Seismic Assessment of Existing Reinforced Concrete Buildings - New Developments, Part 1 of 3

American Concrete Institute
Always advancing

ACI Spring 2014 Convention
March 23 - 25, Reno, NV

Dr. Ghannoum is an assistant professor at the University of Texas at Austin. He specializes in repair and retrofit of reinforced concrete structures for life-span extension. Dr. Ghannoum is the chair of ACI Committee 369, Seismic Repair and Rehabilitation.

ACI Convention Spring 2014
Reno, NV

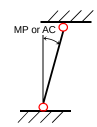
Nonlinear modeling parameters and acceptance criteria for concrete columns

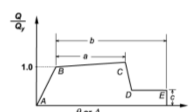
Wassim M. Ghannoum
Assistant Professor, University of Texas at Austin

Adolfo B. Matamoros
Professor, University of Kansas

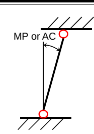
Background

1. ASCE/SEI 41-13 prescribes nonlinear Modeling Parameters (MP) and Acceptance Criteria (AC) for various structural components
2. For columns MP and AC are given as limiting plastic rotations
3. MP are used to build analytical models of structures for seismic evaluation
4. AC provide deformation limits below which member performance is deemed acceptable
5. MP and AC are given in tables for various column conditions (depending on behavior) and key parameters

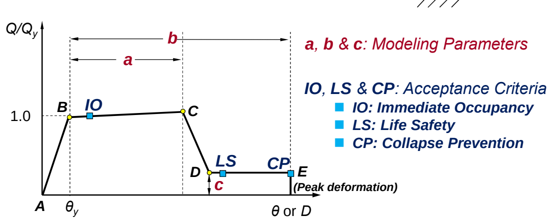




Background

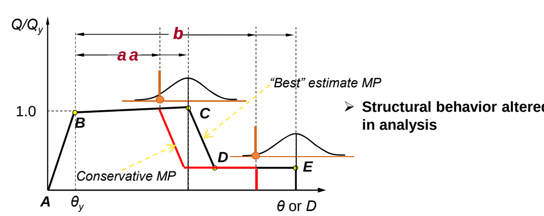


ASCE/SEI 41-13 Generic Backbone Curve



Motivation

1. Current MP were selected conservatively
2. MP for different elements (beams, columns, joints, …) selected with varying conservatism

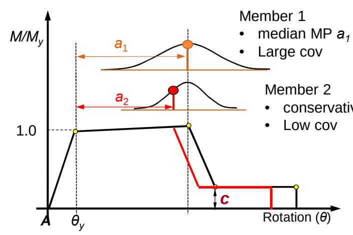


Motivation

Table 10-8. Modeling Parameters and Numerical Acceptance Criteria for Nonlinear Procedures—Reinforced Concrete Columns

Conditions			Modeling Parameters[a] Plastic Rotations Angle (radians) a	b	Residual Strength Ratio c	Acceptance Criteria[a] Plastic Rotations Angle (radians) Performance Level IO	LS	CP
Condition i.[b]								
$\frac{P}{A_g f_c'}$ [c]	$\rho = \frac{A_v}{b_w s}$							
≤ 0.1	≥ 0.006		0.035	0.060	0.2	0.005	0.045	0.060
≥ 0.6	≥ 0.006		0.010	0.010	0.0	0.003	0.009	0.010
≤ 0.1	= 0.002		0.027	0.034	0.2	0.005	0.027	0.034
≥ 0.6	= 0.002		0.005	0.005	0.0	0.002	0.004	0.005

- AC were selected as fractions of MP

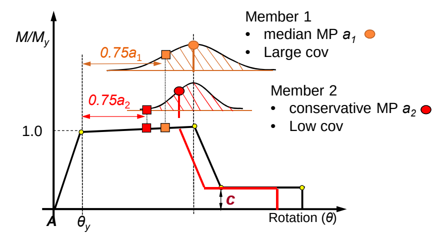


Motivation

Table 10-8. Modeling Parameters and Numerical Acceptance Criteria for Nonlinear Procedures—Reinforced Concrete Columns

- AC generate varying probabilities of exceeding a behavioral milestone across structural members treated in ASCE/SEI 41-13

AC defined as 75% of MP *a*



Objectives

1. Re-evaluate MP for concrete columns to achieve a median estimate
2. Use new extended database with close to 500 column tests

Ghannoum, W. M., and Sivaramakrishnan, B. (2012). "ACI 369 Rectangular Column Database." DOI: 10.4231/D36688J50
Ghannoum, W. M., and Sivaramakrishnan, B. (2012). "ACI 369 Circular Column Database." DOI:10.4231/D39Z90B9T
https://nees.org/resources/3658 ; https://nees.org/resources/3659

3. Treat circular columns
4. Explore cyclic damage effects
5. Adjust AC based on new MP
   - Conservatism should be incorporated in AC not MP
   - Select AC at percentiles of MP to achieve consistent probabilities of exceedance across all members

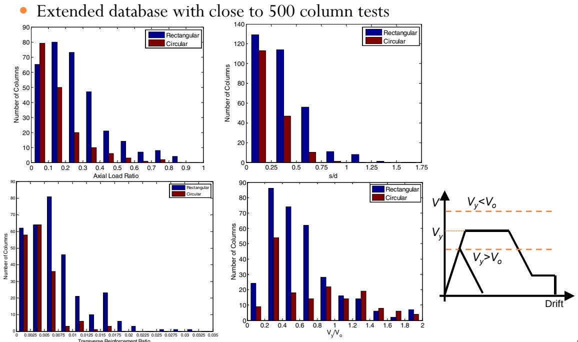
MP for RC columns - Dataset

- Extended database with close to 500 column tests

Ghannoum, W. M., and Sivaramakrishnan, B. (2012). "ACI 369 Rectangular Column Database." DOI: 10.4231/D36688J50
Ghannoum, W. M., and Sivaramakrishnan, B. (2012). "ACI 369 Circular Column Database." DOI:10.4231/D39Z90B9T
https://nees.org/resources/3658 ; https://nees.org/resources/3659

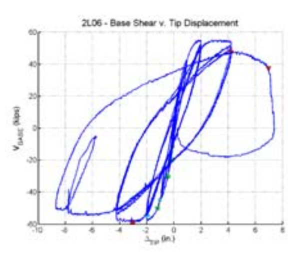
MP for RC columns - Dataset

- Extended database with close to 500 column tests



MP for RC columns - Dataset

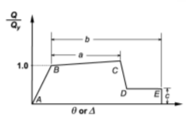
- Data in form of lateral force-deformation plots

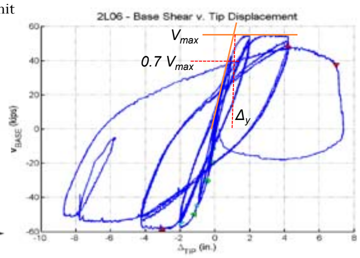


Buenrostro, E. (2013). "Deformations in Non-Seismically Detailed Concrete Columns." MS Report, University of Texas at Austin

MP for RC columns – Data Extraction

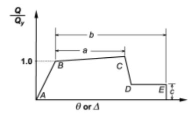
- Target:
  1. plastic rotations at initiations of loss of lateral strength (MP *a*)
  2. plastic rotations at initiations of loss of axial strength (MP *b*)
- Needed:
  1. Drift at elastic limit





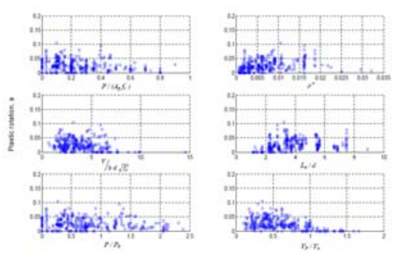
MP for RC columns – Data Extraction

- plastic rotations at initiations of loss of lateral strength (MP *a*)
  1. Selected when lateral load reaches $0.8V_{max}$ on a degrading slope
  2. $a = (\Delta_{0.8}\text{-}\Delta_y)/L$
- plastic rotations at initiations of loss of axial strength (MP *b*)
  - $b = (\Delta_{axial}\text{-}\Delta_y)/L$
  - Not all tests were conducted to axial collapse



MP for RC columns – Parameters

- Most influential parameters were found to be
  - Axial load ratio
  - Transverse reinforcement ratio
  - V_y/V_o



MP for RC columns – Parameters

- Calculating V_y/V_o

V_y is the shear associated with the yield moment strength of a column
- Different from V_p that utilizes $1.25f_y$ for plastic moment strength
- Longitudinal bars will only reach $1.25f_y$ in well confined columns

$$V_o = \Phi \frac{A_v f_{yt} d}{s} + \left(\frac{\alpha\sqrt{f_c'}}{M/Vd} \sqrt{1 + \frac{N_u}{\alpha\sqrt{f_c'}A_g}} \right) 0.8A_g$$

α = 6 in psi units and 0.5 in MPa units

Φ is taken as 1.0 for s/d ≤ 0.75, zero for s/d ≥ 1.0, and linearly interpolated between the two values of s/d

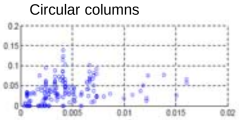
Parameters

Table bounds need updating

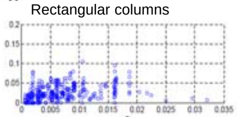
Table 10-8. Modeling Parameters and Numerical Acceptance Criteria for Nonlinear Procedures—Reinforced Concrete Columns

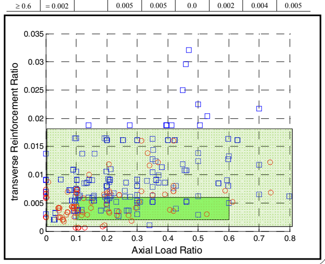
Conditions			Modeling Parameters[a] Plastic Rotations Angle (radians) a	b	Residual Strength Ratio c	Acceptance Criteria[a] Plastic Rotations Angle (radians) Performance Level IO	LS	CP
Condition i.[b]								
$\frac{P}{A_g f_c'}$ [c]	$\rho = \frac{A_v}{b_w s}$							
≤ 0.1	≥ 0.006		0.035	0.060	0.2	0.005	0.045	0.060
≥ 0.6	≥ 0.006		0.010	0.010	0.0	0.003	0.009	0.010
≤ 0.1	= 0.002		0.027	0.034	0.2	0.005	0.027	0.034
≥ 0.6	= 0.002		0.005	0.005	0.0	0.002	0.004	0.005

Circular columns



Rectangular columns





MP for RC columns – *a*

- Regression analysis results
  - Rectangular columns

$$a_R = 0.042 - 0.043\frac{P}{A_g f_c'} + 0.63\rho_t - 0.023\frac{V_y}{V_o} \geq 0.0 \quad \text{(rad)}$$

  - Circular columns (spirals or hoops)

$$a_C = 0.06 - 0.058\frac{P}{A_g f_c'} + 1.3\rho_t - 0.037\frac{V_y}{V_o} \geq 0.0 \quad \text{(rad)}$$

$0.0005 \leq \rho_t \leq 0.0175$

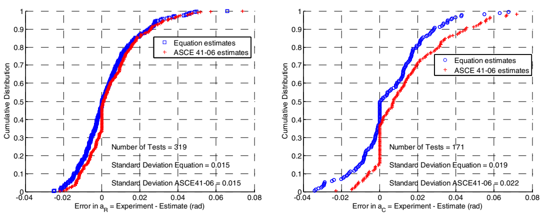
$V_y/V_o \geq 0.2$

Values of *a* at parameter boundaries

$P/(A_g f'_c)$	ρ_t	V_y/V_o	a_R (rad)	a_C (rad)
0	0.0005	0.2	0.038	0.058
0	0.0005	2.0	0.0	0.0
0	0.0175	0.2	0.048*	0.071*
0	0.0175	2.0	0.007	0.0
0.7	0.0005	0.2	0.008	0.016
0.7	0.0005	2.0	0.0	0.0
0.7	0.0175	0.2	0.018	0.029
0.7	0.0175	2.0	0.0	0.0

MP for RC columns – *a*

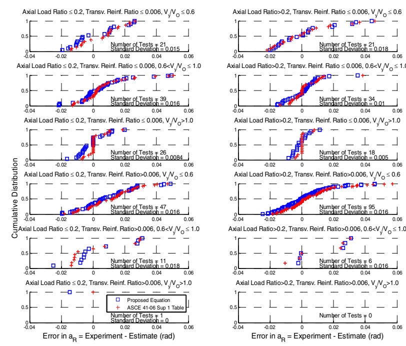
- Analysis of fit



- Median estimate achieved
- Improved fit for circular columns

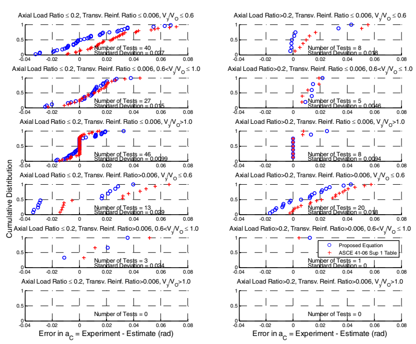
MP for RC columns – *a*

- Analysis of fit



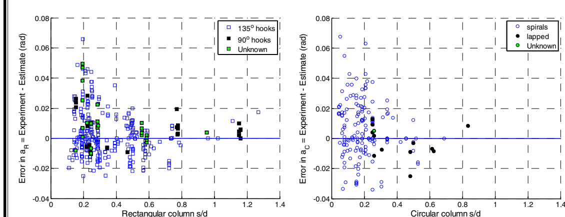
MP for RC columns – *a*

- Analysis of fit



MP for RC columns – *a*

- Analysis of fit



- Little bias with respect to s/d
- Little bias with respect to tie hooks

MP for RC columns – *b*

- Behavioral model
  - Due to the scarcity of columns tested to axial collapse a behavioral-model is selected instead of a regression-based model

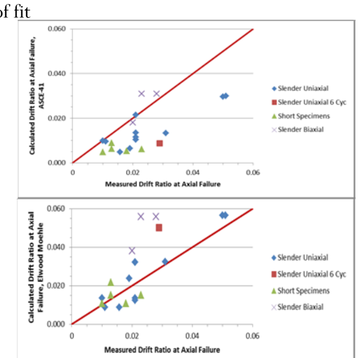
➢ Simplified Elwood-Moehle axial failure model

$$\frac{\Delta}{L} = \frac{0.5}{5 + \frac{P}{A_v f_{yt}} \frac{s}{d_c}}$$

Drift ratio at axial failure

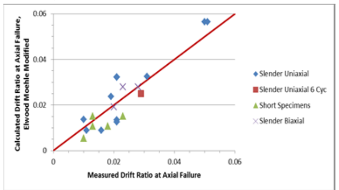
MP for RC columns – *b*

- Analysis of fit



MP for RC columns – *b*

- Analysis of fit

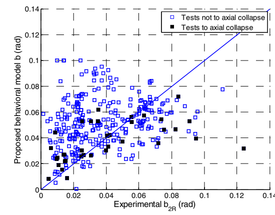


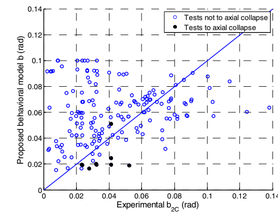
- Including a loading protocol factor of 0.5 on the drift at axial failure for columns tested under 6 load cycle per drift level or bi-axially

Model	Average Measured/ Calculated drift ratio at axial failure	Standard Deviation	Coefficient of Variation
ASCE 41-06 Suppl. 1	1.97	0.93	0.47
Elwood-Moehle	0.97	0.44	0.46
Simplified Elwood – Moehle with loading factor	1.13	0.38	0.33

MP for RC columns – *b*

- Analysis of fit
  - Using full database



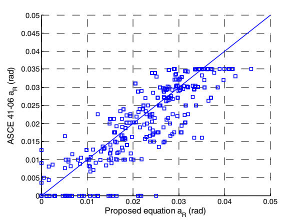


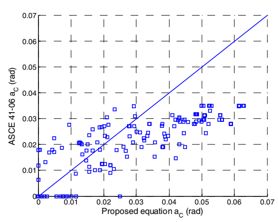
- Model produces median estimates for rect. and circular columns tested to collapse

For tests not conducted to collapse either deformation when shear drops to below 25% of maximum or the maximum deformation the test was pushed to are used to evaluate *b*

ASCE 41-13 versus Proposed MP

- MP *a*

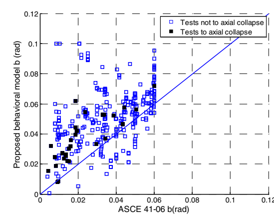


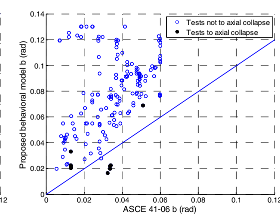


- Shift to median estimates for rectangular columns results in slightly larger estimates
- Large changes for spirally reinforced circular columns that have significantly larger deformation capacity

ASCE 41-13 versus Proposed MP

- MP *b*





- Larger b parameter for most columns

Acceptance Criteria

- AC defined as percentiles of MP *a* and *b*
  - Fixed probability of exceeding a threshold behavior defined by MP *a* and *b*

	IO	LS Primary	CP Primary	LS Secondary	CP Secondary
Criteria	10% of MP a	20th percentile of MP *a*	35th percentile of MP *a*	10th percentile of MP *b*	25th percentile of MP *b*
Rectangular	0.1 a_R	0.50 a_R	0.75 a_R	0.60 b_R	0.75 b_R
Circular	0.1 a_C	0.30 a_C	0.65 a_C	0.60 b_C	0.75 b_C

Summary

1. MP estimated at median → "best" estimate analyses
2. New relations for MP *a* and *b* are proposed
3. Circular columns with spirals are treated separately
   - Significantly higher deformation capacities than rectangular columns
4. MP *a* defined through regression models
5. MP *b* defined through behavioral model due to scarcity of data
6. AC criteria are proposed as percentile values of MP estimates
   - fixed probability of exceeding damage state defined by MP