0 \sim 0.20A_g f'_c$	$-0.33a_{cg}f_y \sim 0.20A_g f'_c$
1.5	371 V 215	377 V 220	398 V 238
3.0		385 V 227	

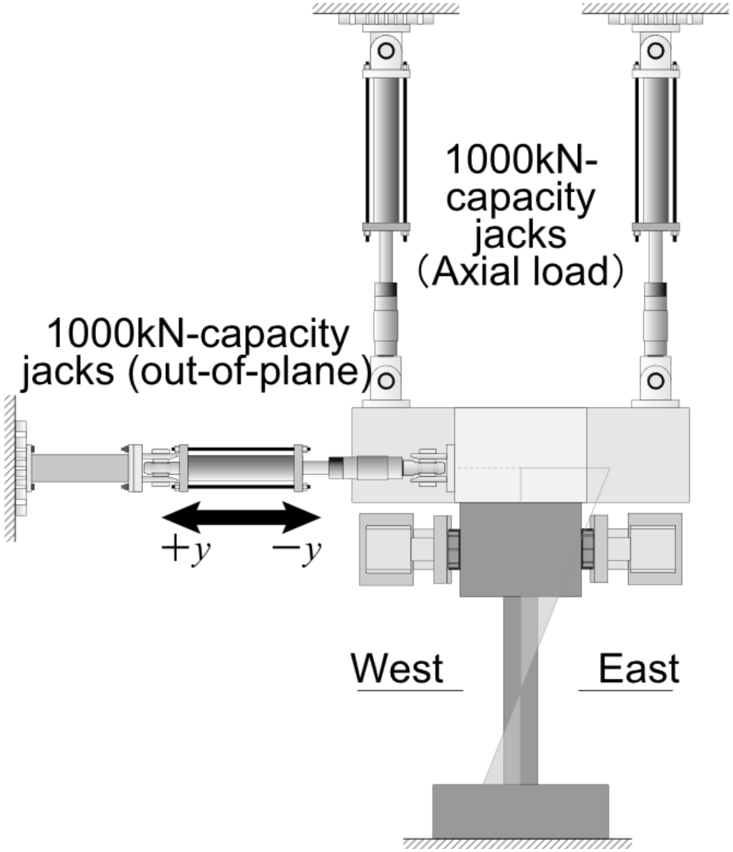
Out-of-plane	shear
	flexural

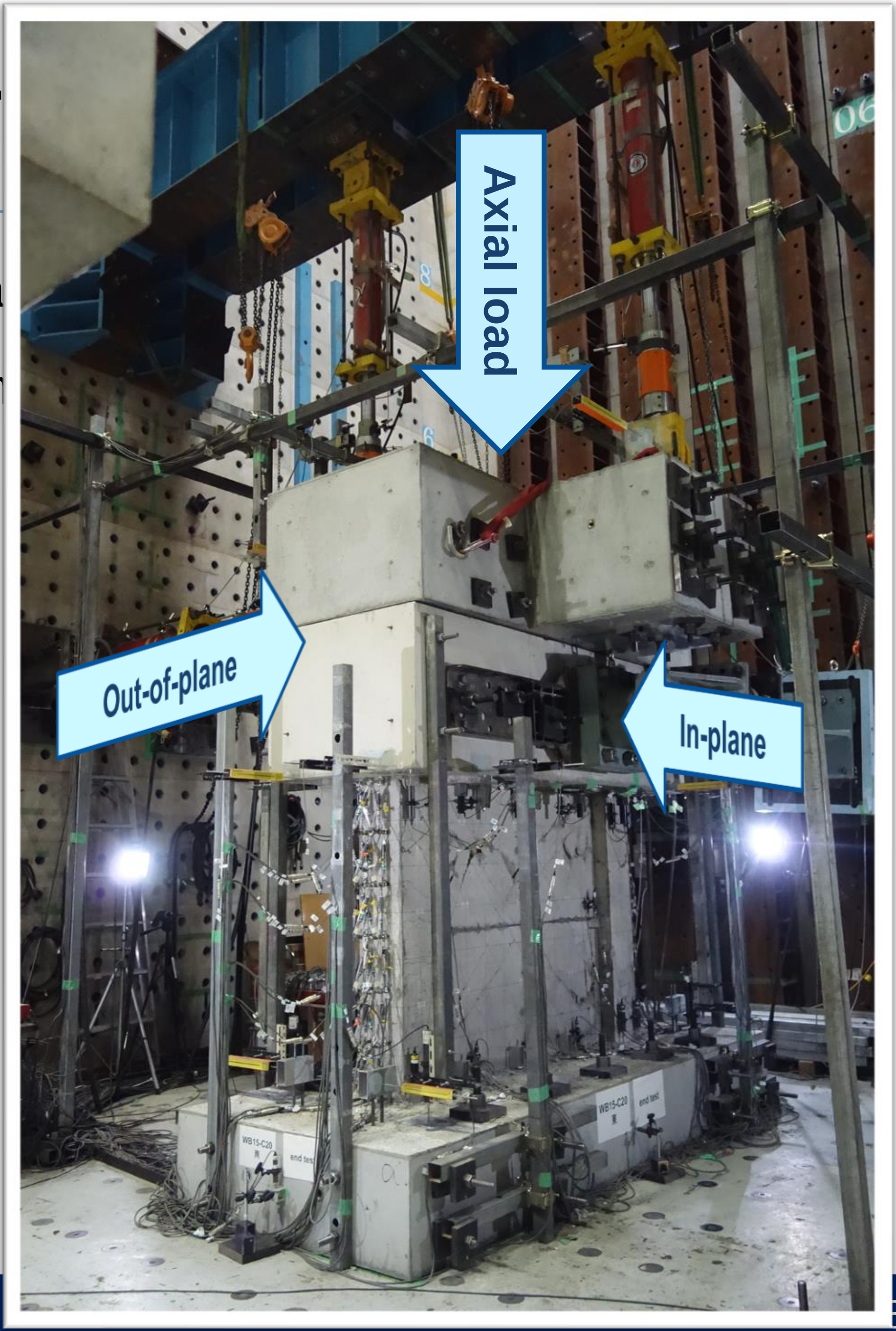
unit: kN

Outline of L

Loading setup

- In-plane: cantilever (shear span ra
- Out-of-plane: double-curvature (sh





TRI-DIRECTIONAL LOADING TESTS ON REINFORCED CONCRETE SHEAR WALLS

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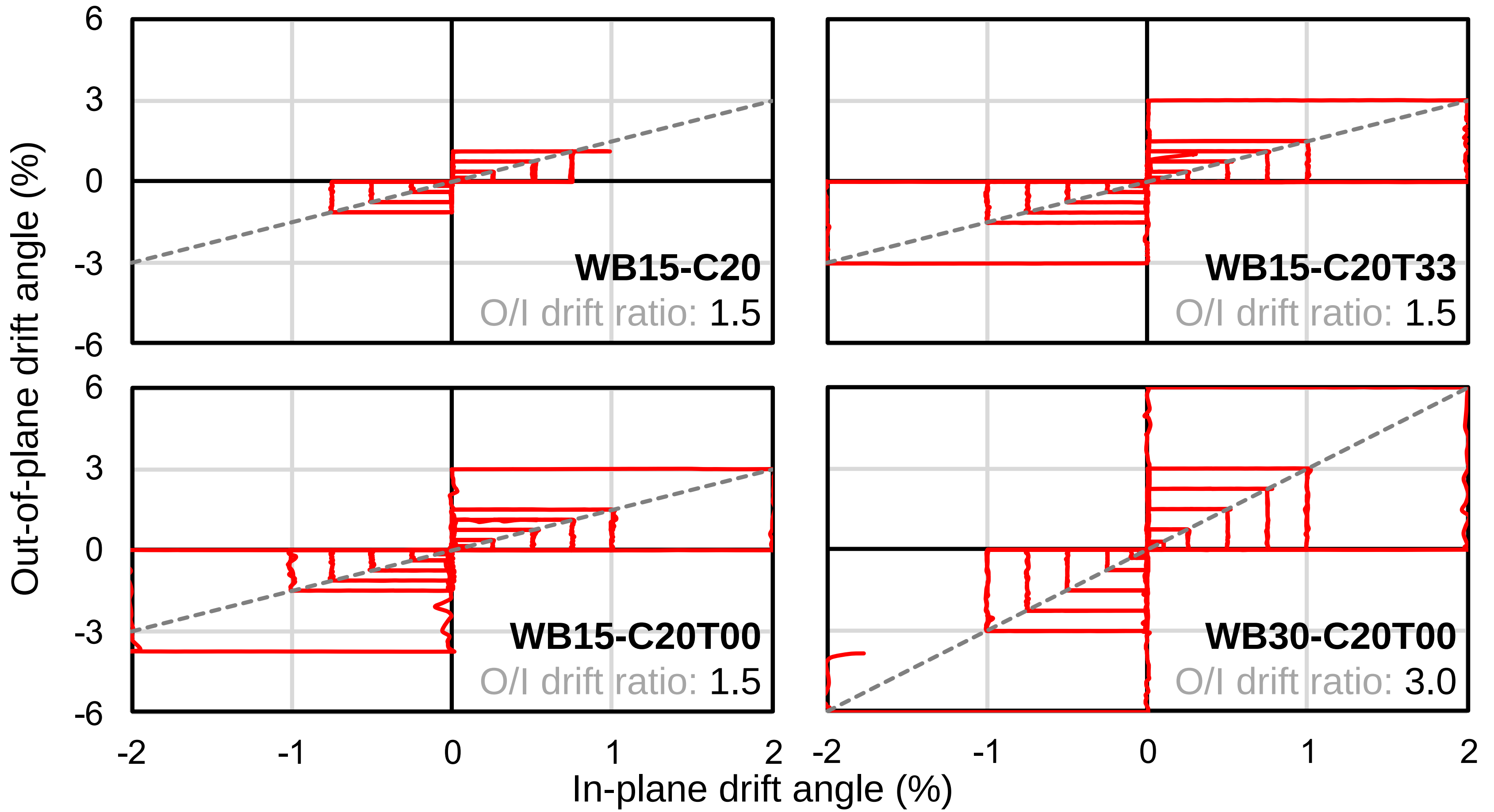
Experimental Results

Loading path

- The loading was carried out as planned generally.

Lateral loading path

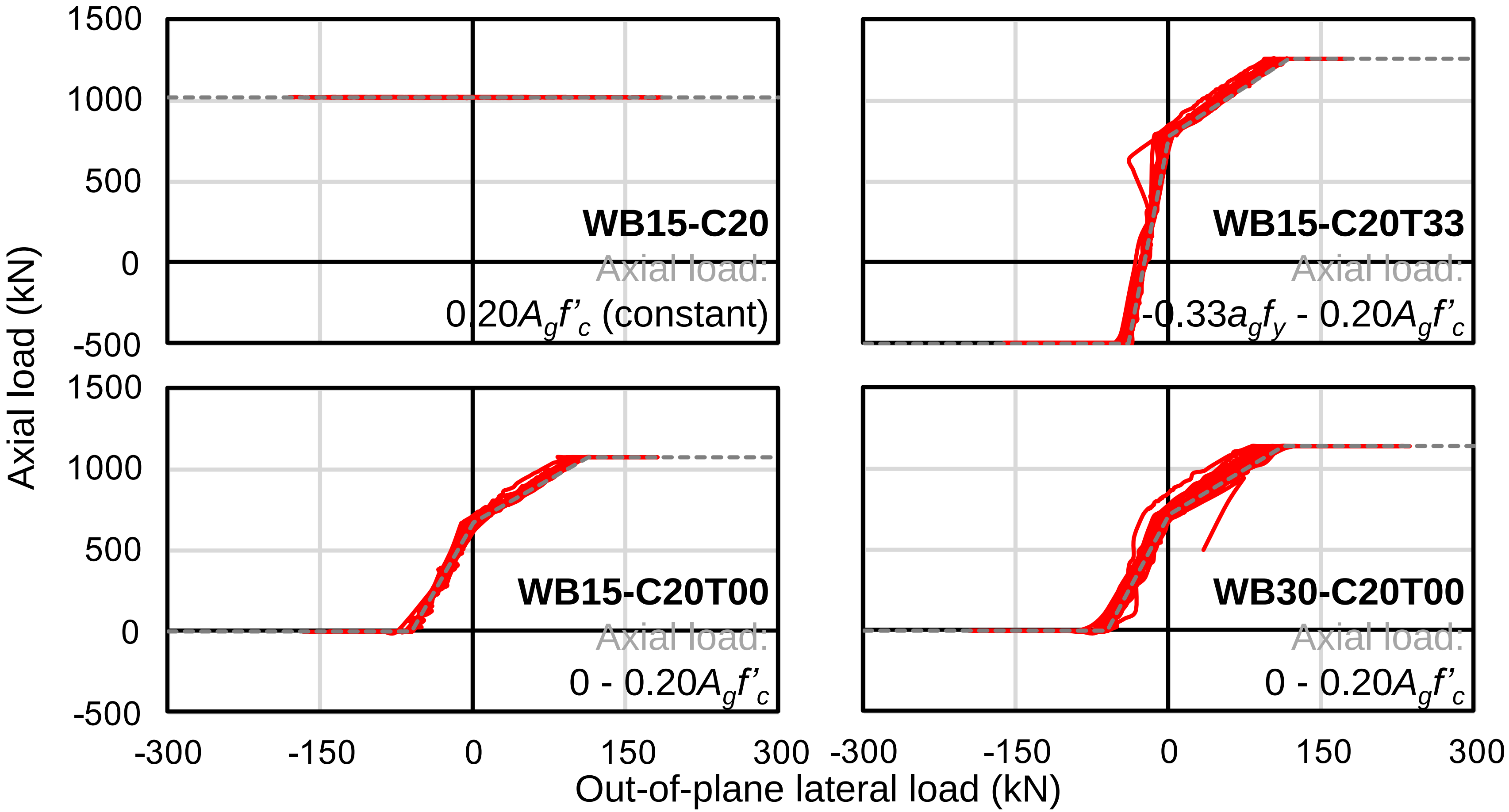


Experimental Results

Loading path

- The loading was carried out as planned generally.

Axial loading path

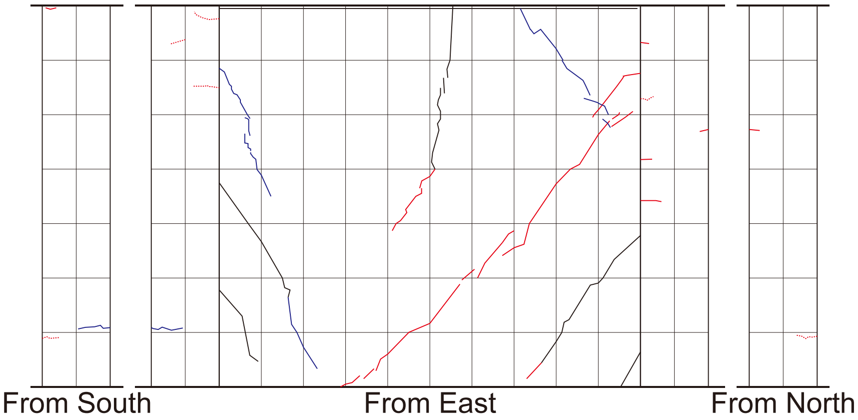


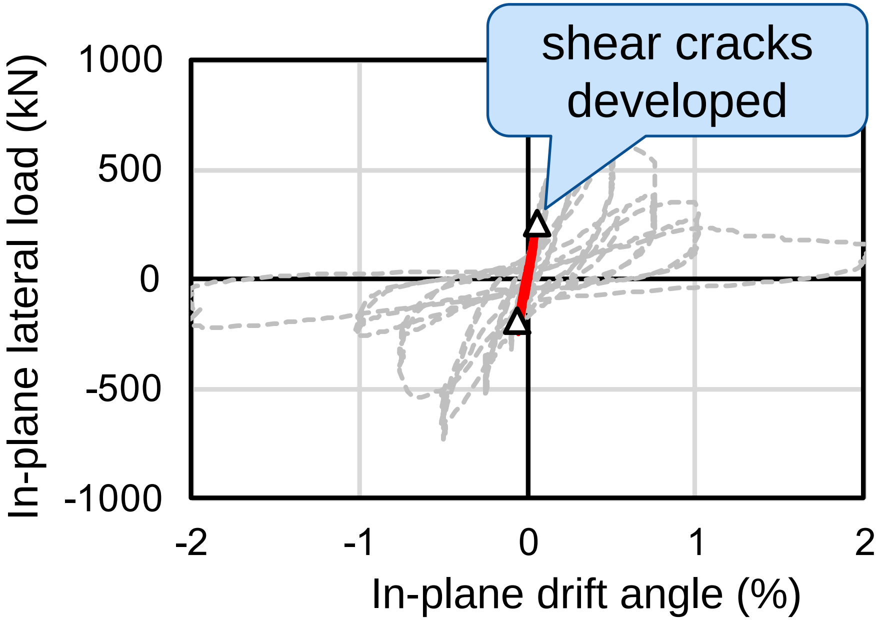
Experimental Results

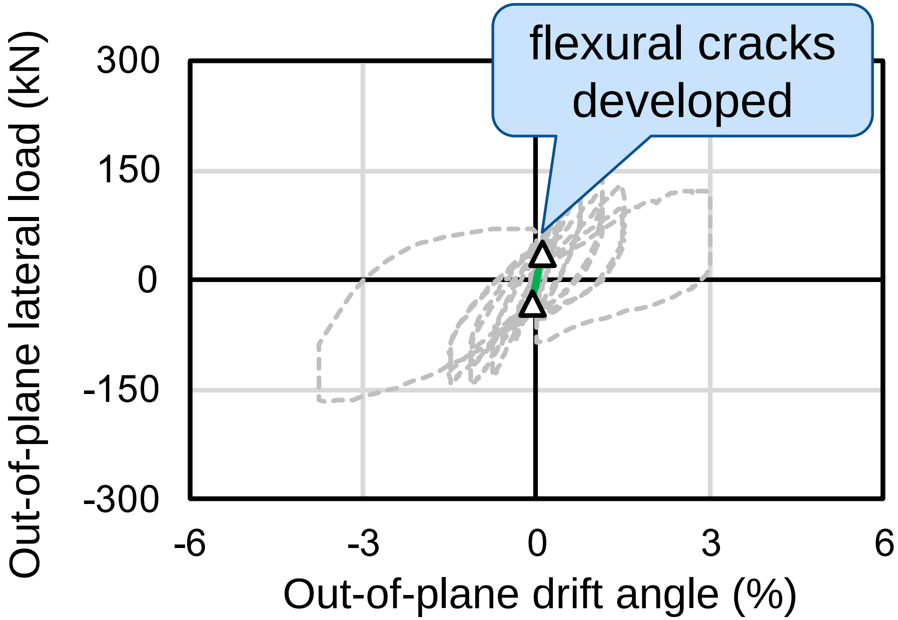
WB15-C20T00 O/I drift ratio: 1.5, Axial load: 0 ~ $0.20A_g f'_c$

until R_x=0.05%

- Shear cracks were observed on the wall panel.
- Flexural cracks were observed on the side columns.





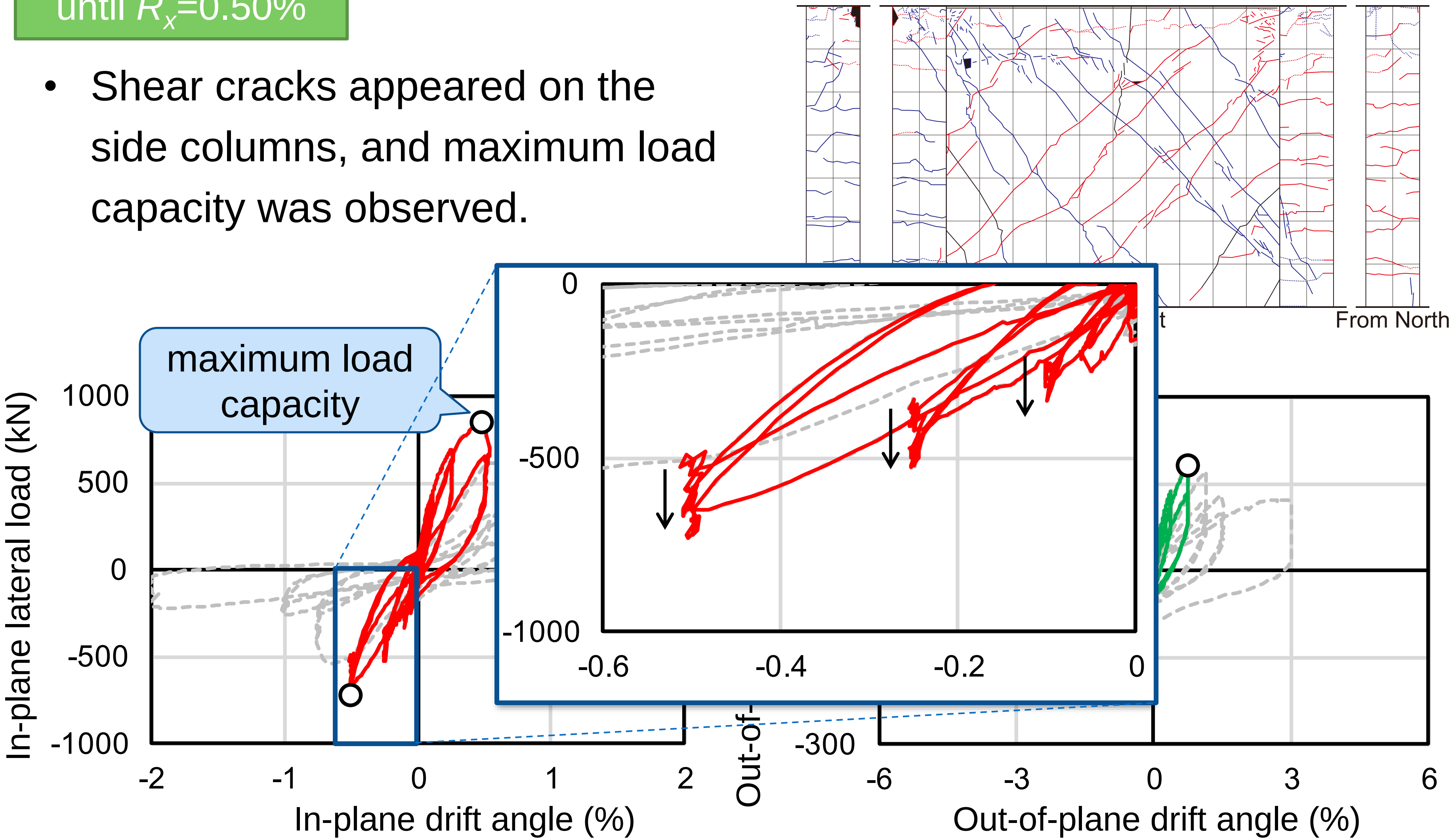


Experimental Results

WB15-C20T00 O/I drift ratio: 1.5, Axial load: 0 ~ $0.20A_gf'_c$

until R_x=0.50%

- Shear cracks appeared on the side columns, and maximum load capacity was observed.

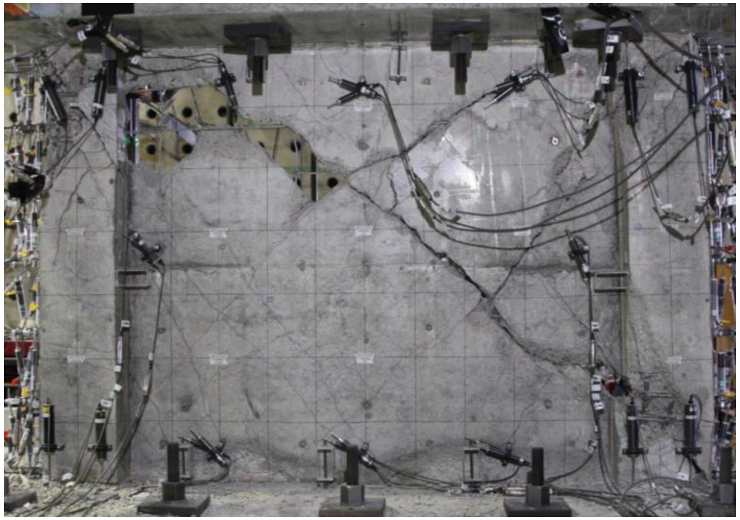


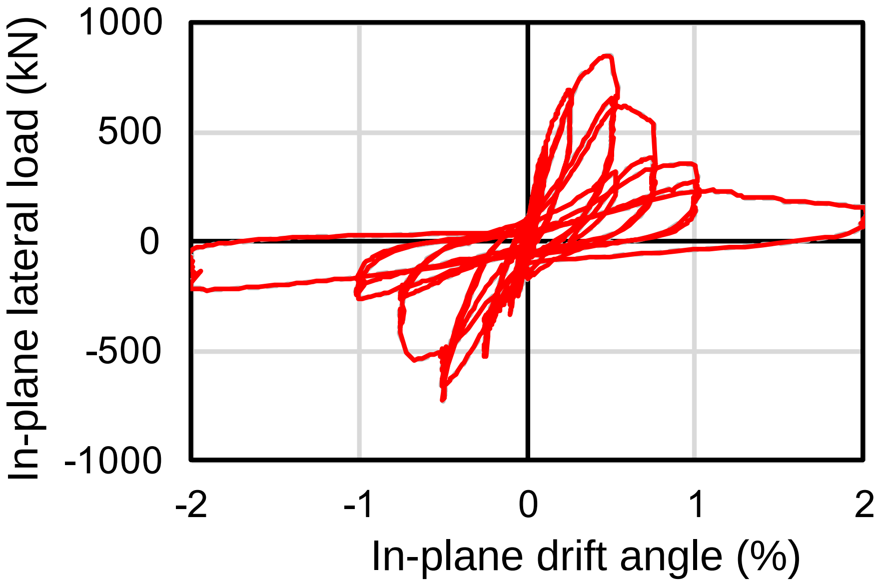
Experimental Results

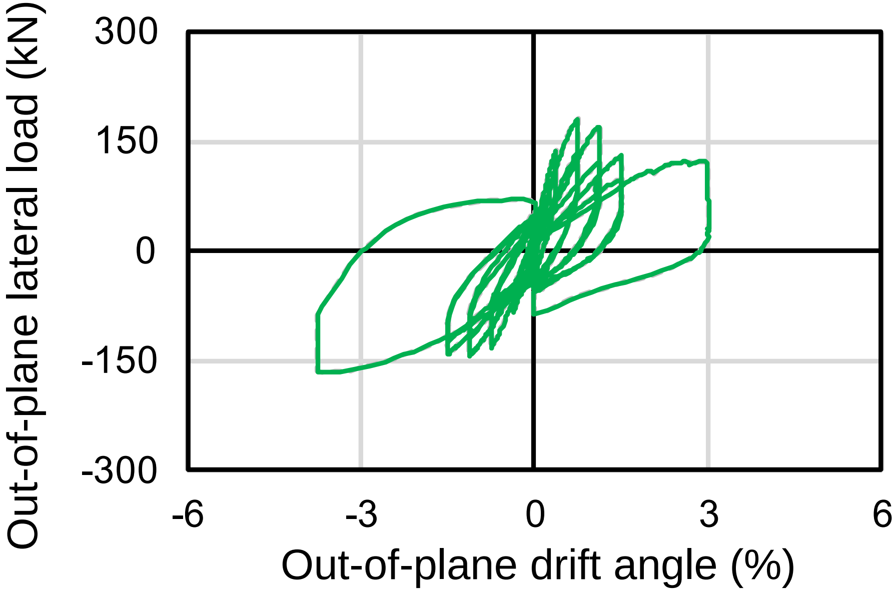
WB15-C20T00 O/I drift ratio: 1.5, Axial load: 0 ~ 0.20$A_g f'_c$

after test

- The concrete of the wall panel spalled, and the lateral load decreased.
- The loading was ceased after the completion of 1st cycle for R_x=2.0%.





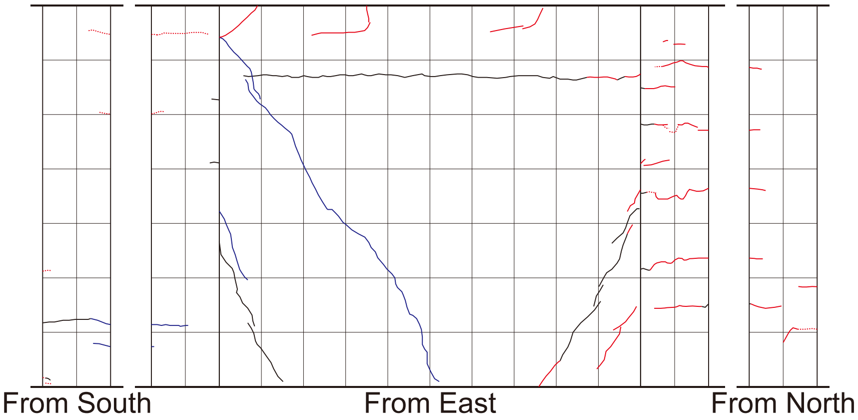


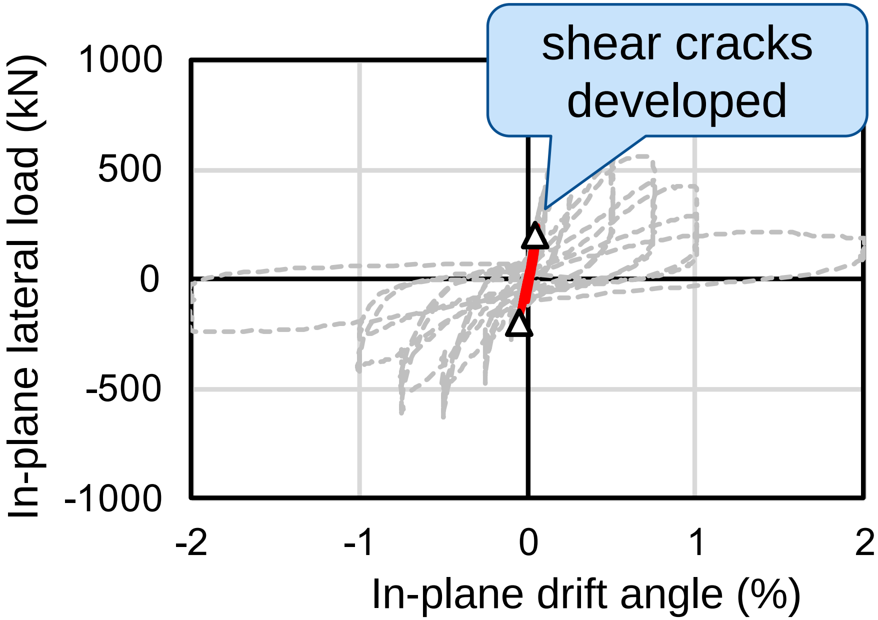
Experimental Results

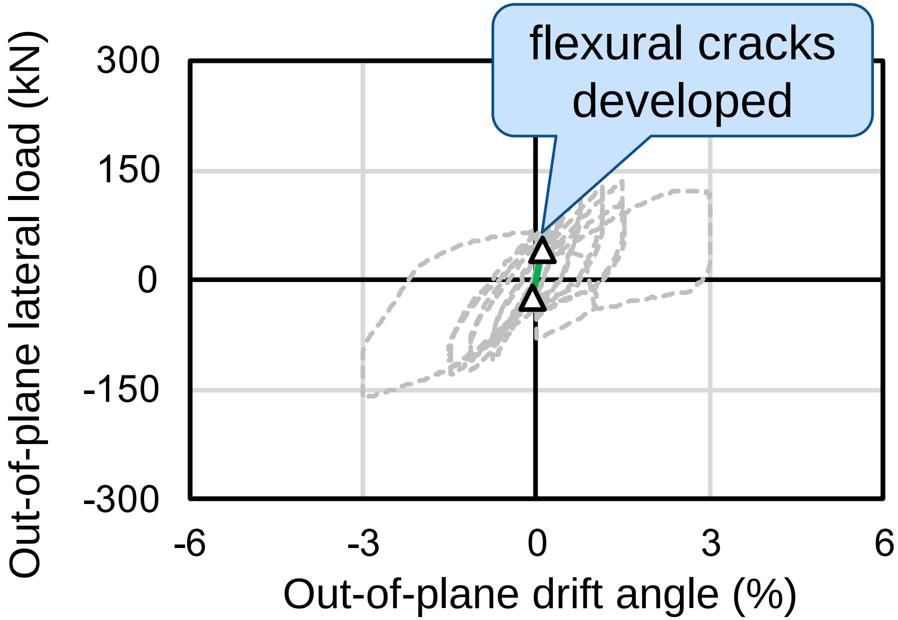
WB15-C20T33 O/I drift ratio: 1.5, Axial load: $-0.33a_g f_y \sim 0.20A_g f'_c$

until R_x=0.05%

- Shear cracks were observed on the wall panel.
- Flexural cracks were observed on the side columns.





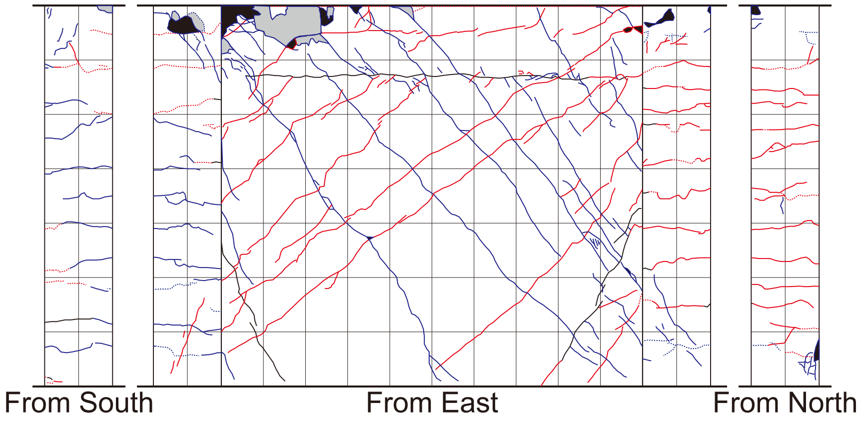


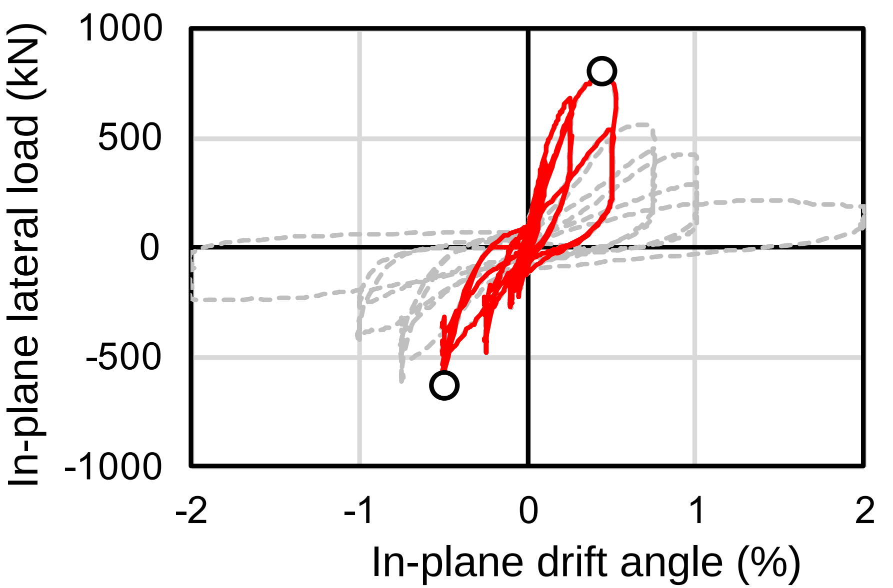
Experimental Results

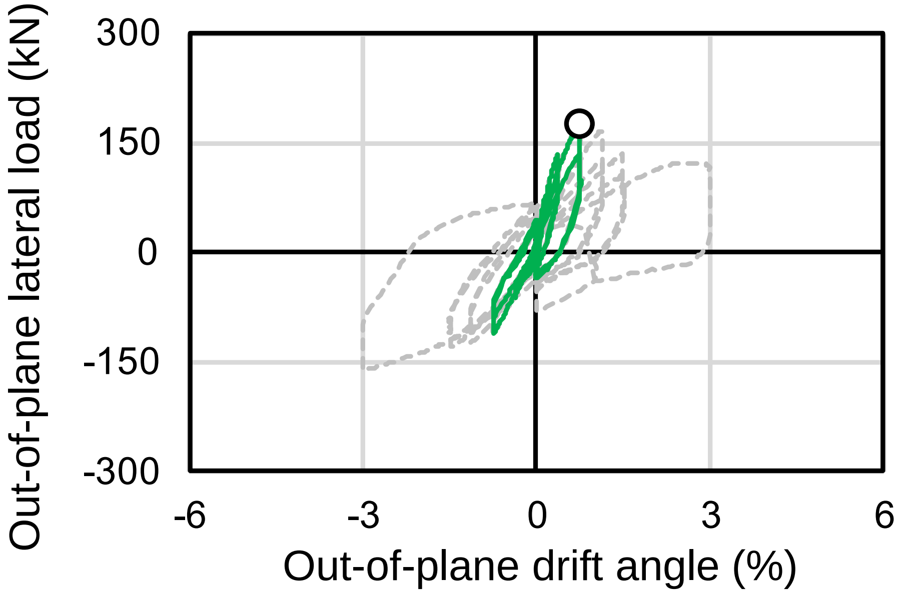
WB15-C20T33 O/I drift ratio: 1.5, Axial load: $-0.33a_g f_y \sim 0.20A_g f'_c$

until R_x=0.50%

- Shear cracks appeared on the side columns, and maximum load capacity was observed.





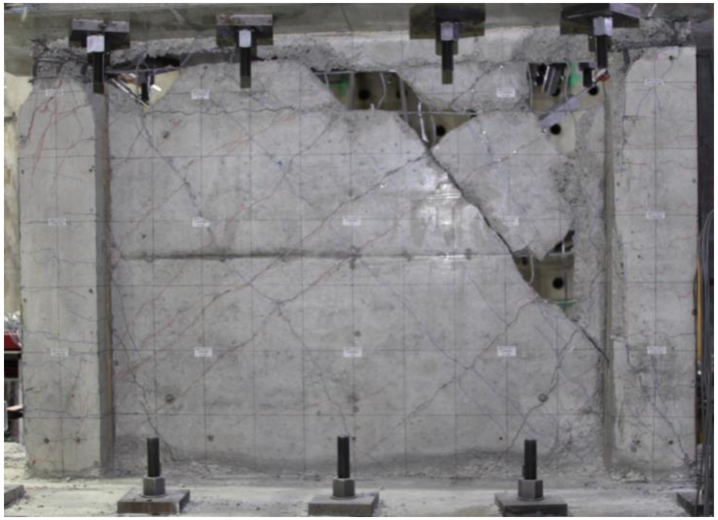


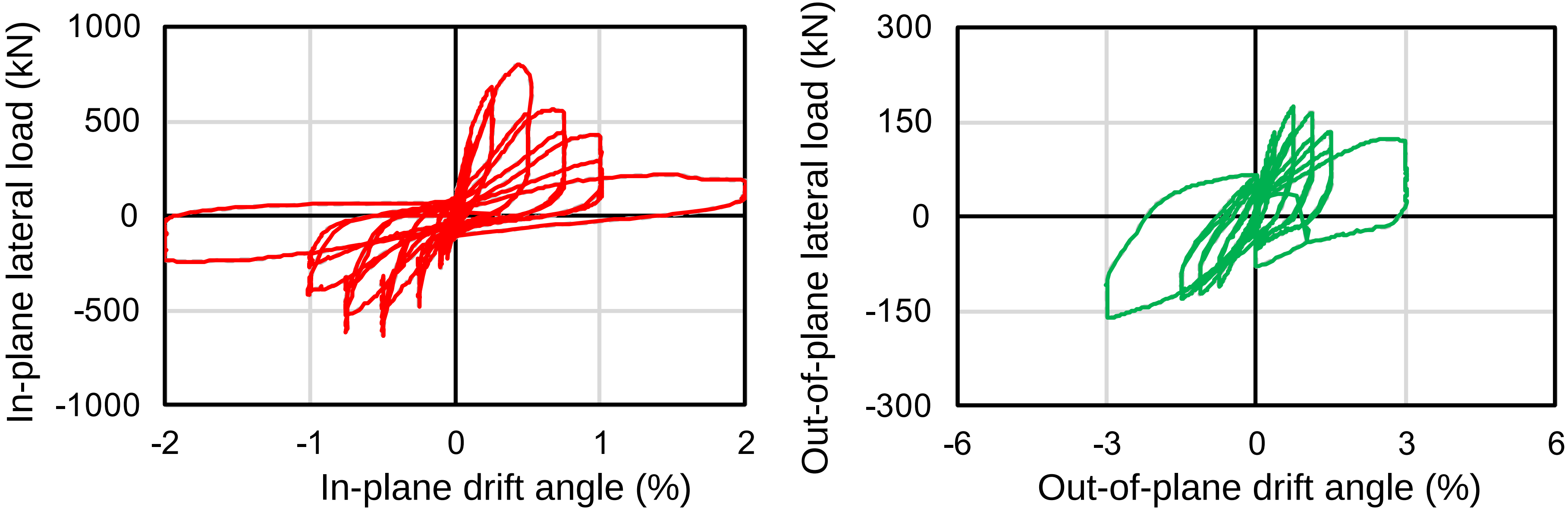
Experimental Results

WB15-C20T33 O/I drift ratio: 1.5, Axial load: $-0.33a_{cg}f_y \sim 0.20A_gf'_c$

after test

- The loading was ceased after completion of 1st cycle for R_x=2.0%.



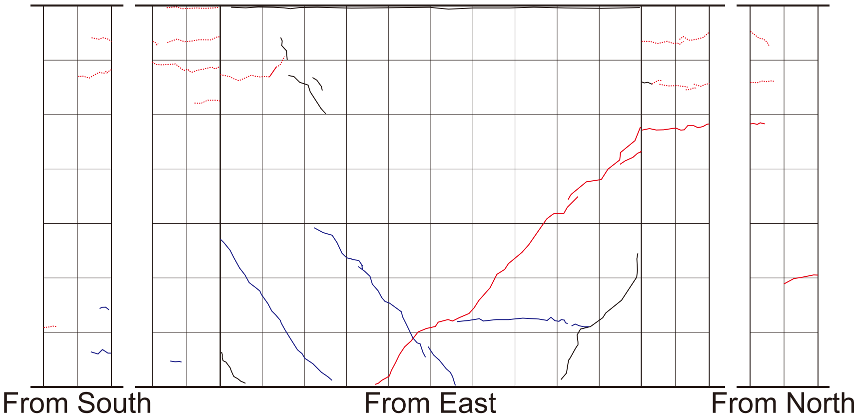


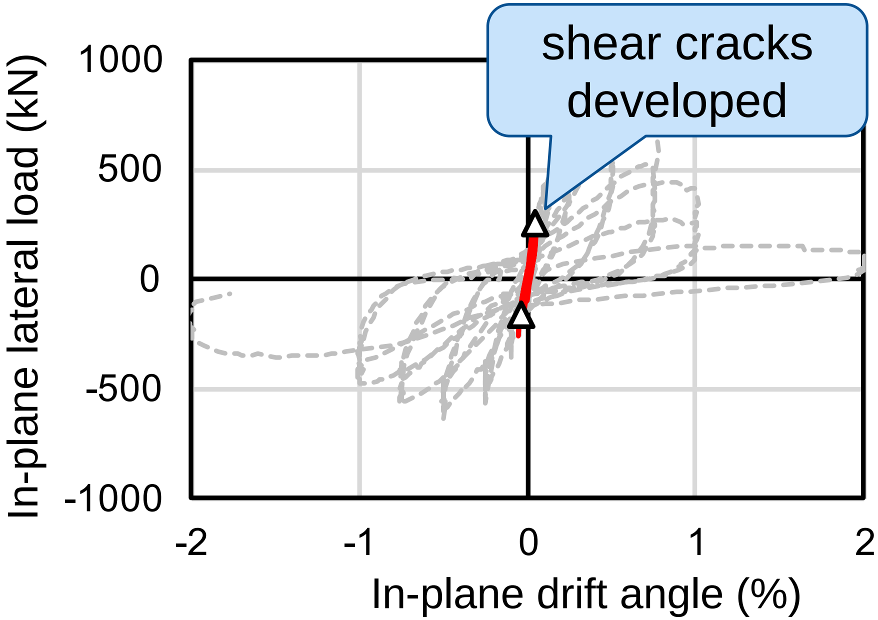
Experimental Results

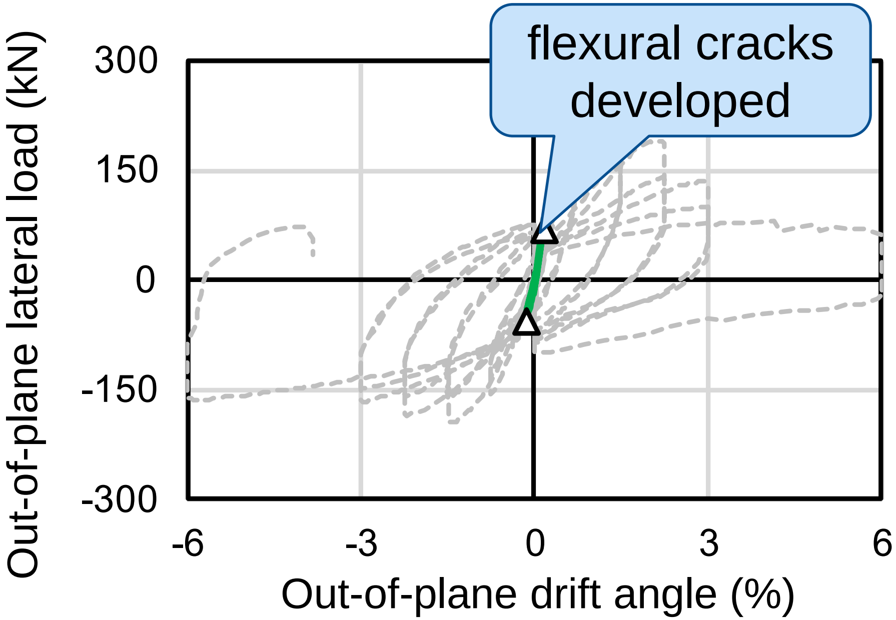
WB30-C20T00 O/I drift ratio: 3.0, Axial load: 0 ~ 0.20$A_g f'_c$

until R_x=0.05%

- Shear cracks were observed on the wall panel.
- Flexural cracks were observed on the side columns.





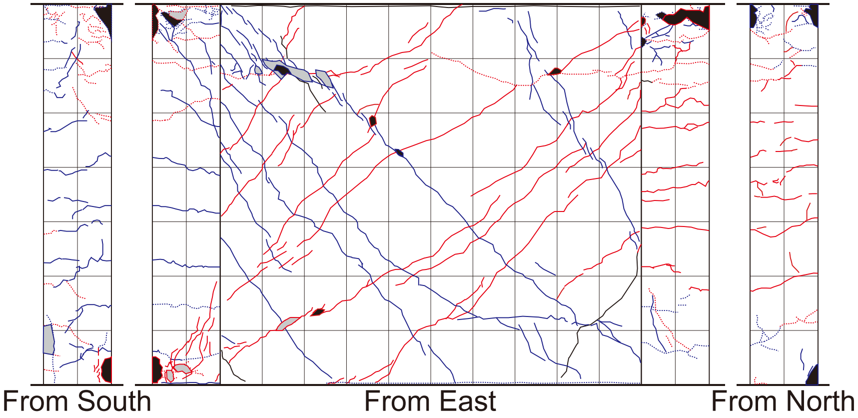


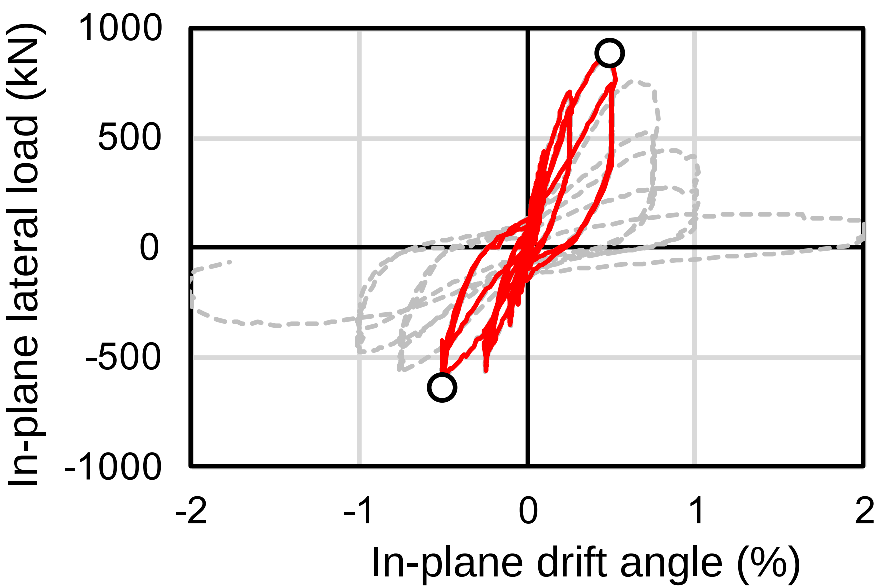
Experimental Results

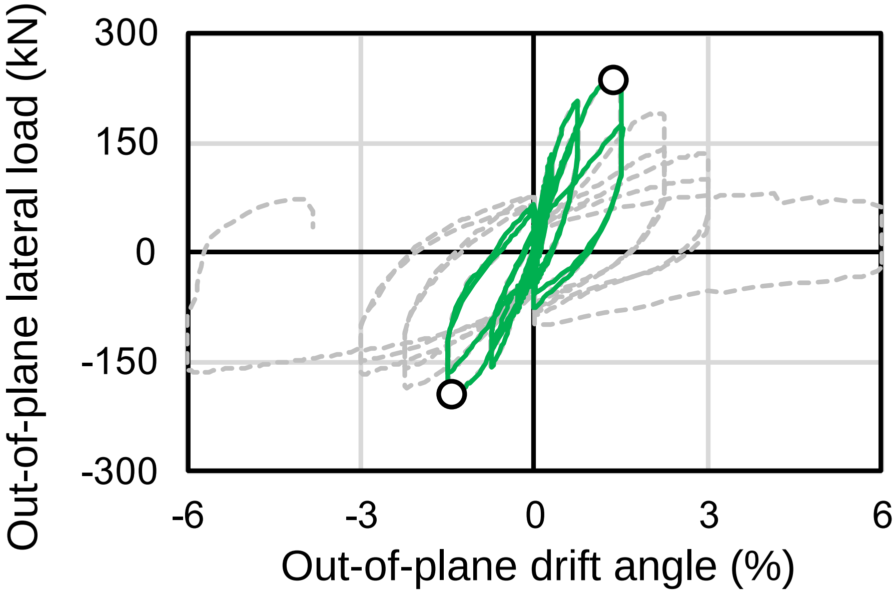
WB30-C20T00 O/I drift ratio: 3.0, Axial load: 0 ~ 0.20$A_g f'_c$

until R_x=0.50%

- Shear cracks appeared on the side columns, and maximum load capacity was observed.





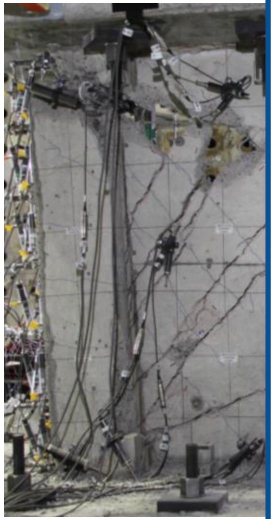


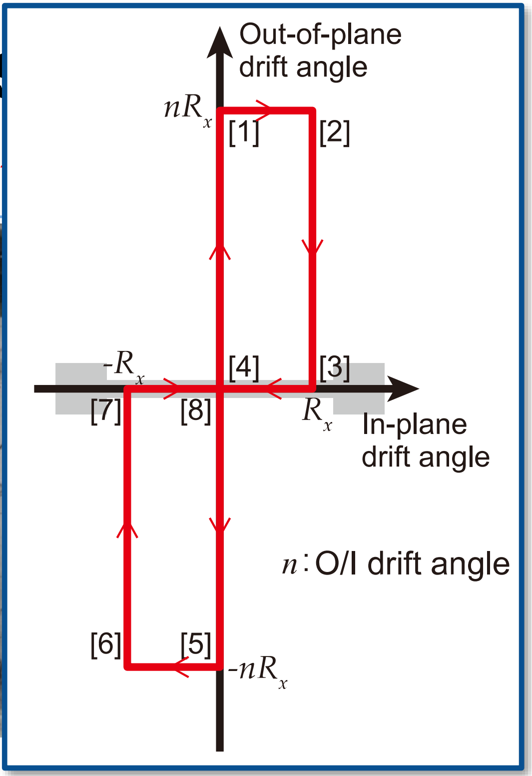
Experimental Results

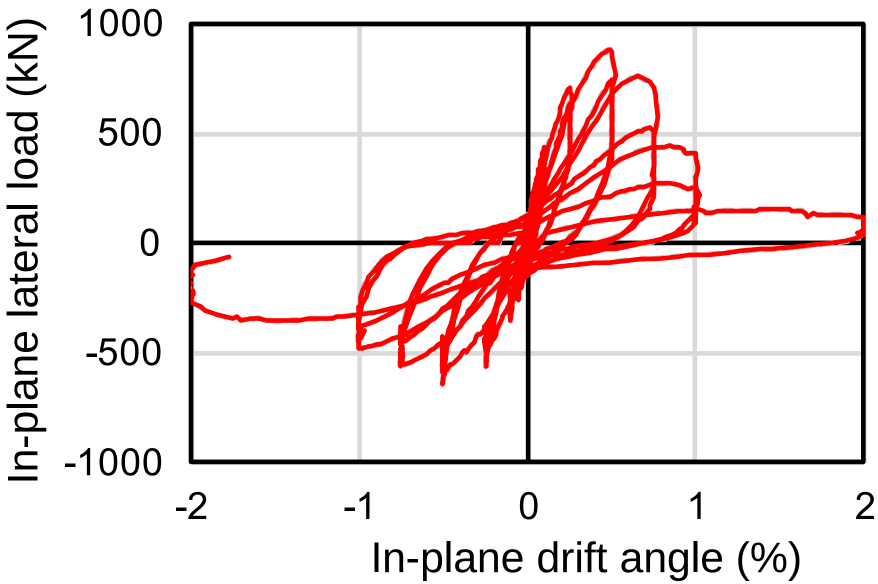
WB30-C20T00 O/I drift ratio: 3.0, Axial load: 0 ~ 0.20$A_g f$

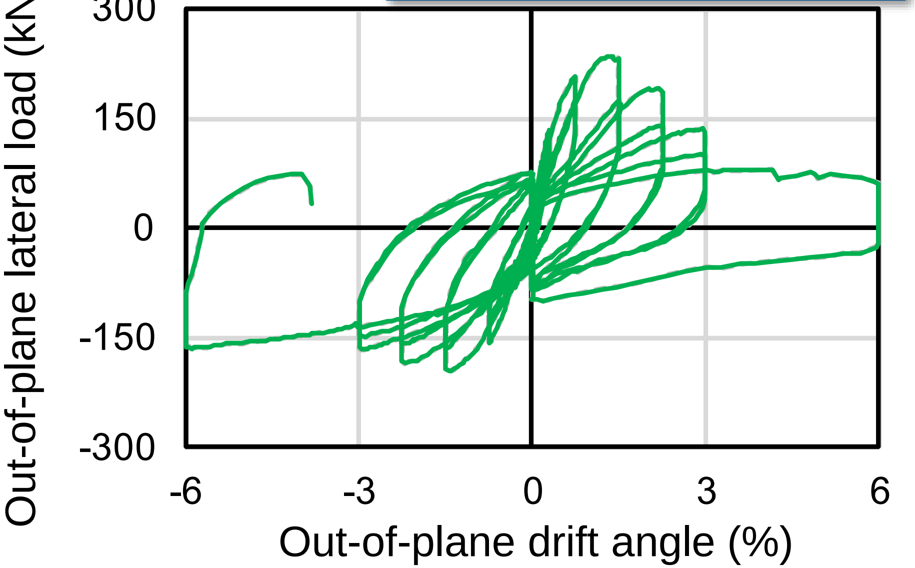
after test

- From the peak point [6] to [7] in the first cycle for R_x=2.0%, the loading was stopped because the specimen was not able to sustain the axial load.









Experimental Results

Envelope curve and maximum load capacity

- The strengths of the concrete of the 4 specimens differed.
  → Standardized value τ_x/f_t was calculated and compared.

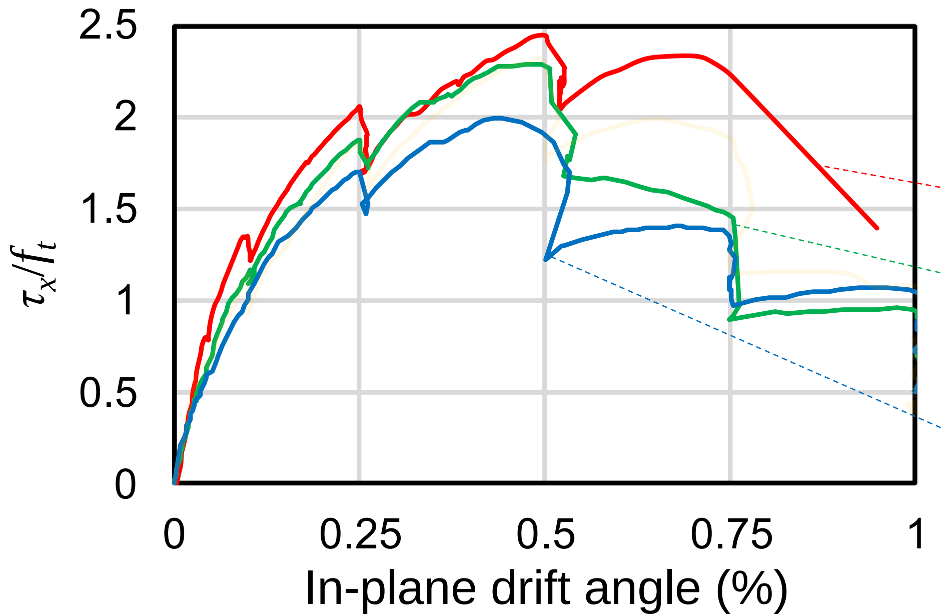
$f_t = 0.33\sqrt{f'_c}$

f'_c : compressive strength of concrete

$\tau_x = Q_x / A_g$

Q_x : in-plane lateral load
A_g : gross area of test region

- The larger difference between the maximum and minimum axial loads was, the more significantly the τ_{max}/f_t decreased.



Axial load	**τ_{max}/f_t (positive)**
$0.20A_gf'_c$ (constant)	2.45
$0 \sim 0.20A_gf'_c$	2.28
$-0.33a_gf_y \sim 0.20A_gf'_c$	2.00

O/I drift ratio: 1.5

Experimental Results

Envelope curve and maximum load capacity

- The strengths of the concrete of the 4 specimens differed.

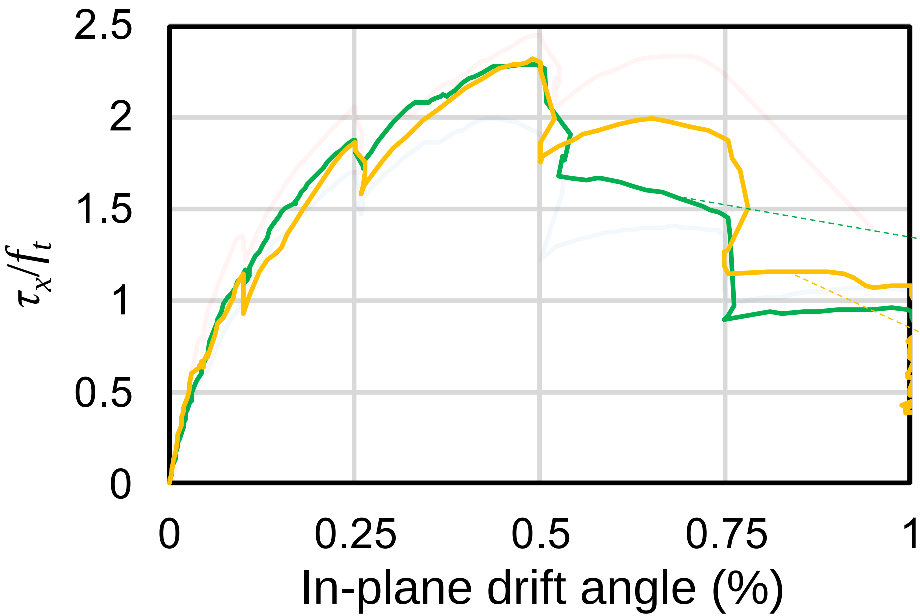
  → Standardized value τ_x/f_t was calculated and compared.

$f_t = 0.33\sqrt{f'_c}$ f'_c: compressive strength of concrete

$\tau_x = Q_x / A_g$ Q_x: in-plane lateral load
A_g: gross area of test region

- The out-of-plane deformation had little influence on τ_{max}/f_t.

- This trend differed from the results obtained by Idosako et al.$^{1)}$.



O/I drift ratio	τ_{max}/f_t (positive)
1.5	2.28
3.0	2.33

Axial load: 0 ~ $0.20A_g f'_c$

1) Idosako et al.: Bi-directional Lateral Loading Tests on RC Shear-dominant Walls, Journal of Structural and Construction Engineering (Transaction of AIJ)

Experimental Results

Shear capacity evaluation

- The in-plane maximum load capacity obtained from the experimental results was compared with the calculated shear capacity.

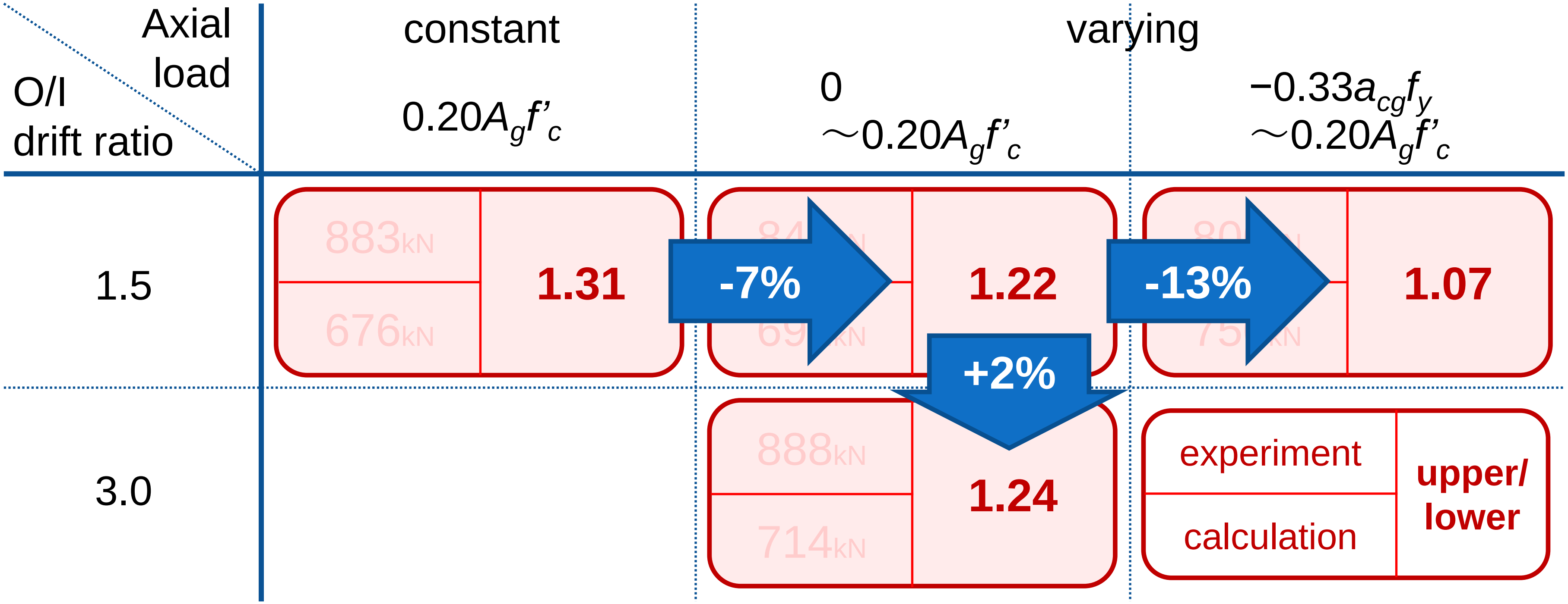
$$Q_{su} = \left\{ \frac{0.068 p_{te}^{0.23}(F_c + 18)}{\sqrt{M/QD + 0.12}} + 0.85\sqrt{\sigma_{wy} p_{wh}} + 0.1\sigma_0 \right\} t_e j$$

Axial load O/I drift ratio	constant	varying	
	$0.20A_g f'_c$	0 $\sim 0.20A_g f'_c$	$-0.33a_{cg}f_y$ $\sim 0.20A_g f'_c$
1.5	883kN 676kN **1.31**	842kN 692kN **1.22**	800kN 750kN **1.07**
3.0		888kN 714kN **1.24**	experiment calculation **exp./ calc.**

Experimental Results

Shear capacity evaluation

- The safety margin decreases as the difference between the maximum and minimum axial loads becomes larger.
- The safety margin was not affected by the out-of-plane deformation.



O/I drift ratio \ Axial load	constant	varying	
	$0.20A_gf'_c$	0 $\sim 0.20A_gf'_c$	$-0.33a_{cg}f_y$ $\sim 0.20A_gf'_c$
1.5	883kN 676kN **1.31**	84 kN 69 kN **1.22**	80 kN 75 kN **1.07**
3.0		888kN 714kN **1.24**	

experiment	**upper/lower**
calculation	

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Contents

Conclusion

- The bigger difference between the maximum axial load and the minimum axial load was, the lower the maximum load capacity the specimen showed.
- Out-of-plane deformation did not affect in-plane maximum load capacity.
- With analytical research, we try to figure out the resistance mechanism of the shear walls under tri-axial loading.

Thank you for your attention.