James K. Wight, FACI, FASCE, is the Frank E. Richart, Jr. Collegiate Professor of Civil Engineering at the University of Michigan. He is currently the Senior Vice President of the American Concrete Institute. He is a former Chair of ACI Committee 318, Structural Concrete Building Code, and the ACI Technical Activities Committee. Wight is a former Chair and member of ACI Committee 352, Joints and Connections in Monolithic Concrete Structures, and a member of ACI Committee 445, Shear and Torsion. His primary research interests are earthquake resistant design of reinforced concrete structures and design of concrete structures utilizing high-performance fiber-reinforced concrete.

ACI
WEB SESSIONS

Historical Development of Design Recommendations for RC Beam-to-Column Connections

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Gustavo J. Parra-Montesinos, Assoc. Professor
University of Michigan

James O. Jirsa Symposium; March 2012

Presentation Outline

- Initial Research
- First ACI/ASCE Committee 352 Report
- Additional Research and Evolution to Second Committee Report
- (Adoptions into ACI 318 Building Code)
- Further Modifications and Coordination with New Zealand and Japan

Problems w/ Beam-Column Joints

Venezuela, 1967

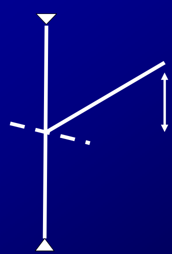
Initial Research Reports

- N. Hanson and Conner, Seismic Resistance of RC Beam-Column Joints, Journ. of Struct. Div., ASCE, Oct. 1967
- N. Hanson, Seismic Resistance of Concrete Frames with Grade 60 Reinf., Journ. of Struct. Div., ASCE, June 1971
- Park and Paulay, Behavior of RC External Beam-Column Joints Under Cyclic Loading, Fifth WCEE, Rome, 1973

Initial Research Reports

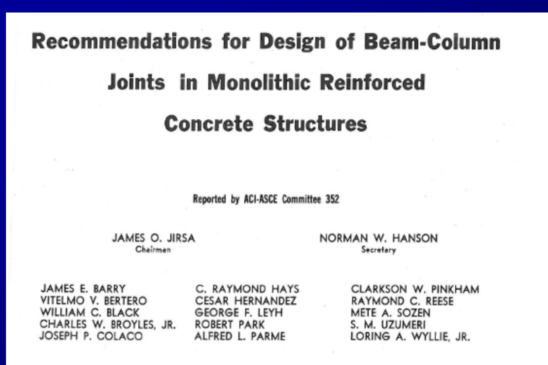
- Uzumeri and Seckin, Behavior of RC Beam-Column Joints Subjected to Slow Load Reversals, Univ. of Toronto Rpt., March 1974
- Higashi and Ohwada, Failing Behaviors of RC Beam-Column Connections Subjected to Lateral Load, Tokyo Metropolitan Univ., 1969

Initial Tests



ACI/ASCE Committee 352

- Formed in 1966
- Initial Chair: Mete Sozen
- Second Chair: Jim Jirsa
- Issued first set of Design Recommendations in 1976



Recommendations for Design of Beam-Column Joints in Monolithic Reinforced Concrete Structures

Reported by ACI-ASCE Committee 352

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CHARLES W. BROYLES, JR.	ROBERT PARK	S. M. UZUMERI
JOSEPH P. COLACO	ALFRED L. PARME	LORING A. WYLLIE, JR.

Key Topics in 1976 report

- Confinement reinforcement req'd. to transmit column axial force through joint
- Joint shear strength, $V_n = V_c + V_s$
- (Hooked) Anchorage of beam reinforcement
- Column flexural strength (moment strength ratio ≥ 1.0)

Key Concepts and Limitations in 1976 report

- Type 1 and Type 2 joints (strength only vs. strength and ductility)
- Concept of $f_s = \alpha f_y$ (from Wight and Sozen)
- Normal weight concrete
- Beam width ≤ column width

Confinement (with spirals) for transmission of axial load

$$\rho_s \geq 0.45\left(\frac{A_g}{A_{ch}} - 1\right)\frac{f_c'}{f_{yh}''}$$

$$\rho_s \geq 0.12\frac{f_c'}{f_y}$$

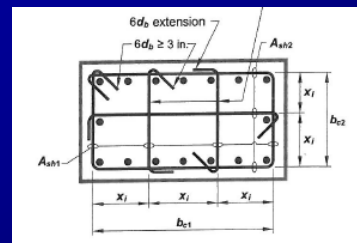
with clear spacing ≤ 1 in., ≤ 3 in.

Confinement (with ties)

$$A_{sh}'' \geq 0.3h''s_h\left(\frac{A_g}{A_{ch}}-1\right)\frac{f_c'}{f_{yh}''}$$

$$\frac{A_{sh}''}{h''s_h} \geq 0.12\frac{f_c'}{f_{yh}''} \text{ and } s_h \leq 4 \text{ in.}$$

Confinement reinforcement



Confinement reinforcement must be continued into adjacent columns a distance ≥18" and $\ell_u/6$

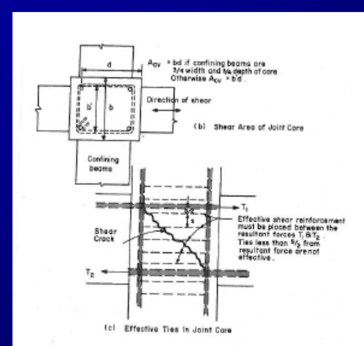
Shear Strength

$$v_u = \frac{V_u}{\phi A_{cv}},\ \phi = 0.85$$

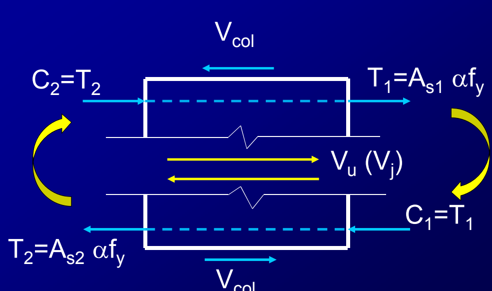
$$A_{cv} = b' \times d,\ b' = h''$$

Can increase *b'* to *b* if adequate confining beams are present (covers ≥ ¾ joint width and ≥ ¾ joint depth)

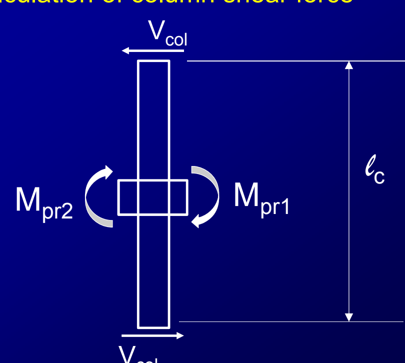
Joint Shear Reinforcement



Joint Shear



Calculation of column shear force



Shear strength from concrete

$$v_c \le 3.5\beta\gamma\sqrt{f_c'\left(1+0.002\frac{N_u}{A_g}\right)}$$

$\gamma = 1.4$ if adequate lat. conf. members present (covers $\ge$ 3/4 jt. width & $\ge$ 3/4 jt. depth)

$\beta = 1.0$ (Type 2 jts.), $= 1.4$ (Type 1 jts.)

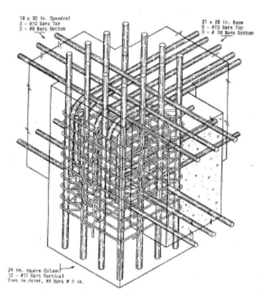
Recomm. $N_u = 0$, for Type 2 joints

Required Shear Reinforcement

$$A_v \ge \frac{(v_u - v_c)A_{cv}\, s}{f_y\, d}$$

Must be within top & bottom reinf.
Ties for confinement can be included

Design Example
(Can this be built?)



Design example No. 2—Exterior joint, Type 2

Anchorage of Beam Reinforcement

- Only considered beam bars terminating at exterior joints; No disc. of straight bars through interior joints
- Calculation of required straight length, ℓ_s, before standard hook
- Anchorage started at front of confined core
- Move tail of hook to far end of confined core

Anchorage of Beam Reinforcement

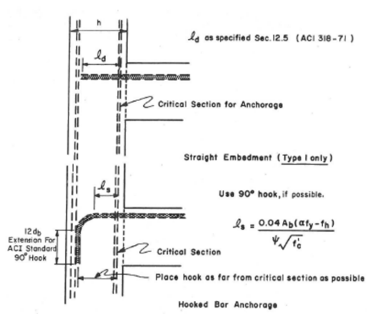


Fig. 10—Anchorage requirements for joints

Hooked Bar Anchorage

Key Ref. – Marques & Jirsa, Study of Hooked Bar Anchorages in Beam-Column Joints, ACI Journal May 1975.

$$f_h = 700(1 - 0.3d_b)\psi\sqrt{f_c'}$$

$\psi = 1.4$, if $d_b \le \#11$, side cover $\ge 2.5''$, tail cover $\ge 2''$

$\psi = 1.8$, if all the above and s(ties) ≤ 3 in.

Otherwise $\psi = 1.0$

Hooked Bar Anchorage

Straight length before std. hook

$$\ell_s = \frac{0.04A_b\left(\alpha f_y - f_h\right)}{\psi\sqrt{f_c'}}$$

Key Research Reports after '76

- Meinheit and Jirsa, Shear Strength of RC Beam-Column Conns., Journ. of Struct. Div., ASCE, Nov. 1981
- Lee, Wight and R. Hanson, RC Beam-Column Joints under Large Load Reversals., Journ. of Struct. Div., ASCE, Dec. 1977
- Zhang and Jirsa, Study of Shear Behavior of Beam-Column Joints, *PMFSEL Rpt.* No. 82-1, Univ. of Texas, Feb. 1982

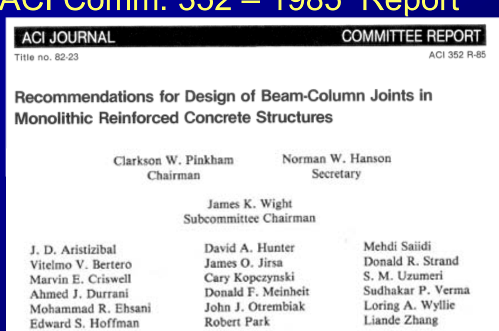
Key Research Reports after '76

- Zhu and Jirsa, Study of Bond Deterioration in RC Beam-Column Joints, *PMFSEL Rpt.* No. 83-1, Univ. of Texas, July 1983
- Ehsani and Wight, Behavior of External RC Beam-Column Conns. Subj. to Earthquake-Type Loading, Univ. of Mich. Rpt. No. 82R5, July 1982
- Durrani and Wight, Behavior of Interior RC Beam-Column Conns. Subj. to Reversed Cyclic Loading, Univ. of Mich. Rpt. No. 82R3, May 1982

Key Research Reports after '76

- Sheikh and Uzumeri, Strength and Ductility of Tied Concrete Columns, Journ. of Struct. Div., ASCE, May 1980
- Paulay, Park and Priestley, Reinf. Conc. Beam-Column Joints Under Seismic Actions, Proc. of ACI Journal, November 1978

ACI Comm. 352 – 1985 Report



ACI JOURNAL | COMMITTEE REPORT

Title no. 82-23 | ACI 352 R-85

Recommendations for Design of Beam-Column Joints in Monolithic Reinforced Concrete Structures

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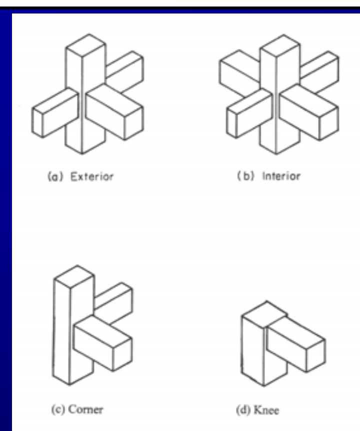


Key Design Considerations for RC Beam-Column Connections

- Shear Strength
- Confinement
- Moment Strength Ratio
- Reinforcement Anchorage

Shear Strength and Confinement

- Meinheit and Jirsa showed adding more transv. reinf. beyond that required for confinement had little or no benefit
- Well-confined joints could carry much higher shear stresses than previously allowed
- Define V_n directly, components V_c and V_s cannot be independently defined

Required Shear Strength of Joint

$$\phi V_n \geq V_u$$

$$\phi = 0.85$$

V_u determined as shown previously

Shear Strength of Well-Confined Joints

$$V_n = \gamma \sqrt{f_c'}\, b_j\, h_c$$

γ– values

Joint Type	Joint Configuration: Interior	Exterior	Corner
Type 2	20	15	12
Type 1	24	20	15

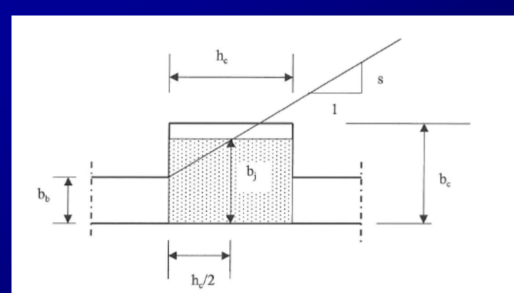
Effective Joint Width, b_j

$b_b \leq b_c$ for Type 2 joints

$$b_j \leq \frac{b_b + b_c}{2} \leq b_c$$

$$b_j \leq b_b + \sum_{1 \text{ or } 2} \left(\frac{h_c}{2}\right) \leq b_c$$

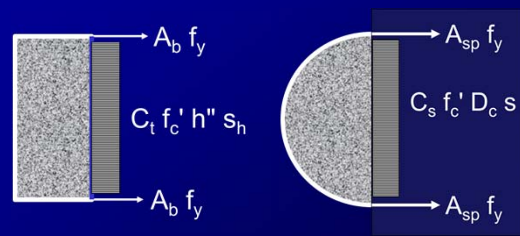
Shear Strength – Joint Width, b_j



Confinement Requirements

- Changes made to reflect good behavior of well-detailed tied columns and joints
- Confinement reinforcement can be reduced by 50% for interior joints confined* by lateral beams

Confinement Requirements
Comparison of spirals and ties



Confinement Requirements
Comparison of spirals and ties

$$\rho_s = \frac{\text{Vol. of steel}}{\text{Vol. of concrete}} = \frac{\pi D_c \times A_{sp}}{\frac{1}{4}\pi D_c^2 \times s} = \frac{4A_{sp}}{D_c s_h}$$

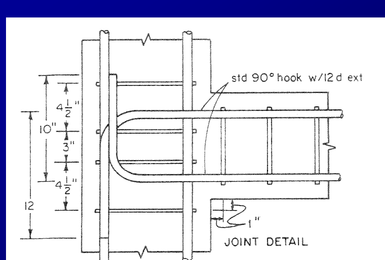
$$\rho_s = \frac{4A_{sp}}{D_c s_h} \geq 0.12\frac{f_c'}{f_{yt}}$$

$$\frac{A_{sh}''}{h'' s_h} = \frac{2A_b}{h'' s_h} \geq 0.12\frac{f_c'}{f_{yh}''}\left(\geq 0.09\frac{f_c'}{f_{yt}}\right)$$

Moment Strength Ratio

- Earthquake resistant design of RC frames assumed a strong column – weak beam approach
- What value should be selected for the strength ratio (not seriously considered for 1976 comm. report)

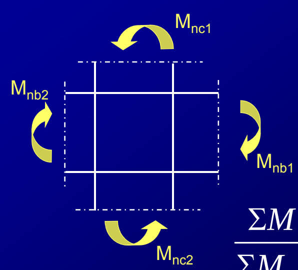
Why test that?



Details of Beam-Column Subassemblage for Type I Design

An unexpected result!?

Moment Strength Ratio at Connection



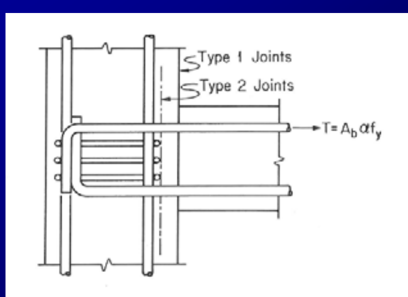
$$\frac{\Sigma M_n(col.)}{\Sigma M_n(beam)} \geq 1.2\ (1.4)$$

Reinforcement Anchorage

- For well-confined exterior joints, developed new value for ℓ_{dh}
- Developed anchorage criteria for non-terminating beam and column bars in well-confined interior connections

Hooked Bar Anchorage

Type 1 and Type 2 exterior joints



Hooked Bar Anchorage

Type 1 and Type 2 exterior joints

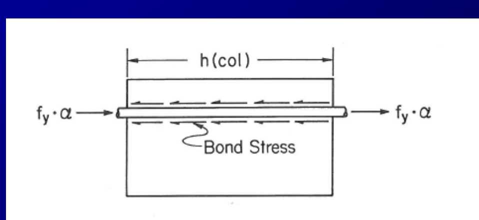
$$\ell_{dh} = \frac{f_y\, d_b}{50\sqrt{f_c'}} \quad \text{(Type 1 joints)}$$

$$\ell_{dh} = \frac{\alpha\, f_y\, d_b}{75\sqrt{f_c'}} \quad \text{(Type 2 joints)}$$

$$\ell_{dh} = \frac{f_y\, d_b}{65\sqrt{f_c'}} \quad \text{(318 Code; Special)}$$

Straight Bars at Interior Joints

Bond stress related to ratio, d_b/h



Straight Bars at Interior Joints

Bond stress related to ratio, d_b/h

$$\frac{h\text{(col)}}{d_b\text{(beam)}} \geq 20\ \text{(24; Leon)}$$

$$\frac{h\text{(beam)}}{d_b\text{(col)}} \geq 20\ \text{(not in 318 Code)}$$

Continuing Research and Modifications

- Use of headed bars for anchorage (Wallace et al.)
- Use of beams wider that columns (Wight et al.)
- Evaluation of eccentric connections (Wight et al. and LaFave et al.)

Coordination of Joint Design Recom-mendations with Japan and New Zealand

- Four coordination meetings in
  - Monterrey, CA, Aug. 1984
  - Tokyo, Japan, May 1985
  - Christchurch, NZ, Aug. 1987
  - Honolulu, Hawaii, May 1989
- ACI SP-123, Design of Beam-Column Joints for Seismic Resistance, James Jirsa, Editor, 1991

Thank you Jim

for all of your contributions to
the safe design of beam-column joints