Reinforced Concrete Wall Research Based on the Experience and Observations from the February 2010 Maule, Chile, Earthquake

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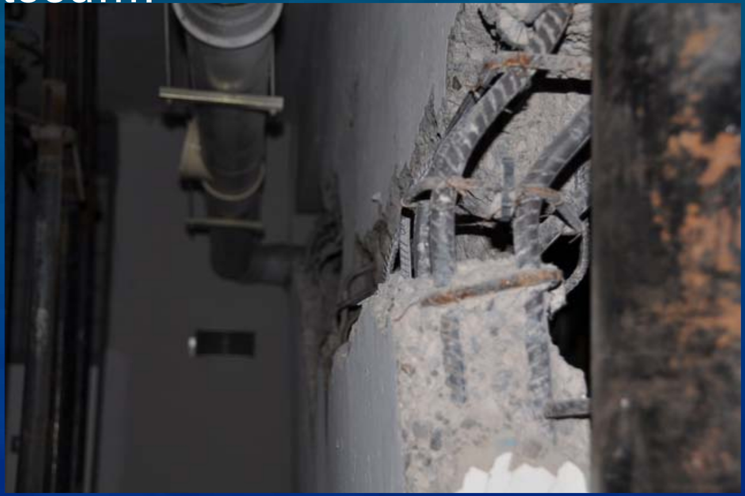
What is the problem?

The effects of structural and wall design parameters for slender walls on overall performance are not well understood. Importantly, failure mechanisms also are not well understood….



San Pedro de la Paz, Building A (Alto Huerto)

Photos courtesy of Jack Moehle, UC Berkeley

What is the problem?

Walls designed essentially to US customary practice, aside from confinement detailing, *appear* to have exhibited out-of-plane buckling due to slenderness.

Consensus of the experts is that this observed behavior has *serious implications* for US design practice, and is not well understood.

Current US model building codes do not have a limit on wall slenderness, the poor behavior of walls as observed in Chile could be realized in the US.

Focus of Study

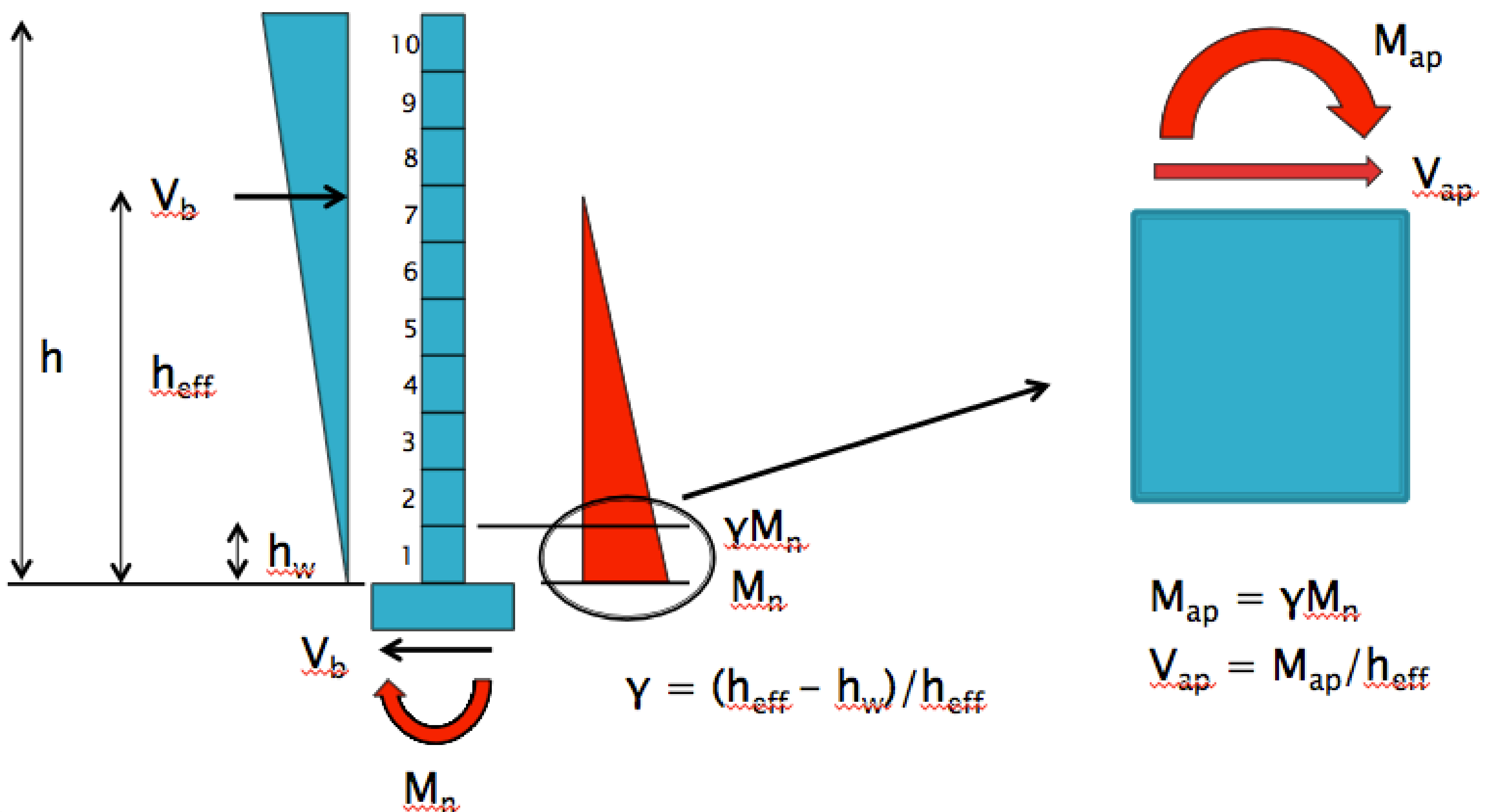
- Study the performance of slender walls to determine how typical design parameters affect the ultimate capacity
- Parameters of interest
  - Flexural reinforcement configuration (uniform or bundled in boundary element region)
  - Flexural reinforcement ratio
  - Axial load level
  - Wall configuration
  - Splices
  - Lateral loading protocol

Proposed Loading

- Cyclic lateral loading via static load protocol with imposed drift levels up to about 2%
- Constant shear span ratio (M/V^*L_w) in the range of 2-4
  - Consistent with comparable wall tests
- Static and variable axial load application
  - Static 10% $f_c'A_g$ axial load for majority of tests
  - Vary axial load between 5-10% $f_c'A_g$ based on cyclic direction to mimic effects of unintentional wall coupling (and rocking)

Proposed Static Cyclic Loading

First Floor Simplification

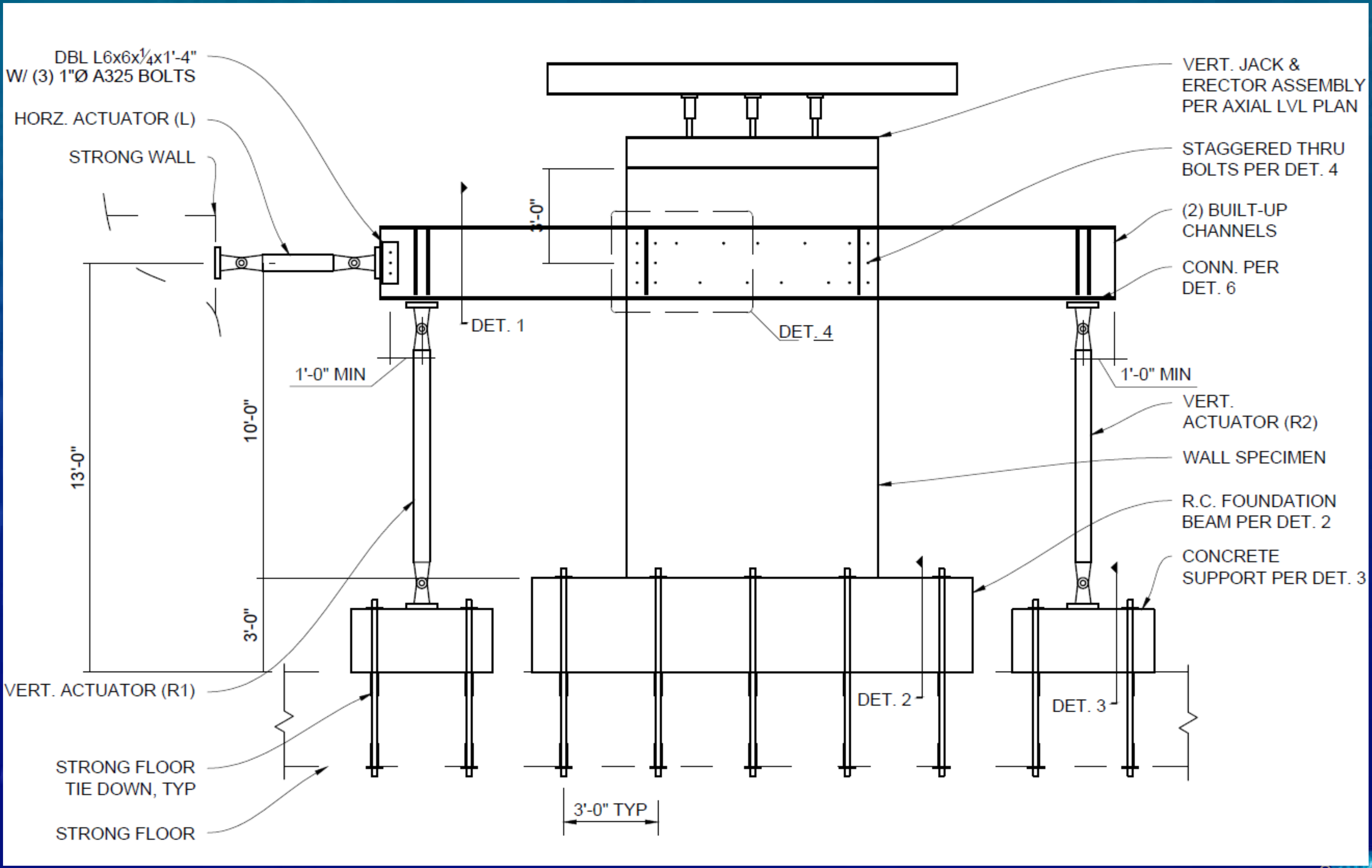


$\Upsilon = (h_{eff} - h_w)/h_{eff}$

$M_{ap} = \Upsilon M_n$

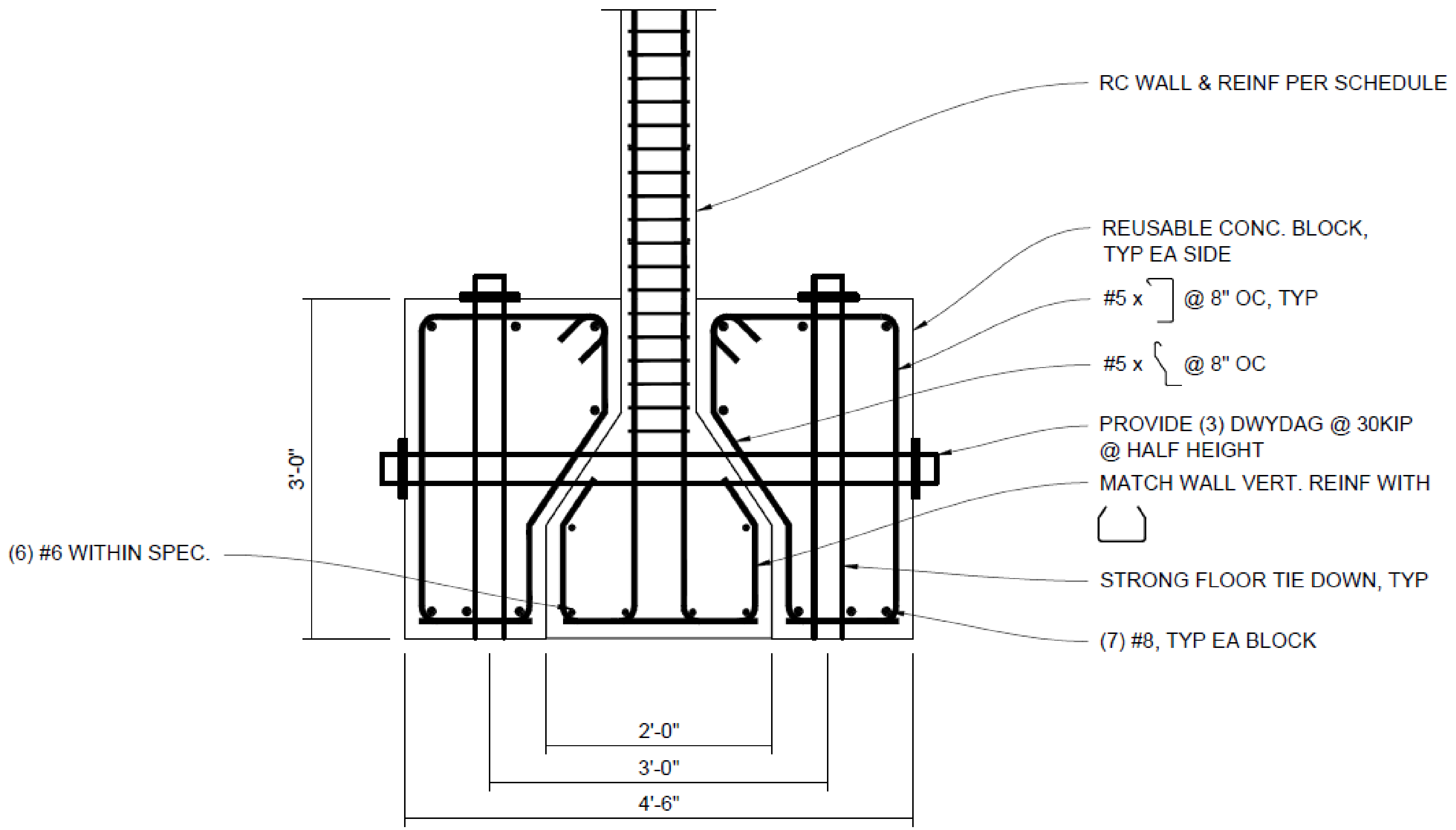
$V_{ap} = M_{ap}/h_{eff}$

Elevation



engineering laboratory

Base Detail



DETAIL 2: FOUNDATION BEAM (REUSABLE OPTION)

UW Planar Wall Database (Pugh 2012)

Courtesy of Dawn Lehman U. of Washington

Specimen ID	Author	Load Type	l_w/t	$M/(Vl_w)$	λ_n^1	α_v^2	V_{max}/V_n	Δ_y (%)	Δ_u (%)	Tension Controlled (Y/N)	Failure Mode
WSH1	Dazio, et al.	UC	13.3	2.28	0.055	2.01	0.44	0.24	1.04	Y	BR
WSH2	Dazio, et al.	UC	13.3	2.28	0.063	2.27	0.53	0.27	1.75	Y	BR
WSH3	Dazio, et al.	UC	13.3	2.28	0.064	2.92	0.67	0.32	2.07	Y	BR
WSH4	Dazio, et al.	UC	13.3	2.28	0.063	2.77	0.62	0.29	1.60	Y	CB
WSH5	Dazio, et al.	UC	13.3	2.28	0.137	2.81	0.59	0.20	1.52	Y	BR
WSH6	Dazio, et al.	UC	13.3	2.26	0.114	3.58	0.83	0.31	2.04	Y	CB
W1	Liu	UC	6.07	3.13	0.077	2.31	0.46	0.64	2.98	Y	CB
W2	Liu	UC	6.07	3.13	0.036	1.67	0.37	0.55	2.91	Y	BR
PW1	Lowes, et al.	UC	20.0	2.84	0.099	3.51	0.71	0.38	1.53	Y	BR
PW2	Lowes, et al.	UC	20.0	2.08	0.133	5.31	1.11	0.45	1.50	Y	CB
PW3	Lowes, et al.	UC	20.0	2.00	0.104	4.41	0.88	0.24	1.22	Y	CB
PW4	Lowes, et al.	UC	20.0	2.00	0.122	4.63	0.88	0.40	1.01	Y	CB
RW1	Thomsen, et al.	UC	12.0	3.13	0.105	2.57	0.50	0.48	2.26	Y	BR
RW2	Thomsen, et al.	UC	12.0	3.13	0.092	2.65	0.52	0.55	2.35	Y	CB
R1	Oesterle, et al.	UC	18.8	2.35	0.004	1.14	0.23	0.15	2.30	Y	BR
R2	Oesterle, et al.	UC	18.8	2.35	0.004	2.05	0.42	0.34	2.89	Y	BR
S5	Vallenas, et al.	M	21.2	1.60	0.048	6.81	0.85	0.31	1.47	Y	CB
S6	Vallenas, et al.	UC	21.2	1.60	0.048	6.42	0.80	0.32	1.65	Y	CB
WR20	Oh, et al.	UC	7.50	2.00	0.104	3.00	0.76	0.35	2.82	Y	CB
WR10	Oh, et al.	UC	7.50	2.00	0.098	2.87	0.65	0.47	2.82	Y	CB
WR0	Oh, et al.	UC	7.50	2.00	0.108	2.97	0.74	0.52	2.14	Y	CB

[1] Axial Load Ratio Including Self-Weight ($P/(A_g f'_c)$)

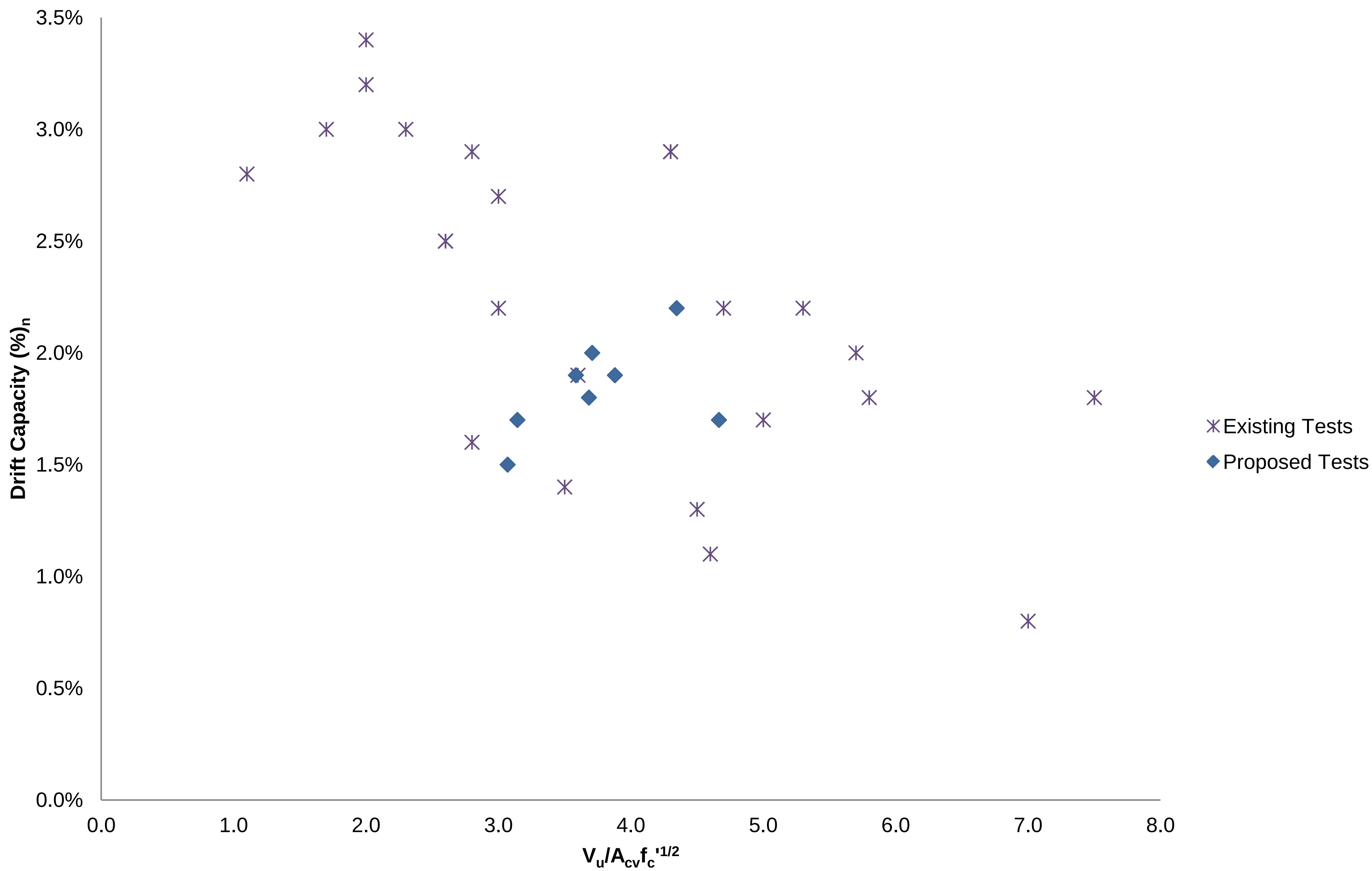
[2] Shear Demand ($V_{max} = \alpha_v(A_{cv}\sqrt{f'_c(psi)})$)

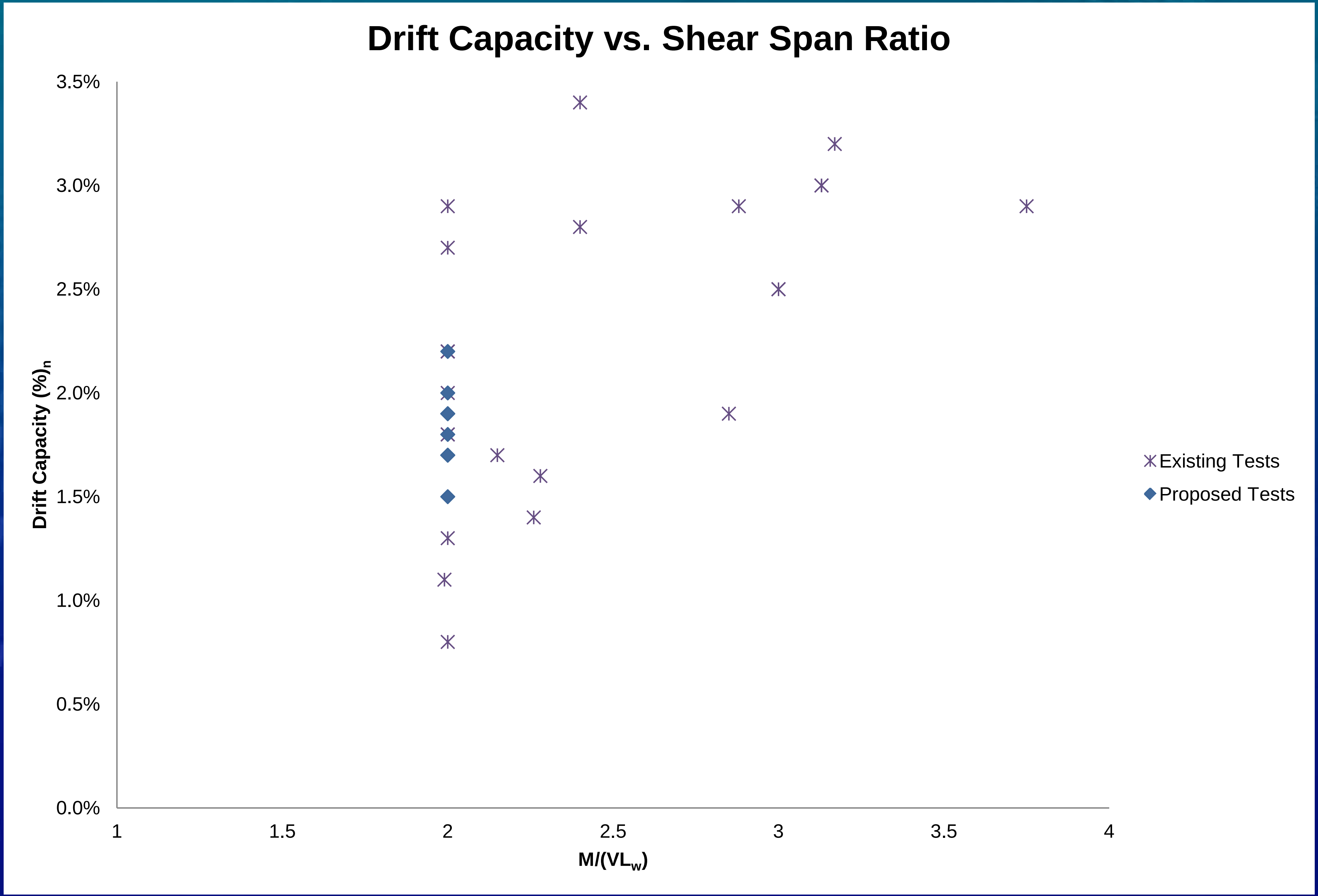
UW Building Inventory of Planar Walls

Courtesy of Dawn Lehman U. of Washington

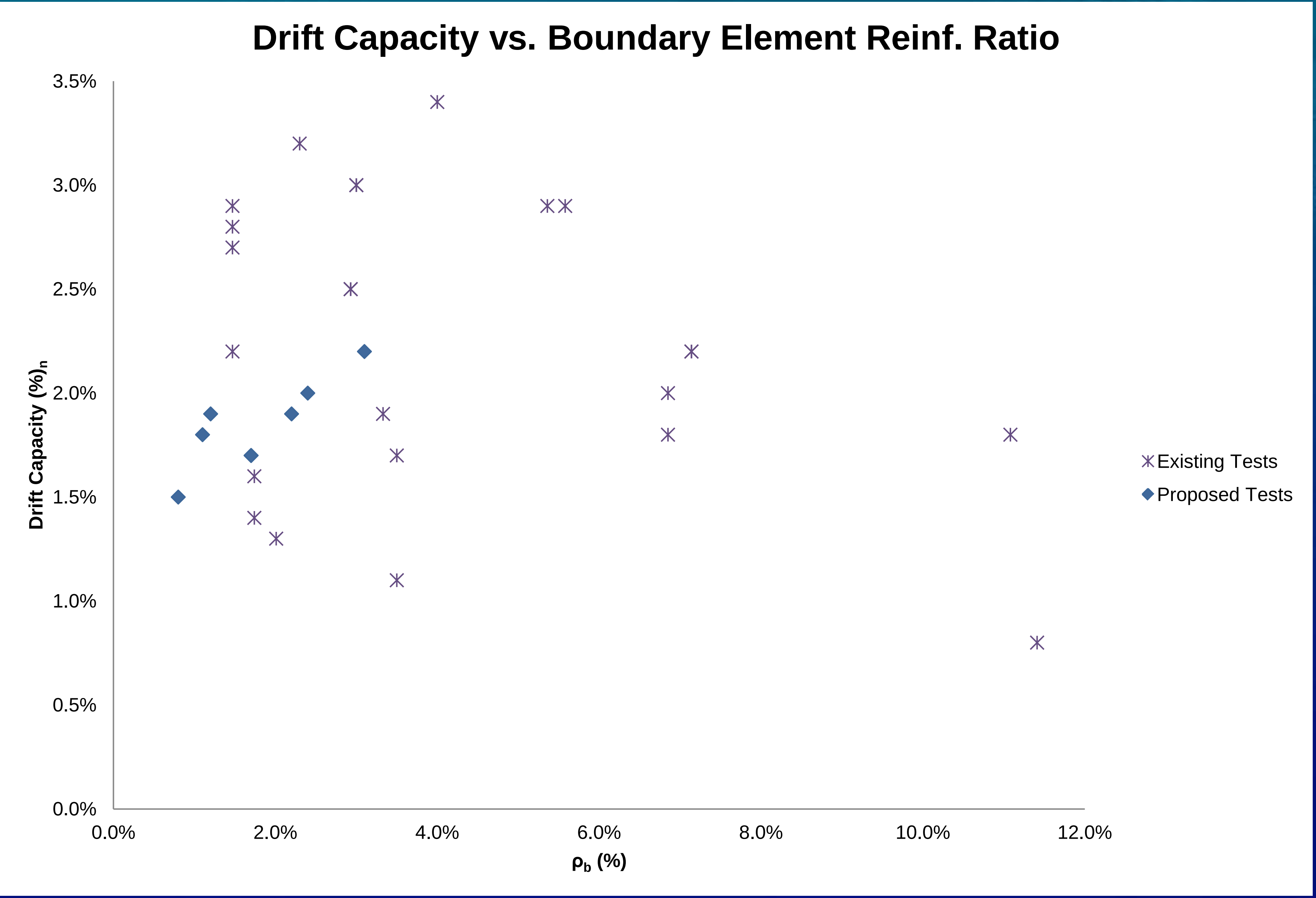
Wall Design Characteristic	Min. Value	Avg. Value	Max. Value	Coeff. of Var.	Prototype Design Value
Thickness	12 in	21.9 in.	30 in	0.270	18 in.
Length	4.3 ft	24.3 ft.	44.5 ft	0.463	30 ft.
Boundary-element longitudinal reinforcement ratio	1.54%	3.22%	4.70%	0.306	3.5%
Mid-span vertical reinforcement ratio	0.21%	0.50%	0.99%	0.575	0.25%
Gross vertical reinforcement ratio	0.31%	0.98%	1.81%	0.544	1.4%
Mid-span horizontal reinforcement ratio	0.24%	0.46%	1.38%	0.688	0.27%

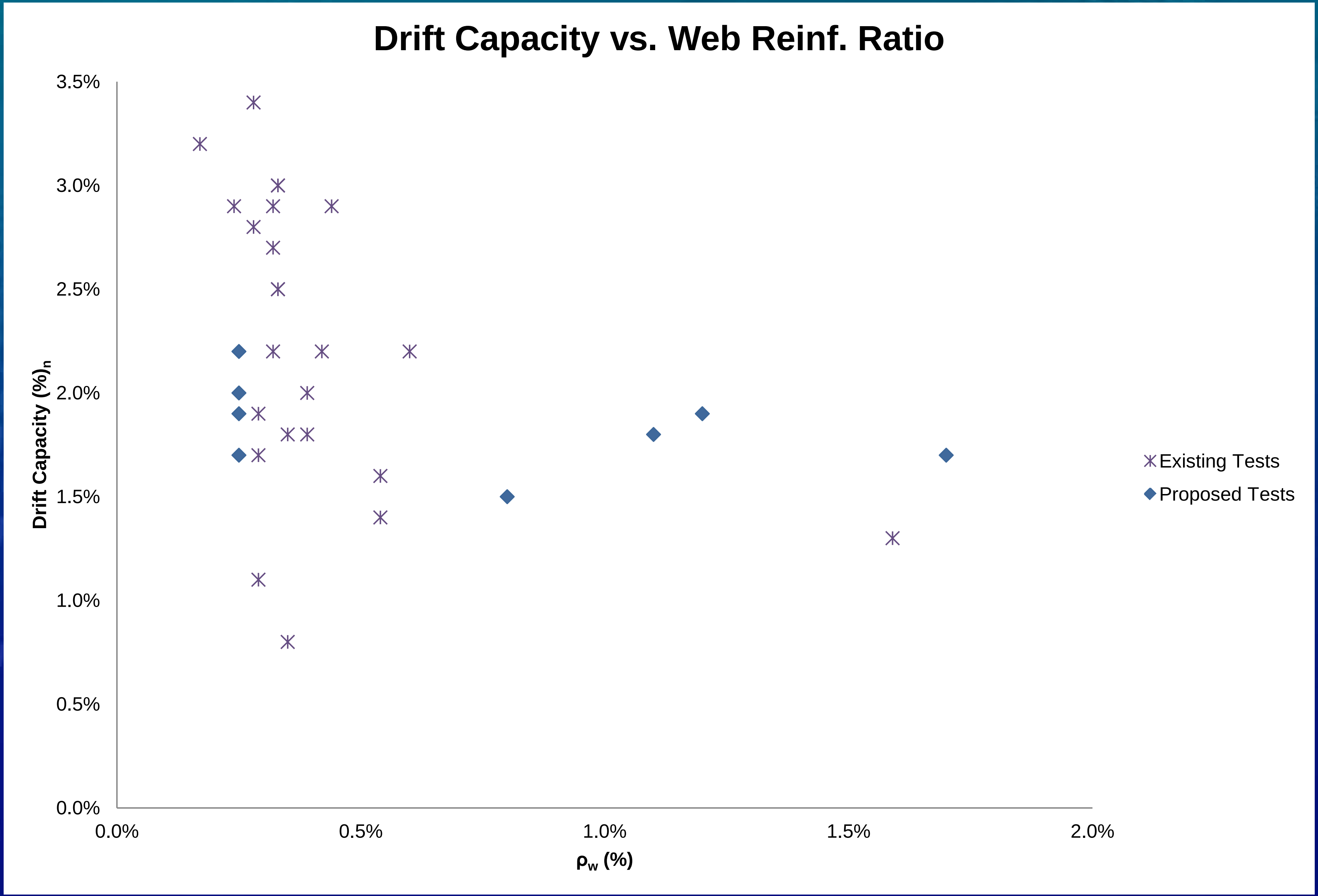
Drift Capacity vs. Applied Shear Stress



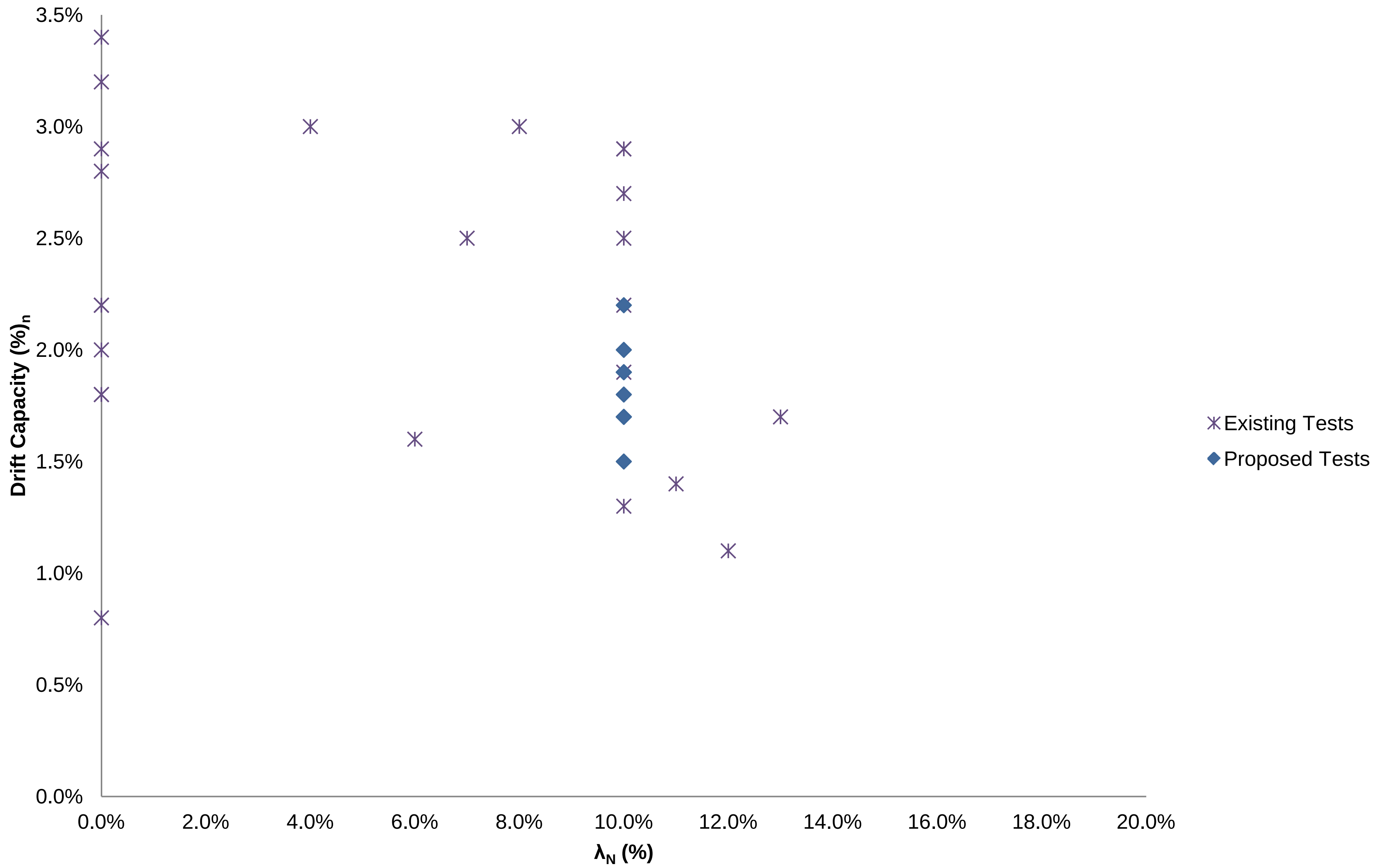


Drift Capacity vs. Shear Span Ratio
3.5%
3.0%
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
Drift Capacity (%)$_n$
1
1.5
2
2.5
3
3.5
4
M/(VL$_w$)
Existing Tests
Proposed Tests


Drift Capacity vs. Boundary Element Reinf. Ratio
Drift Capacity (%)n
3.5%
3.0%
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
0.0%
2.0%
4.0%
6.0%
8.0%
10.0%
12.0%
ρb (%)
Existing Tests
Proposed Tests


Drift Capacity vs. Web Reinf. Ratio
Drift Capacity (%)n
3.5%
3.0%
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
0.0%
0.5%
1.0%
1.5%
2.0%
ρw (%)
Existing Tests
Proposed Tests

Drift Capacity vs. Axial Stress Ratio



Overall Testing Objectives

- Static Cyclic Loading Protocol with up to ~2% Drift
- Slender Walls (200 mm typical)
- Low Reinforcement Ratios (< 2%); Uniform Steel Distribution, Boundary Elements
- Axial load target of 0.10 $f'_c A_g$
- Investigation of Large Tension Strains Early in Loading Protocol
- Initial Program of 15 tests
- Later Tests May Include Retests of Repaired Wall Specimens
- Possible Look at 1970's Wall Designs Strengthened to Improve Performance

Thank you for your attention

Questions?