ANALYTICAL AND EXPERIMENTAL STUDY OF UNREINFORCED CONCRETE BEAM-COLUMN JOINTS

Part of NEES Grand Challenge Project

Principal Investigator: Khalid M. Mosalam, Professor and Vice Chair, UC Berkeley

Student Investigator: Sangjoon Park, Ph.D Candidate, UC Berkeley

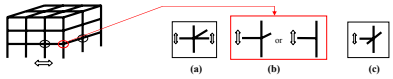
nees@berkeley Laboratory, University of California Berkeley

Motivation

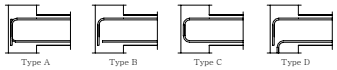
- Effect of joint deformation
  - Significant change of response due to joint deformation
  - Collapse of building by joint shear failure
- Seismic performance of old existing RC building joints
  - No seismic design code prior to 1970's
  - No transverse reinforcement in the joint region
- Existing joint strength models
  - Inappropriate application from reinforced joints to unreinforced joints
  - Overly simplified failure mechanism
  - Underestimation of shear strength (FEMA 273/ ASCE 41)
- Dependency of joint shear strengths on beam reinforcement

Database of Literature Tests

- Unreinforced exterior joint tests without or one lateral beam



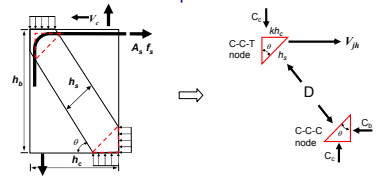
- Anchorage details of selected specimens



- Column width (b_c) ≥ beam width (b_b)
- 62 test data are collected
- Failure mode: J (joint shear failure without beam yielding); BJ (joint shear failure with beam yielding)

Develop Equations of Parameters

1. Parameter of Joint Aspect Ratio

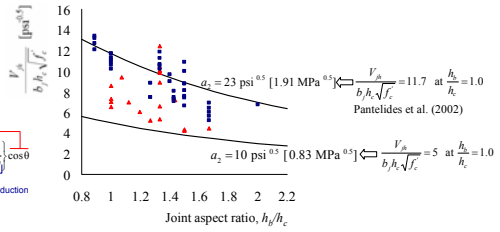


- Equilibrium: $V_{jh} = c_0 (\sigma_d\, b_j\, h_j) \cos\theta$, where $\theta = \tan^{-1}(h_b / h_c)$
- C-C-T node zone: $h_c = \frac{kh_c}{\sin\theta}$ where $\sin\theta = \frac{1}{\sqrt{1+(h_c/h_b)^2}} \propto \frac{h_b}{h_c}$
- Constitutive: $\sigma_d = \frac{a_1\sqrt{f_c'}}{0.8+170\varepsilon_1}$ Vollum (1998)

$$\frac{V_{jh}}{b_j h_c \sqrt{f_c'}} = c_1 \left\{ \frac{a_1}{(0.8+170\varepsilon_1)\sin\theta} \right\} \cos\theta$$ (Equilibrium; C-C-T node strength reduction)

- Proposed equation for joint aspect ratio

$$\frac{V_{jh}}{b_j h_c \sqrt{f_c'}} = c_1 \left\{ \frac{a_1}{(0.8+170\varepsilon_1)\sin\theta} \right\} \cos\theta \approx a_2 \frac{\cos\theta}{1.31+0.085\frac{h_b}{h_c}}$$



2. Parameter of Beam Reinforcement

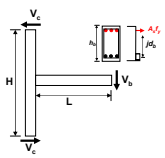
- Equilibrium

$$V_{jh} = A_s f_s - V_c = A_s f_s \left(1 - \frac{L + h_c/2}{H} \frac{jd_b}{L}\right)$$

$$jd_b = 0.8 h_b$$

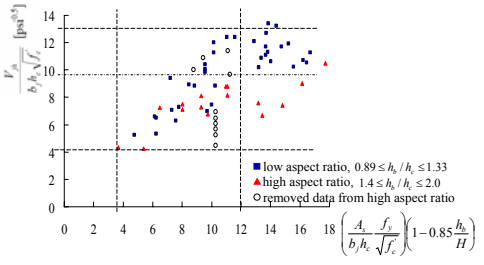
$$\frac{L+h_c/2}{H} \frac{jd_b}{L} = \frac{L+h_c/2}{L} \frac{0.8h_b}{H} \approx 0.85\frac{h_b}{H}$$

If beam reinforcement is yielding, $f_s = f_y$



- Normalized form

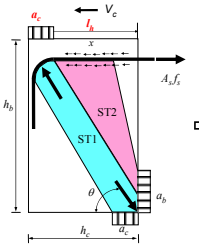
$$\frac{V_{jh}}{b_j h_c \sqrt{f_c'}} \approx \left(\frac{A_s f_y}{b_j h_c \sqrt{f_c'}}\right)\left(1 - 0.85\frac{h_b}{H}\right)$$: Beam reinforcement index = Joint shear demand at $f_s = f_y$



Develop Analytical Model

1. Assumptions

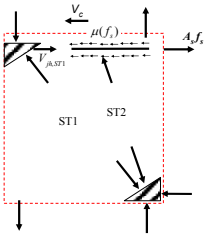
- Two inclined struts mechanism



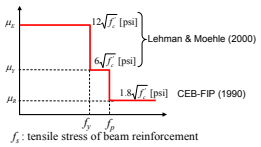
2. Formulation

- Equilibrium: $V_{jh} = V_{jh,ST1} + V_{jh,ST2}$

$$\begin{cases} V_{jh,ST1} = A_s f_s - n\pi\phi_b \int_0^{f_s} \mu(f_s)\,dx \\ V_{jh,ST2} = n\pi\phi_b \int_0^{f_s} \mu(f_s)\,dx - V_c \end{cases}$$



μ: Bond strength

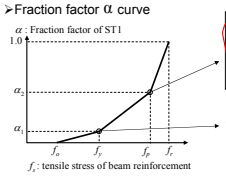


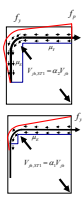
- Fraction factor α of ST1

$$\begin{cases} V_{jh} = V_{jh,ST1} + V_{jh,ST2} \approx A_s f_y \left(1 - 0.85\frac{h_b}{H}\right) \\ V_{jh,ST1} = \alpha V_{jh} = A_s f_s - n\pi\phi_b \int_0^{f_s} \mu(f_s)\,dx \\ V_{jh,ST2} = (1-\alpha) V_{jh} = n\pi\phi_b \int_0^{f_s} \mu(f_s)\,dx - V_c \end{cases}$$

$$\Rightarrow \alpha = \frac{H}{H - 0.85h_b}\left(1 - \frac{4}{\phi_b}\frac{\int_0^{f_s}\mu(f_s)\,dx}{f_s}\right)$$

- Fraction factor α curve





$$f_s = \frac{4}{\phi_b}\frac{H}{0.85h_b}\int_0^{f_s}\mu(f_s)dx \ge f_p$$

$$f_p = f_y + \frac{4}{\phi_b}\mu_y l_b$$

$$\alpha_2 = \frac{H}{H-0.85h_b}\left(1 - \frac{4}{\phi_b}\frac{\mu_y}{f_y + \frac{4}{\phi_b}\mu_y l_b}\right) \le 1.0$$

$$\alpha_1 = \frac{H}{H-0.85h_b}\left(1 - \frac{4}{\phi_b}\frac{\mu_E}{f_y}\right)$$

$$f_o = \frac{4}{\phi_b}\mu_E l_b$$

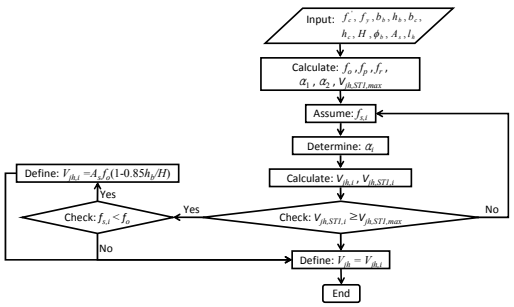
- Definition of joint shear failure

: Joint shear failure is defined when the demand of ST1 reaches its capacity

$$V_{jh,ST1,\max} = c\frac{b_j h_c \sqrt{f_c'}\cos\theta}{1.31+0.085\left(\frac{h_b}{h_c}\right)}$$

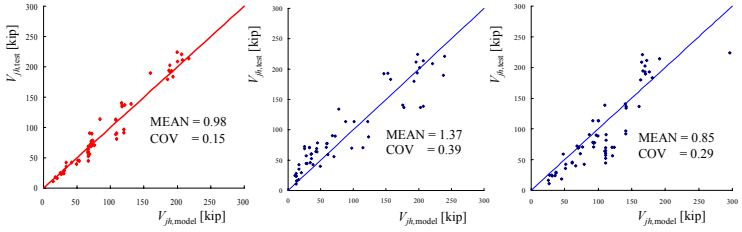
$c = 8.3$ $\frac{V_{jh}}{b_j h_c \sqrt{f_c'}} = 4$ at $\frac{h_b}{h_c} = 1.1$ from Hakuto et al. (2000)

3. Solution algorithm



4. Evaluation

	$a_c = 0.4h_c$	$a_c = 0.35h_c$	$a_c = 0.3h_c$	$a_c = 0.25h_c$
Mean	1.016	0.985	0.955	0.927
COV	0.149	0.149	0.150	0.147



(a) Proposed Model (b) Hwang and Lee (1999) (c) Tsonos (2007)

This project was made possible with support from:

PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

UC Berkeley ▪ Caltech ▪ Stanford ▪ UC Davis ▪ UC Irvine ▪ UC Los Angeles ▪ UC San Diego ▪ USC ▪ U Washington

peer.berkeley.edu

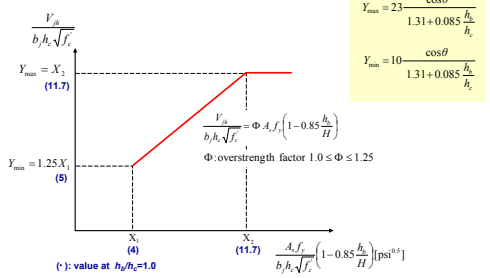
ANALYTICAL AND EXPERIMENTAL STUDY OF UNREINFORCED CONCRETE BEAM-COLUMN JOINTS

Part of NEES Grand Challenge Project

Principal Investigator: Khalid M. Mosalam, Professor and Vice Chair, UC Berkeley
Student Investigator: Sangjoon Park, Ph.D Candidate, UC Berkeley
nees@berkeley Laboratory, University of California Berkeley

Develop Semi-Empirical Model

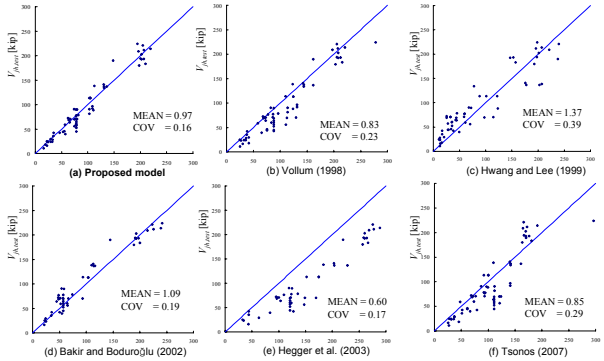
1. Proposed Model



$$Y_{max} = 23 \frac{\cos\theta}{1.31 + 0.085 \frac{h_b}{h_c}}$$

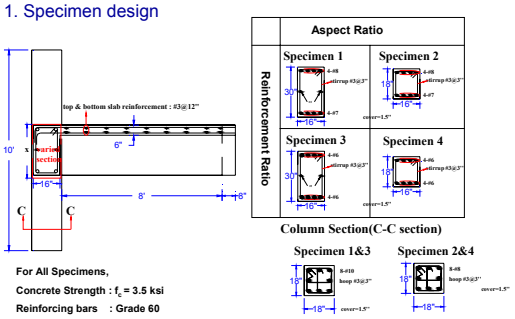
$$Y_{min} = 10 \frac{\cos\theta}{1.31 + 0.085 \frac{h_b}{h_c}}$$

2. Evaluation



Ongoing Experimental Program

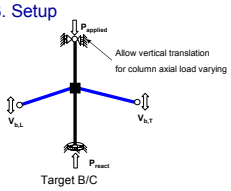
1. Specimen design

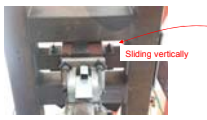


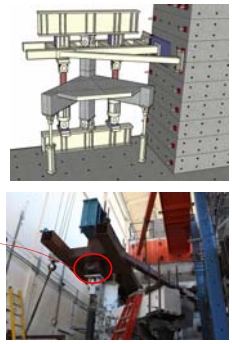
For All Specimens,
Concrete Strength : f_c' = 3.5 ksi
Reinforcing bars : Grade 60

2. Construction

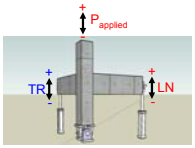
3. Setup

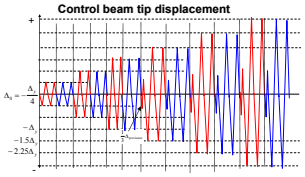




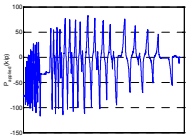


4. Loading





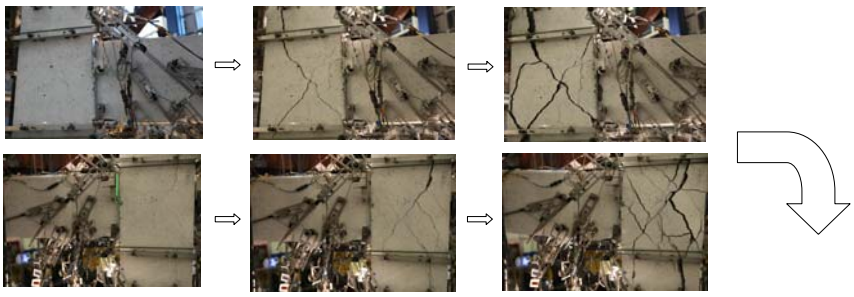
Applied column axial load-SP4



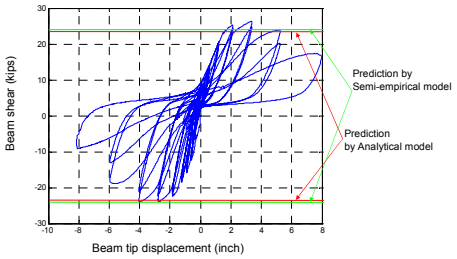
- Pre-defined equation for column axial loading

SP1&3 : $P_{applied}$=-95 + 2$V_{b,x}$ + 2$V_{b,y}$
SP2&4 : $P_{applied}$=-95 + 4$V_{b,x}$ + 4$V_{b,y}$

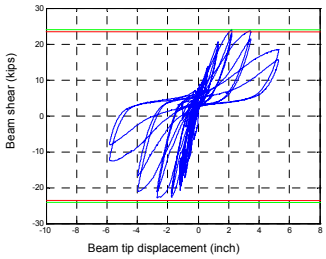
5. Test-SP4: Beam yielding ⇨ Joint shear failure



6. Comparison of test results with predictions by proposed two models



Longitudinal direction



Transverse direction

This project was made possible with support from:

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