Effect of Base Stiffness in the Performance of Slender Masonry Walls

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THE MASONRY SOCIETY

1

Outline

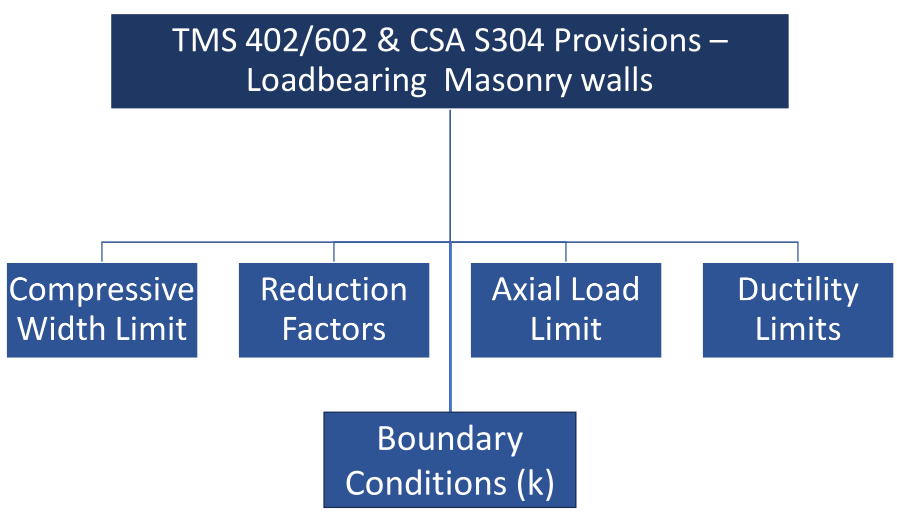
- Background
- Experimental Study
- Numerical Simulation
- Conclusions

James E. Amrhein inspecting a tall masonry wall, 1998.

2

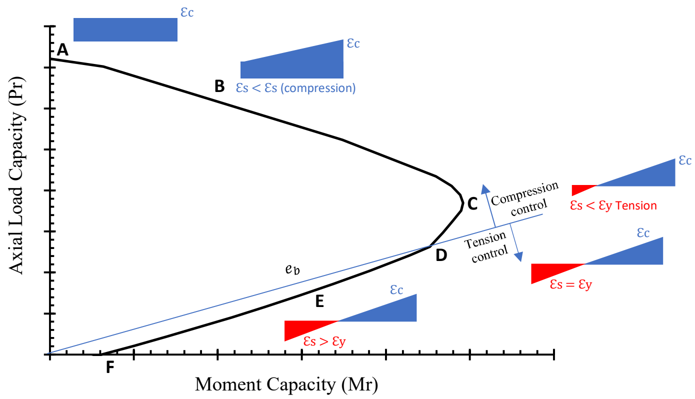
Background

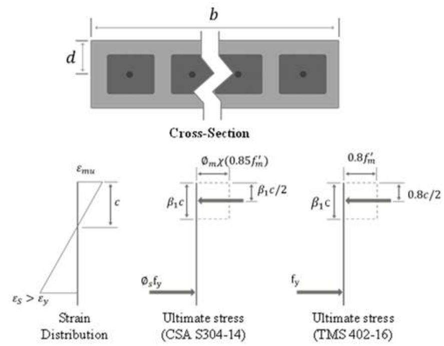
3



4

Strength of Materials and Mechanics

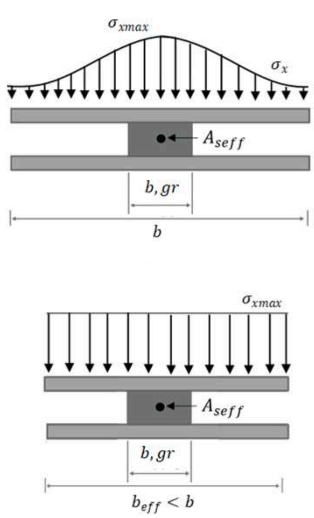


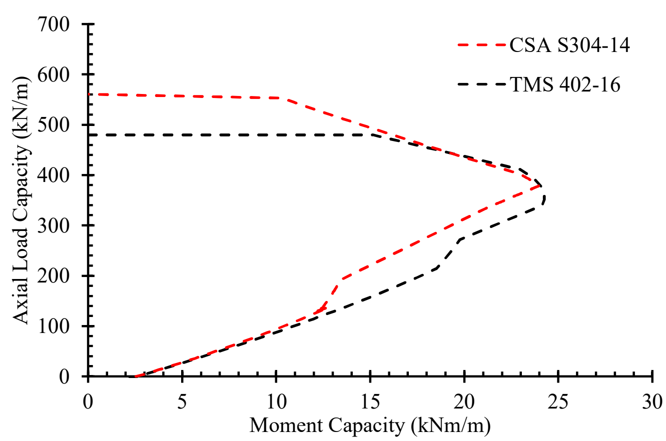


5

Compressive width limit

Standard	Compressive Width Limit
CSA S304-14	$b_{eff} = \min(4t, rebar\ spacing)$
TMS 402-16	$b_{eff} = \min(6t, rebar\ spacing, 72\ inches)$

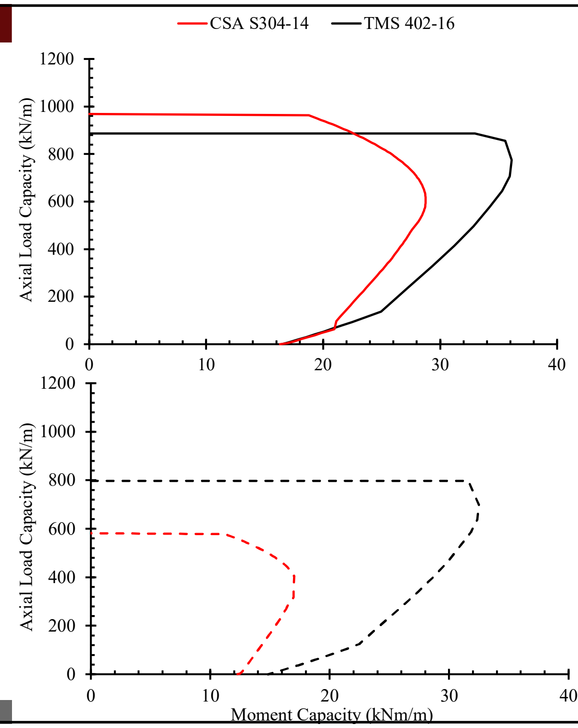




6

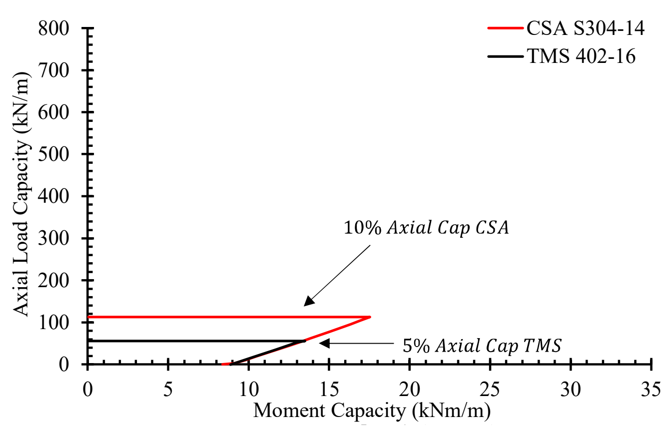
Reduction factors

Standard	Reduction factor
CSA S304-14	Masonry Strength: $\emptyset_m = 0.6$
	Steel Strength: $\emptyset_s = 0.85$
	OOP wall stiffness: $\emptyset_e = 0.75$
TMS 402-16	Flexure Capacity: $\emptyset = 0.9$
	Axial capacity: $\emptyset = 0.9$



7

Axial Load Limits



CSA S304-14

For $\frac{kh}{t} \leq 30$

$P_r(max) = 0.80(0.85\phi_m f'_m A_e)$

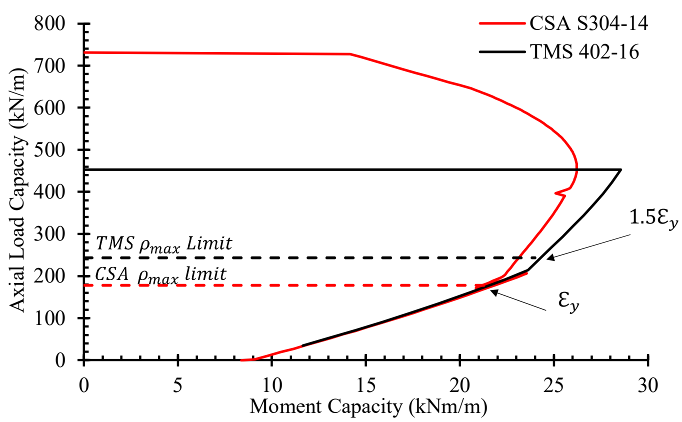
TMS 402-16

For $\frac{h}{t} \leq 30$

$P_r(max) = 0.80\phi_m f'_m A_n\left(1-\left(\frac{h}{140r}\right)^2\right)$

8

Ductility Limits



CSA S304-14

For $\frac{kh}{t} > 30$

All load Combinations (1.25DL + 1.5 L)

TMS 402-16

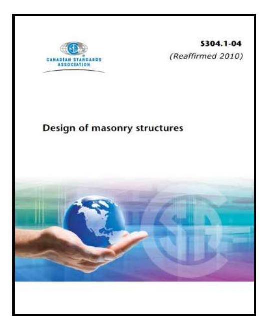
For all $\frac{h}{t}$

$D + 0.75L + 0.525Q_e$.

9

CSA S304 requirements for very slender walls

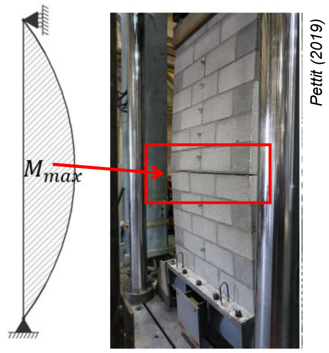
- Minimum wall thickness (t >140 mm)
- Ductile behaviour ($\rho \leq \rho_{balanced}$)
- Low axial loads ($< 10\% \ f'_m A_e$)
- Pinned-pinned boundary conditions ($k = 1.0$)

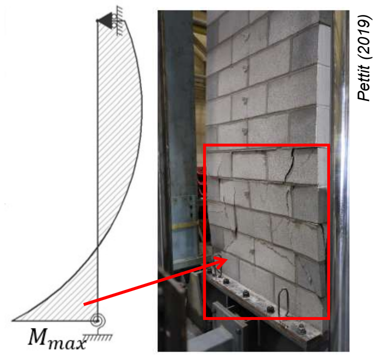


10

Neglecting the stiffness of the foundation: Engineering significance

- Underestimation of capacity
- Moments that occur at the base may lead to unexpected behaviour





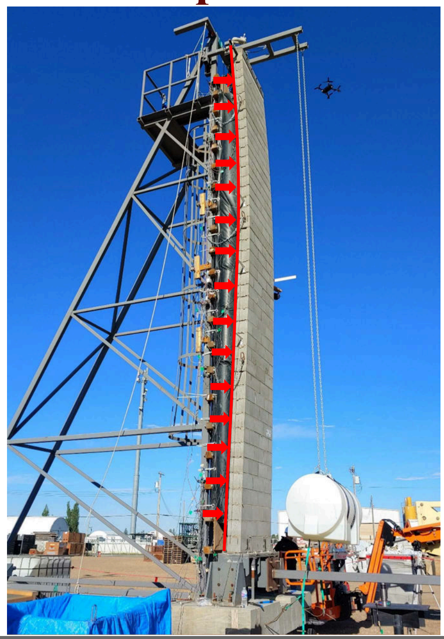
11

Experimental Study

12

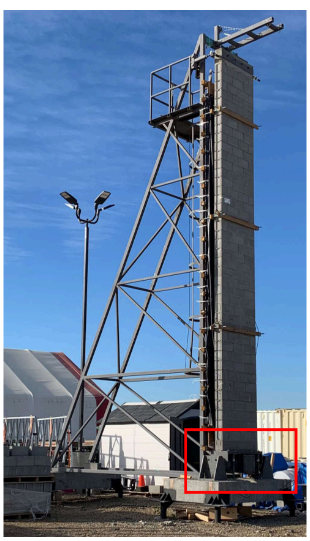
Experimental Study → Experimental Setup

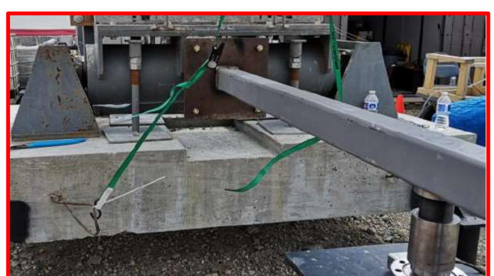
ACI-SEASC Study on Slender Walls, 1982



13

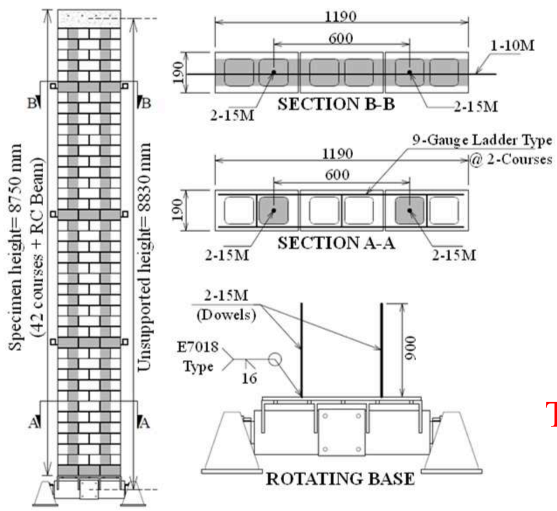
Experimental Study → Different Base Conditions

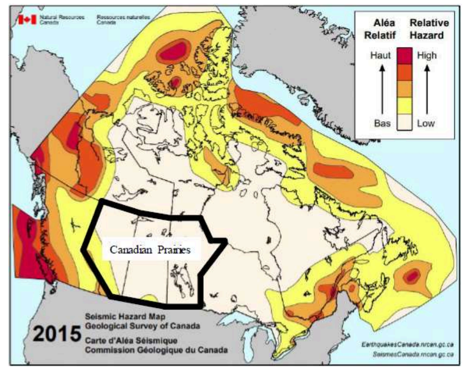




14

Experimental Study → Details of Specimens





Typical reinforcement details for low-seismic areas in the prairie region of Canada

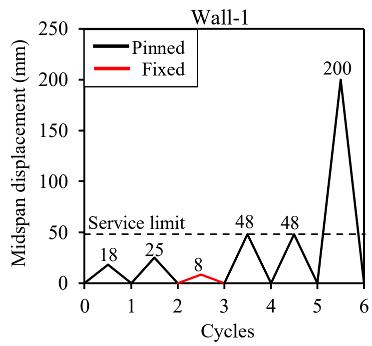
(Alberta, Saskatchewan, and Manitoba)

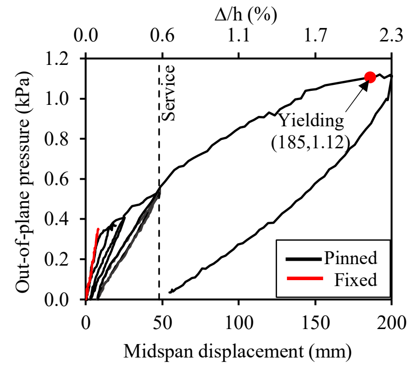
15

Experimental Results

16

Experimental Results → Test Procedure (Wall-1)





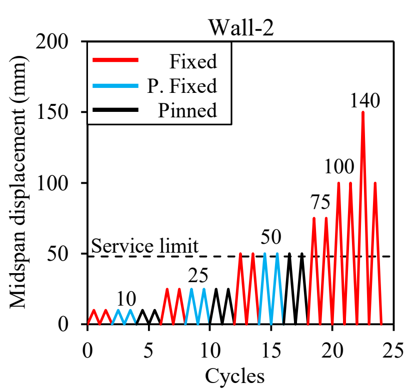
Baseline wall

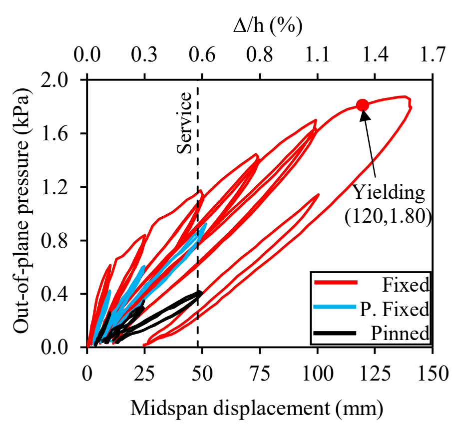
17

Experimental Results → Test Procedure (Wall-2)

Note:

*P. Fixed= 1150 kN-m/rad**

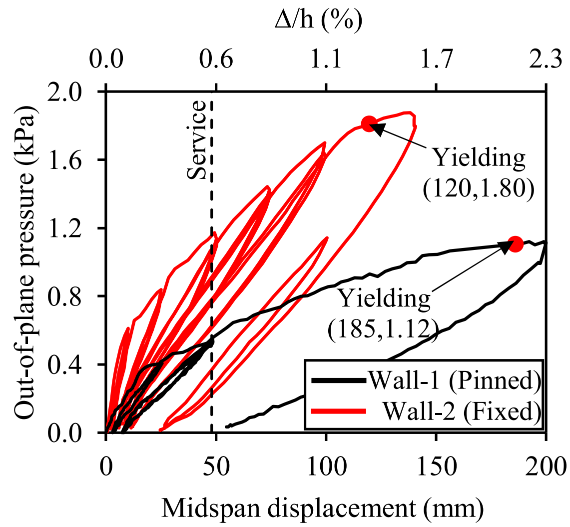




18

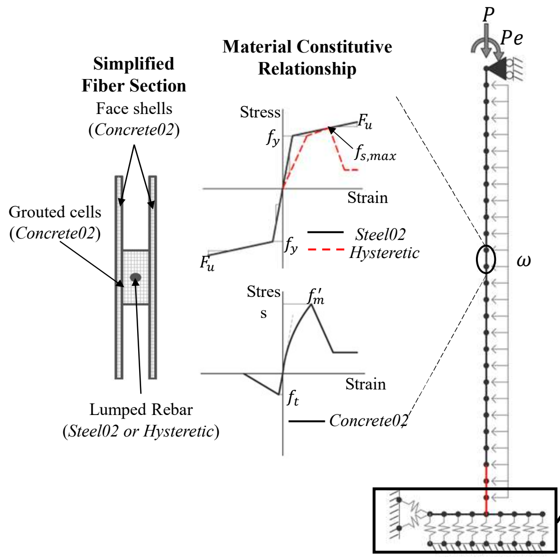
Experimental Results → Wall-1 and Wall-2 Comparison

VS

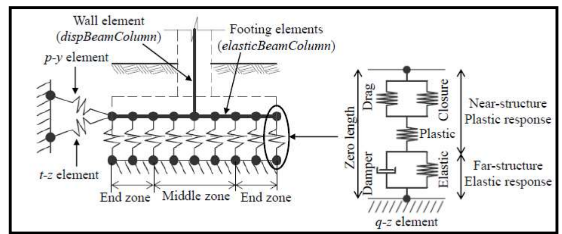


Soil-structure interaction Analytical Study

Numerical Simulation → FE Macro Model

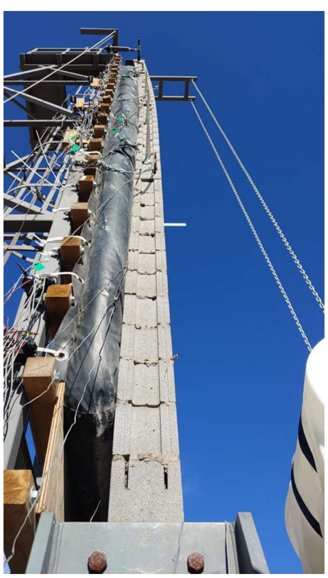


Beam-on-Nonlinear-Winkler-Foundation (BNWF) – Harden et al. 2005

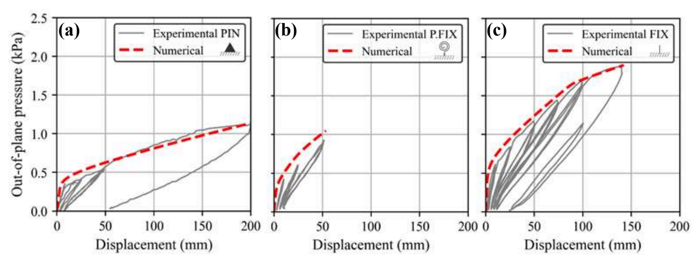


21

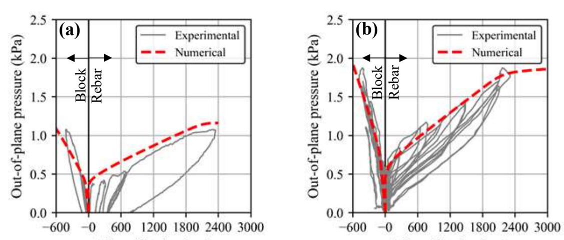
Numerical Simulation → Model Validation



Global



Local

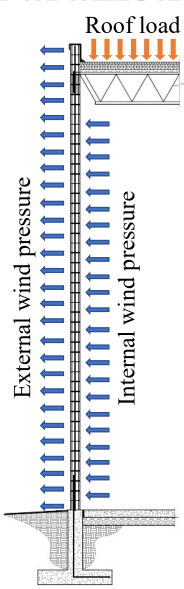


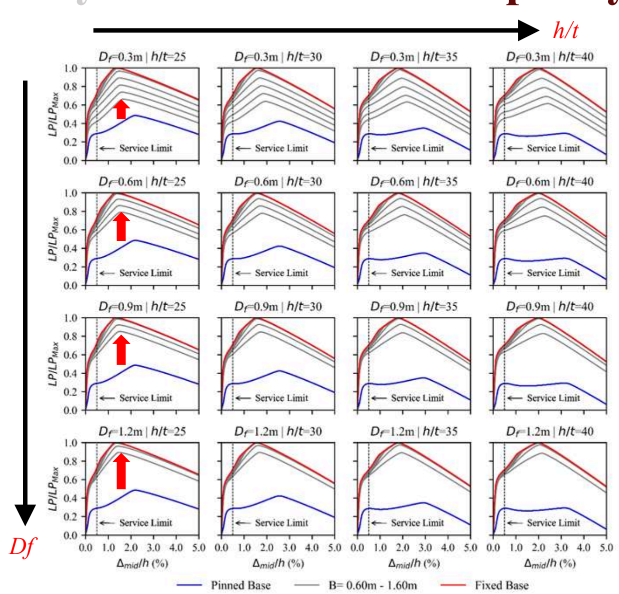
22

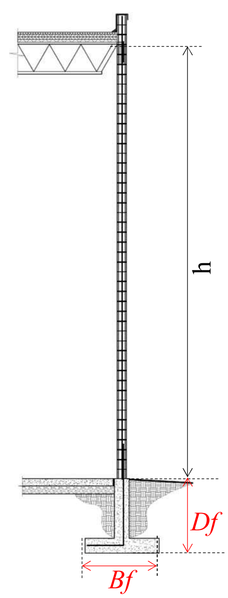
Parametric Study

23

Parametric Study Results → OOP Capacity on SAND

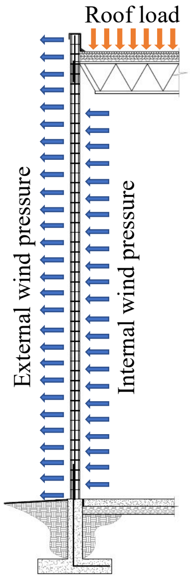


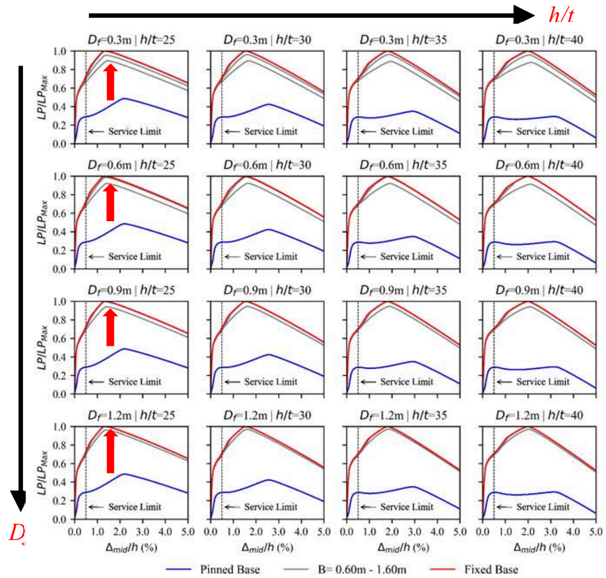


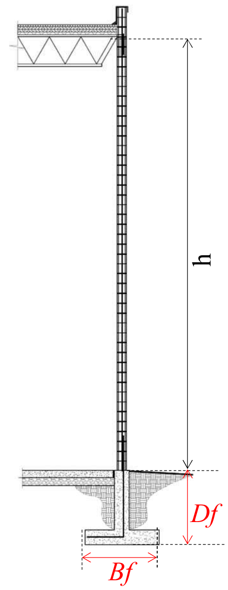


24

Parametric Study Results → OOP Capacity on CLAY







Parametric Study Results → Equivalent RBS per Soil type

Sand

D_f (m)	B_f (m)	Loose	Medium	Dense
		RBS (kN-m/rad)		
0.3	0.6	80 – 95	200 – 290	320 – 460
0.3	0.8	210 – 300	530 – 730	1,500 – 2,260
0.3	1.0	720 – 840	4,800 – 5,600	40,600 – 41,550
0.3	1.2	4,600 – 5,300	14,000 – 14,960	56,200 – 56,400
0.6	0.6	170 – 250	300 – 430	420 – 600
0.6	0.8	490 – 650	1,300 – 1,780	10,400 – 19,950
0.6	1.0	3,000 – 3,400	9,800 – 10,600	43,600 – 44,050
0.6	1.2	7,250 – 7,500	24,800 – 26,600	56,800 – 56,900
0.9	0.6	250 – 400	350 – 550	510 – 700
0.9	0.8	950 – 1,170	3,800 – 4,850	28,800 – 30,550
0.9	1.0	5,200 – 5,500	17,800 – 19,600	45,250 – 45,450
0.9	1.2	8,700 – 9,070	28,350 – 28,500	57,200 – 57,250
1.2	0.6	360 – 500	490 – 660	700 – 870
1.2	0.8	2,100 – 2,500	8,500 – 9,500	32,300 – 33,100
1.2	1.0	6,250 – 6,500	22,100 – 22,250	45,800 – 45,900
1.2	1.2	11,700 – 12,300	28,800 – 28,900	57,500 – 57,550

Clay

D_f (m)	B_f (m)	Soft	Medium	Stiff
		RBS (kN-m/rad)		
0.3	0.6	110 – 150	250 – 370	350 – 520
0.3	0.8	240 – 340	640 – 860	2,700 – 4,100
0.3	1.0	580 – 750	8,500 – 8,900	23,200 – 23,800
0.3	1.2	3,120 – 3,450	12,850 – 13,000	32,900 – 33,150
0.6	0.6	140 – 200	300 – 450	430 – 600
0.6	0.8	300 – 410	1,800 – 3,000	8,300 – 12,000
0.6	1.0	950 – 1,250	9,300 – 9,520	24,650 – 24,950
0.6	1.2	3,450 – 3,700	12,900 – 13,000	32,750 – 33,000
0.9	0.6	140 – 190	350 – 500	500 – 700
0.9	0.8	340 – 450	4,200 – 5,350	15,500 – 16,550
0.9	1.0	1,650 – 1950	9,700 – 9,850	25,200 – 25,500
0.9	1.2	3,800 – 4,000	13,000 – 13,150	33,050 – 33,300
1.2	0.6	150 – 200	390 – 570	650 – 850
1.2	0.8	400 – 480	5,750 – 6,150	17,150 – 17,650
1.2	1.0	1,500 – 1,800	9,700 – 9,850	25,200 – 25,350
1.2	1.2	4,050 – 4,200	13,150 – 13,250	33,350 – 33,600

Parametric Study Results → Elastic Effective Height factors (k)

Increased by 10% →

h/t	RBS (kN-m/rad)	P_e (kN)	P_{cr} (kN)	$k_{calculated}$	$k_{proposed}$
25	80 – 150	146	182 – 200	0.9	1.0
25	170 – 650	146	205 – 259	0.8	0.9
25	> 700	146	262 – 313	0.7	0.8
30	80 – 110	100	128 – 134	0.9	1.0
30	150 – 530	100	140 – 177	0.8	0.9
30	> 580	100	180 – 214	0.7	0.8
35	80	73	99	0.9	1.0
35	110 – 360	73	105 – 129	0.8	0.9
35	> 420	73	131 – 162	0.7	0.8
40	80	58	78	0.9	1.0
40	110 – 360	58	82 – 103	0.8	0.9
40	> 420	58	104 – 125	0.7	0.8

27

Parametric Study Results → Example of using "k"

Equivalent RBS for Sand
Effective Height Factors (k)

Loose Medium Dense

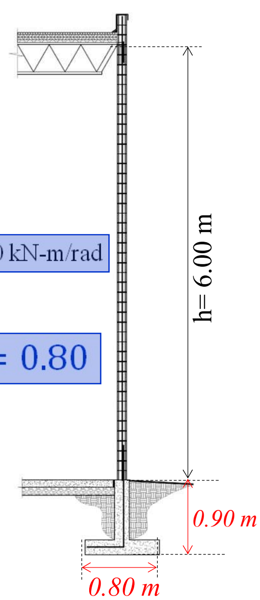
h/t	RBS (kN-m/rad)	P_e (kN)	P_{cr} (kN)	$k_{calculated}$	$k_{proposed}$
25	80 – 150	146	182 – 200	0.9	1.0
25	170 – 650	146	205 – 259	0.8	0.9
25	> 700	146	262 – 313	0.7	0.8
30	80 – 110	100	128 – 134	0.9	1.0
30	150 – 530	100	140 – 177	0.8	0.9
30	> 580	100	180 – 214	0.7	0.8
35	80	73	99	0.9	1.0
35	110 – 360	73	105 – 129	0.8	0.9
35	> 420	73	131 – 162	0.7	0.8
40	80	58	78	0.9	1.0
40	110 – 360	58	82 – 103	0.8	0.9
40	> 420	58	104 – 125	0.7	0.8

1.2 1.2 11,700 – 12,300 28,800 – 28,900 57,500 – 57,550

Loose Sand
h/t= 30
Df= 0.90 m
Bf= 0.80 m

RBS= 950 – 1,170 kN-m/rad

Proposed k for design → $k = 0.80$



28

Conclusions

29

Conclusions

The wall-foundation interaction is an untapped source of stiffness that enhances the out-of-plane performance of masonry walls, increasing their capacity and decreasing their lateral deflections

- The increased capacity may be important for capacity-controlled buildings (performance-based design)

- Even a shallow foundation on weak soil provides some base stiffness, making a pinned base difficult to achieve in the wall-foundation-soil interaction

30

Thank you

31

The Masonry Society

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32