COLLAPSE ASSESSMENT OF DUCTILE COUPLED WALLS

Project Sponsors:

CHARLES PANKOW FOUNDATION

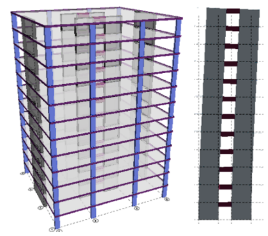
aci Foundation
Knowledge to Practice®

Negin A. Tauberg[1], Kristijan Kolozvari[2], John W. Wallace[2]

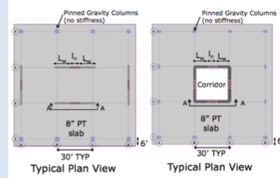
1) PhD Student, University of California, Los Angeles
2) Assistant Professor, California State University, Fullerton
3) Professor, University of California, Los Angeles

UCLA ENGINEERING
Civil and Environmental Engineering
Engineering Sustainable Infrastructure for the Future

Research Objectives

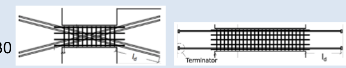


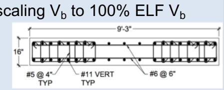
- Define a new ASCE 7 lateral system for Reinforced Concrete Ductile Coupled Walls
  - In lieu of using the same seismic design parameters for Special Reinforced Concrete Shear Walls
- Reliably quantify the performance of Ductile Coupled Wall systems
- Propose and validate seismic response parameters: $\boldsymbol{R}$ = 8, $\boldsymbol{C_d}$ = 8, $\boldsymbol{\Omega_0}$ = 2.5.
- Assess collapse using the FEMA P695 methodology and verify target response parameters
  - Design a set of Archetypes for a range of variables
  - Create a nonlinear model for each Archetype and validate the modeling approach
  - Perform pushover and incremental dynamic analyses to determine the collapse margin ratio

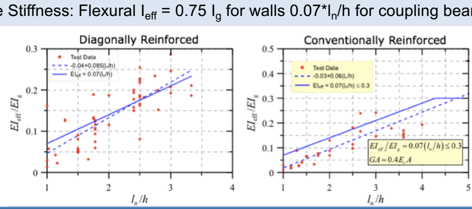


Archetype Design

- 39 Archetype Design Variations
  - Number of stories: 4,6,8,12,18, 24,30
  - Coupling beam type & aspect ratio: Diagonally-reinforced (l_n/h = 2.0, 2.4, 3.0, 3.3)
    Conventionally-reinforced (l_n/h = 3.3,4.0, 5.0)
  - Wall pier configuration: Planar walls for 4-12 story, Flanged walls for 18,24,30 story
- Design per ASCE 7-16 and ACI 318-19 provisions including code change proposals for wall shear amplification and drift capacity check
- Elastic Design using Response Spectrum Analysis and scaling V_b to 100% ELF V_b
  - Seismicity Dmax: S_{DS} = 1.0 g, S_{D1} = 0.6g
  - Accidental torsion effects, I_e = 1.0, ρ = 1.0
- Typical loading: D = 125 psf (100 slab+25 superimposed), L = 40-50 psf, L_{roof} = 20 psf
- Effective Stiffness: Flexural I_{eff} = 0.75 I_g for walls 0.07*l_n/h for coupling beams

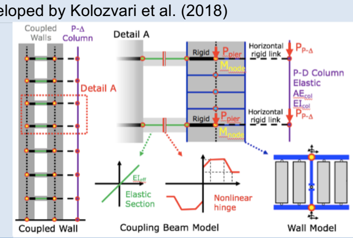






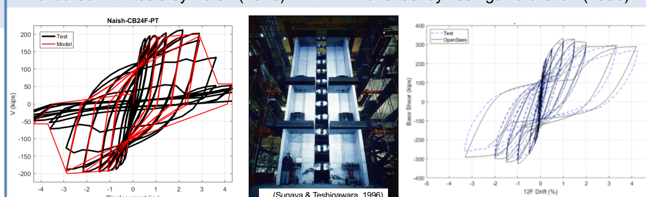
Nonlinear Modeling

- Nonlinear 2D OpenSees MVLEM developed by Kolozvari et al. (2018)
  - Walls: fiber models with defined force-deformation relations
  - Wall shear response:
    a) with a linear elastic shear stiffness
    b) with a model capturing shear-flexure interaction (SFI) effects
  - Coupling beams: elastic beam element with nonlinear shear hinge
  - Tributary mass assigned at nodes
  - P-delta effects considered



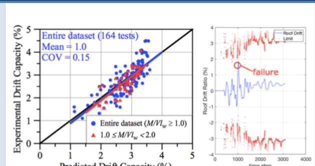
Model Validation

- Coupling beam hysteretic model validated with tests by Naish (2010)
- Model validated with BRI 12-story coupled T-walls test by Teshigawara et al. (1996)

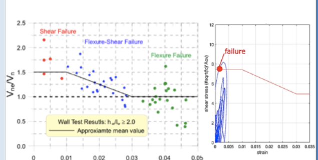


Failure Assessment

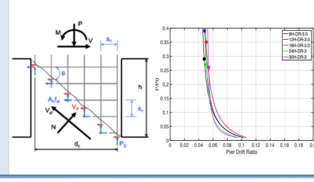
1. Wall Flexural Failure via Drift Capacity Model by Abdullah & Wallace (2018)
   - Accounts for concrete crushing, bar buckling/fracture, and lateral instability
   - Based on robust database of wall tests assessing trends for total displacement or rotation at which wall strength degrades 20% from the peak strength
   - Conservative since "failure" is defined at initiation of strength loss (not collapse)



2. Wall Shear Failure
   - Model per LATBSDC guide (2017) relating tensile strain (or curvature) to shear derived from experimental data from wall tests that experienced shear and flexure-shear failures tracking wall
   - Track shear demand for a given strain

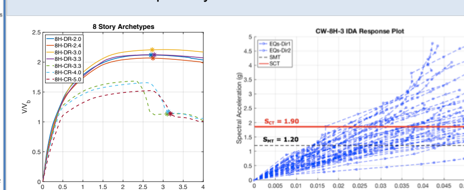


3. Wall Axial Failure using a lateral drift capacity model by Wallace et al. (2008)
   - Defines a lateral drift at which axial failure is thought to occur using a shear friction model with an assumed critical shear crack angle
   - Typically not the governing failure mode



Analysis Results & Conclusions

- Pushover analyses used to obtain system overstrength factor ($\boldsymbol{\Omega_0}$) and ductility ($\boldsymbol{\mu_T}$):
  - Mean $\boldsymbol{\Omega_0}$ of Performance Groups: 1.31 - 2.13 → Ω_0 = 2.5
- Incremental dynamic analyses using the 44 far-field ground motion records of FEMA P695 used to determine the median collapse intensity (S_{CT}) and collapse margin ratio (CMR) using a total system uncertainty β_{TOT} = 0.525:
  - Archetype ACMRs: 1.96 - 2.91 > $ACMR_{10\%}$ = 1.96 → R = 8 Acceptable
  - Mean maximum lateral story drifts at DBE & MCE level shaking from the 44 records, obtained using $\boldsymbol{C_d}$ = 8 and wall I_{eff} = 0.75I_g, do not exceed the ASCE 7 design allowable drift of 2% → Using wall I_{eff} = 0.50I_g: → C_d ~ 5.5 for Design
- Wall shear amplification is needed in design because preliminary analysis results indicated that archetypes, using R = C_d = 8 and designed conforming to ACI 318-14 shear provisions, did not meet the FEMA P695 acceptability criteria due to a high number of shear failures experienced during incremental dynamic analysis.
- Archetypes designed per ASCE 7-16 & ACI 318-19 provisions using R = 8 meet the FEMA P695 acceptability criteria



Archetype ID	Pushover Results: Static Ω	μ_T	IDA Results: S_{MT} [T]	S_{CT} [T]	CMR	Acceptability: SSF	ACMR	Accept. ACMR	Pass /Fail
8H-DR-2.0	2.12	6.27	1.20	1.85	1.54	1.32	2.03	1.56	Pass
8H-DR-2.4	2.07	6.00		1.85	1.54	1.31	2.02		Pass
8H-DR-3.0	2.21	5.28		1.90	1.58	1.29	2.03		Pass
8H-DR-3.3	2.12	5.46		1.85	1.54	1.29	1.99		Pass
Mean:	2.13	5.75				Mean:	2.02	1.96	Pass
8H-CR-3.3	1.68	7.68	1.20	1.85	1.54	1.38	2.12	1.56	Pass
8H-CR-4.0	1.66	7.43		1.85	1.54	1.37	2.10		Pass
8H-CR-5.0	1.52	7.09		1.85	1.54	1.35	2.08		Pass
Mean:	1.62	7.40				Mean:	2.10	1.96	Pass
12H-DR-2.0	1.44	6.62	0.89	1.29	1.46	1.41	2.05	1.56	Pass
12H-DR-2.4	1.49	6.02		1.29	1.46	1.38	2.01		Pass
12H-DR-3.0	1.61	5.46		1.33	1.50	1.36	2.03		Pass
12H-DR-3.3	1.67	5.90		1.36	1.53	1.38	2.11		Pass
Mean:	1.55	6.00				Mean:	2.05	1.96	Pass
12H-CR-3.3	1.35	8.02	0.89	1.19	1.34	1.46	1.96	1.56	Pass
12H-CR-4.0	1.37	7.68		1.22	1.38	1.46	2.01		Pass
12H-CR-5.0	1.31	7.59		1.22	1.38	1.45	2.01		Pass
Mean:	1.34	7.76				Mean:	1.99	1.96	Pass
18H-DR-2.0	1.79	7.22	0.65	0.91	1.39	1.55	2.15	1.56	Pass
18H-DR-2.4	1.78	5.95		0.91	1.39	1.48	2.05		Pass
18H-DR-3.0	1.84	5.35		0.91	1.39	1.44	2.00		Pass
18H-DR-3.3	1.93	5.46		0.91	1.39	1.45	2.01		Pass
Mean:	1.83	6.00				Mean:	2.05	1.96	Pass
18H-CR-3.3	1.53	6.38	0.65	0.91	1.39	1.50	2.08	1.56	Pass
18H-CR-4.0	1.51	6.18		0.91	1.39	1.49	2.07		Pass
18H-CR-5.0	1.55	5.88		0.91	1.39	1.47	2.04		Pass
Mean:	1.53	6.15				Mean:	2.07	1.96	Pass
24H-DR-2.0	1.44	13.63	0.53	0.75	1.42	1.61	2.29	1.56	Pass
24H-DR-2.4	1.39	10.13		0.75	1.42	1.61	2.29		Pass
24H-DR-3.0	1.69	8.35		0.75	1.42	1.61	2.29		Pass
24H-DR-3.3	1.64	8.19		0.75	1.42	1.61	2.29		Pass
Mean:	1.54	9.54				Mean:	2.29	1.96	Pass
24H-CR-3.3	1.36	10.28	0.53	0.74	1.40	1.61	2.26	1.56	Pass
24H-CR-4.0	1.36	9.62		0.74	1.40	1.61	2.26		Pass
24H-CR-5.0	1.49	8.30		0.75	1.42	1.61	2.29		Pass
Mean:	1.40	9.40				Mean:	2.27	1.96	Pass
30H-DR-2.0	1.20	14.86	0.45	0.80	1.81	1.61	2.91	1.56	Pass
30H-DR-2.4	1.24	13.71		0.80	1.81	1.61	2.91		Pass
30H-DR-3.0	1.31	11.43		0.80	1.81	1.61	2.91		Pass
30H-DR-3.3	1.49	9.27		0.80	1.81	1.61	2.91		Pass
Mean:	1.31	12.32				Mean:	2.91	1.96	Pass
30H-CR-3.3	1.24	14.38	0.45	0.75	1.68	1.61	2.71	1.56	Pass
30H-CR-4.0	1.27	10.29		0.75	1.68	1.61	2.71		Pass
30H-CR-5.0	1.42	10.15		0.73	1.64	1.61	2.64		Pass
Mean:	1.31	11.61				Mean:	2.69	1.96	Pass

This project was made possible with support from:

PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER
UC Berkeley • Caltech • OSU • Stanford • UC Davis • UC Irvine • UC Los Angeles • UC San Diego • UNR • USC • U Washington
peer.berkeley.edu