NARLabs 2015
國家實驗研究院
國家地震工程研究中心
高強度鋼筋混凝土(New RC)結構設計手冊研討會

應用高強度鋼筋與高強度混凝土於橋墩耐震設計之可行性研究

NCREE

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104.12.11

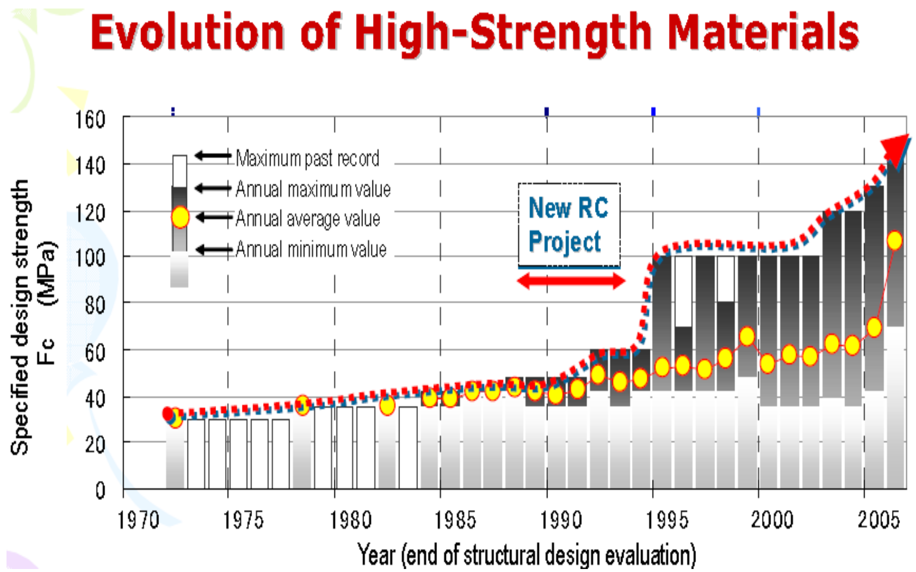
NARLabs

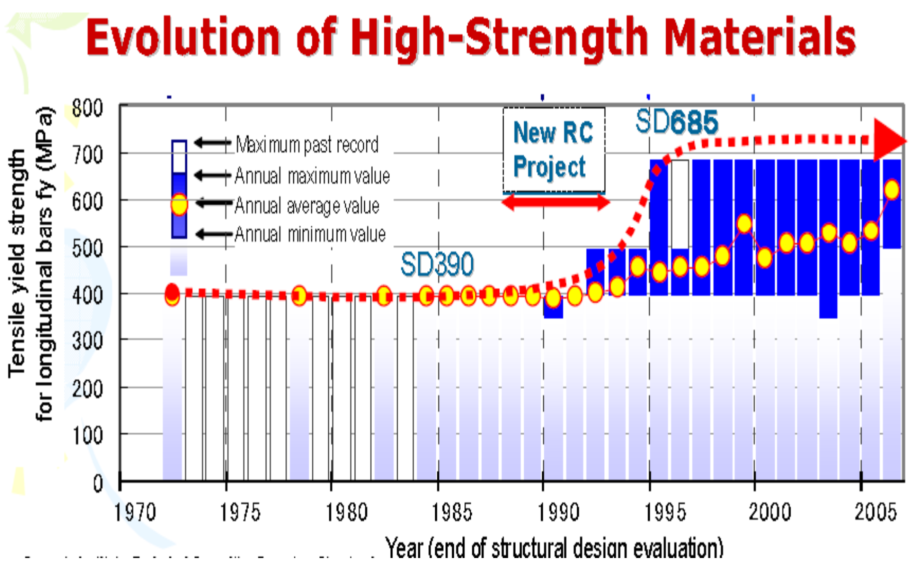
- Background
- Experimental study
  - single pier column
  - column bent
- Simulation & Comparison
- Summary

Background


The new iPad


10:08
新 htc one

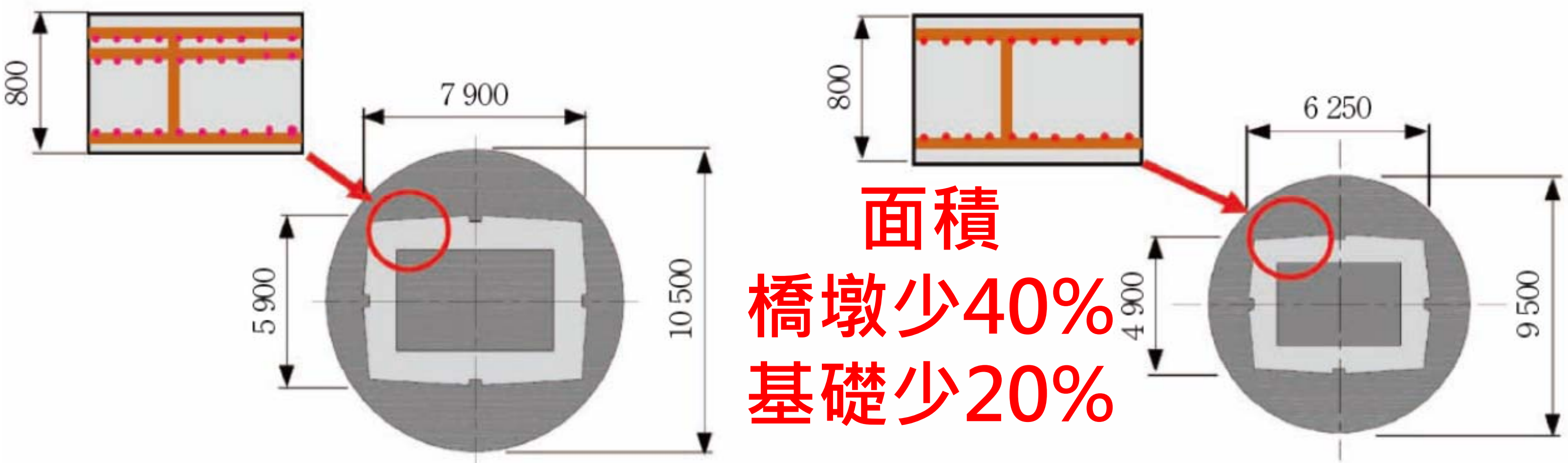

Evolution of High-Strength Materials
Specified design strength Fc (MPa)
Maximum past record
Annual maximum value
Annual average value
Annual minimum value
New RC Project
0
20
40
60
80
100
120
140
160
1970
1975
1980
1985
1990
1995
2000
2005
Year (end of structural design evaluation)


Evolution of High-Strength Materials
Tensile yield strength for longitudinal bars fy (MPa)
Maximum past record
Annual maximum value
Annual average value
Annual minimum value
New RC Project
SD390
SD685
0
100
200
300
400
500
600
700
800
1970
1975
1980
1985
1990
1995
2000
2005
Year (end of structural design evaluation)

Super-RC Case：佐奈川橋

⑥上部工構造：PRC 6 径間連続ラーメン箱桁橋
⑦上部工支間割：
　上　り　線：81. 25 m＋112. 5 m＋105. 0 m＋126. 0 m
　　　　　　　＋123. 0 m＋85. 75 m
　下　り　線：76. 75 m＋2＠128. 0 m＋2＠142. 0 m
　　　　　　　＋79. 75 m
⑧下部工構造：RC 橋台：4 基，RC 橋脚：10 基（橋脚高 21. 5～89. 0 m）
⑨基 礎 構 造：深礎杭（ϕ 3.0 m×12 本，杭延長 94.0 m）
　大口径深礎：10 基（ϕ 8. 5，9. 0 m×10 本，杭 延 長 63. 5 m）

＜従来構造＞　　＜Super-RC 構造＞



面積
橋墩少40%
基礎少20%

＜橋脚使用材料＞
コンクリート：f'_{ck}=30 N/mm^2
鉄筋：SD 345

＜橋脚使用材料＞
コンクリート：f'_{ck}=50 N/mm^2
鉄筋：USD 685 B

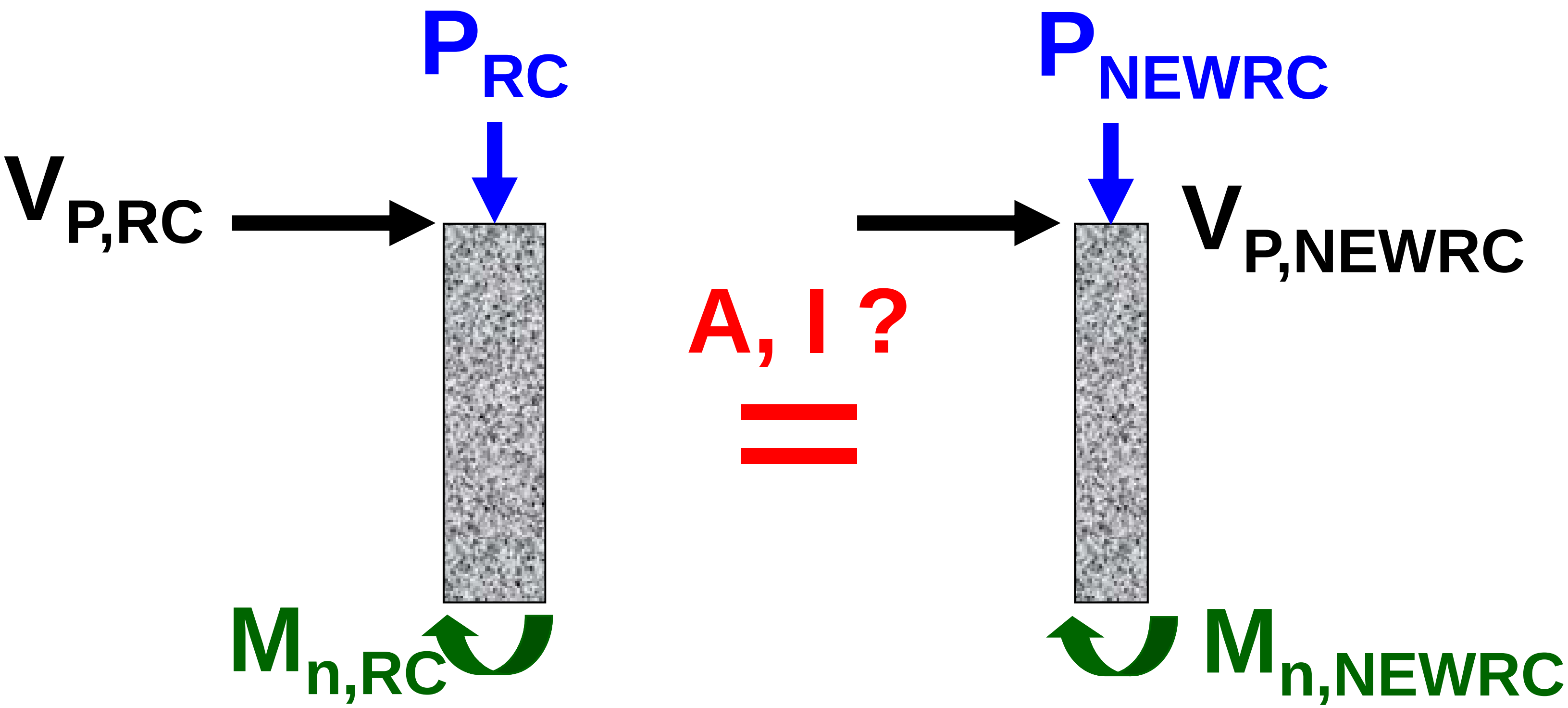
図-6　Super-RC 構造

Research Objective

- New RC material: size & material ↓
- Geometry: span ↑ piers ↓
- Precast construction: quality ↑
- Re-centering: damages after EQ ↓

Feasibility for bridge structure?

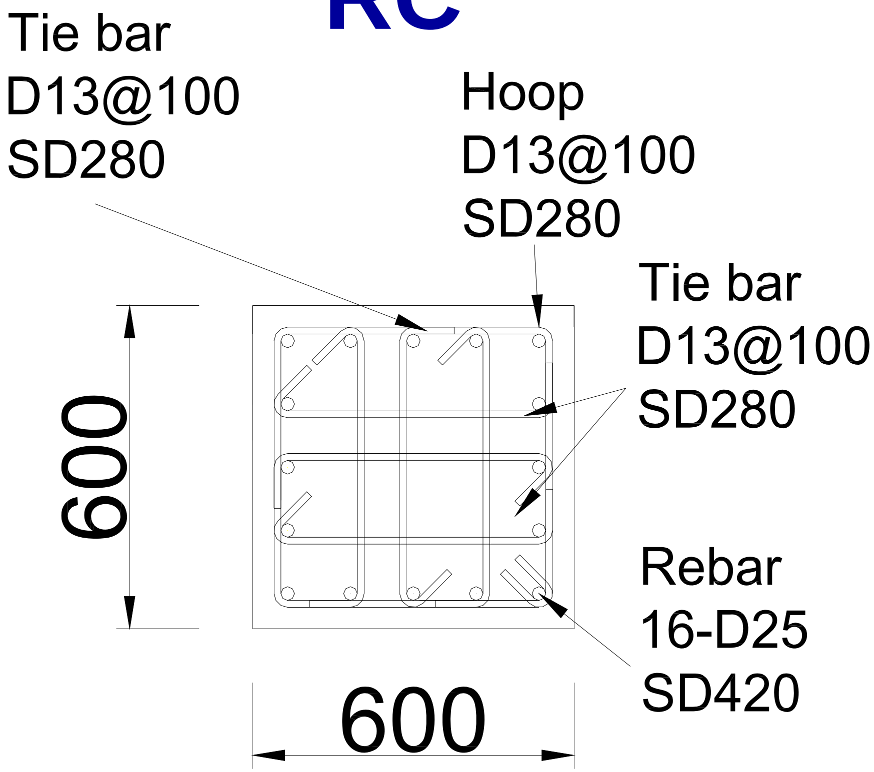
- **Equivalent strength capacity**
- **Flexural failure: column → beam** $\frac{P}{A_g f'_c} \leq 0.1$



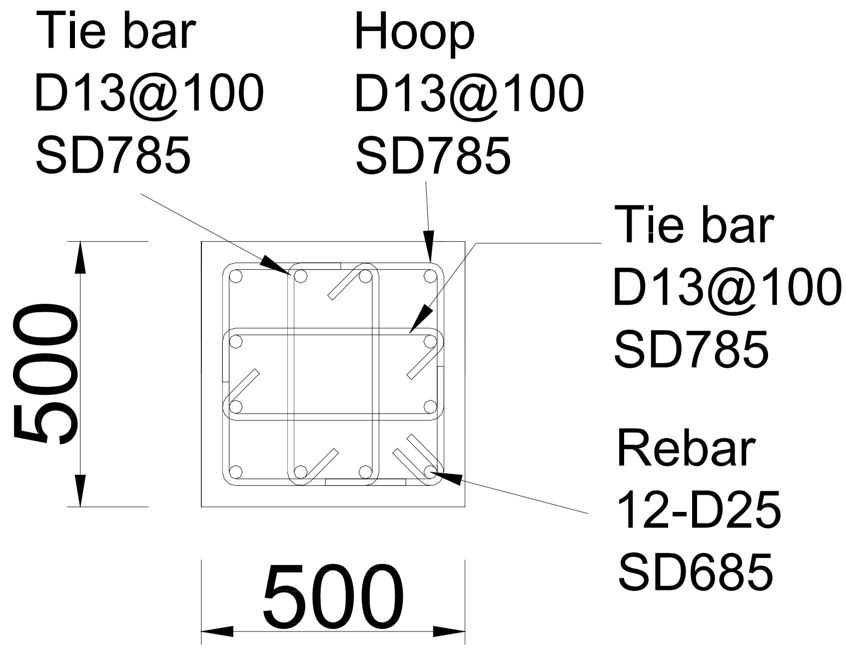
RC & New RC section

Given same moment and shear for RC
NEWRC save: size30%, reinforcement 20-25%

RC



New RC



unit: mm, MPa

Detail of the Specimens

Item	Unit	Specimen					
		BMRC1	NEWRC1	NEWRC5	NEWRCH1	NEWRCH2	NEWRCH3
width	cm	60	50	50	60	60	60
height	cm	60	50	50	60	60	60
length	cm	360	360	360	360	360	360
cover	cm	4	4	4	4	4	4
f’c	N/mm^2	36.7	80.9	80.9	94.0	94.0	94.0
fy	N/mm^2	534	736	736	733	733	733
fyt	N/mm^2	341	813	341	488	488	488
main bar	-	16-D25	12-D25	12-D25	12-D25	10-D25	4-D25
lateral reinforcement	-	5-D13 @10	4-D13 @10	4-D13 @10	5-D13 @10	5-D13 @10	5-D13 @10
axial load	tf	136	136	136	136	136	136
axial load ratio	-	0.1	0.066	0.066	0.066	0.066	0.066

Design requirement
lateral reinforcement

$$A_{sh} = 0.30ah_c \frac{f_c'}{f_{yh}}\left[\frac{A_g}{A_c} - 1\right]$$

$$A_{sh} = 0.12ah_c \frac{f_c'}{f_{yh}}\left(0.5 + \frac{1.25P_e}{f_c' A_g}\right)$$

Design requirement
lateral shear strength

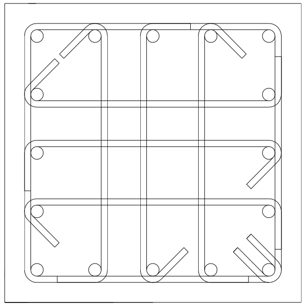
$$V_n = V_s + V_c$$

$$V_c = 0.53(0.33 + F)\sqrt{f_c^{'}}\,A_e \geq 0$$

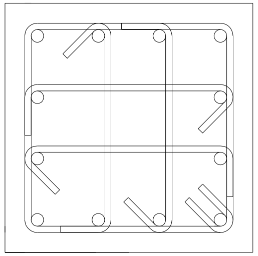
$$F = \frac{N}{140 A_g}$$

$$V_s = A_{sh} f_{yh} d / a$$

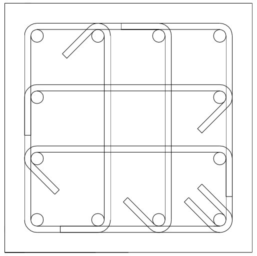
Design drawing of specimens



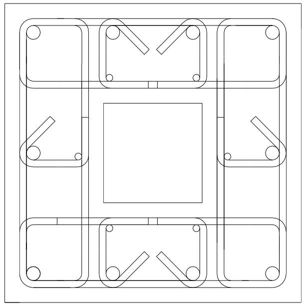
BMRC1 **(CIP)**
B:60cm, f'c:28MPa
SD685:16-D25
SD785:D13@10cm



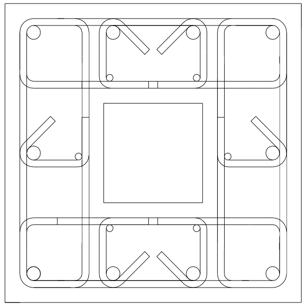
NEWRC1 **(CIP)**
B:50cm, f'c:70MPa
SD685:12-D25
SD785:D13@10cm



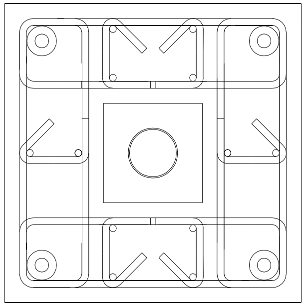
NEWRC5 **(CIP)**
B:50cm, f'c:70MPa
SD685:12-D25
SD280:D13@10cm



NEWRCH1 **(CIP)**
B:60cm, f'c:70MPa
SD685:10-D25
SD420:D13@10cm



NEWRCH2 **(PRE)**
B:60cm, f'c:70MPa
SD685:10-D25
SD420:D13@10cm



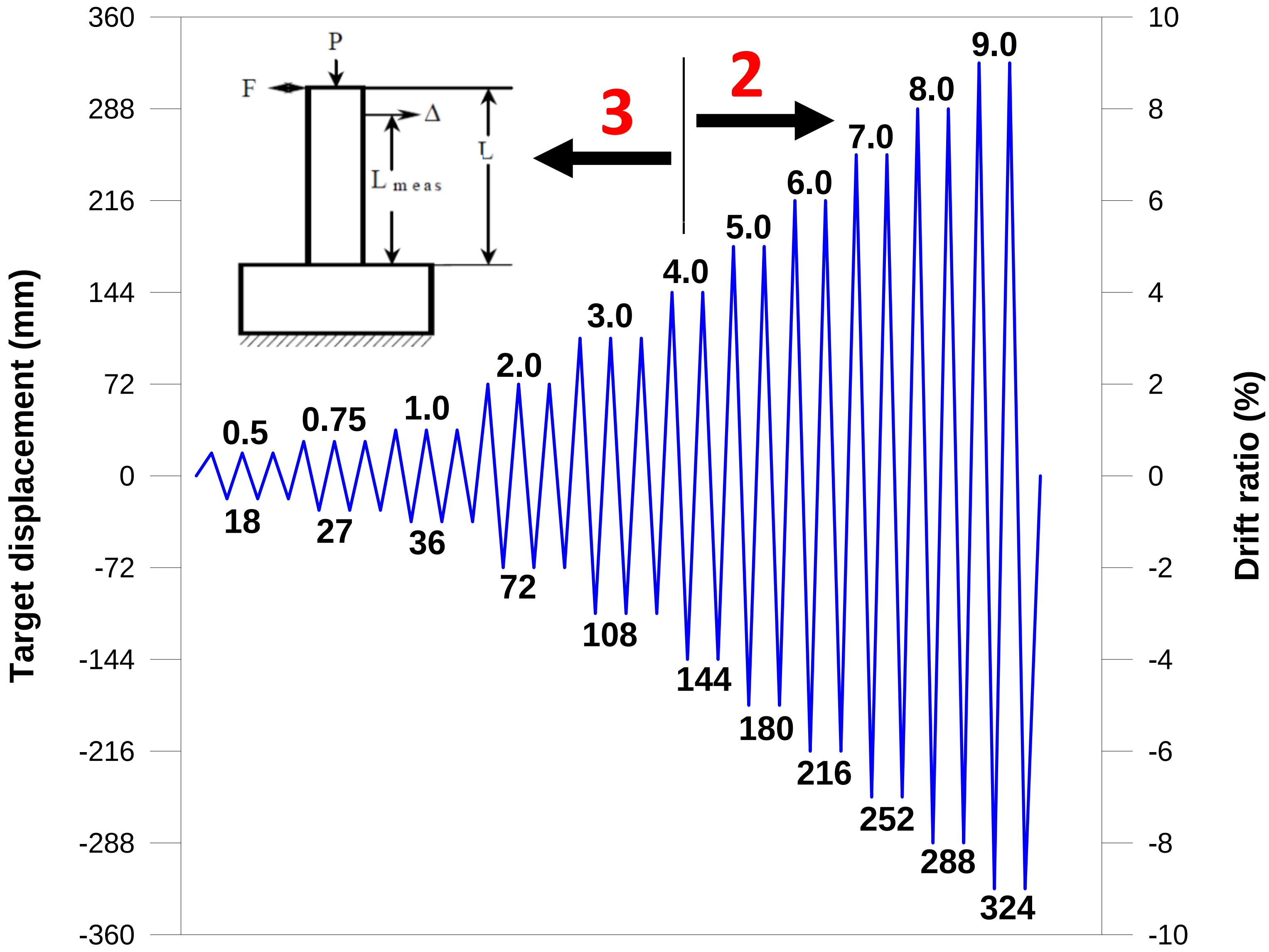
NEWRCH3 **(PRE)**
B:60cm, f'c:70MPa
SD685:4-D25
SD420:D13@10cm

Test setup and sensors

Global view

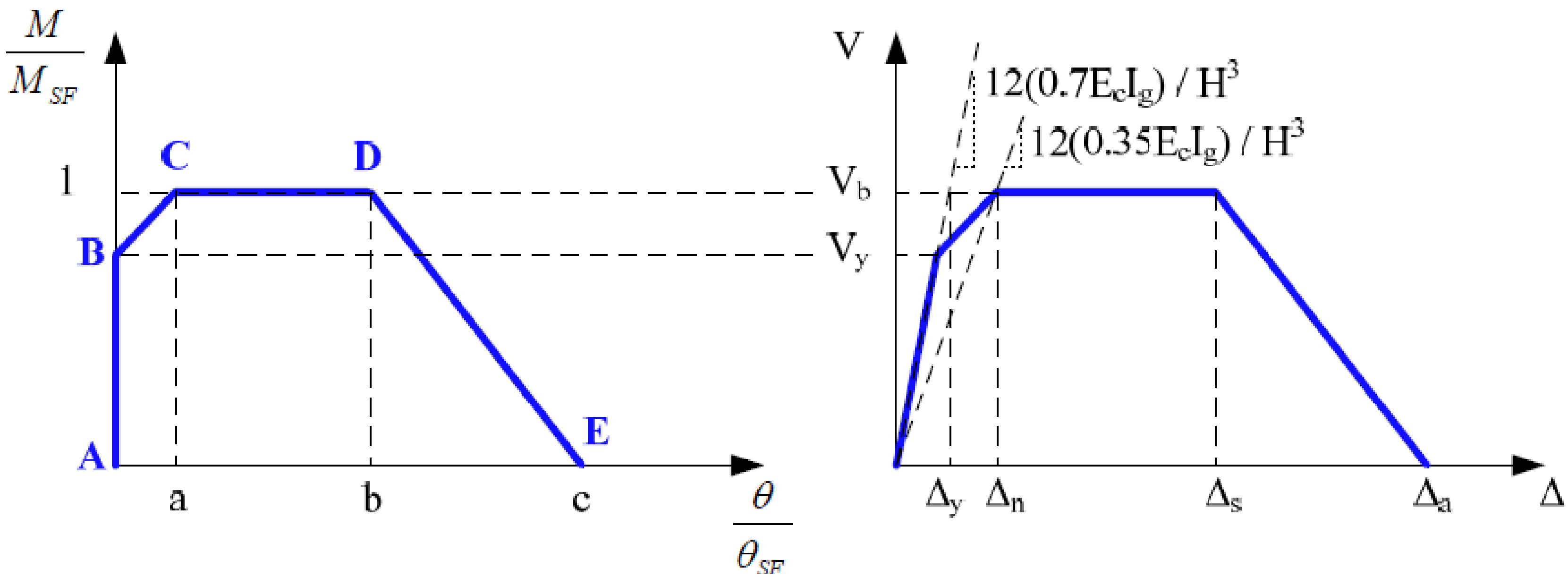
LVDTs & NDI markers

Loading protocol



TEASPA pushover analysis

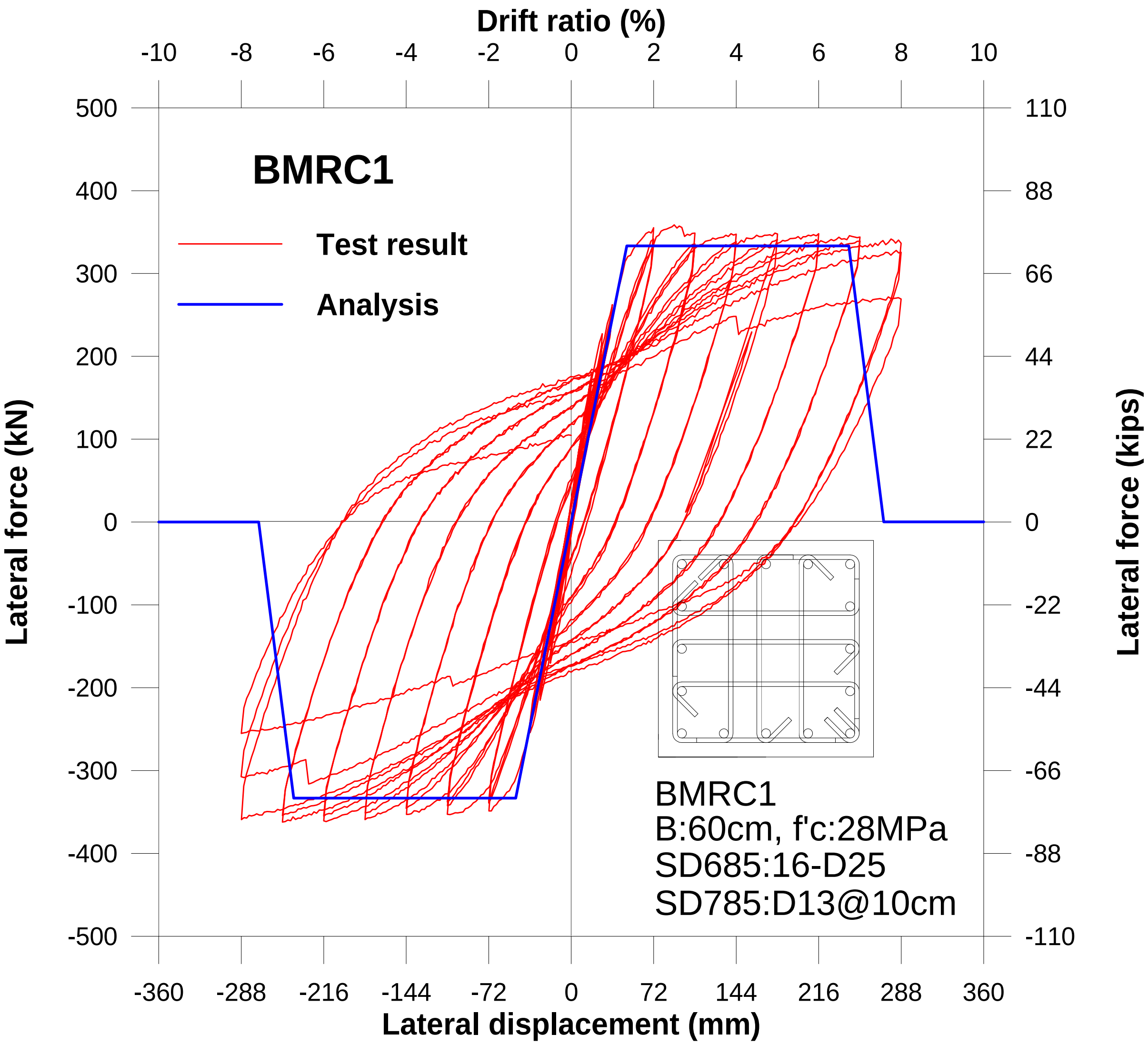
(Taiwan Earthquake Assessment of Static Pushover Analysis)

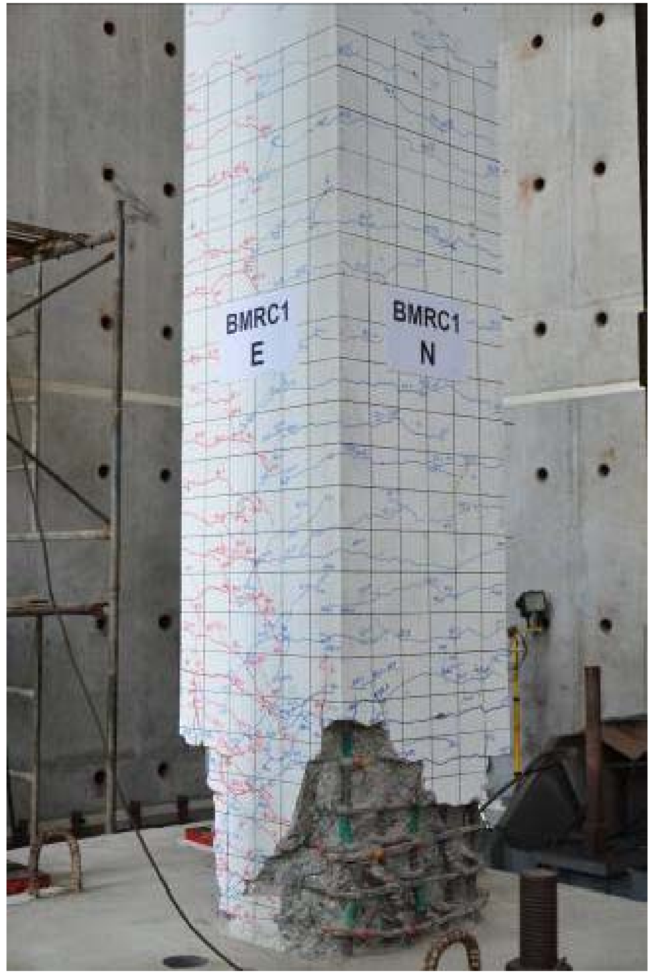


剪力強度點 $$\frac{\Delta_s}{H}=\frac{3}{100}+4\rho''-\frac{1}{40}\frac{v_m}{\sqrt{f_c'}}-\frac{1}{40}\frac{P}{A_g f_c'}\geq\frac{1}{100}$$

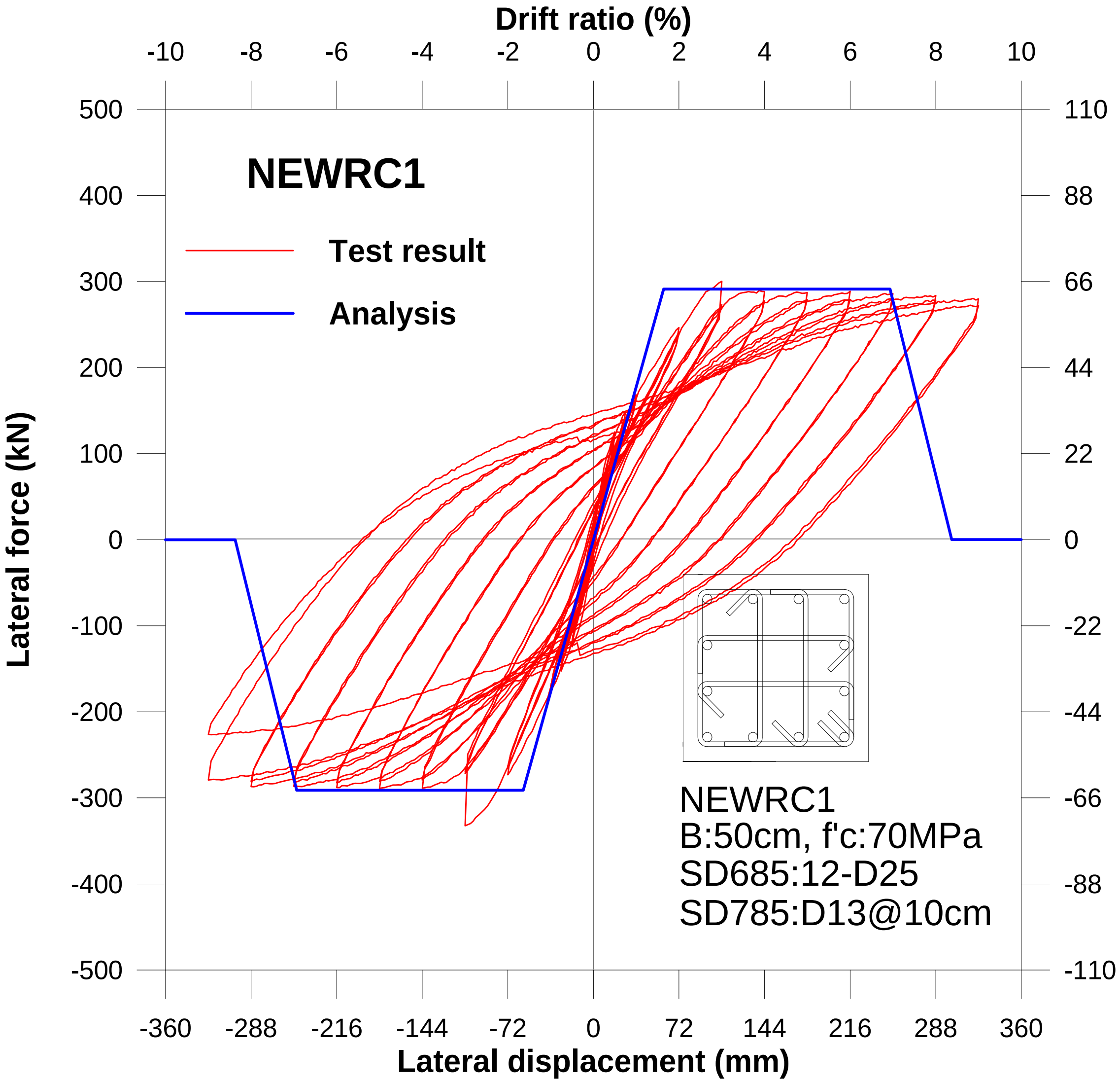
軸力破壞點 $$\frac{\Delta_a}{H}=\frac{4}{100}\frac{1+(tan\,\theta)^2}{tan\,\theta+P\dfrac{s}{A_{st}f_{yt}d_c\,tan\,\theta}}$$

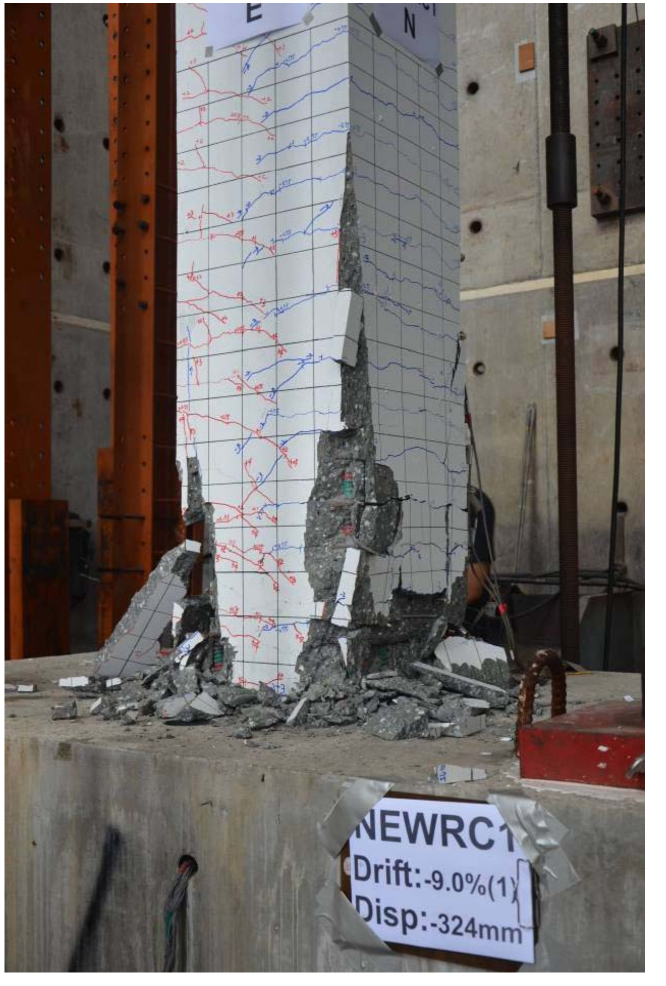
BMRC1 test result (CIP)



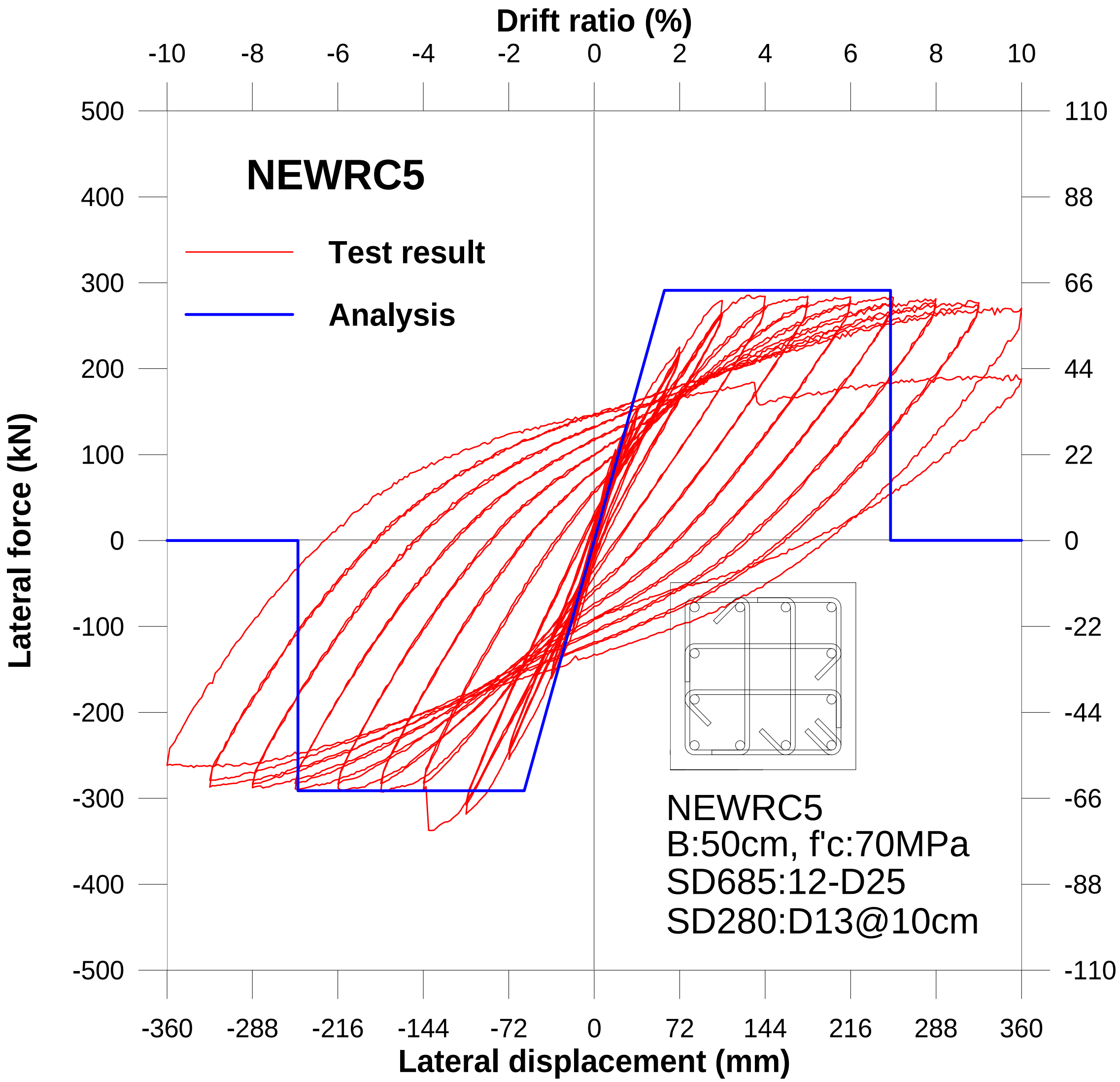


NEWRC1 test result (CIP)

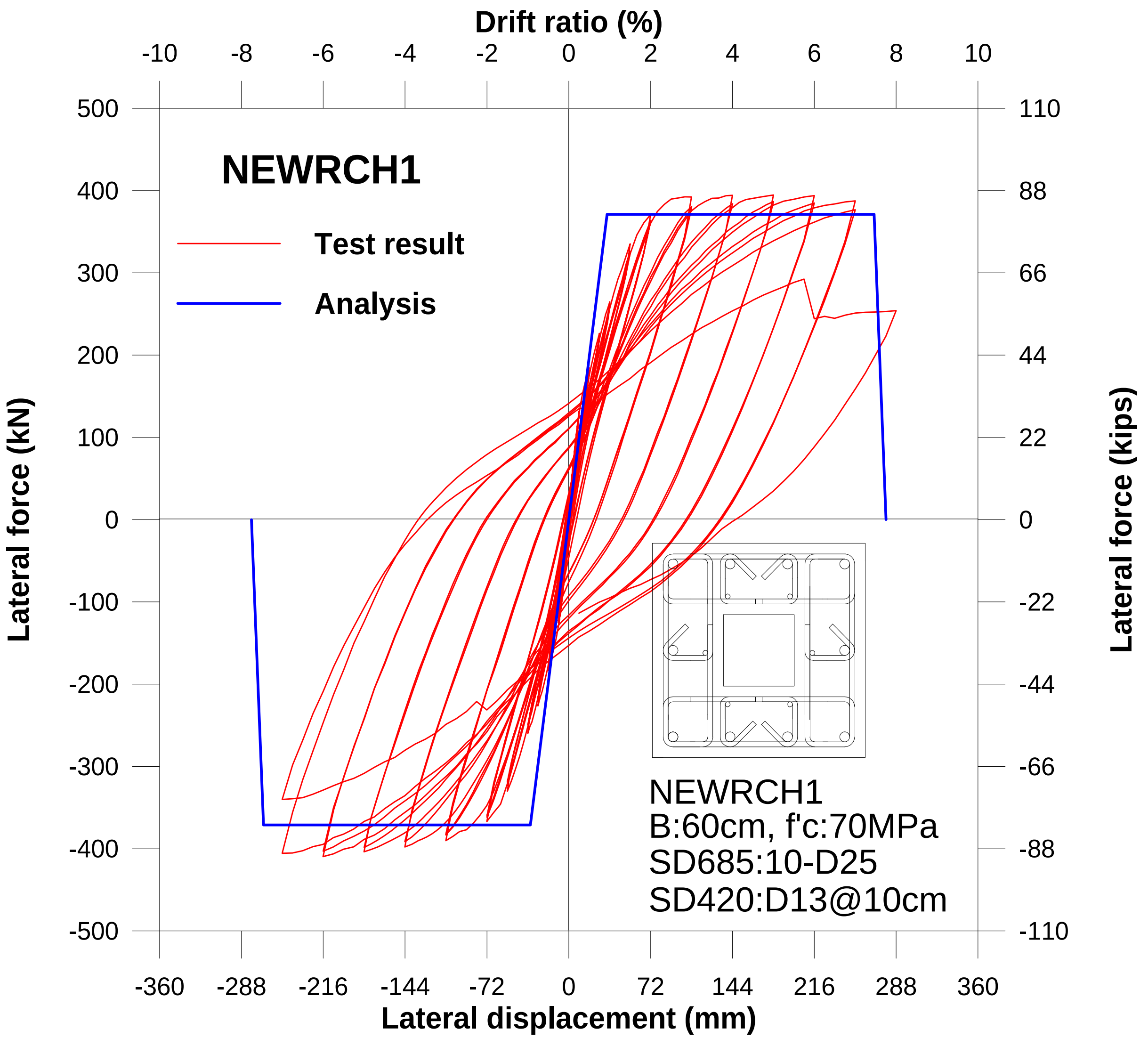




NEWRC5 test result (CIP)



NEWRCH1 test result (CIP)



NEWRCH2 test result (PRE)

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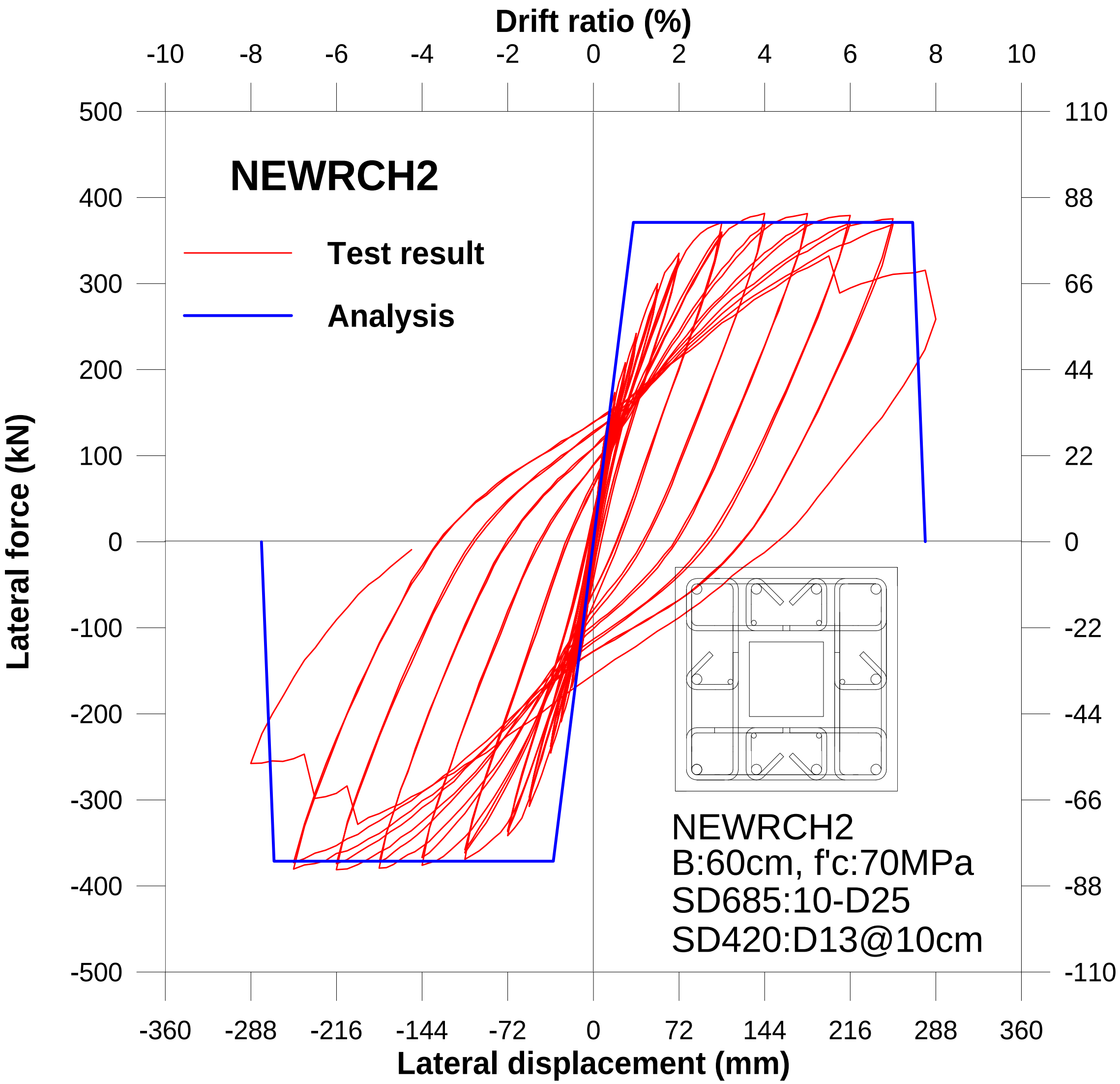
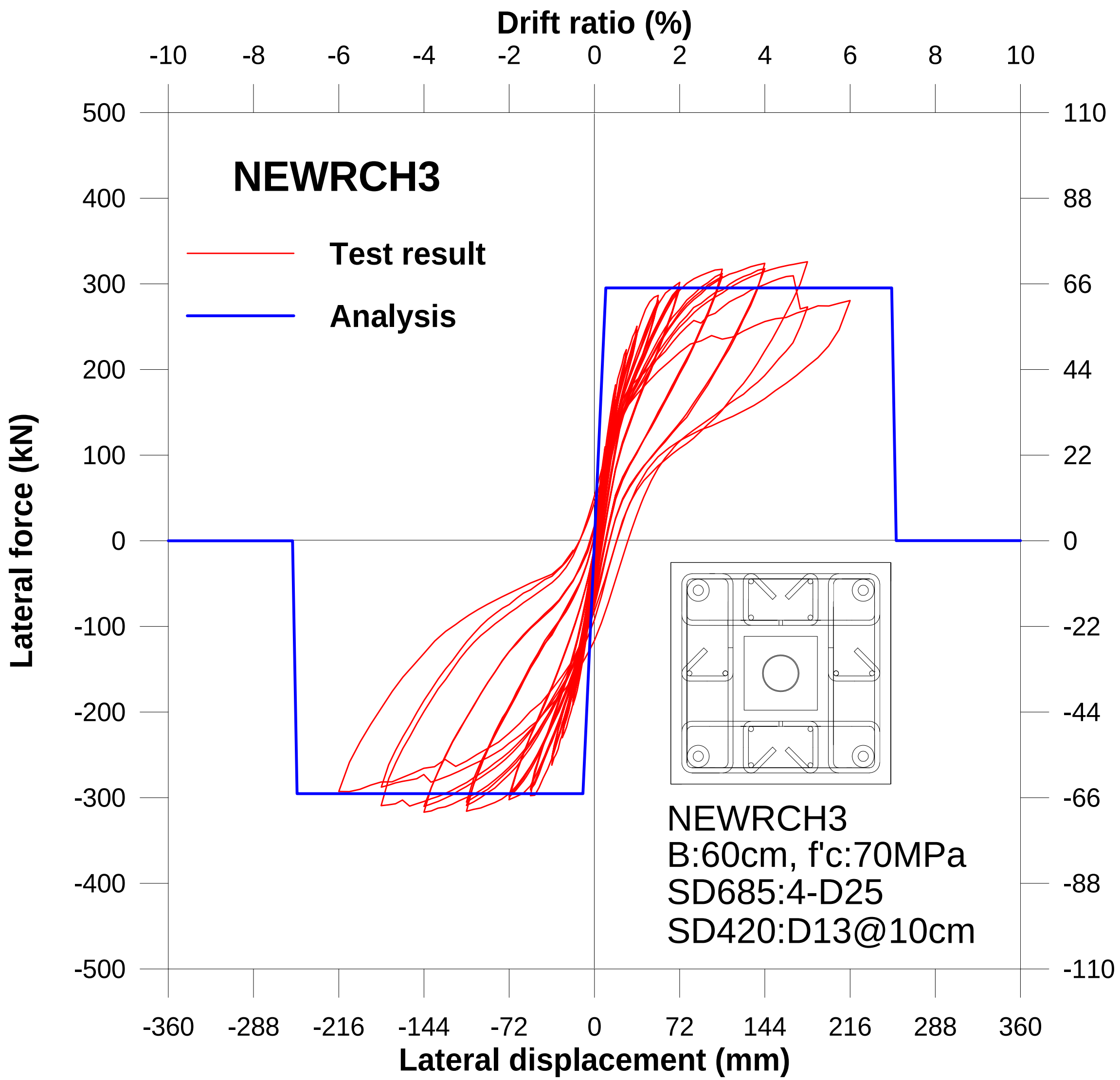
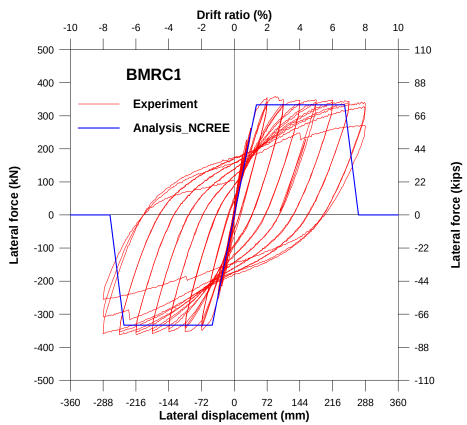


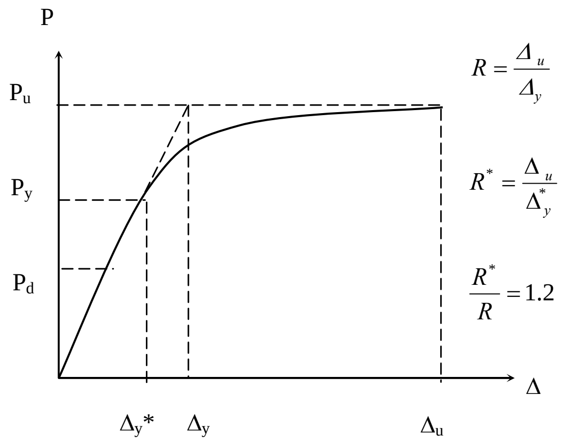
NEWRCH3 test result (PRE)



Displacement ductility > 3

Specimen	Yielding strength (kN)	Yielding displacement (mm)	Ultimate displacement (mm)	Displacement ductility
BMRC1	352	49.8	288	5.8
NEWRC1	287	58.9	324	5.5
NEWRC5	280	62.1	360	5.8
NEWRCH1	397	57.0	252	4.4
NEWRCH2	378	57.0	252	4.4
NEWRCH3	306	31.8	216	6.8





$$R = \frac{\Delta_u}{\Delta_y}$$

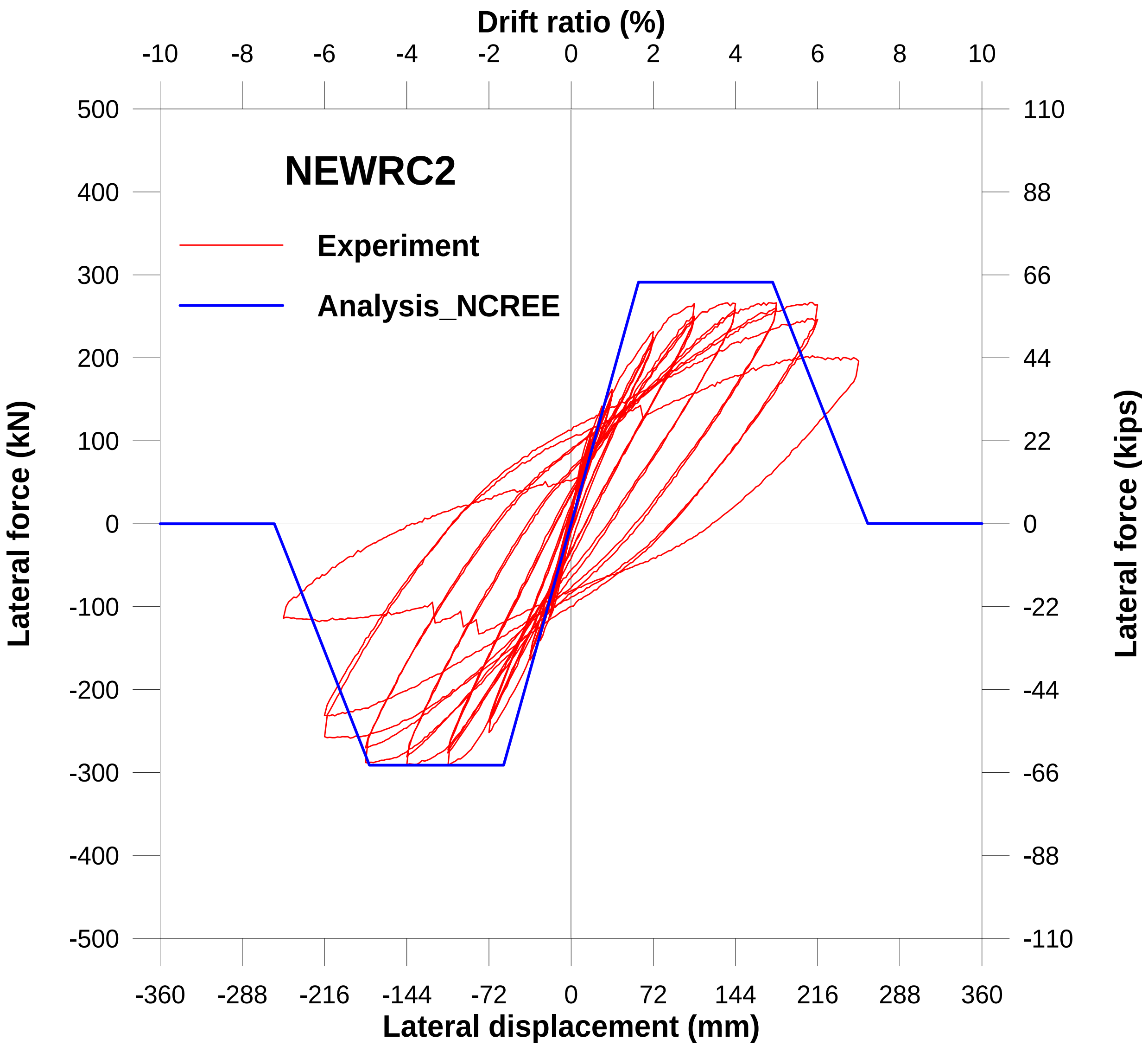
$$R^* = \frac{\Delta_u}{\Delta_y^*} \qquad \frac{P_y}{P_d} = \alpha_y$$

$$\frac{R^*}{R} = 1.2 \qquad \frac{P_u}{P_y} = 1.2$$

Detail of the Specimens

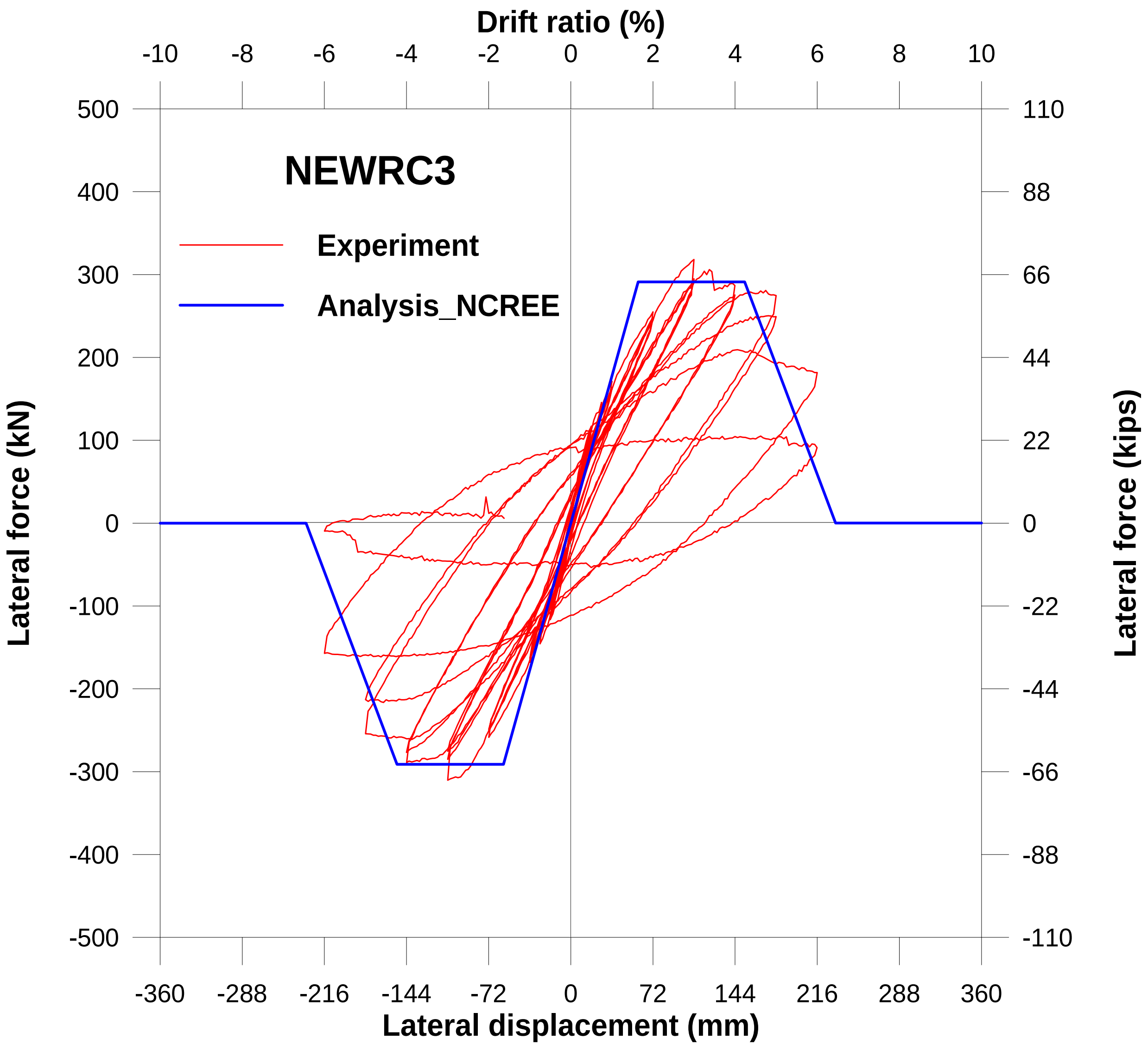
項目	單位	試體名稱					
		BMRC1	NEWRC1	NEWRC2	NEWRC3	NEWRC4	NEWRC5
柱寬	cm	60	50	50	50	50	50
柱深	cm	60	50	50	50	50	50
柱高	cm	360	360	360	360	360	360
保護層	cm	4	4	4	4	4	4
f'c設計值	kgf/cm²	280	700	700	700	700	700
fy 設計值	kgf/cm²	4200	7000	7000	7000	7000	7000
fyt 設計值	kgf/cm²	2800	8000	8000	8000	8000	2800
縱向鋼筋	-	16-D25	12-D25	12-D25	12-D25	12-D25	12-D25
橫向鋼筋	-	5-D13 @10	4-D13 @10	4-D13 @20	4-D13 @30	4-D13 @10	4-D13 @10
柱軸力	tf	136	136	136	136	272	136
軸力係數	-	0.1	0.066	0.066	0.066	0.13	0.066

NEWRC2 test result (CIP)



箍筋間距20cm

NEWRC3 test result (CIP)



箍筋間距30cm

NEWRC4 test result (CIP)

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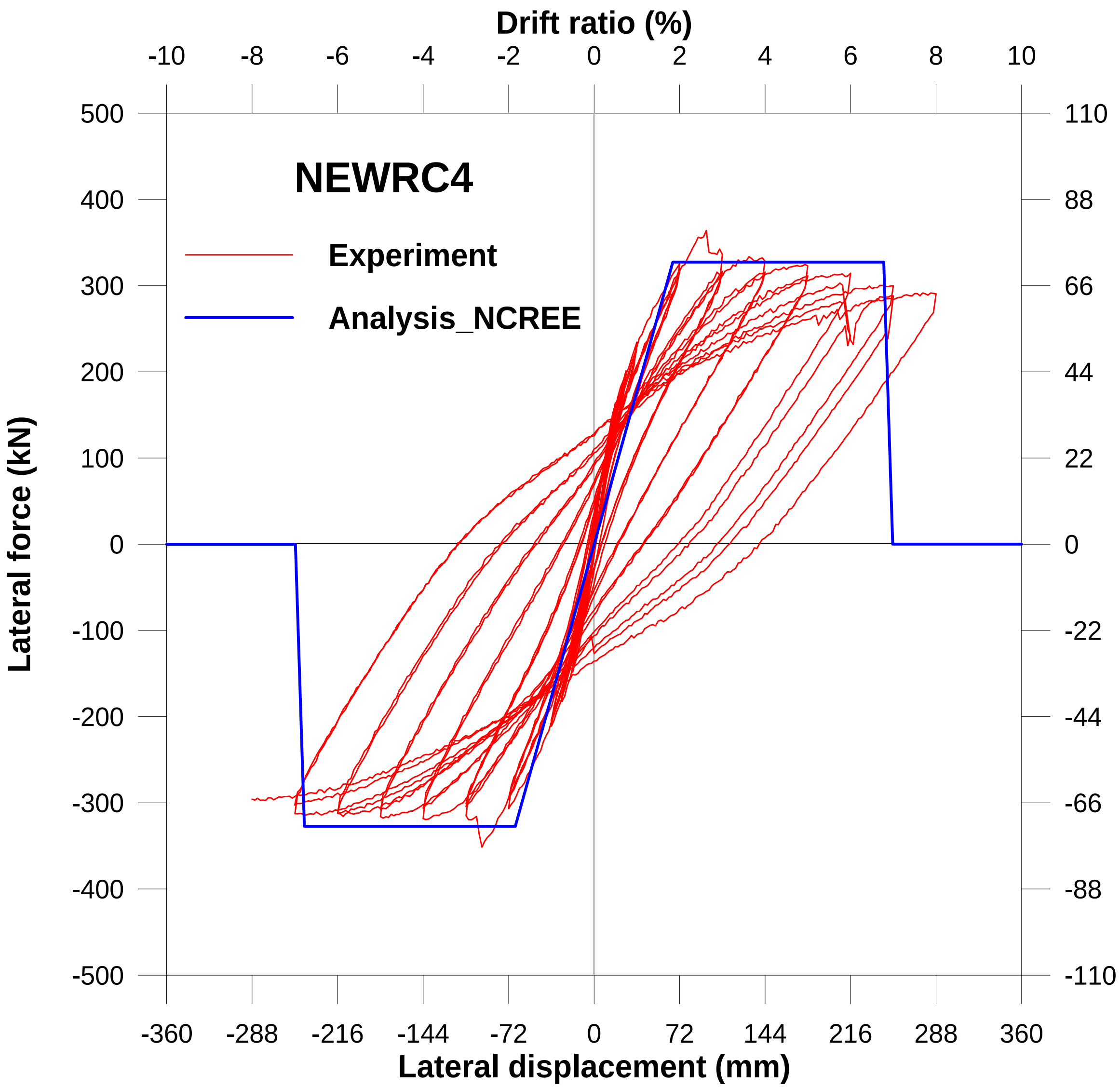
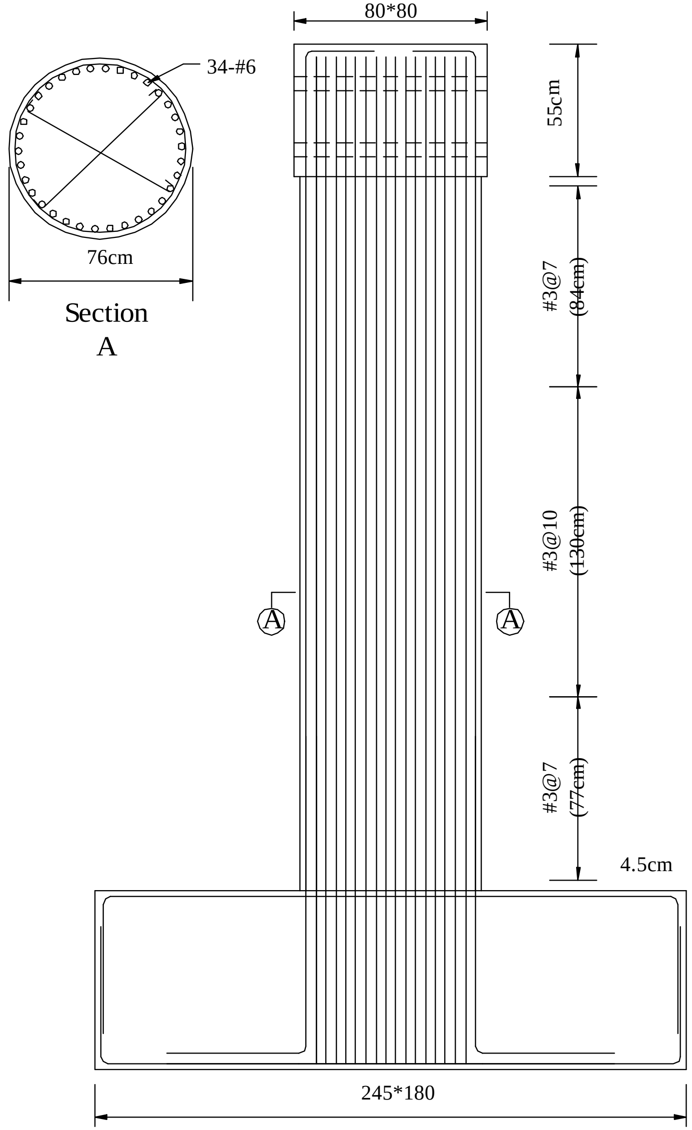


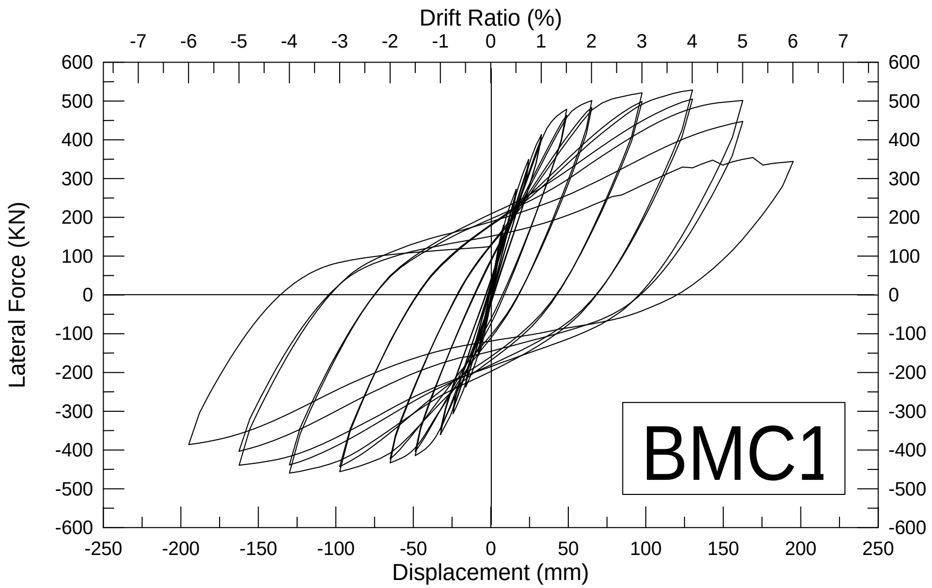
箍筋間距10cm

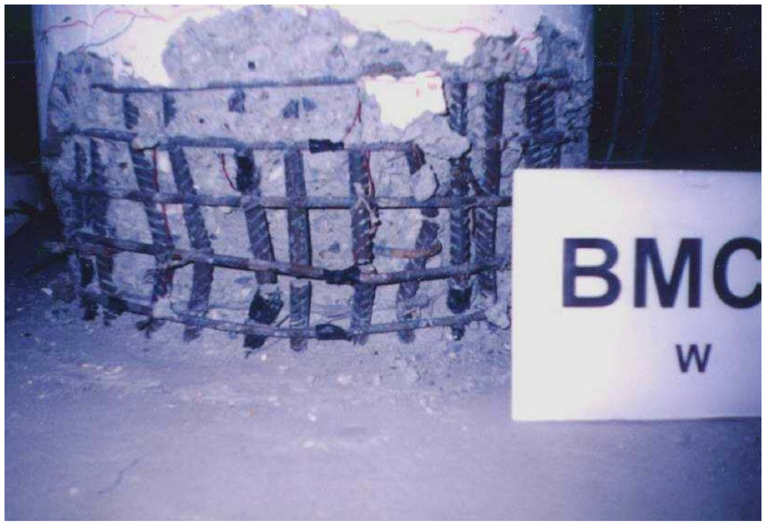
Benchmark BMC1 column



試體編號	BMC1
柱高(cm)	325
直徑(cm)	76
主筋降伏應力（kg/cm^2）	4200
箍筋降伏應力（kg/cm^2）	2800
繫筋降伏應力（kg/cm^2）	2800
主筋配置	34 #6
箍筋配置	#3@ 7-10
繫筋配置	1-#3@7-10
柱軸力(tons)	143
主筋號數	#6
主筋標稱降伏強度（kg/cm^2）	4200
主筋實驗值降伏強度（kg/cm^2）	5000
主筋降伏應變	0.25%
箍筋號數（kg/cm^2）	#3
箍筋標稱降伏強度（kg/cm^2）	2800
箍筋實驗降伏強度（kg/cm^2）	5000
箍筋降伏應變	0.25%
標稱混凝土抗壓強度（kg/cm^2）	210
實驗值稱混凝土抗壓強度（kg/cm^2）	265

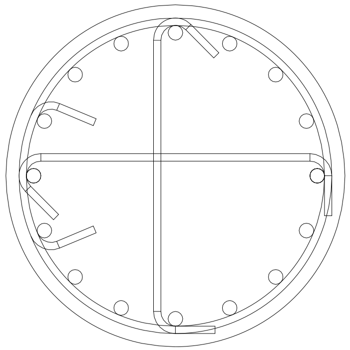
Test result of BMC1

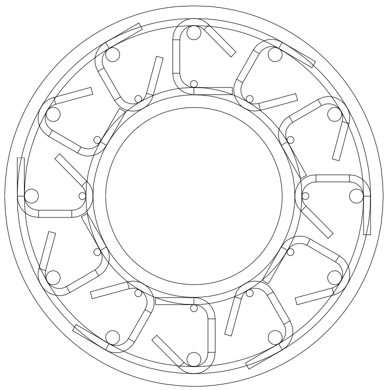




Design parameters

Item	Unit	D65	H75
Do	cm	65	75
Di	cm	0	35
h	m	3.25	3.25
f'c	kgf/cm2	700	700
fy	kgf/cm2	7000	7000
fyt	kgf/cm2	4200	4200
Main bar		16-D25	12-D25
Hoop		D13@10	D13@10
Mp	tf-m	157	159
P	tf	140	140
P / f'cAg		0.06	0.06





Design requirement
lateral reinforcement

$$\rho_s = 0.45 \frac{f'_c}{f_{yh}} \left[\frac{A_g}{A_c} - 1 \right]$$

$$\rho_s = 0.12 \frac{f'_c}{f_{yh}} \left(0.5 + \frac{1.25 P_e}{f'_c A_g} \right)$$

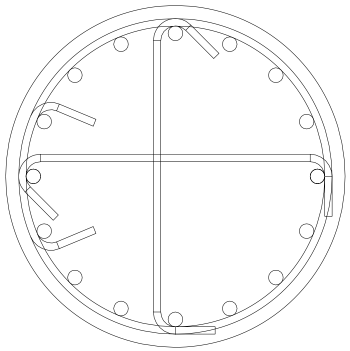
$$A_{ch} = \frac{\rho_s S D_2}{4} \times (1 - \alpha)$$

$$A'_{ch} = \frac{4\pi \overline{R} (1 - \alpha_1) f_{yt}}{D_2 (1 - \alpha) f'_{yt}} A_{ch}$$

$$\overline{R} = \frac{2(r_2^3 - r_1^3)}{3(r_2^2 - r_1^2)}$$

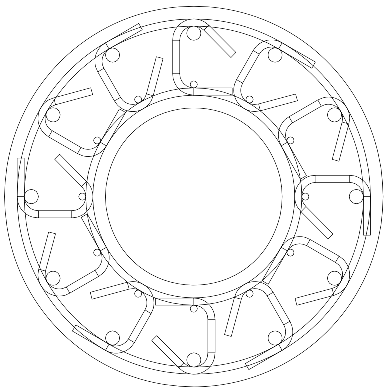
α	α_1
0.2	0.7000
0.4	0.4180
0.6	0.2411
0.8	0.1324

Design requirement
lateral shear strength



$$V_s = V_{sh1} + V_{sh2} + V'_{sh}$$

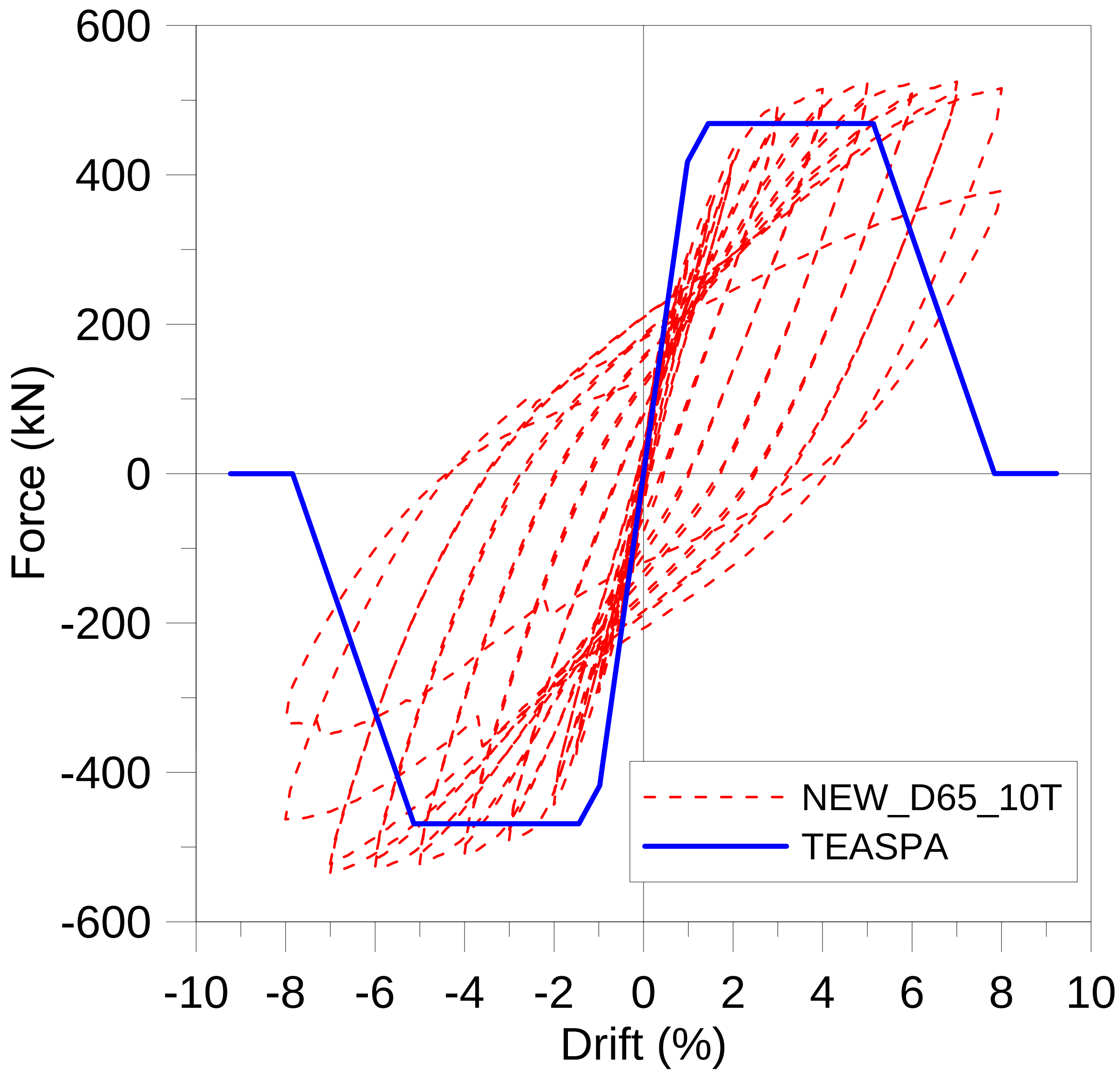
$$V_{sh1} = \frac{\pi}{2}\left(\frac{nA_h f_{yt} D_1}{s}\right)$$

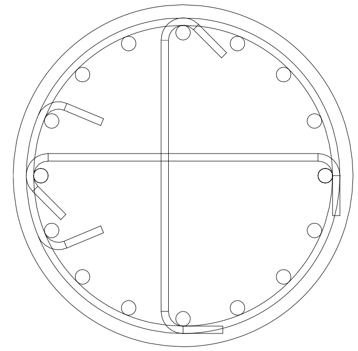


$$V_{sh2} = \frac{\pi}{2}\left(\frac{nA_h f_{yt} D_2}{s}\right) \qquad \alpha = \frac{r_1}{r_2}$$

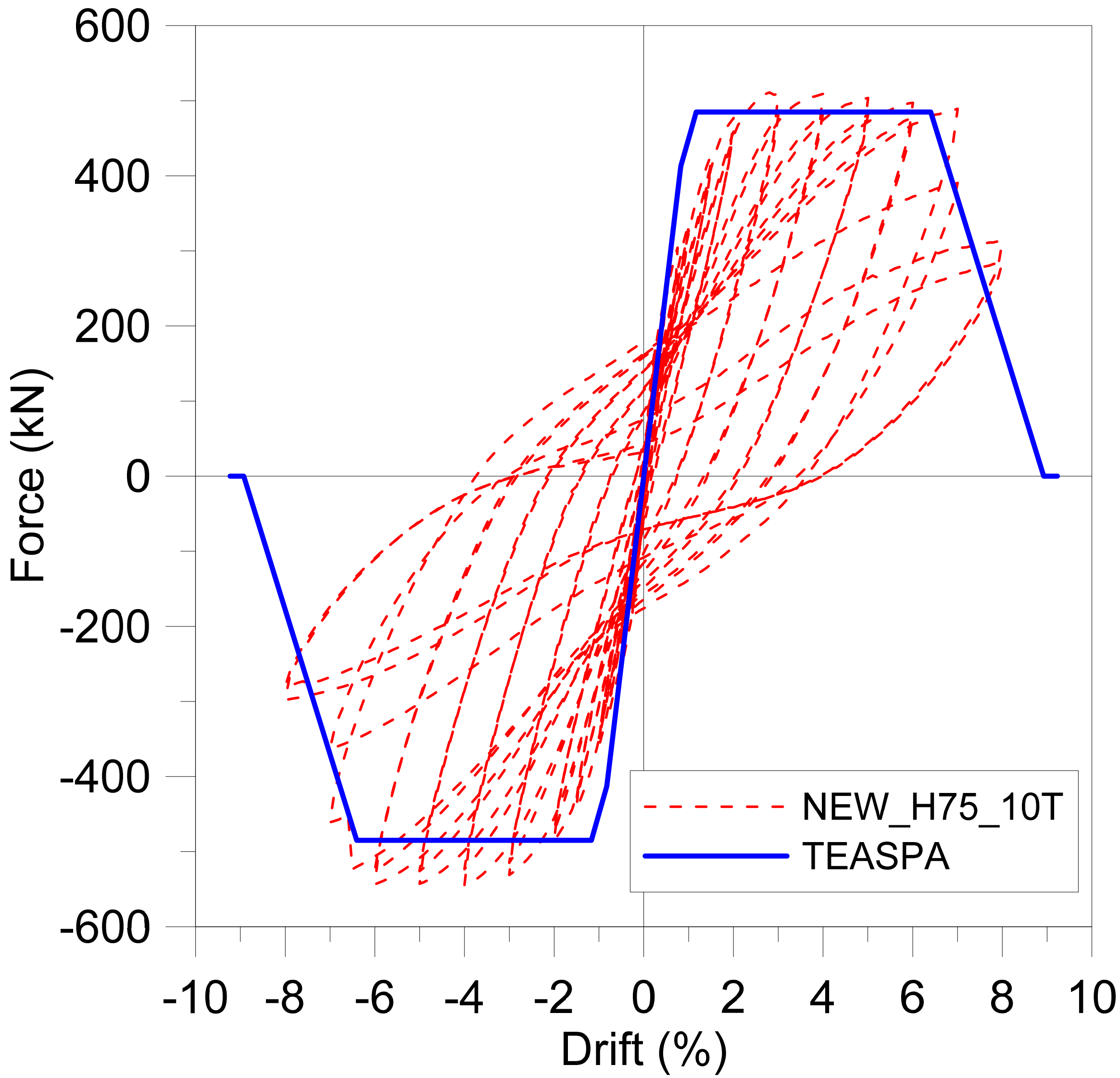
$$V'_{sh} = \frac{1}{4}\left(\frac{A'_h f'_{yt} D_2}{s}\right) \times (1-\alpha)$$

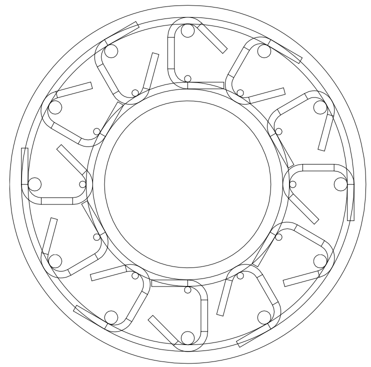
D65 test result





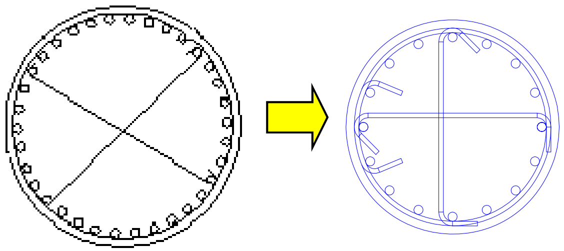
H75 test result



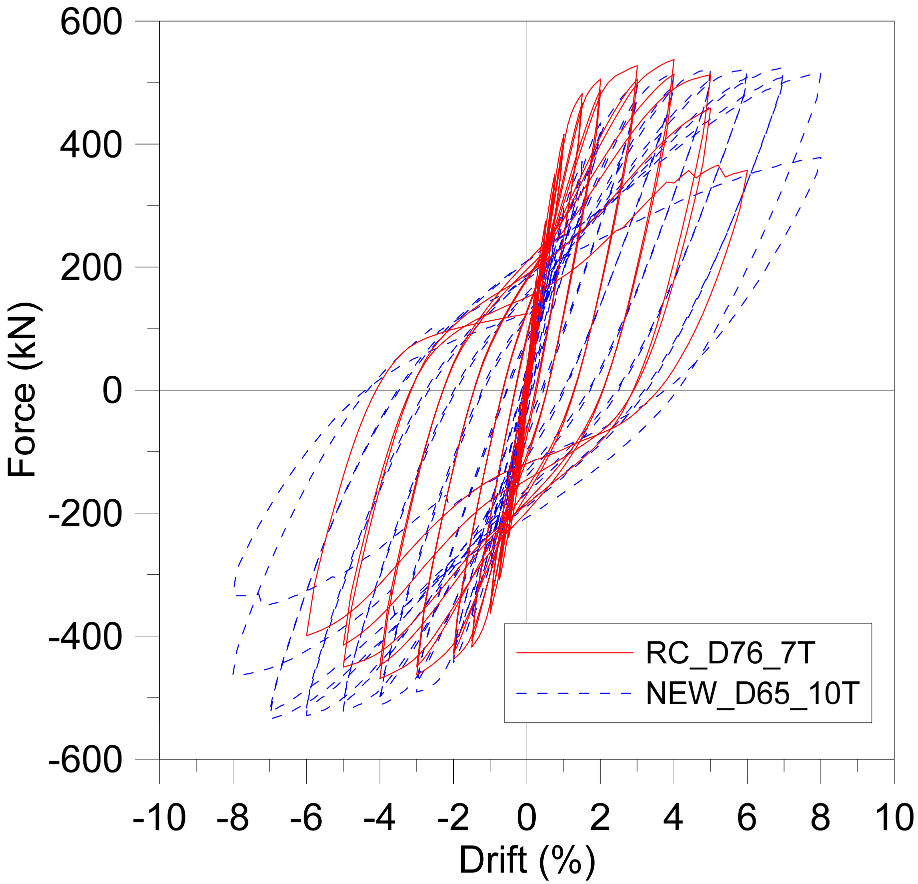


Comparison: RC vs. New RC

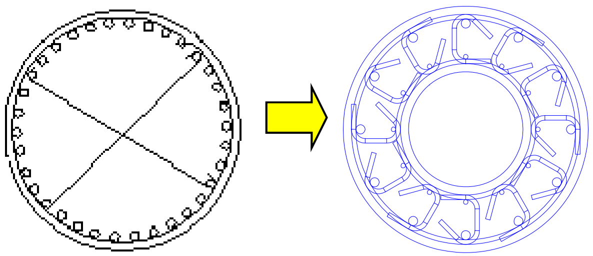
D76



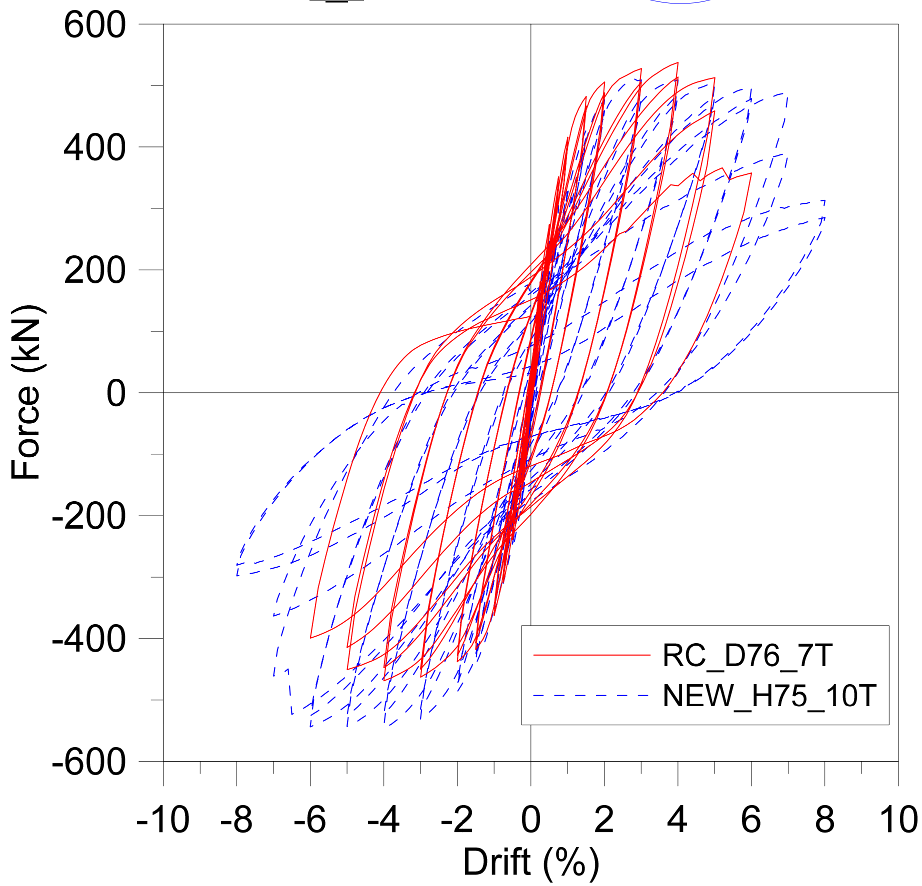
D65



D76

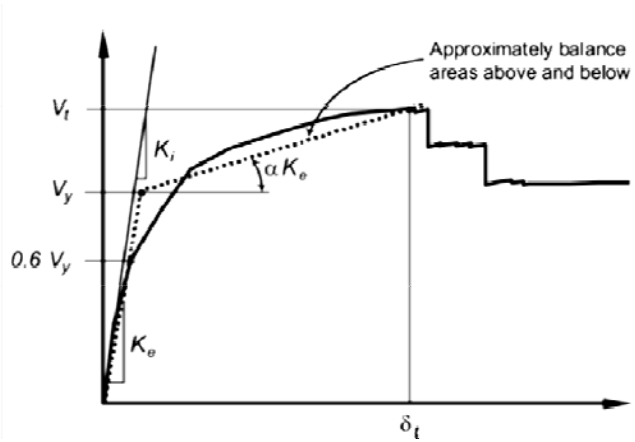


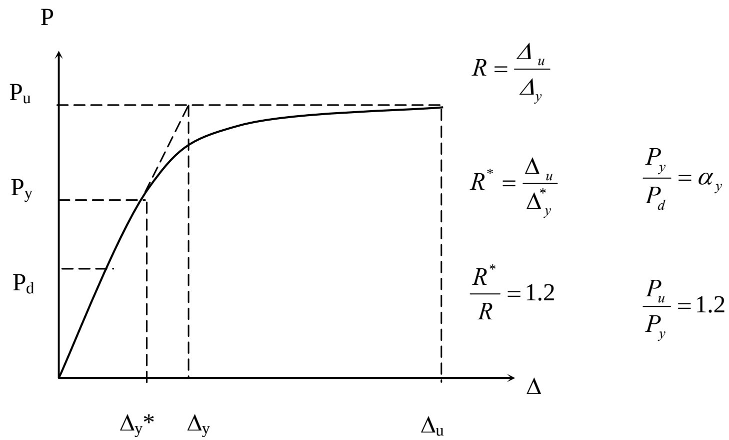
H75



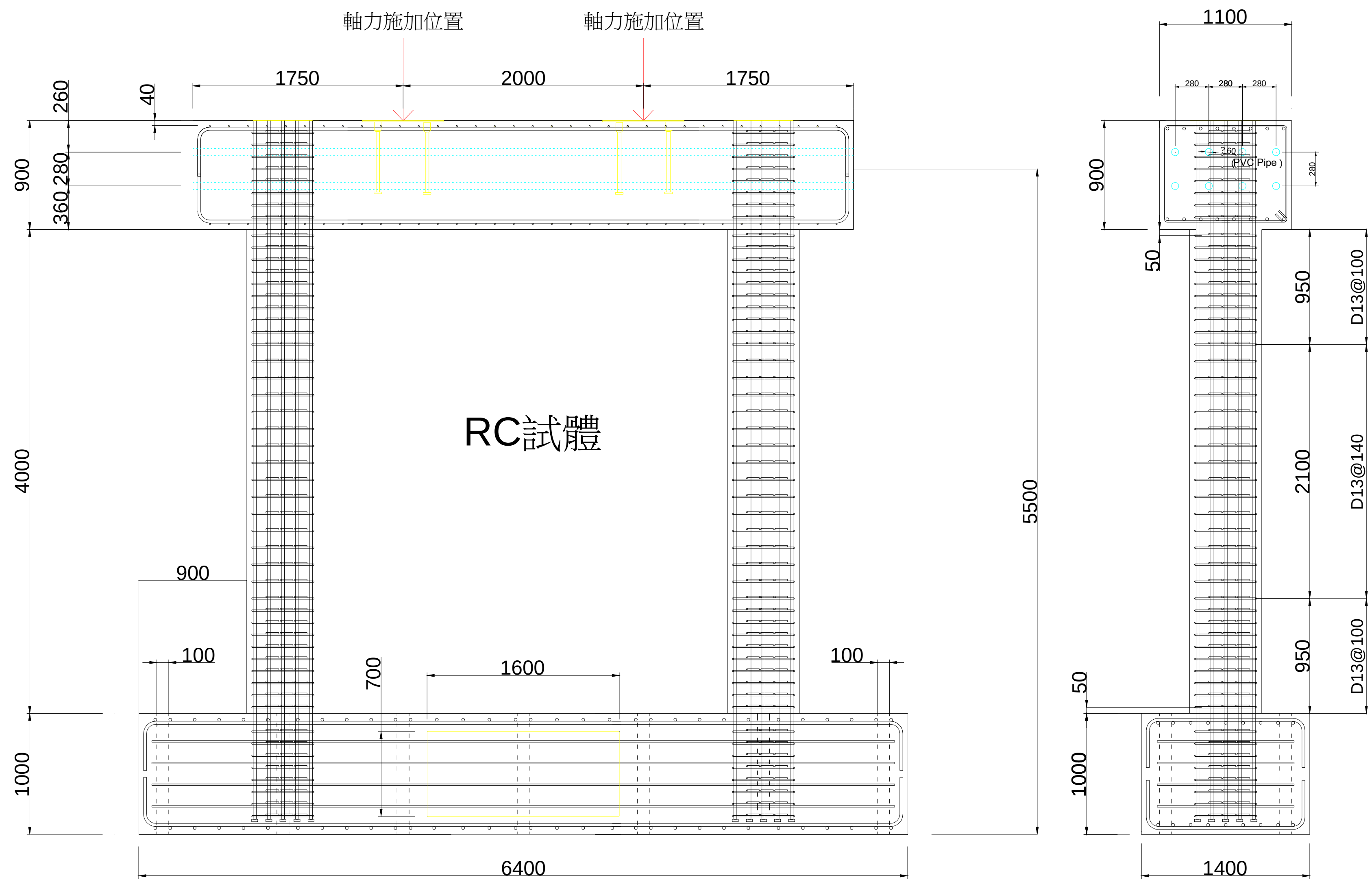
Displacement ductility > 3

Specimen	BMC1	D65	H75
Δ_y (%)	1.00	1.75	1.16
Δ_u (%)	5.54	8.00	7.47
$\mu = \Delta_u / \Delta_y$	5.52	4.58	6.44

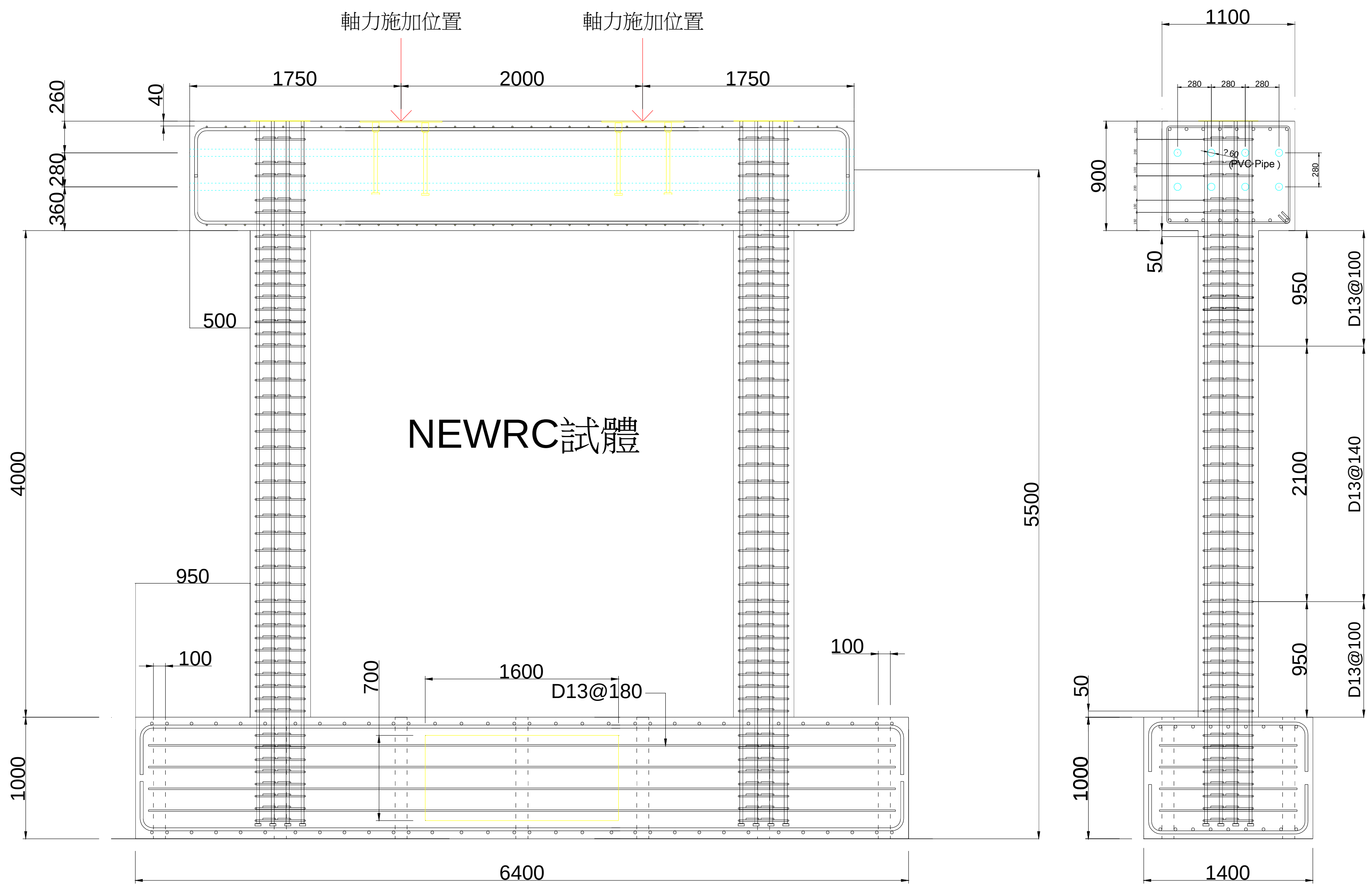




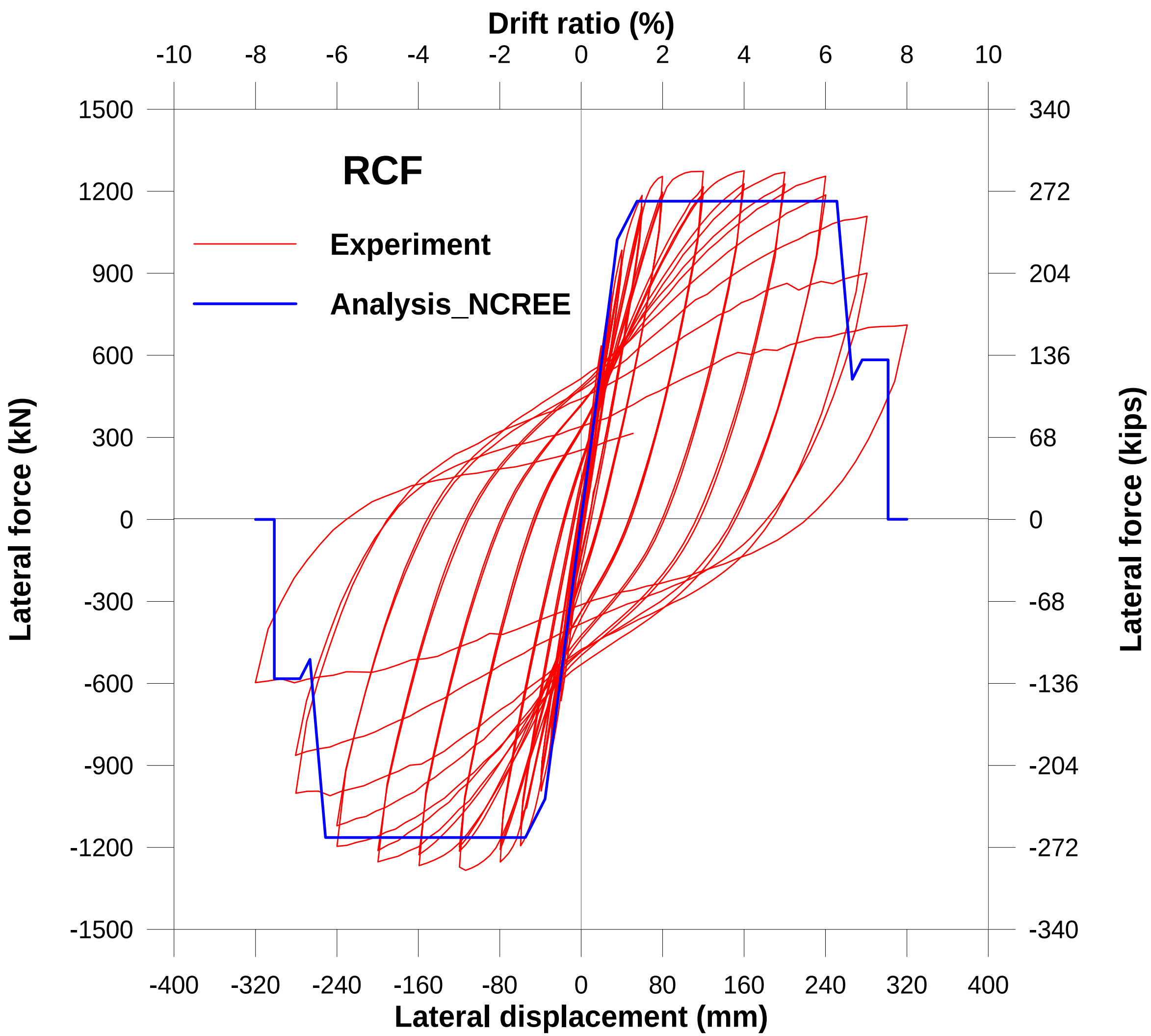
RCF design drawing



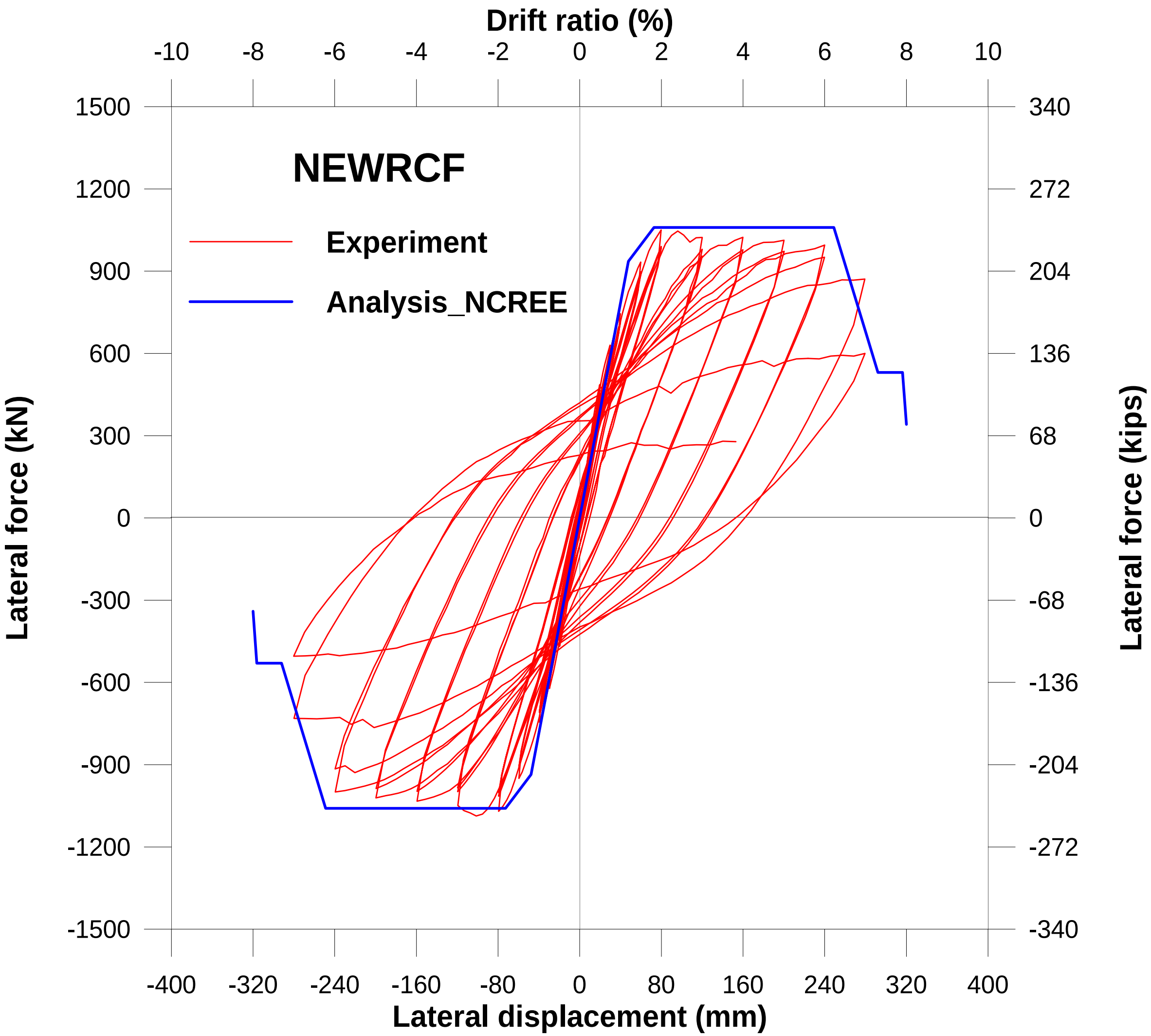
NEWRCF design drawing



RCF test result



NEWRCF test result



Summary

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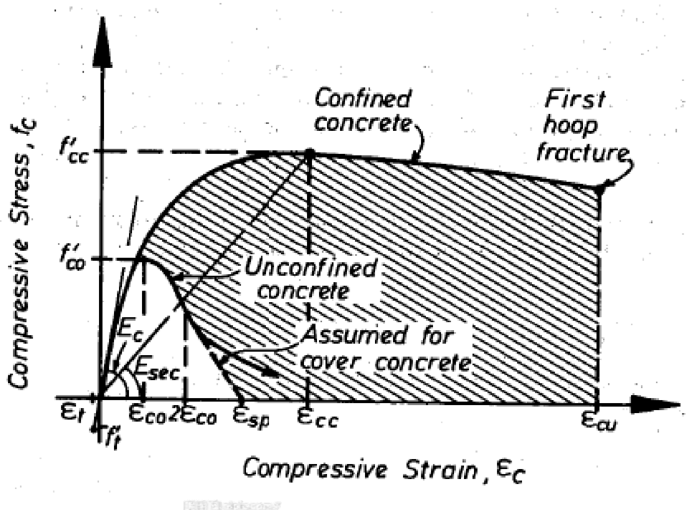
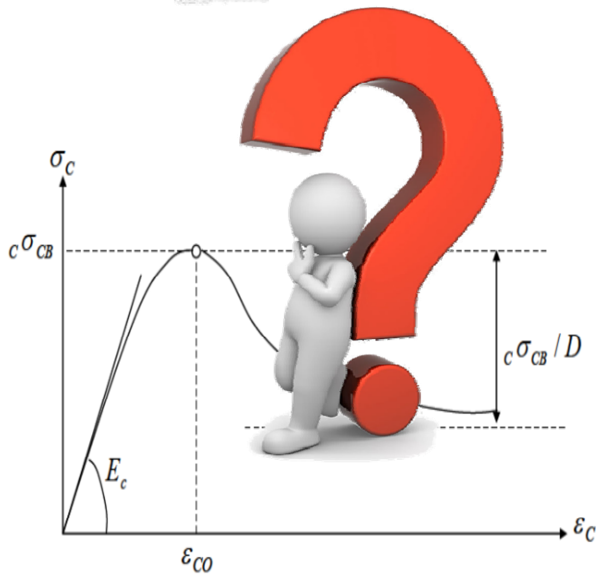
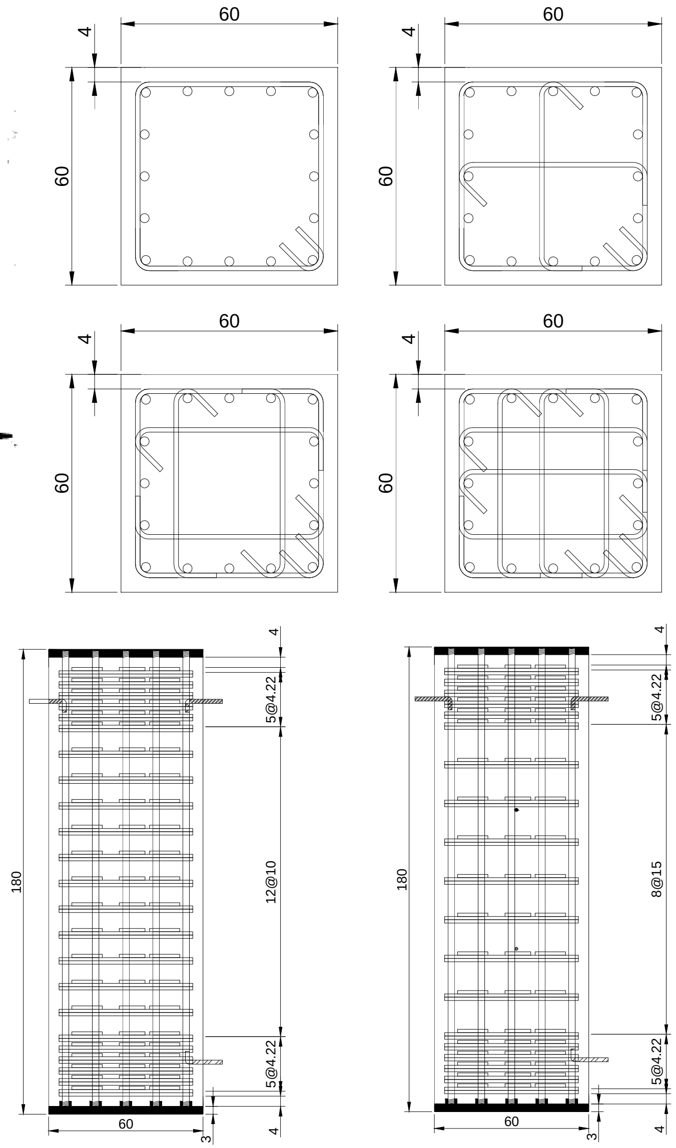
- New RC material
  - save space and material ✓
- Experimental test
  - satisfy design code ✓
- Construction
  - no change on seismic hook ✓
- Performance prediction
  - TEASPA ✓

New RC stress-strain model?







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Thanks for your attentions!