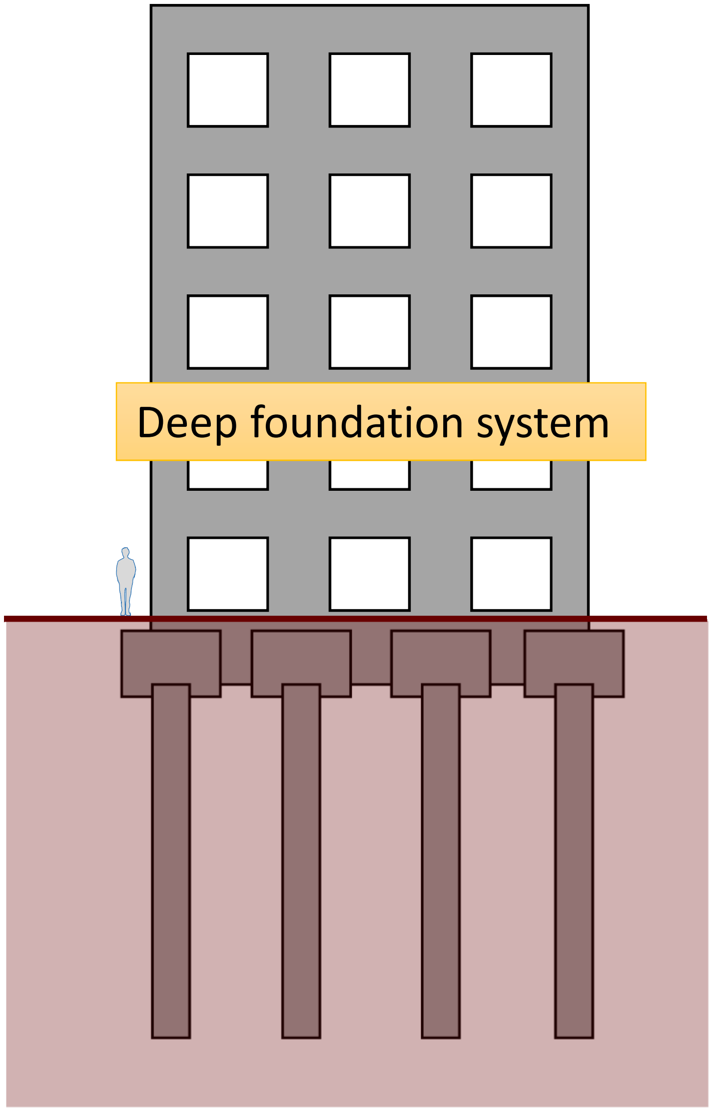
SHEAR CAPACITY FOR FULL-SCALE PRECAST CONCRETE PILE

Hidekazu Watanabe, Tomohisa Mukai, Susumu Kono, Taiga Ohtaki, Shinji Kishida, Osamu Kaneko, Takeshi Fukuda, Yoshinobu Kiya and Yasuyuki Imai

Background

Under Japanese law, the precast concrete pile is designed based on the allowable stress concept. Generally, design flow of structural design for the pile is shown as follows.

1. Elastic frame analysis for superstructure of the buildings is conducted using static earthquake load (base shear factor 0.2).
2. Design loads of a pile (shear load and axial load) are determined by the elastic frame analysis.
3. Geomaterial properties are measured by geotechnical investigation.
4. Elastic analysis for a pile is conducted using the design loads and the geomaterial property.

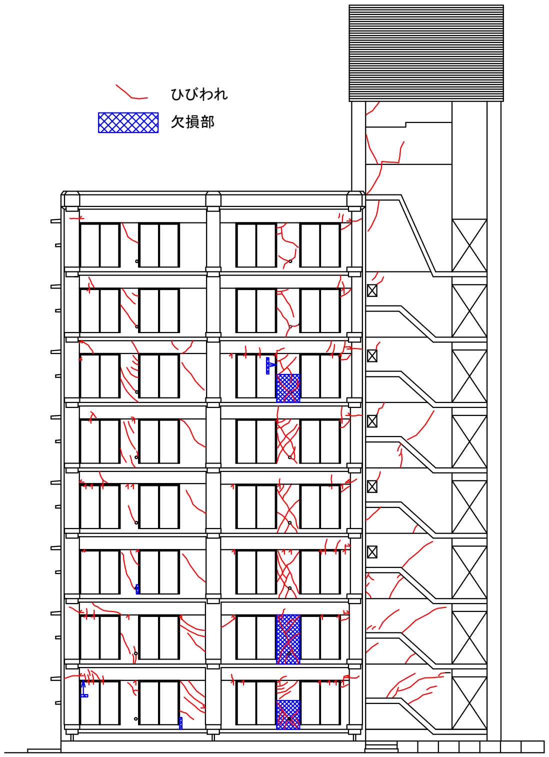


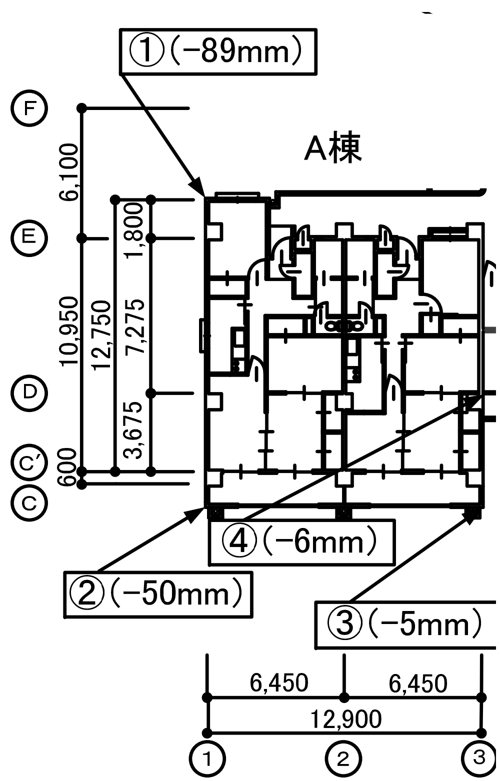
Precast concrete pile

- hollow circle section
- high strength spun concrete casted using centrifugal method (more than 100MPa)
- prestressed concrete (pre-tension)

Background

In the 2011 Tohoku Earthquake, the pre-cast concrete piles in a building were heavily damaged.





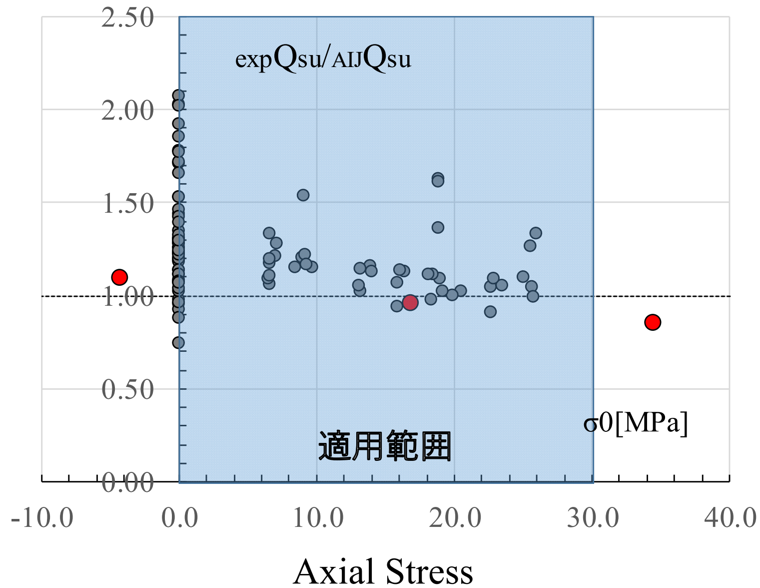
Building tilted due to the pile damage.

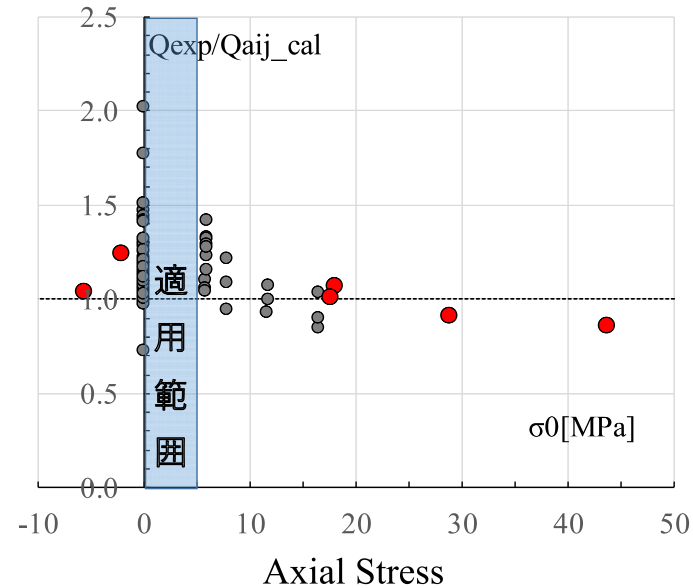
Damage of pre-cast concrete piles

It was difficult that these buildings were used continuously after the earthquake. It is important to evaluate capacity of precast concrete pile for considering about post-earthquake functional use.

Objectives

Existing evaluation formulae[1)] for shear capacity for precast concrete pile do not cover under high compressive axial force or tensile axial force

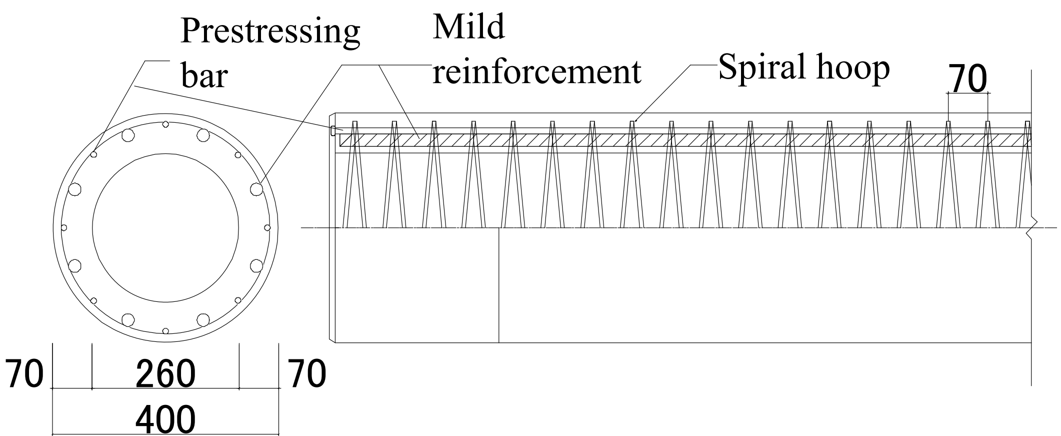




In order to evaluate the shear capacity of precast concrete pile, static loading test was conducted using 9 precast concrete pile specimens.

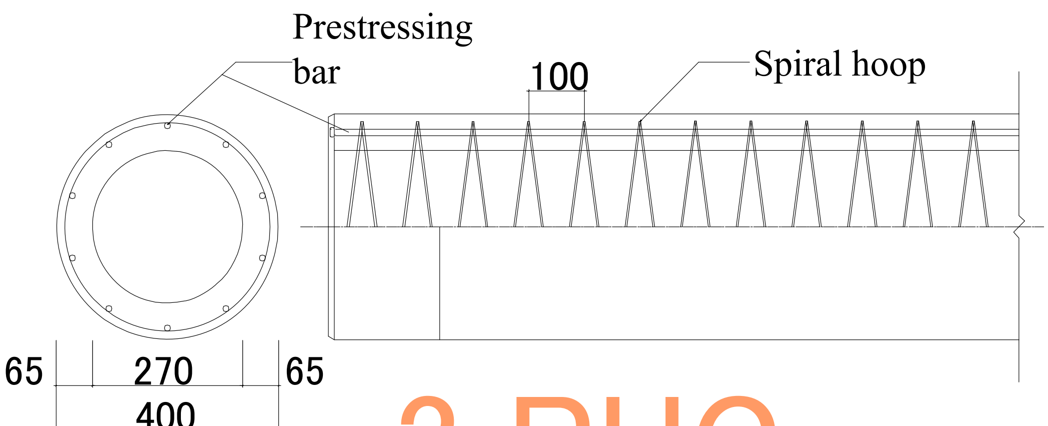
1) Architectural Institute of Japan : Guidelines for Seismic design of reinforced concrete foundation members (draft), 2017

Specimen details



Axial force	high compressive compressive tensile
Shear span ratio	1.4 2.1

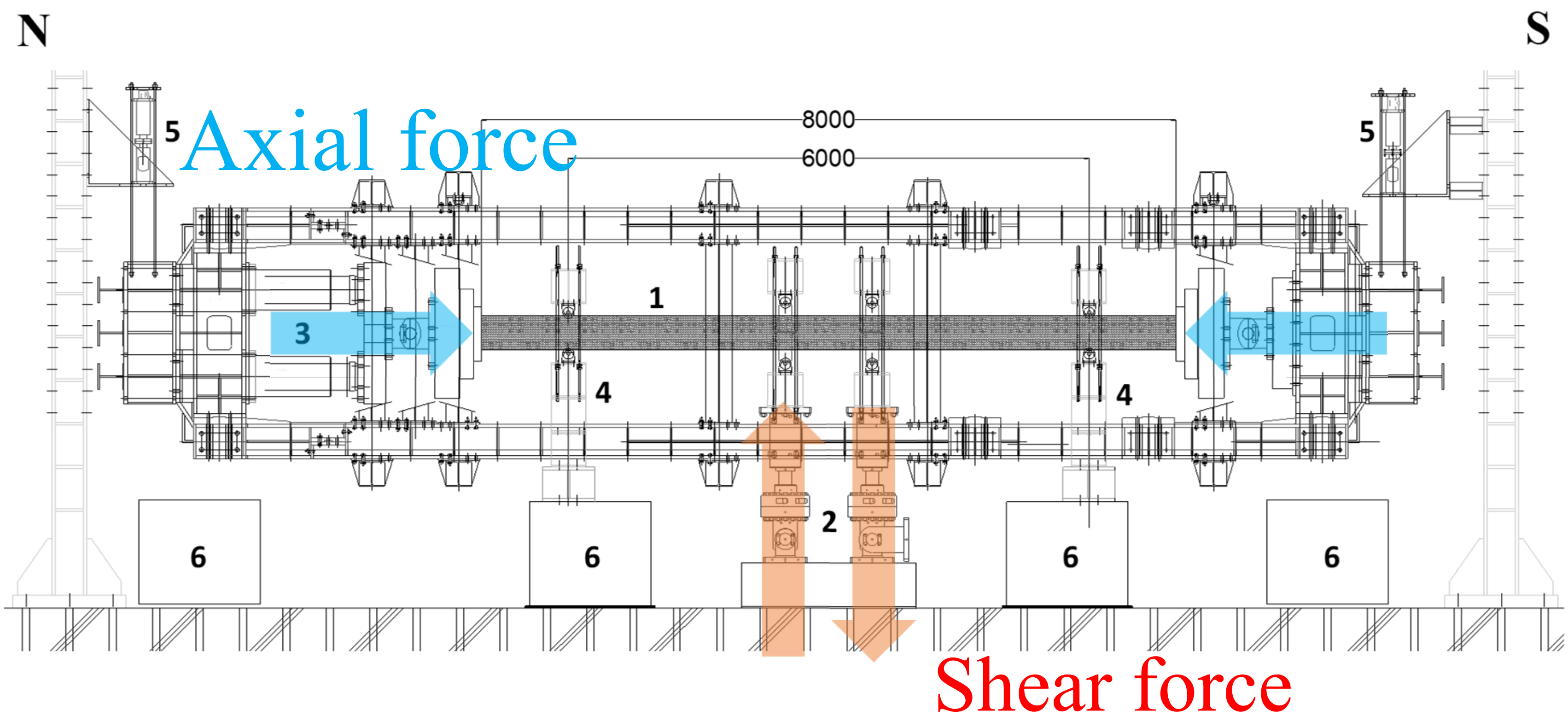
6 PRC Specimens



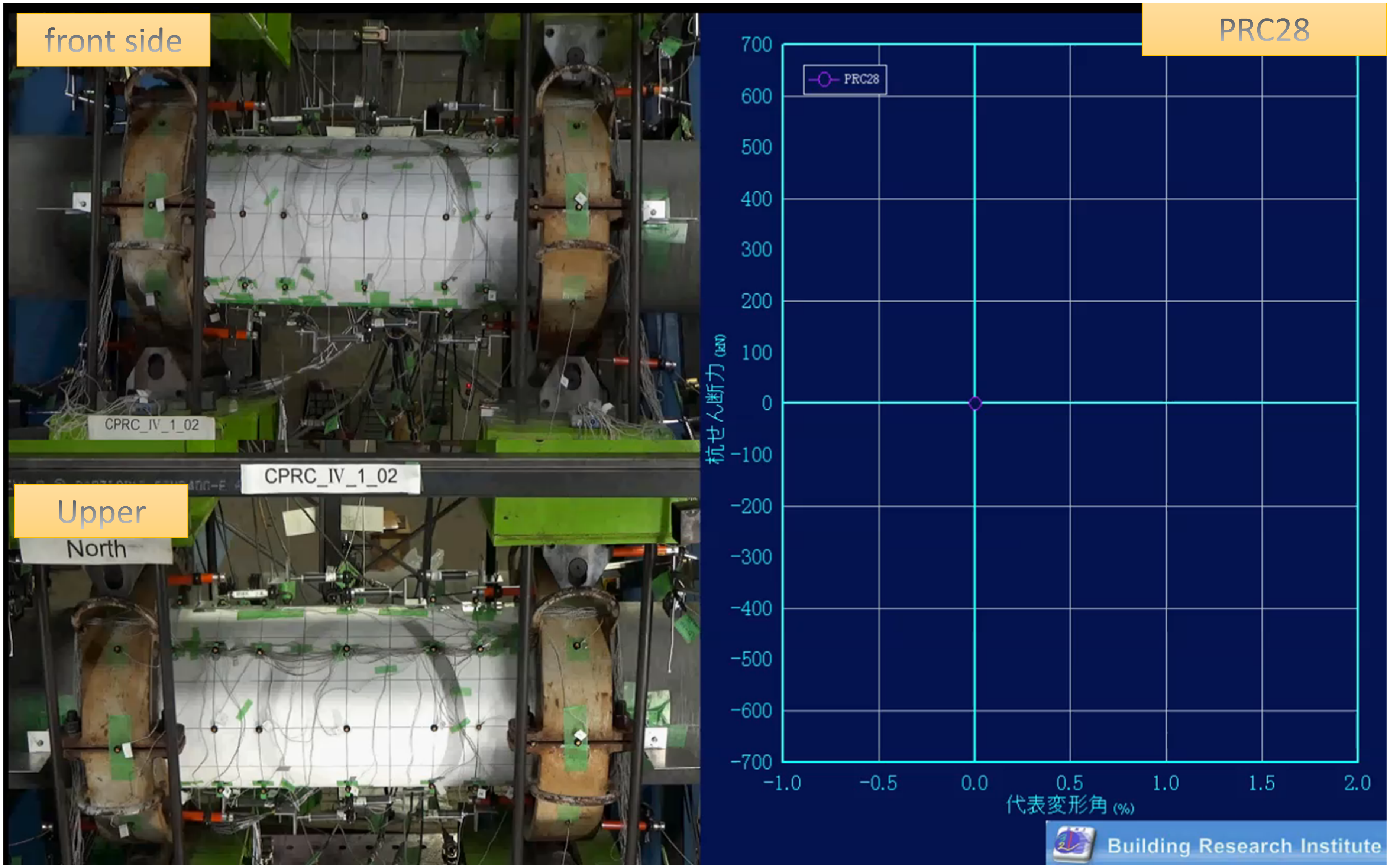
Axial force	high compressive compressive tensile

3 PHC Specimens

Test setup

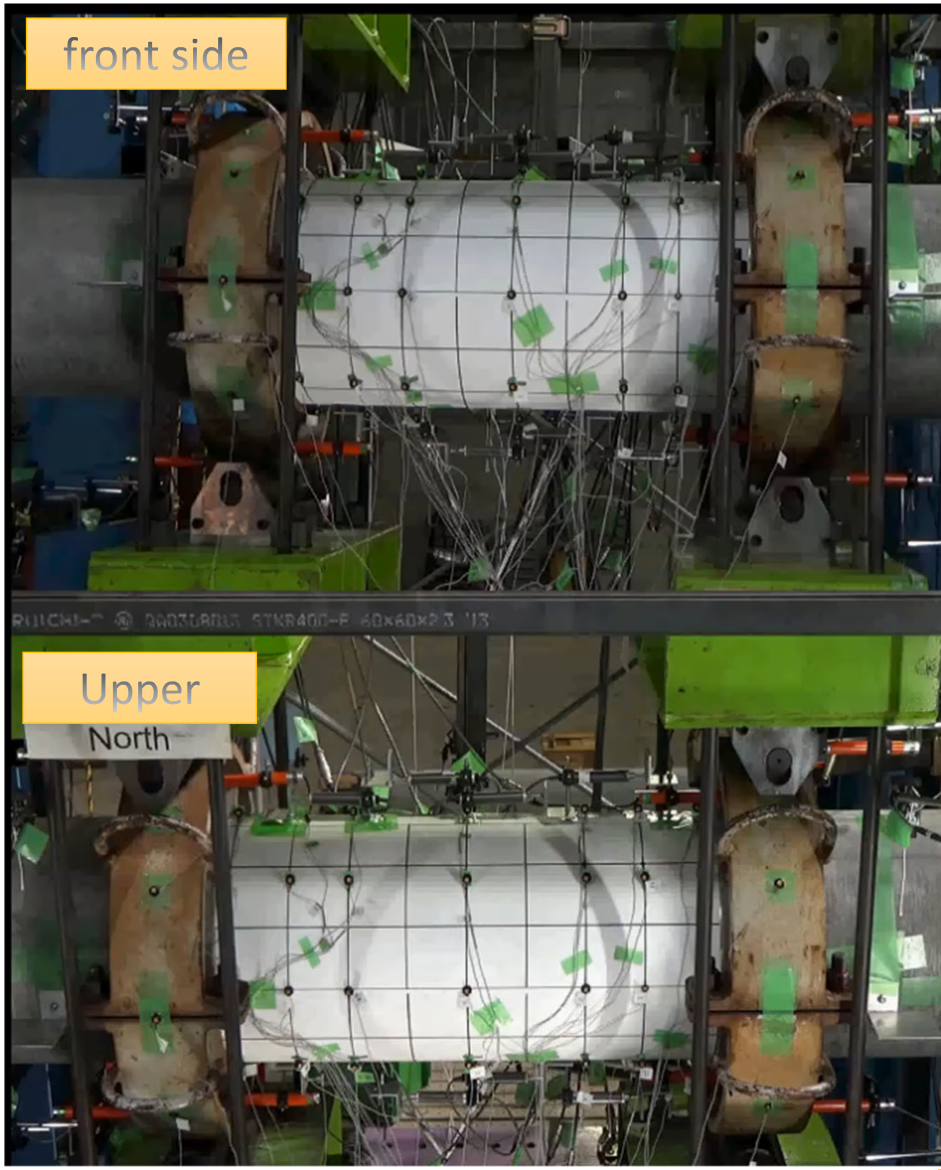


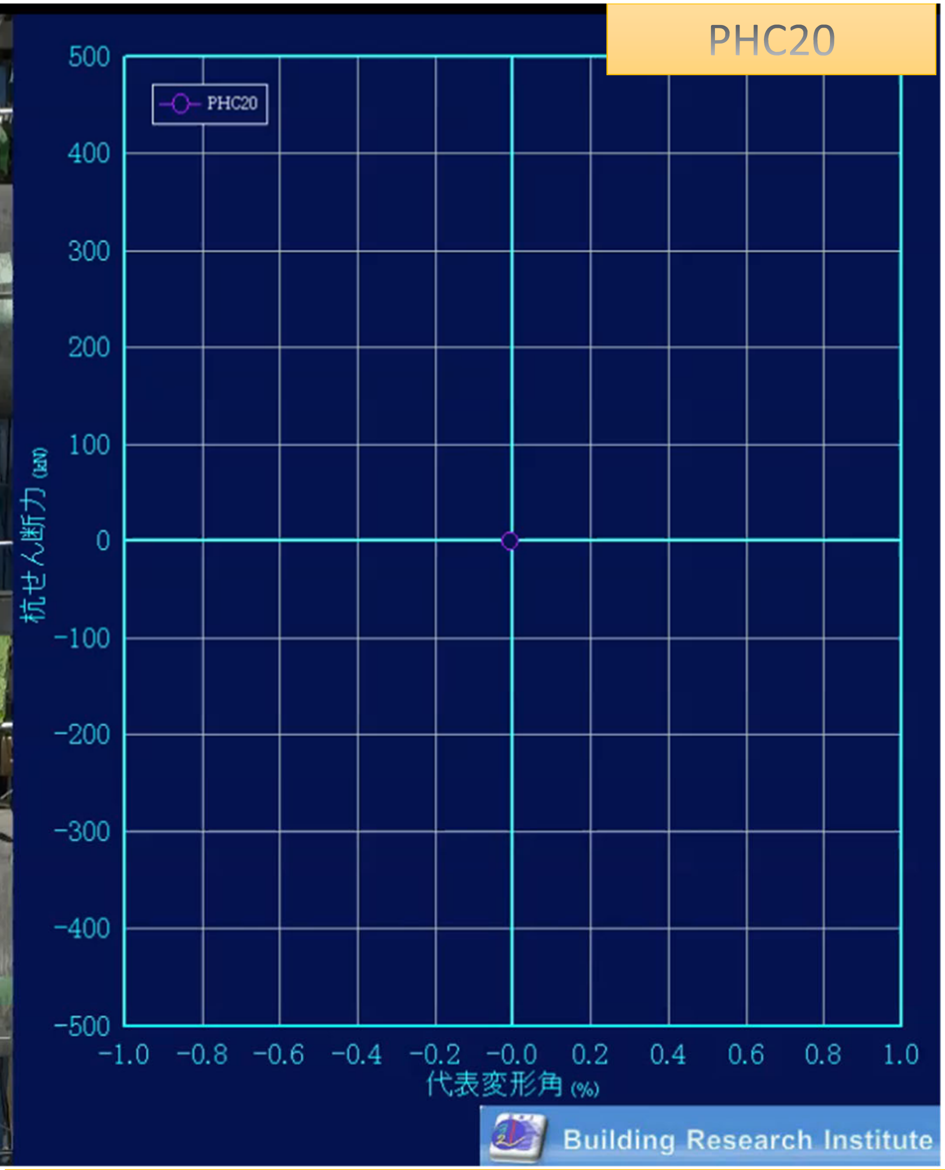
▪Axial load of specimens was applied by four horizontal hydraulic jacks.
▪Shear force of specimens was applied by two vertical hydraulic jacks at the center.
▪The loading is displacement -controlled



Diameter：400mm, thickness：83.4mm,
Axial force ratio：0.17, Shear span ratio：1.4,
Mild rebar：8-D22, PS-bar：8-φ10, f'c：132MPa

0.50% cycle ： shear cracks were observed
0.75% cycle ：reached the maximum shear force
During loading test, PRC28 kept constant axial force.





Diameter : 400mm, thickness : 75.5mm,
Axial force ratio : 0.32, Shear span ratio : 1.4,
PS-bar : 10-φ11.2, f'c : 114MPa

0.50% cycle : axial cracks were observed
0.75% cycle : the specimen was crashed and unable to keep axial force

Summary of Test Results

			PHC18	PHC19	PHC20	PRC24	PRC25	PRC26	PRC27	PRC28	PRC29
Axial stress σ_0		[MPa]	-4.3	16.8	34.5	-2.1	18	28.8	-5.6	17.5	43.7
Failure mode			S	A	A	YS	S	A	YS	S	A
shear capacity	Q_{exp}	[kN]	247.6	420.6	467.5	433.1	525.5	508.7	464.1	627	671
	Q_{cal}	[kN]	228	442	551	349	490	557	445	620	784
	Q_{exp}/Q_{cal}		1.09	0.95	0.85	1.24	1.07	0.91	1.04	1.01	0.86

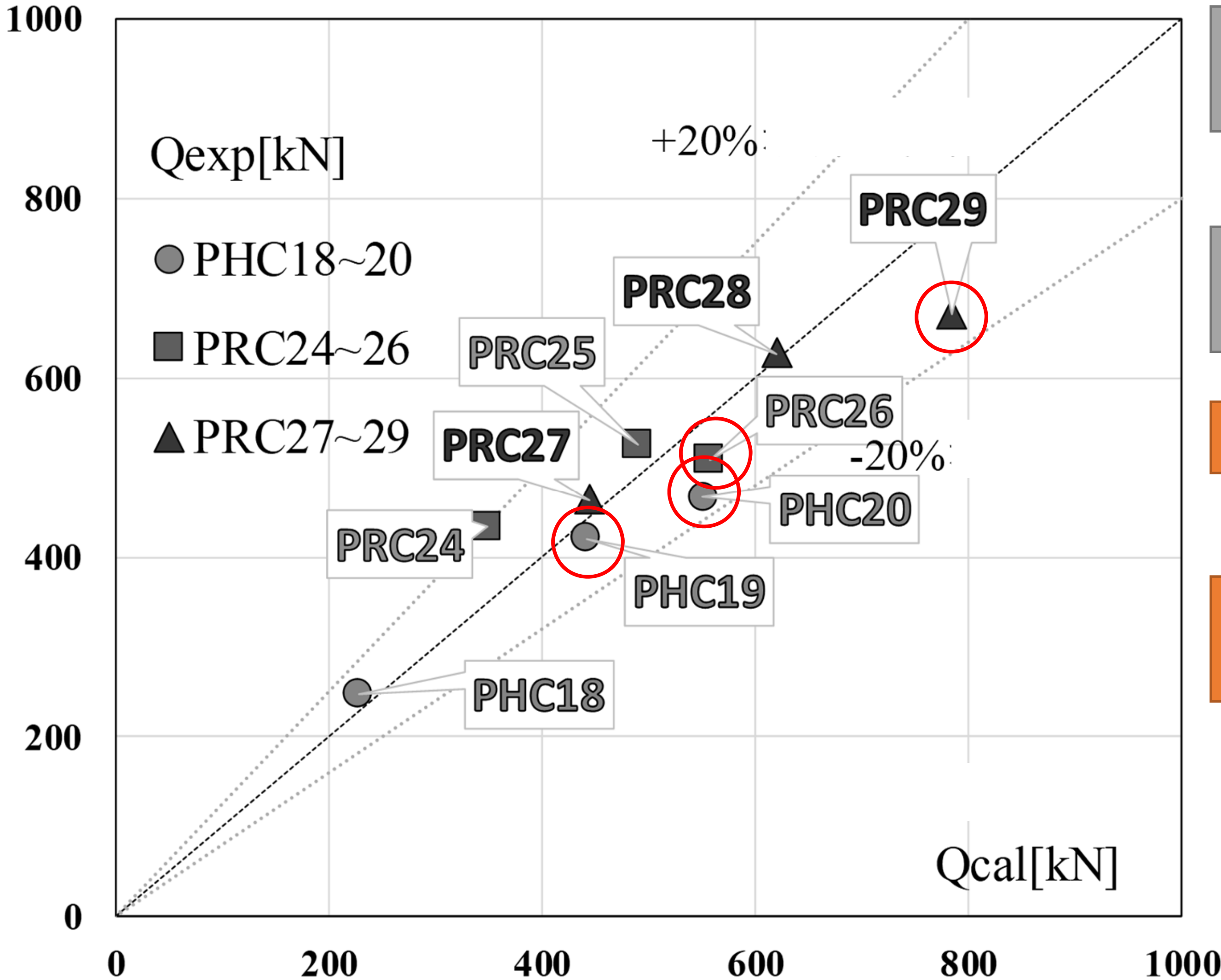
Failure mode classification

- S : Shear failure
- YS : Shear failure after yielding
- A: Failure with axial crack

Evaluation of shear capacity

Evaluation formulae for shear capacity for precast concrete pile was shown in AIJ guidelines.

Comparison of test results and calculation



Shear failure
Shear failure after yielding

the existing formulae underestimated test results

failure with axial crack

the existing formulae overestimated test results

Conclusions

- Failure mode of specimens under tensile axial force are shear failure. During loading test, specimens under tensile axial force kept constant axial force.
- The failure with axial cracks was observed in the case of specimens under compressive axial force.
- In the case of shear failure and shear failure after yielding, the existing formulae underestimated the shear capacity of test results. However, In the case of failure with axial crack, the existing formulae overestimated the shear capacity of test results. The existing formulae was developed for shear failure; thus, it is difficult to evaluate capacity for different failure mode.

Thank you for your attention

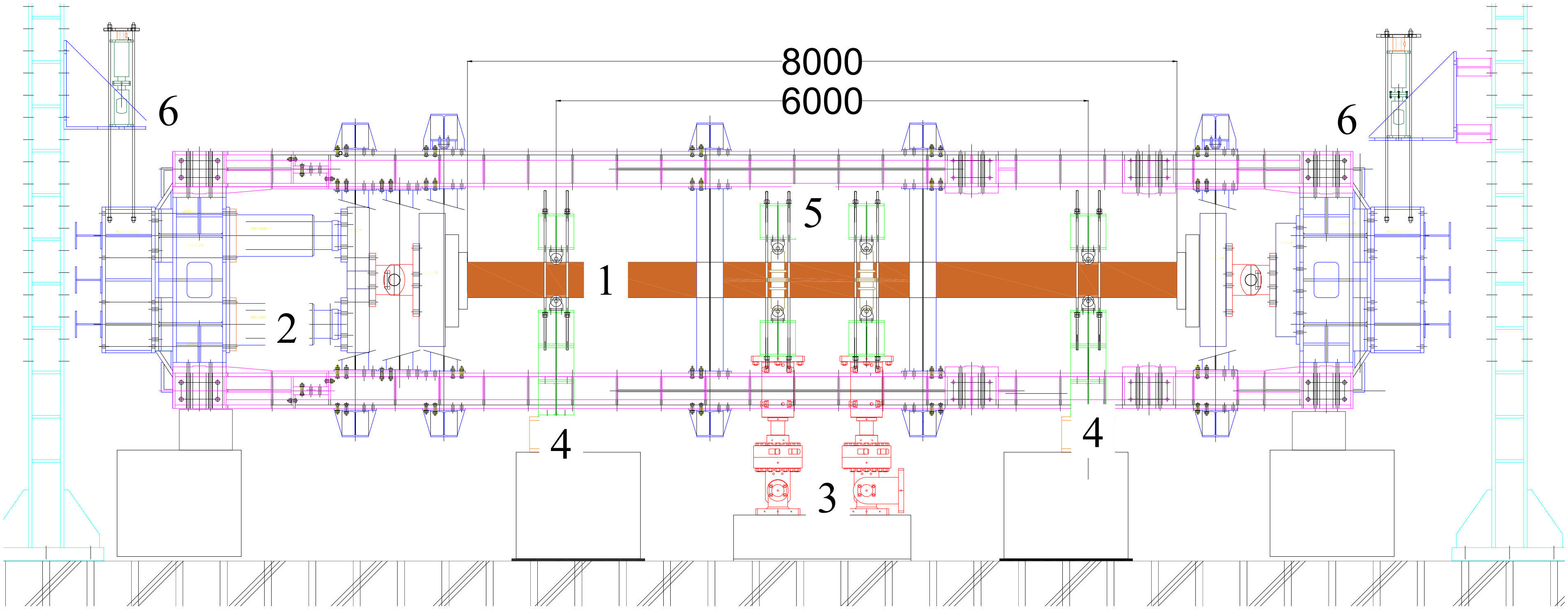
Table 1. Specifications of the specimens

Concrete		PHC18	PHC19	PHC20	PRC24	PRC25	PRC26	PRC27	PRC28	PRC29
Pile type		PHC pile			PRC pile					
Diameter D	[mm]	400								
Specified thickness	[mm]	65			70					
Actual thickness t	[mm]	76.1	77.3	75.5	81.2	80.7	83.4	80.6	83.4	83.7
Prestressing bar		10-Φ11.2			8-Φ10					
Longitudinal mild reinforcement		-			8-D22					
Spiral hoop		Φ3.2@100			Φ6.5@70					
Shear span ratio		1.4			2.1			1.4		
Specified effective prestressing stress	[MPa]	10			5.3					
Actual effective prestressing force N_e	[kN]	789	794	786	512	515	518	520	516	518
Actual effective prestressing stress σ_e *1	[MPa]	10.3	10.3	10.3	6.6	6.7	6.5	6.7	6.5	6.5
Axial Force N	[kN]	-344	1368	2752	-196	1655	2731	-510	1655	4137
Axial stress σ_0 *2	[MPa]	-4.3	16.8	34.5	-2.1	18	28.8	-5.6	17.5	43.7
Axial Force ratio $(N+N_e)/N_0$ *3		0.04	0.19	0.32	0.03	0.18	0.27	0.00	0.17	0.36

Table 2. Material properties

Steel		Yield stress [MPa]	Tensile strength [MPa]	Young's modulus [GPa]
Prestressing bar	Φ10	1360	1431	199
	Φ11.2	1323	1439	198
Spiral hoop	Φ3.2	631	695	148
	Φ6.5	597	649	186
Longitudinal mild reinforcement	D22	387	563	190

Concrete		PHC18	PHC19	PHC20	PRC24	PRC25	PRC26	PRC27	PRC28	PRC29
Compressive strength f'c	[MPa]	116	117	114	119	127	121	124	132	129
strain at f'c	[μ]	2323	2403	2304	2398	2519	2564	2411	2688	2658
Splitting tensile strength	[MPa]	5.1	5.2	5.5	6.5	8.5	8.6	8.6	7.8	8.0
Young's modulus	[GPa]	49.1	48.7	50.4	49.6	50.4	47.2	51.4	49.1	48.5

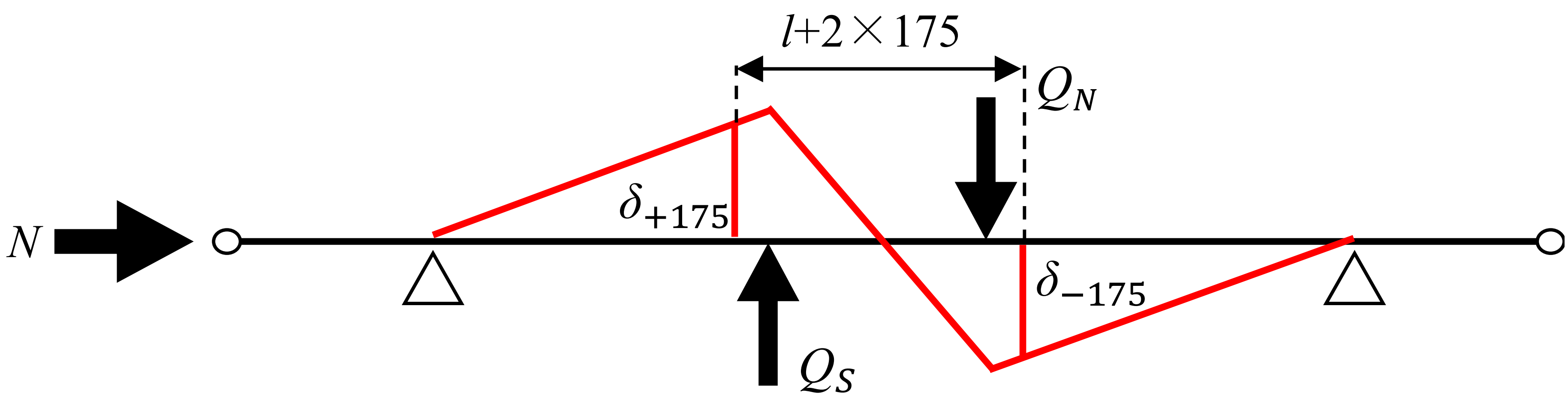


1: specimen
2: horizontal hydraulic jacks
3: vertical hydraulic jacks
4: support point
5: loading point
6: hanging hydraulic jack

The loading is displacement -controlled with control drift angle R. The control drift angle *R* is calculated as Equation (1).

$$R = (\delta_{+175} - \delta_{-175})/(l + 175 \times 2) \qquad (1)$$

where, $\delta_{+175}, \delta_{-175}$: displacement measured by displacement gauge placed 175mm outside of the test area as shown in Figure 3.

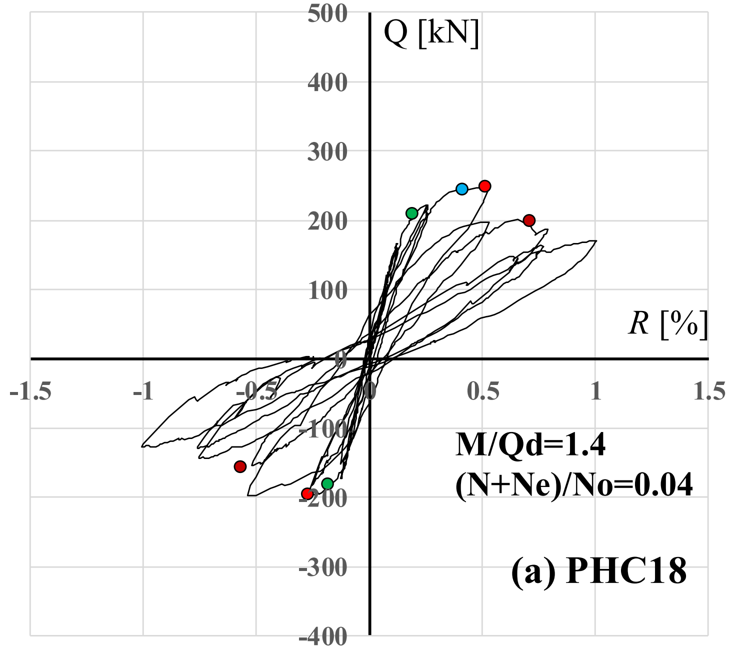


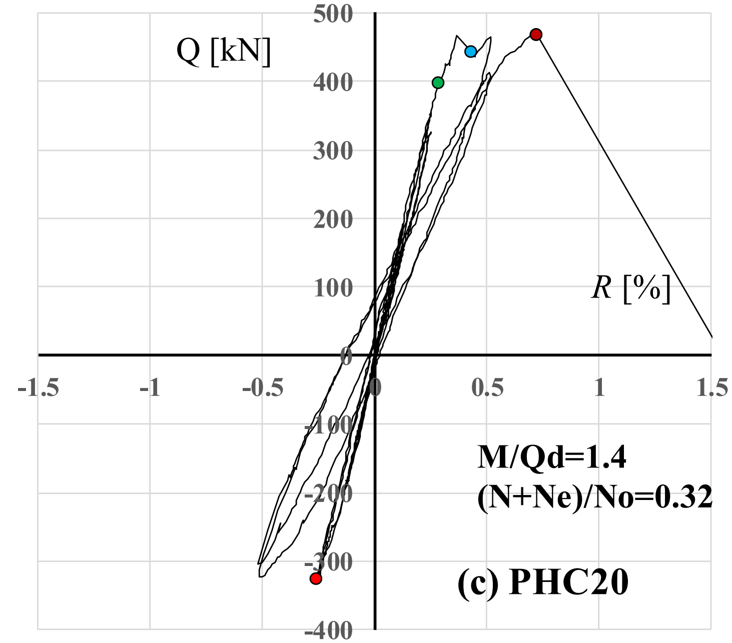
Moment distribution for specimens

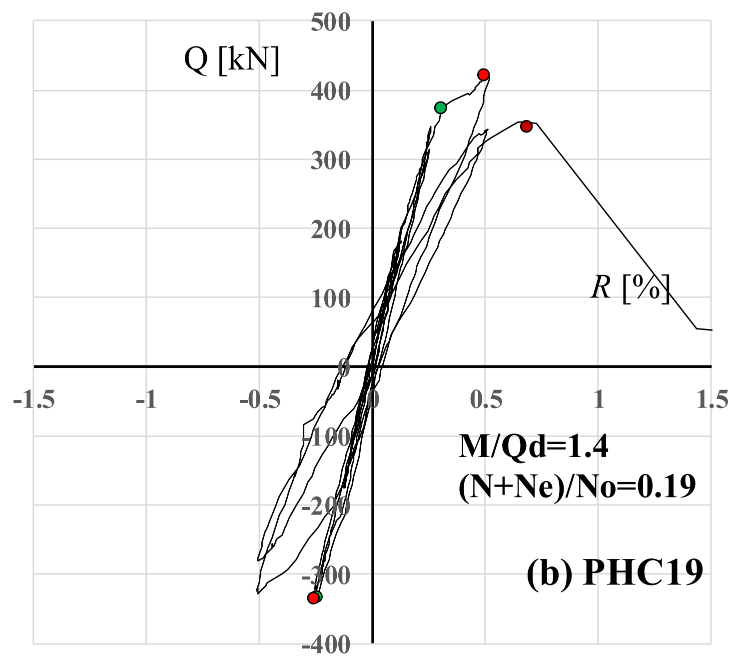
Table 3. Test Results

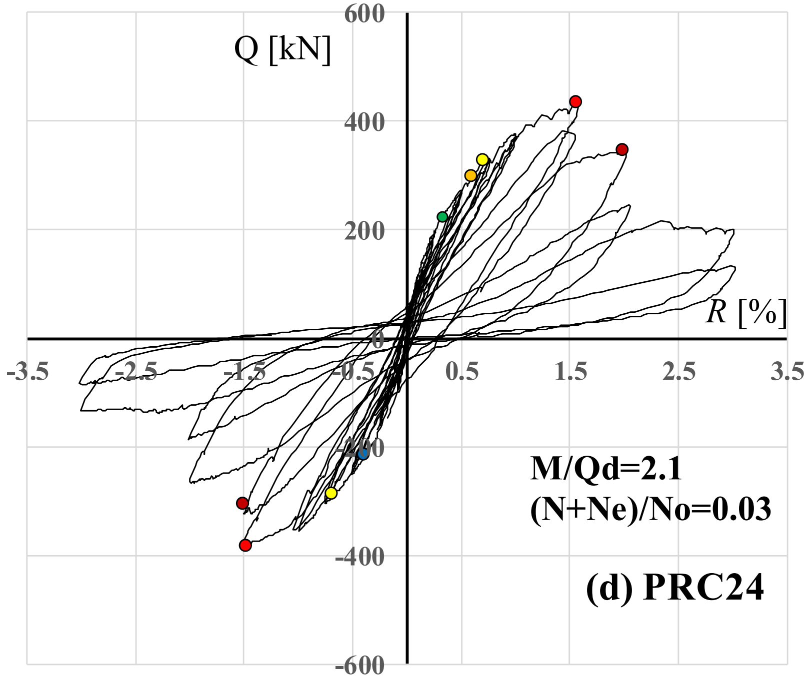
				PHC18	PHC19	PHC20	PRC24	PRC25	PRC26	PRC27	PRC28	PRC29
Axial Force ratio $(N+N_e)/N_0$				0.04	0.19	0.32	0.03	0.18	0.27	0.00	0.17	0.36
Failure mode *				S	A	A	YS	S	A	YS	S	A
Shear Cracking	Pos.	Q	[kN]	207.4	372	397.1	222.4	373.7	-	219.3	437	-
		R*	(%)	0.2	0.31	0.29	0.328	0.372	-	0.418	0.291	-
	Neg.	Q	[kN]	-183.8	-333.5	-	-213.8	-459.3	-407.1	-193.8	-356	391.6
		R*	(%)	-0.18	-0.24	-	-0.388	-0.493	-0.399	-0.304	-0.276	-0.319
Spiral hoop tensile yielding	Pos.	Q	[kN]	241.6	372	442	-	-	-	404.1	536	563.3
		R*	(%)	0.416	0.31	0.433	-	-	-	1.062	0.417	0.359
	Neg.	Q	[kN]	-	-	-	-216.7	-413.1	-305.8	-	-	-
		R*	(%)	-	-	-	-0.393	-0.396	-0.964	-	-	-
Prestressing bar tensile yielding	Pos.	Q	[kN]	-	-	-	326.7	-	-	379.7	-	-
		R*	(%)	-	-	-	0.705	-	-	0.932	-	-
	Neg.	Q	[kN]	-	-	-	-288.8	-	-	-291.7	-	-
		R*	(%)	-	-	-	-0.683	-	-	-0.675	-	-
Longitudinal mild reinforcement tensile yielding	Pos.	Q	[kN]	-	-	-	297.6	-	-	420.4	-	-
		R*	(%)	-	-	-	0.6	-	-	1.147	-	-
	Neg.	Q	[kN]	-	-	-	-	-	-	-	-	-
		R*	(%)	-	-	-	-	-	-	-	-	-
Longitudinal mild reinforcement compressive yielding	Pos.	Q	[kN]	-	-	-	-	254.8	-	-	373	447.5
		R*	(%)	-	-	-	-	1.382	-	-	1.071	0.257
	Neg.	Q	[kN]	-	-	-	-	-	481.9	-	-	-357.7
		R*	(%)	-	-	-	-	-	0.716	-	-	-0.276
The maximum shear force	Pos.	Q	[kN]	247.6	420.6	467.5	433.1	525.5	508.7	464.1	627	671
		R*	(%)	0.518	0.498	0.726	1.564	0.76	0.499	1.453	0.584	0.502
	Neg.	Q	[kN]	-198.5	-337.4	-326.8	-382.8	-482.6	-453.9	-424.8	-517	-547.9
		R*	(%)	-0.269	-0.257	-0.255	-1.484	-0.757	-0.505	-1.491	-0.518	-0.509

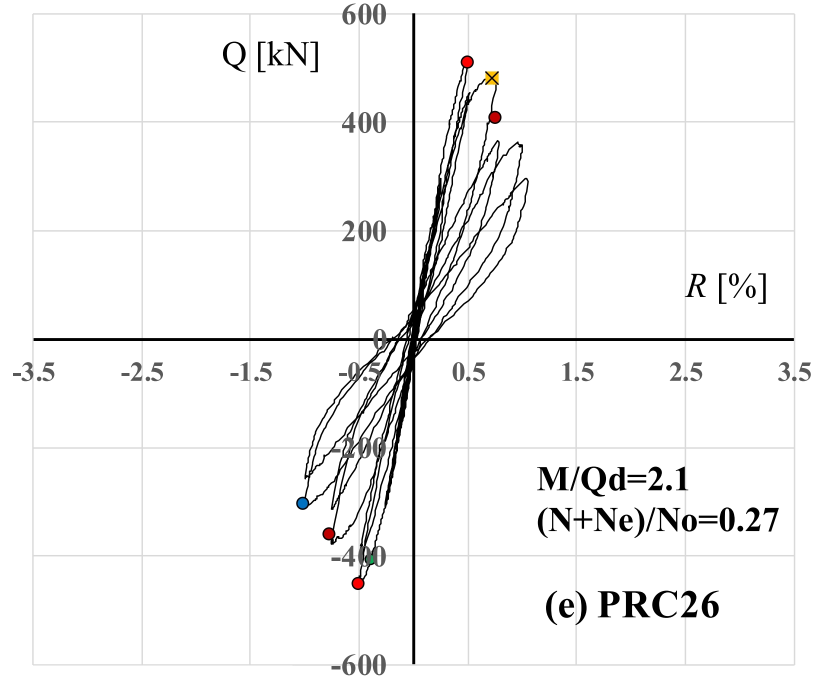
* S: Shear failure, YS: Shear failure after yielding, A: Failure with axial crack

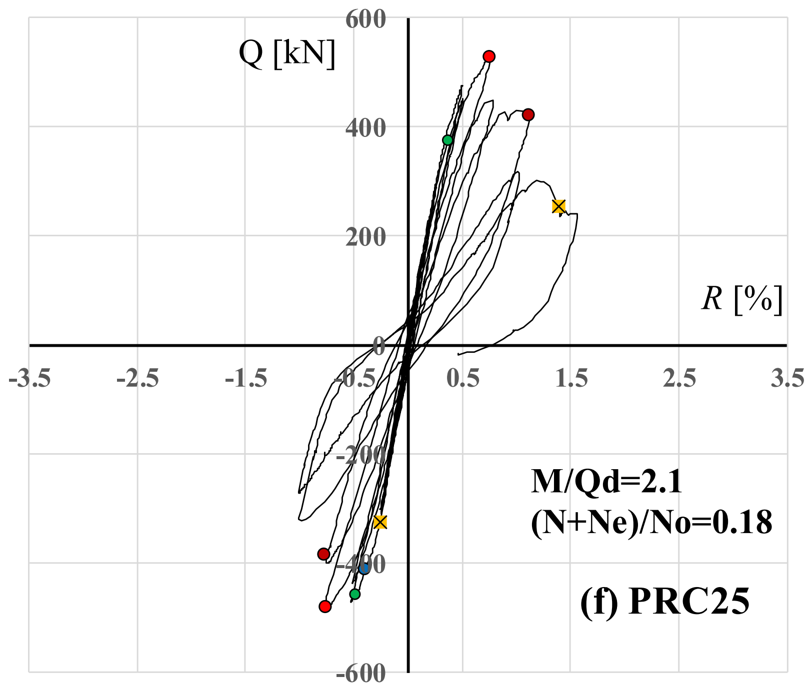

Q [kN]
R [%]
M/Qd=1.4
(N+Ne)/No=0.04
(a) PHC18

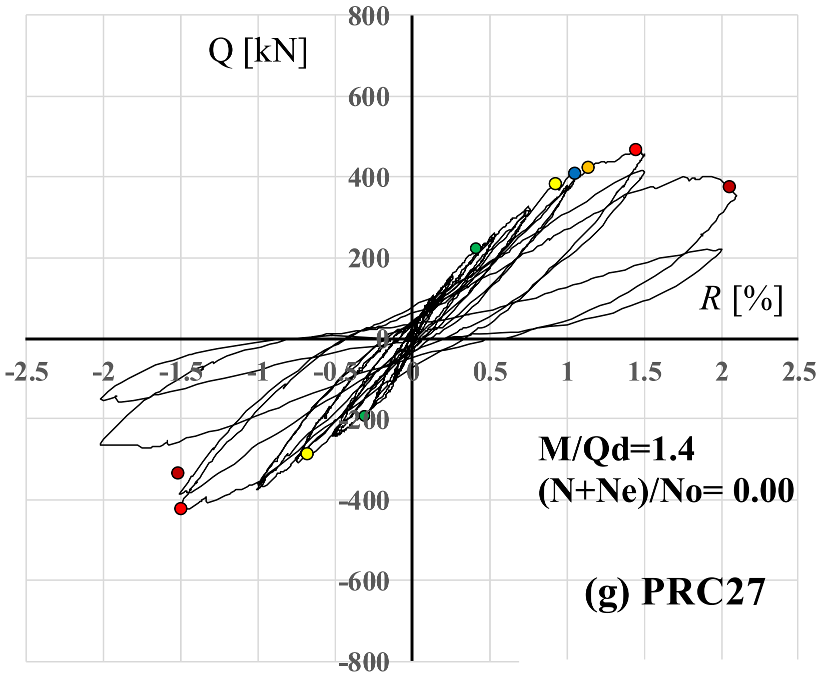

Q [kN]
R [%]
M/Qd=1.4
(N+Ne)/No=0.32
(c) PHC20

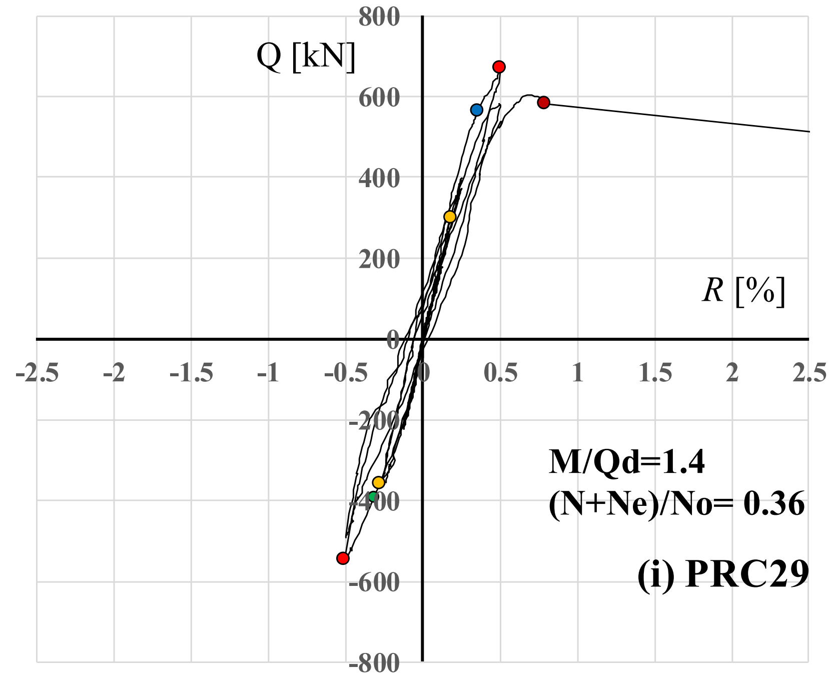

Q [kN]
R [%]
M/Qd=1.4
(N+Ne)/No=0.19
(b) PHC19

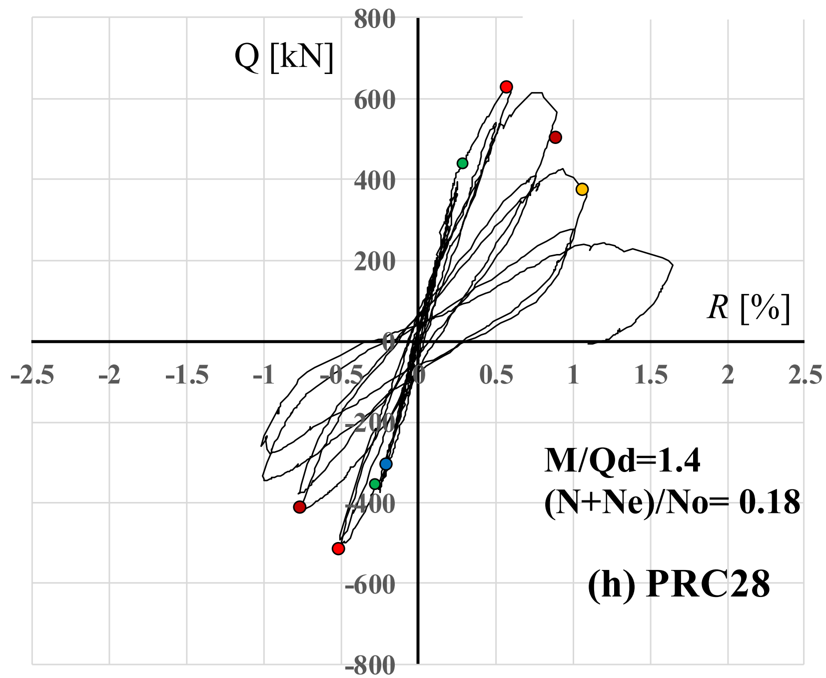

Q [kN]
R [%]
600
400
200
0
-200
-400
-600
-3.5
-2.5
-1.5
-0.5
0.5
1.5
2.5
3.5
M/Qd=2.1
(N+Ne)/No=0.03
(d) PRC24


Q [kN]
R [%]
600
400
200
0
-200
-400
-600
-3.5
-2.5
-1.5
-0.5
0.5
1.5
2.5
3.5
M/Qd=2.1
(N+Ne)/No=0.27
(e) PRC26


Q [kN]
R [%]
600
400
200
0
-200
-400
-600
-3.5
-2.5
-1.5
-0.5
0.5
1.5
2.5
3.5
M/Qd=2.1
(N+Ne)/No=0.18
(f) PRC25


Q [kN]
800
600
400
200
0
-200
-400
-600
-800
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
R [%]
M/Qd=1.4
(N+Ne)/No= 0.00
(g) PRC27


Q [kN]
800
600
400
200
0
-200
-400
-600
-800
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
R [%]
M/Qd=1.4
(N+Ne)/No= 0.36
(i) PRC29


Q [kN]
800
600
400
200
0
-200
-400
-600
-800
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
R [%]
M/Qd=1.4
(N+Ne)/No= 0.18
(h) PRC28