出國報告（出國類別：其他：國際會議）

美國混凝土學會 2016 年春季大會
(暨參觀普度大學學生參加 ASCE 學生鋼構橋梁競賽)

服務機關：國立雲林科技大學
姓名職稱：李宏仁 營建技術服務暨材料檢測中心 主任
派赴國家：美國
出國期間：105 年 4 月 15 日 至 105 年 4 月 22 日
報告日期：105 年 4 月 25 日

摘要

美國混凝土學會每年春秋兩次大會除了有公開的演講時段，還有許多閉門的委員會會議，與會者均為美國混凝土工程界學者及專家，討論技術規範之更新及編修，彙整全球最先進之工程技術討論，赴會汲取相關資訊對於我國相關產業技術提升及規範更新應有裨益。

筆者此行參加在密爾瓦基市舉行之美國混凝土學會 ACI 2016 年春季大會，先代表台灣混凝土學會出席大會第一天的國際論壇(International Forum)報告台灣的混凝土工程設計規範與美國 ACI 318 規範之淵源，特別是過去一年多以來台灣混凝土學會、中國土木水利工程學會及 ACI 台灣分會合作翻譯 ACI 318-14 規範之過程，繁體中文版終於今年 4 月份出版，後續可以進一步轉換為簡體中文版。報告內容深獲 ACI 相關工作同仁及與會各界來賓之肯定，會後 ACI Executive Vice President, Ronald G. Burg 及 Director of International Business Development, Bernard A. Pekor 先生特別感謝我方委員會投入的人力時間及資源，為 ACI 318 規範的多國語言國際化，台灣分會亦立下汗馬功勞。

接著在 ACI 352 梁柱接頭委員會發表近五年來我方在梁柱接頭之實驗及設計建議，特別是針對使用高強度鋼筋及混凝土部分，需要修訂的規範條款。此部分研究為筆者科技部研究計畫成果。最後參加 ACI 318J 梁柱接頭子委員會了解最新 ACI 318 規範修正案之方向，對於我方編撰 New RC 設計手冊有幫助。近年來台灣都市土地不敷使用，開發高強度鋼筋混凝土構造有助於提升我國混凝土相關產業技術水準。

此外，在前往密爾瓦基之前，筆者先前往普度大學西北校區會同該校陳建中教授，觀摩陳教授指導之大學部學生參加美國土木工程學會(ASCE)之年度學生鋼橋競賽五大湖區預賽，參加隊伍大約 15 隊，競賽規則考慮非常嚴謹，學生從結構設計、構件加工製造、組搭、承載試驗均須納入考慮，令人印象深刻，是非常完整的專案計畫工程的迷你實踐競賽，對於我方推動工程教育認證及 Capstone 課程設計，具有高度參考價值。

目次

一、目的

此行參加在密爾瓦基市舉行的美國混凝土學會 2016 年春季大會目的有三，一為代表台灣混凝土學會出席國際活動論壇，說明我方翻譯 ACI 318-14 規範中文版之成果；二為 ACI 352 梁柱接頭委員會翻新設計建議報告作專題演講，提升我國相關研究之國際能見度；三為觀察 ACI 318 各委員會討論規範修正案之情況，作為後續相關研究之參考。

普度大學為美國印第安那州公立大學的指標學府，其辦學績效剖受肯定。此行先前往芝加哥伊利諾理工學院校區舉行的 ASCE 學生鋼橋競賽五大湖區分組預賽，觀摩普度大學陳建中教授指導大學部學生參與學生競賽，汲取實務專題競賽指導經驗，作為我方創新 Capstone 課程的參考。

二、過程

此行 16 日先到普度大學校區，觀摩陳建中教授之教學環境及 Capstone 課程的實踐方法，接著到芝加哥伊利諾理工學院校區，觀摩 ASCE 學生鋼橋競賽五大湖區分組預賽，該競賽規則十分複雜，學生必須設計一座鋼橋，並且自行準備所有材料及零件，在限定的時間內，以有限的人力及空間，將鋼橋組搭完成，所有零組件必須密合鎖固，鋼橋除造型之外，有跨度及勁度之要求，接著執行靜載重試驗，綜合載重得分除以人力時間成本換算為積分，最高分者勝出參加全國總決賽。觀摩照片如圖 1 至圖 8。

接著 17 日開始至密爾瓦基市參加美國混凝土學會 2016 年春季大會，過程如下：

4/17 星期日

上午出席代表台灣混凝土學會出席大會國際論壇(International Forum)報告台灣混凝土學會過去一年多翻譯 ACI 318-14 規範之過程，並向來賓介紹 4 月出版之繁體中文版。報告內容深獲 ACI 相關工作同仁及與會各界來賓之肯定。

下午出席 ACI 352 梁柱接頭委員會，議程及摘要簡報如附件，筆者此行報告題目為高強度鋼筋混凝土構架接頭試驗結果及設計建議，內容為我方近五年來最新研究成果，有助於提升我國研究之能見度。報告內容深受與會學界大老之讚賞，他們也提出不少建議，此番交流最大收穫是了解我方研究及簡報不夠清楚之處，可以持續改進更新。

4/18 星期一

上午先至一個公開時聆聽混凝土構件行為之相關研究發表，接著列席 ACI 374 耐震

設計委員會，了解耐震設計修正方案。

下午出席 ACI 352 梁柱接頭委員會小組工作會議，編修 ACI 352 梁柱接頭委員會報告，原 2002 年版報告將參考 ACI 2014 規範更新重組。

4/19 星期二

上午列席 ACI IAC 國際事務委員會，了解美國混凝土分析其全球行銷分析及計畫，未來仍將以北美、中東、拉丁美洲、及巴西為最優先市場，其次才是亞洲。

下午出席 ACI 318J 梁柱接頭子委員會，了解美國 ACI 318 規範最新修正方案。蒐集相關規範異動方向，作為我國相關研究，特別是相關設計手冊編撰之參考依據。

出席 Concrete Mixer 晚宴與會者交流，席間遇到不少韓國首爾大學及仁川大學的教授攜帶數位碩士班學生一同出席此次大會，得知韓國對於高教投入大量資源及經費，鼓勵教授帶碩士生出席國際研討會，這方面我國已經遠遠落後。

4/20 星期三

列席 318 委員會，瞭解 ACI 規範修訂情況。

4/21 星期四

由芝加哥搭機、經舊金山轉機回桃園。

三、心得

筆者觀摩美國大學生鋼橋競賽，強烈感受到學生參與之主動積極及學習動機，迷你的橋樑工程專案讓學生組隊實踐四年大學所學，以一具體的橋樑模型設計、製造、組搭、到承載能力的過程，給予學生一個理論求知及實踐的過程訓練，足堪我方 Capstone 課程的設計跟推動之借鏡。

筆者每年參加美國混凝土學會年會，與會人士包括教授、研究生、及專業工程師，對於瞭解最新研究進度、規範變革趨勢、學術人際交流均亟有幫助，在委員會報告我方研究成果及近況，除了發表論文之外，汲取相關規範之修訂與更新資訊，更有助於我方推動相關工程新技術之發展。美國混凝土學會之技術委員會提供一個非常好的學術交流平台，應有助於提升我國學術研究成果於之國際能見度。此行遇到東京大學塩原等教授，了解日本九州熊本地震最新勘災情報，算是意外收穫。

四、建議事項

1.建議本校營建系可以實務專題課程讓教師指導學生組隊參加學生競賽，除了國內學會舉辦之橋梁競賽，應爭取經費補助讓學生出國參加國際競賽，對於學生的學習動機及成效會有非常不一樣的成效，亦能真正提升學生之國際觀。

2.本次會議差旅費係由報告人單位管理費結餘款勻支方得以成行，此行見到韓國政府大力補助碩士生出國參加國際研討會，建議我國政府應從寬補助國內學人出席相關專業技術交流會議，除了教授可將國內研究成果國際化，亦可提升學生之國際觀跟膽識。

3.美國相關學會所舉辦之年會、學生競賽等行之有年，經驗相當豐富，各項安排與活動設計可以作為我方舉辦類似活動之參考。

4.我國技術規範更新長久以來以美國 ACI 318 規範為藍本，今後各界期待能夠加緊腳步提升我國相關產業之技術水準，緊盯美國最新科技及規範發展，建議我方持續投入相關人力資源，持續更新相關標準及規範，提升產業競爭力。

五、(附錄)

圖 1 鋼橋競賽成果展

圖 2 與普度大學學生作品合影

圖 3 限時組搭競賽

圖 4 裁判作品評分

圖 5 ACI 318-14 中文版規範成果合影

圖 6 與 ACI 工作人員合影

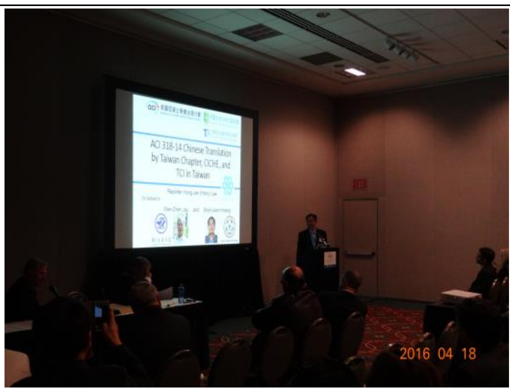


圖 7 國際論壇代表台灣混凝土學會報告

圖 8 演講會場照片

ACI-ASCE Committee 352
"Joints and Connections in Monolithic Concrete Structures"

<u>Meeting Agenda</u>
ACI Spring 2016 Convention
Sunday, April 17, 2016
2:00 pm – 5:00 pm
Meeting Room "C-102 D", Wisconsin Center
Milwaukee, Wisconsin

---

1. Welcome and introductions (All)

2. Approval of meeting agenda (All)

3. Approval of minutes from the Fall 2015 committee meeting in Denver, CO (All)

4. Membership and Chair updates (M. Hueste)

5. Ballot Results – Errata to ACI 352R-02(10) (M. Hueste)

6. Update from Task Group 1 (352-TG1): Slab-Column Joints and Connections
   - Status of report updates (D. Fick)
   - Status of examples (R. Lequesne, M.-Y. Cheng, D. Fick, J. Dragovich)
   - 352-TG1 Meeting: Monday, 3:00-4:30 pm, C-101 D (Wisconsin Center)

7. Update from Task Group 2 (352-TG2): Beam-Column Joints and Connections
   - Status of report updates (M. Hueste, J. LaFave)
   - Working group reports (T. Kang, S.-J. Hwang, J. LaFave, H.-J. Lee, G. Parra-Montesinos)
   - 352-TG2 Meeting: Monday, 1:30-3:00 pm, C-101 D (Wisconsin Center)

8. High-Strength Reinforced Concrete Frame Connections: Test Results and Proposed Updates to Design Recommendations (H.-J. Lee and S.-J. Hwang)

9. Ongoing ACI technical committee activities related to slab-column connections (M. Hueste)
   - ACI-ASCE Committee 421 - Design of Reinforced Concrete Slabs (Mustafa Mahamid, Chair)
   - ACI-ASCE Committee 445 – Shear and Torsion (R. Lequesne)

10. Update on ACI *Structural Journal* article (M. Hueste and D. Fick)

11. Barrier Wall-Slab Joints in Parking Garages (M. Iqbal)

12. Update on Activities of Subcommittee ACI 318-J "Joints and Connections" (G. Parra-Montesinos)

13. Technical sessions and educational activities
    - Special Publication for Technical Sessions held in Washington, DC, Fall 2014 -- James K. Wight: A tribute from his students and colleagues (G. Parra-Montesinos)

- Proposal for Technical Sessions for 2017 Fall Convention in Anaheim (T. Kang)
- Suggestions for future technical sessions or educational activities

14. Other business / presentations / new business (please notify M. Hueste in advance of any items in these categories)

15. Schedule for the next committee meeting

16. Adjournment

Presentation at Joint ASCE-ACI Committee 352, Joints and Connections in Monolithic Concrete Structures. 2016/4/17

High-Strength Reinforced Concrete Frame Connections: Test Results and Proposed Updates to Design Recommendations

Hung-Jen (Harry) Lee

Shyh-Jiann Hwang

YUNTECH

NCREE

National Taiwan University

Acknowledgements

Ministry of Science and Technology, Taiwan New RC Project – sub-project
Behavior, Design, and Modeling of New RC Frame Joints Subjected to Seismic Loading
Grant No. MOST 104-2625-M-224-002 -

科技部

NCREE

TTK

Yali

An NCREE report to be published in 2016.

高強度鋼筋混凝土結構設計手冊

Structural Design Guidelines for High-Strength Reinforced Concrete (in Chinese)

Contents

YunTech

Outline

6.1 Shear Strength

- **Design shear force V_u**
- **Nominal shear strength ϕV_n**

6.2 Joint transverse reinforcement

6.3 Development and Anchorage

- **Minimum column depth for beam bars passing through the joint**
- **Development length for beam bars terminated within the joint**

YunTech

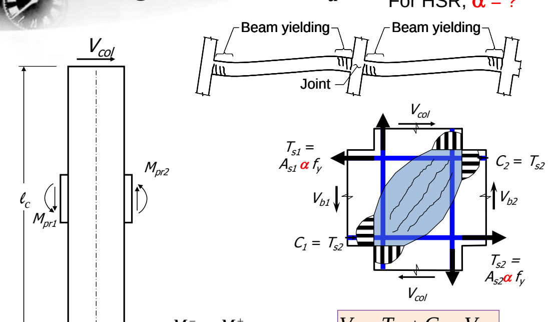
Scope

- Reinforced concrete special moment frame joints
- Normal-weight concrete and $f_c' \leq$ 100 MPa (14,500 psi)
- Specified yield strength of longitudinal reinforcement f_y shall not exceed 690 MPa (100,000 psi)
- Specified yield strength of transverse reinforcement f_{yt} shall not exceed 800 MPa (116,000 psi)

YunTech

Design shear force V_u

Typical α = 1.25
For HSR, α = ?



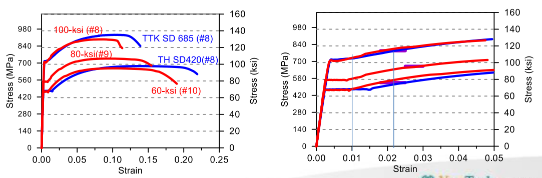
$$V_{col} \approx \frac{M^-_{pr1} + M^+_{pr2}}{\ell_c}$$

$$V_u = T_{s1} + C_2 - V_{col}$$

YunTech

Over-strength factor for bar f_y

Grade, ksi [MPa]	Grade 60 [420]	Grade 80 [550]	Grade 100 [690]
Overstrength Factor	α = 1.25	α = 1.20	α = 1.15
αf_y	75 [525]	96 [660]	115 [794]
$\alpha f_y - f_y$	15 [105]	16 [110]	15 [104]

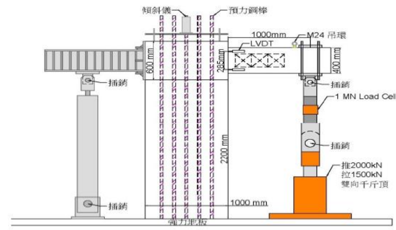


Stress-strain relations for 60, 80, and 100-ksi bars

Beam bending tests

- 15 cantilever beams made with 100-ksi [690 MPa] bars
- Positive and negative bending moment strengths, 30 data

$$\frac{M_{max,test}}{M_n} \approx 1.14 \text{ in average}$$



Setup at NCU, Taiwan

Outline

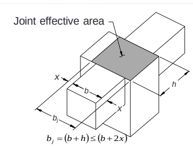
6.1 Shear Strength
- Design shear force V_u
- Nominal shear strength ϕV_n

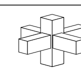
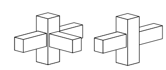
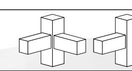
6.2 Joint transverse reinforcement
6.3 Development and Anchorage
- Minimum column depth for beam bars passing through the joint
- Development length for beam bars terminated within the joint

ACI 318 Code

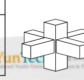
Nominal Joint Shear Strength

$$V_n = \gamma \sqrt{f'_c} A_j \quad \text{(psi)}$$



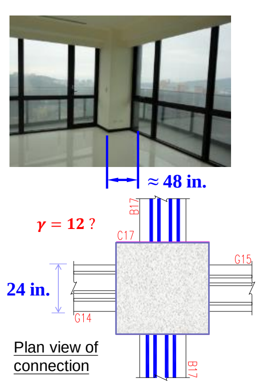
Joint configuration	V_n for f'_c in psi	Qualified Confinement
For joints confined by beams on all four faces	$20\sqrt{f'_c}A_j$	
For joints confined by beams on three faces or on two opposite faces	$15\sqrt{f'_c}A_j$	
For other cases	$12\sqrt{f'_c}A_j$	

Disqualified Confinement



Example

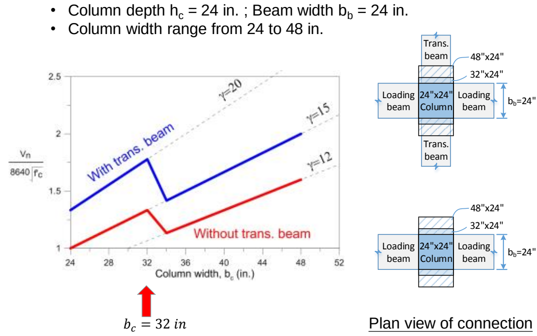
Blue Ocean, 150-m, 38F residential building in Taipei, Taiwan.



Plan view of connection

Case study, b_j and γ-value per ACI 318

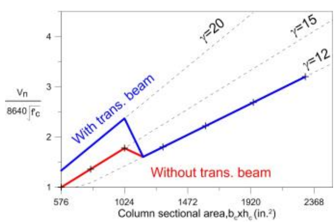
- Column depth h_c = 24 in. ; Beam width b_b = 24 in.
- Column width range from 24 to 48 in.



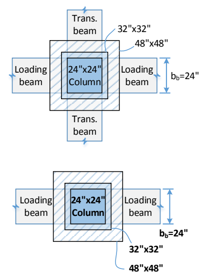
Plan view of connection

Case study, b_j and γ-value per ACI 318

- Beam width b_b= 24 in.
- Increasing square column section from 24x24 in. to 48x48 in.



Beyond $b_c x h_c = 32\text{x}32$, $\frac{b_b}{b_j} < 0.75$，both γ values drop to 12

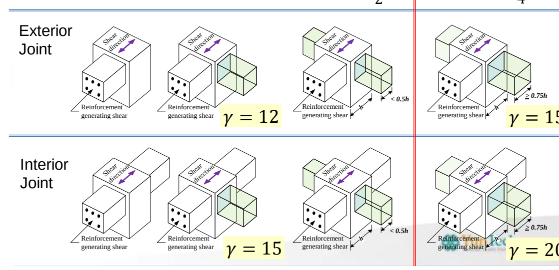


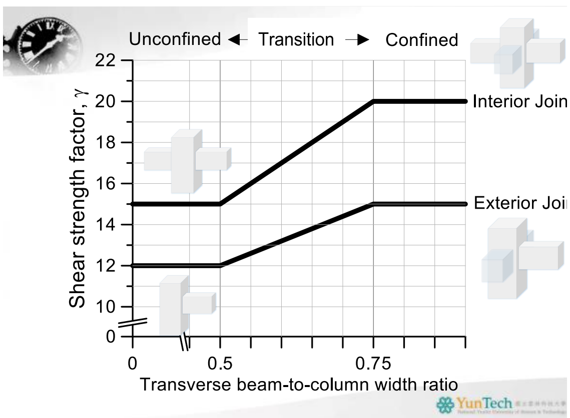
Plan view of connection

Nominal Shear Strength $V_n = \gamma\sqrt{f_c'}A_j$ (psi)

$V_n = 0.083\gamma\sqrt{f_c'}A_j$ (MPa)

Joint without continuous transverse beams | **Joint with continuous transverse beams**, but $b_{b,tr} < \frac{1}{2}h_c$ and $b_{b,tr} \geq \frac{3}{4}h_c$



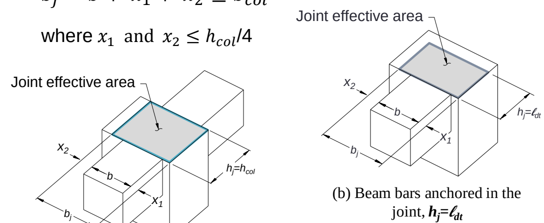


Effective Joint Area $A_j = b_j \cdot h_j$

Effective joint width

$$b_j = b + x_1 + x_2 \leq b_{col}$$

where x_1 and $x_2 \leq h_{col}/4$



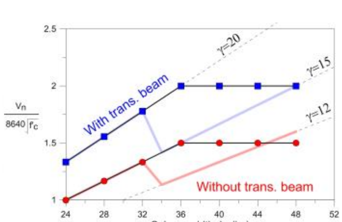
(a) Beam bars passing through the joint, $h_j = h_{col}$

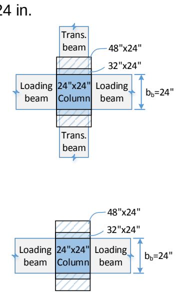
(b) Beam bars anchored in the joint, $h_j = \ell_{dt}$

Unless the provided development length of the beam bars is not less than 3/4 of the column depth, $h_j = h_{col}$

Case study, b_j and γ-value per ACI 318

- Column depth h_c = 24 in. ; Beam width b_b = 24 in.
- Column width range from 24 to 48 in.

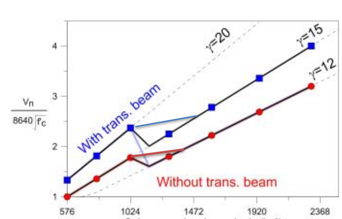




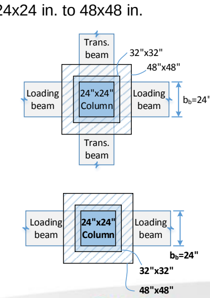
Plan view of connection

Case study, proposed b_j and γ-value

- Beam width b_b= 24 in.
- Increasing square column section from 24x24 in. to 48x48 in.



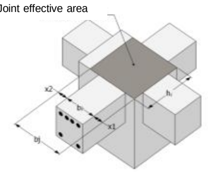
$\frac{b_{b,tr}}{h_c} < 0.75$，γ value drop down one category

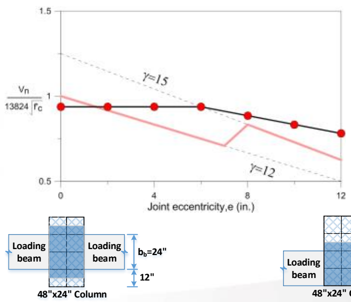


Plan view of connection

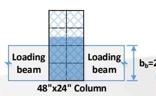
Case study for eccentric joints

- 48x24-in. Column
- Beam width b_b = 24 in.
- Eccentricity range from 0 to 12 in.





where x_1 and x_2 should be the lesser of $h_c/4$ and the edge distance between beam and column faces.



Exterior beam-column joints

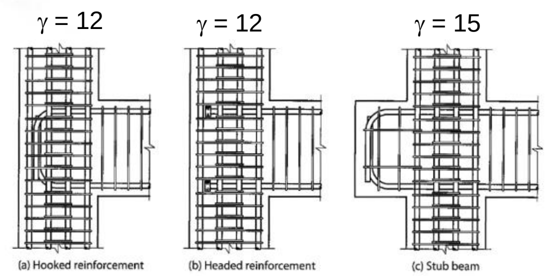


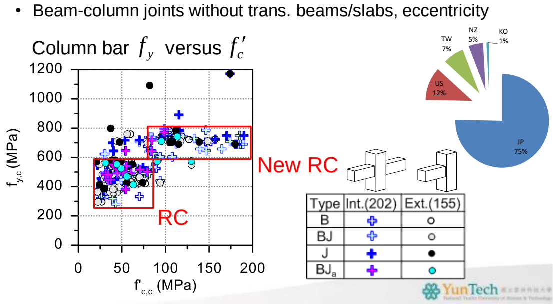
FIGURE 9.24 Elevation views of typical reinforcement for exterior beam-column connections with joint transverse reinforcement.

Source: Jack Moehle, Seismic Design of Reinforced Concrete Buildings

Database construction

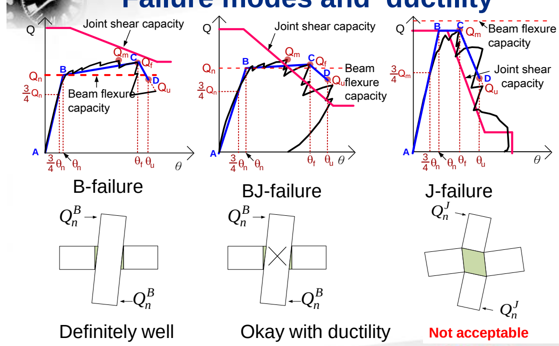
- 357 test data published in Japan, US, NZ, and Taiwan
- Unified database for normal-strength and high-strength RC
- Beam-column joints without trans. beams/slabs, eccentricity

Column bar f_y versus f'_c



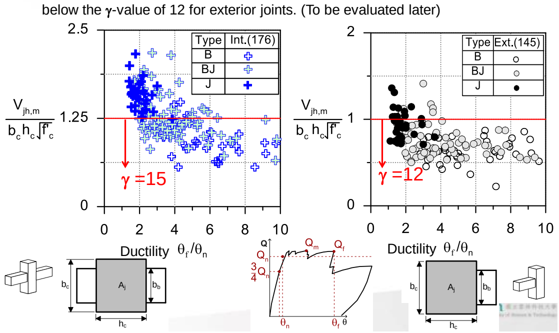
Type	Int.(202)	Ext.(155)
B	✚	○
BJ	✚	○
J	✚	●
BJ_a	✚	●

Failure modes and ductility



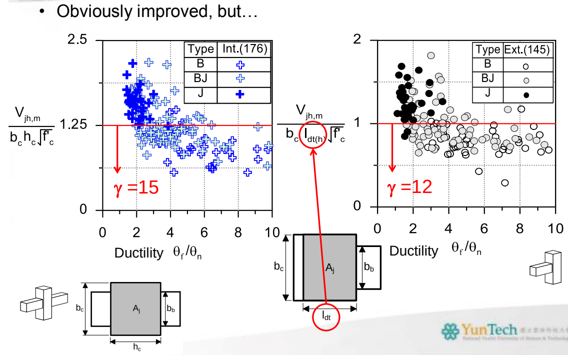
Joint Shear Strength-Ductility Trends

- Experimental joint shear force, normalized to effective joint area and $\sqrt{f'_c}$ in MPa
- There is no J failures below the γ-value of 15 for interior joints, but quite a few below the γ-value of 12 for exterior joints. (To be evaluated later)



Change of Effective Joint Depth

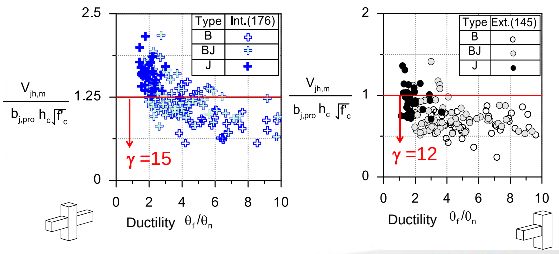
- Obviously improved, but…



Change of Effective Joint Width

- All test data are concentric joints
- $b_j = b_c$ for the majority of the data

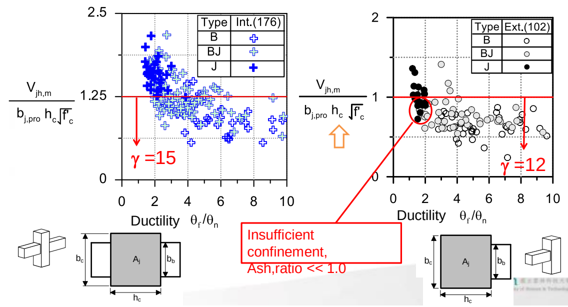
$$b_{j,pro} = b_b + \sum \min\left(\frac{h_c}{4}, x_i\right) \le b_c$$



Change of Effective Joint Width + Conditions

- Joint shear strength is quite sensitive to anchorage length
- Add a condition of $\ell_{dt(h)} \ge 0.75h_c$

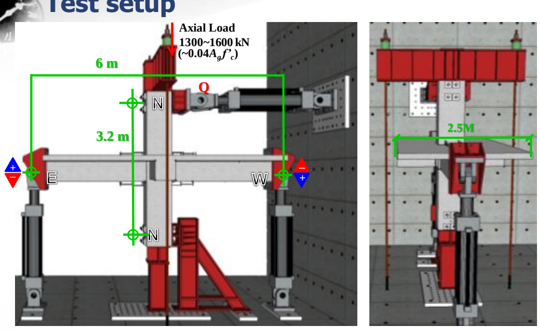
145 – 43 = 102 joints herein



Seismic Testing for Interior Beam-Column Joints (2013)

Seismic Testing for Interior Beam-Column Joints (2015)

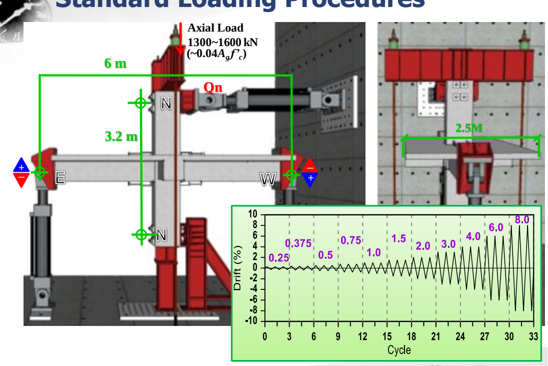
Test setup



North face

West face

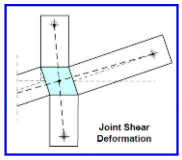
Standard Loading Procedures

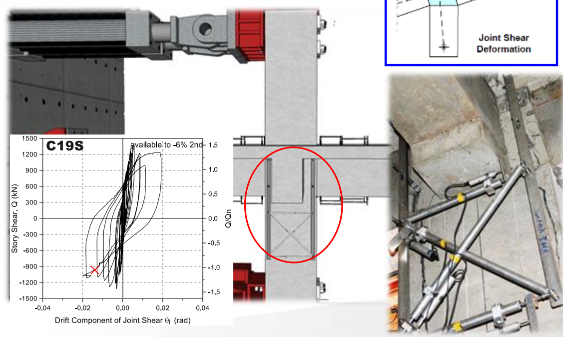


(Ref. to ACI 374.1-05 report)

Instrumentation

- Transducers for measuring joint deformation





Material Properties

Bar tensile tests

	#10 SD685	#8 SD685	#4 SD785	#3 SD420W
fy (MPa)	697	715	844	484
fu (MPa)	901	905	1020	687
Elong.(%)	14	13.5	15	21

Cylinder compressive strengths

Specified f'c= 100 MPa (14,500 psi)

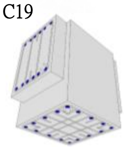
	A24S	A24B	C19S	C19B
Joint & Slab	104 (122)	95 (119)	117 (129)	116 (132)
Beam Web	109 (122)	104 (122)		
Lower Column				
Upper Column			110 (121)	108 (121)

Note: the concrete strength measured at 28 days and testing date (in parenthesis

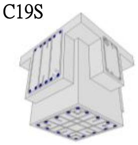
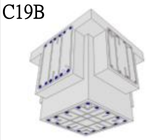
Test matrix

Prior Tests in 2013

C19



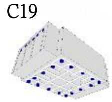
A24

試體設計參數	$\frac{b_{b,tr}}{h_{col}}=\frac{1}{2}$	$\frac{b_{b,tr}}{h_{col}}=\frac{3}{4}$
$\sim 20\sqrt{f'_c}$ psi $\frac{\Sigma M_{nc}}{\Sigma M_{nb}}=1.26$ 600x600-mm Col. 16-D32 500x600 mm 6-D32 top & 6-D32 bot	C19S 	C19B 
$\sim 15\sqrt{f'_c}$ psi $\frac{\Sigma M_{nc}}{\Sigma M_{nb}}=1.16$ 600x600-mm Col. 16-D25 500x600 mm 8-D25 top & 6-D25 bot.	A24S 	A24B 

Connection parameters

Prior Tests in 2013

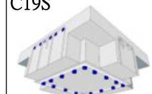
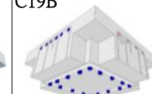
C19



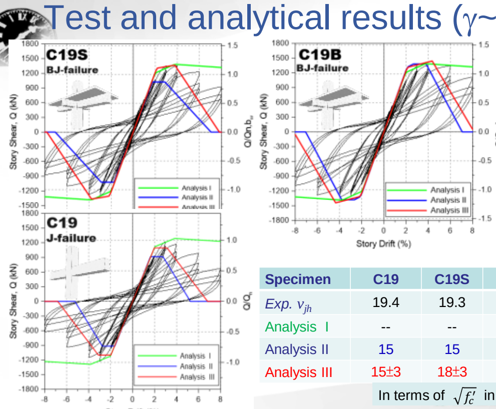
$A_{sh,ratio}=0.90$

A24

$A_{sh,ratio}=0.90$

Test Parameters	$\frac{b_{b,tr}}{h_{col}}=\frac{1}{2}$	$\frac{b_{b,tr}}{h_{col}}=\frac{3}{4}$
$\sim 20\sqrt{f'_c}$ psi $\frac{\Sigma M_{nc}}{\Sigma M_{nb}}=1.26$ 600x600-mm Col. 16-D32 500x600 mm 6-D32 top & 6-D32 bot	C19S  $A_{sh,ratio}=0.40$	C19B  $A_{sh,ratio}=0.40$
$\sim 15\sqrt{f'_c}$ 1.16 $\frac{\Sigma M_{nc}}{\Sigma M_{nb}}=1.26$ 600x600-mm Col. 16-D25 500x600 mm 8-D25 top & 6-D25 bot.	A24S  $A_{sh,ratio}=0.40$	A24B  $A_{sh,ratio}=0.40$

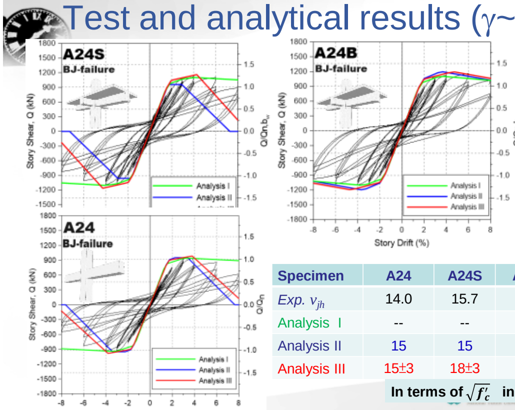
Test and analytical results (γ~20)



Specimen	C19	C19S	C19B
Exp. v_{jh}	19.4	19.3	19.0
Analysis I	--	--	--
Analysis II	15	15	20
Analysis III	15±3	18±3	20±3

In terms of $\sqrt{f'_c}$ in psi.

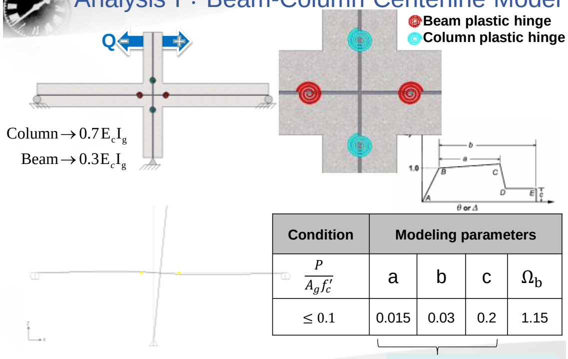
Test and analytical results (γ~15)



Specimen	A24	A24S	A24B
Exp. v_{jh}	14.0	15.7	17.6
Analysis I	--	--	--
Analysis II	15	15	20
Analysis III	15±3	18±3	20±3

In terms of $\sqrt{f'_c}$ in psi.

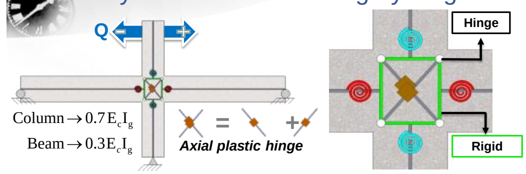
Analysis I：Beam-Column Centerline Model



Condition	Modeling parameters			
$\frac{P}{A_g f_c'}$	a	b	c	Ω_b
≤ 0.1	0.015	0.03	0.2	1.15

Ref to ASCE-41, ACI 369-11

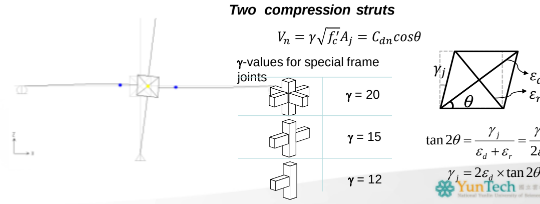
Analysis II：Joint modeling by diagonal struts



Two compression struts

$V_n = \gamma\sqrt{f_c'}A_j = C_{dn}\cos\theta$

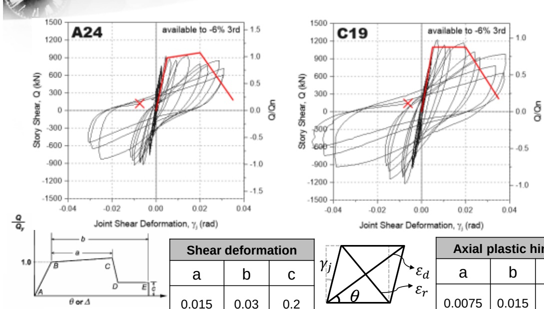
γ-values for special frame joints



$\tan 2\theta = \frac{\gamma_j}{\varepsilon_d+\varepsilon_r} = \frac{\gamma_j}{2\varepsilon_d}$

$\gamma_j = 2\varepsilon_d \times \tan 2\theta$

Modeling parameters for diagonal struts



Shear deformation		
a	b	c
0.015	0.03	0.2

Ref to ASCE-41, ACI 369-11

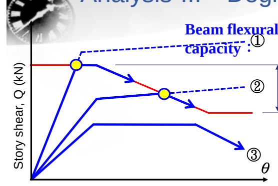
Axial plastic hinge		
a	b	c
0.0075	0.015	0.2

$\tan 2\theta = \frac{\gamma_j}{\varepsilon_d+\varepsilon_r} = \frac{\gamma_j}{2\varepsilon_d}$

$\gamma_j = 2\varepsilon_d \times \tan 2\theta$

Analysis III：Degraded Strength Model

$V_{jh} = \frac{M_{nb}^{+} \cdot M_{nb}^{-}}{jd}\left[1 - \frac{jd}{l_c}\frac{l_b}{(l_b-h_c)}\right]$

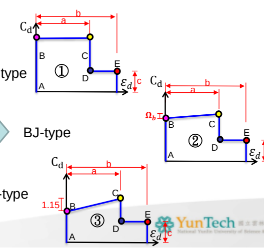


Joint shear capacity：$(\gamma \pm 3)\sqrt{f_c'}A_j$

① $V_{jh} > (\gamma+3)\sqrt{f_c'}A_j$ → J-type

② $(\gamma-3)\sqrt{f_c'}A_j < V_{jh} < (\gamma+3)\sqrt{f_c'}A_j$ → BJ-type

③ $V_{jh} < (\gamma-3)\sqrt{f_c'}A_j$ → B-type



Outline

6.1 Shear Strength

- **Design shear force V_u**
- **Nominal shear strength ϕV_n**

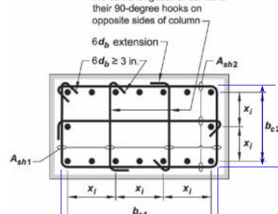
6.2 Joint transverse reinforcement

6.3 Development and Anchorage

- **Minimum column depth for beam bars passing through the joint**
- **Development length for beam bars terminated within the joint**

A_{sh}/sb_c for rectilinear hoop

(ACI 318-14)



The dimension x_i from centerline to centerline of laterally supported longitudinal bars is not to exceed 14 inches. The term h_x used in Eq. (18.7.5.3) is taken as the largest value of x_i.

$$\frac{A_{sh}}{sb_c} \geq \begin{cases} 0.3\left(\frac{A_g}{A_{ch}}-1\right)\frac{f_c'}{f_{yt}} & \text{(a)} \\ 0.09\frac{f_c'}{f_{yt}} & \text{(b)} \\ 0.2k_f k_n \frac{P_u}{f_{yt}A_{ch}} & \text{(c)} \end{cases}$$

(c): $P_u > 0.3A_g f_c'$ or $f_c' > 10{,}000$ psi (70 MPa)

$k_f = \frac{f_c'}{25{,}000psi} + 0.6 \geq 1.0$

$k_n = \frac{n_l}{n_l - 2}$

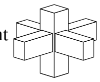
Allow the use of crossties with 90-degree and 135-degree hooks for HSC columns

~~$f_{yt} \leq 100{,}000\ psi\ (700\ MPa)$~~

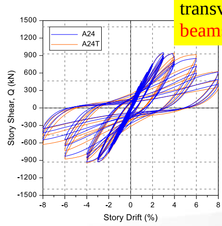
$f_{yt} \leq 116{,}000\ psi\ (800\ MPa)$

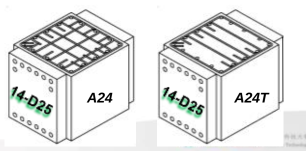
ACI 318

Where beams frame onto all four sides of the joint and where each beam width is at least ¾ the column width, the required amount of transverse reinforcement shall be permitted to be reduced by 50%...



Where beams frame onto two opposite sides of the joint and where each beam width is at least ¾ the column width, the required amount of transverse reinforcement parallel to the framing beams shall be permitted to be reduced by 50%...





Outline

6.1 Shear Strength

- Design shear force V_u
- Nominal shear strength ϕV_n

6.2 Joint transverse reinforcement

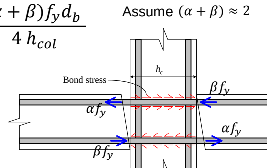
6.3 Development and Anchorage

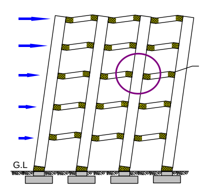
- Minimum column depth for beam bars passing through the joint
- Development length for beam bars terminated within the joint

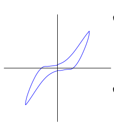
Probable bond stress along the beam bars passing through joint (Bond index, *Kitayama et al.*)

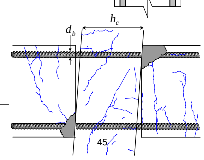
$$u_B = \frac{(\alpha f_y + \beta f_y)\frac{\pi d_b^2}{4}}{\pi d_b h_{col}} = \frac{(\alpha+\beta) f_y d_b}{4\, h_{col}}$$

Assume $(\alpha+\beta) \approx 2$









Pinching effect

ACI 318

$$\frac{h_{col}}{d_b} \geq 20$$

AIJ.G.L.1988

$$u_B = \frac{2 f_y d_b}{4\, h_{col}} \leq u_n = 1.6\sqrt{f_c'} \text{ MPa}$$

Bond strength in the joint

$$\frac{h_{col}}{d_b} \geq \frac{2}{4}\cdot\frac{f_y}{1.6\sqrt{f_c'}} = \frac{f_y}{3.2\sqrt{f_c'}}$$

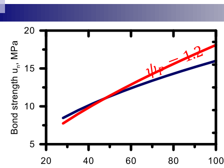
AIJ.G.L.1999

$$u_B = \frac{2 f_y d_b}{4\, h_{col}} \leq u_n = \psi_P 0.7 f_c'^{2/3} \text{ MPa}$$

Bond strength in the joint

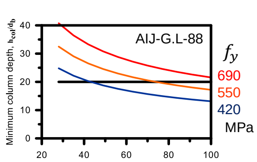
$$\frac{h_{col}}{d_b} \geq \frac{2}{4}\cdot\frac{f_y}{\psi_P 0.7 f_c'^{2/3}} = \frac{f_y}{\psi_P 1.4 f_c'^{2/3}}$$

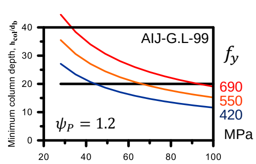
Axial load factor $\psi_P = 1 + \frac{P}{A_g f_c'} \leq 1.25$



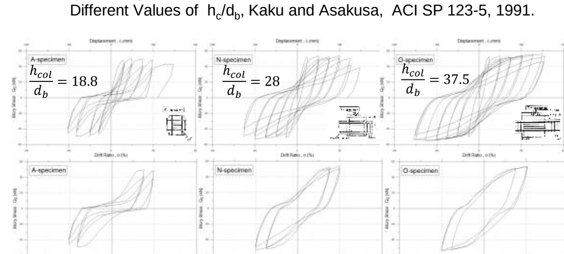
$u_n = \psi_P 0.7 f_c'^{2/3}$ MPa AIJ-G.L-99

$u_n = 1.6\sqrt{f_c'}$ MPa AIJ-G.L-88





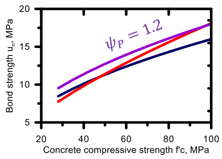
Cyclic Response of Reinforced Concrete Beams-Column Joints with Different Values of h_c/d_b, Kaku and Asakusa, ACI SP 123-5, 1991.



	A-specimen		N-specimen		O-specimen	
	3%	4%	3%	4%	3%	4%
ξ_{eq}	0.13	0.10	0.20	0.28	0.23	0.34
k_o/k_i	0.02	0.01	0.10	0.07	0.14	0.11

Our proposal

Axial load factor $\psi_P = 1 + \frac{P}{A_g f_c'} \le 1.25$

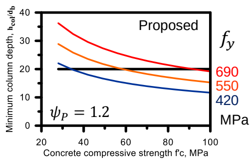


$u_n = \psi_P 1.5\sqrt{f_c'}$ MPa

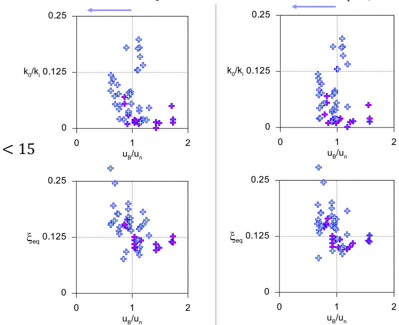
$$u_B = \frac{2 f_y d_b}{4\, h_{col}} \le u_n$$

$$\frac{h_{col}}{d_b} \ge \frac{2}{4} \cdot \frac{f_y}{\psi_P 1.5\sqrt{f_c'}} = \frac{f_y}{\psi_P 3\sqrt{f_c'}}$$

but not less than 20



$\frac{h_{col}}{d_b} \ge \frac{f_y}{\psi_P 1.4 f_c'^{2/3}}$ $\qquad$ $\frac{h_{col}}{d_b} \ge \frac{f_y}{\psi_P 3\sqrt{f_c'}}$



$\frac{V_{jh,m}}{A_j\sqrt{f_c'}} < 15$

$u_n = \psi_P 0.7 f_c'^{2/3}$ MPa $\qquad$ $u_n = \psi_P 1.5\sqrt{f_c'}$ MPa

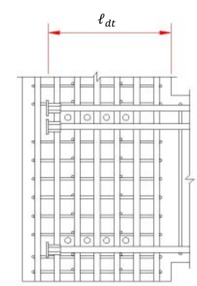
Recommendation for Minimum column depth

$\frac{h_{col}}{d_b} \ge \frac{f_y}{\psi_P 3\sqrt{f_c'}}$ in MPa $\quad$ but not less than **20** $\qquad$ $\psi_P = 1 + \frac{P}{A_g f_c'} \le 1.25$

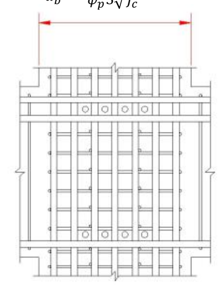
f_c'		SD 420		SD 550		SD 685	
psi	MPa	α_p =1.0	α_p = 1.25	α_p =1.0	α_p = 1.25	α_p =1.0	α_p = 1.25
4000	28	26	21				
5000	35	24	20				
6000	42	22	20	28	23		
7000	49	20	20	26	21		
8000	56	20	20	24	20	31	24
9000	63	20	20	23	20	29	23
10000	70	20	20	22	20	27	22
12000	84	20	20	20	20	25	20
14500	100	20	20	20	20	23	20

Anchorage and Bond

$\frac{h_{col}}{d_b} \ge \frac{f_y}{\psi_P 3\sqrt{f_c'}}$, and 20



Elevation
(sectionA-A)



Elevation
(sectionA-A)

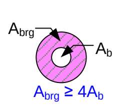
Development length for Headed Deformed Bars

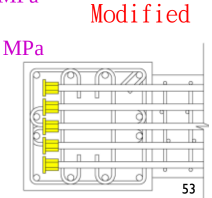
(ACI 318-14)

$$\ell_{dt} = 0.016\frac{f_y d_b}{\sqrt{f_c'}}\ (f_c' \text{ in psi})\ \text{ or }\ 0.192\frac{f_y d_b}{\sqrt{f_c'}}\ (f_c' \text{ in MPa})$$

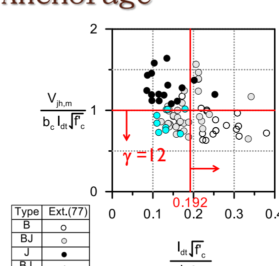
- fy ≤ 420 MPa ➢ 690 MPa
- Minimum bar spacing **3**d_b ➢ $2d_b$
- f'c ≤ 42MPa ➢ 100 MPa

Modified





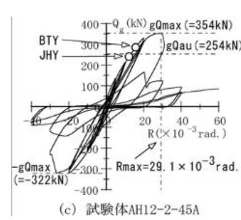
Anchorage

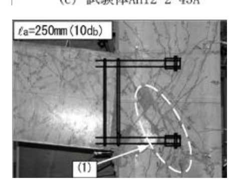


Headed bars

$$\text{Required } \ell_{dt} \ge 0.192\frac{f_y d_b}{\sqrt{f_c'}}$$

*liberate f_y & f_c' limits



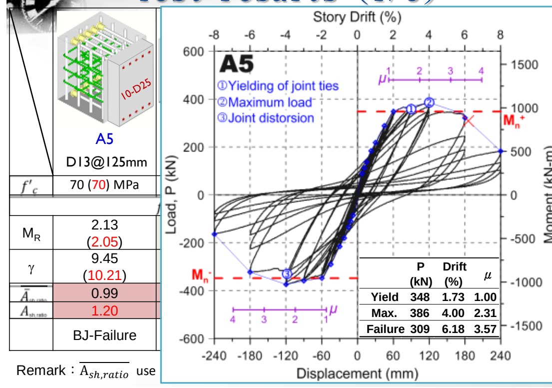


Masuo, K., Adachi, M., and Imanishi, T. (2006)

Seismic Testing for Exterior Beam-Column Joints

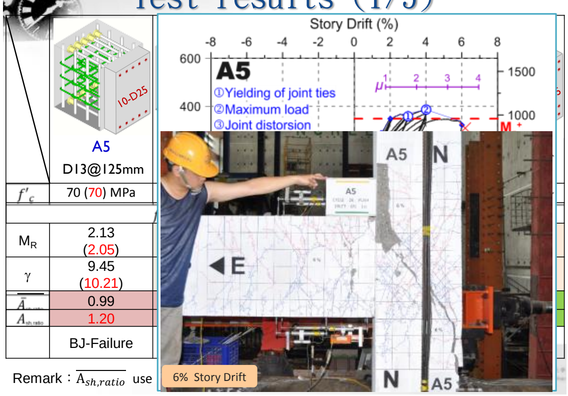
55

Test results (1/5)



Remark : $\overline{A}_{sh,ratio}$ use

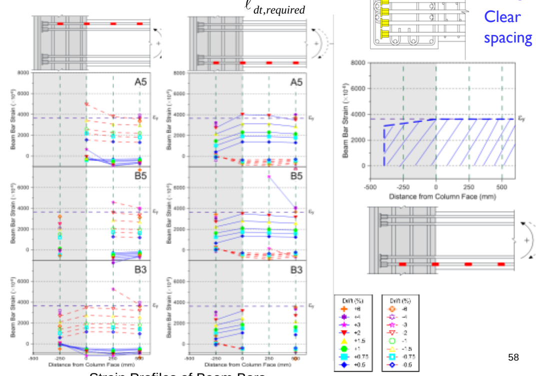
Test results (1/5)



Remark : $\overline{A}_{sh,ratio}$ use

$$\frac{\ell_{dt,provided}}{\ell_{dt,required}} = 1.04$$

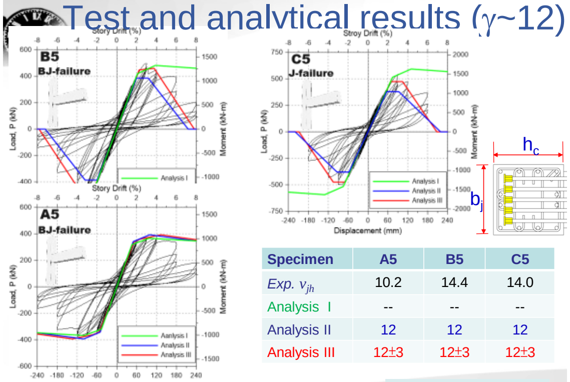
2 d_b Clear spacing



Strain Profiles of Beam Bars

58

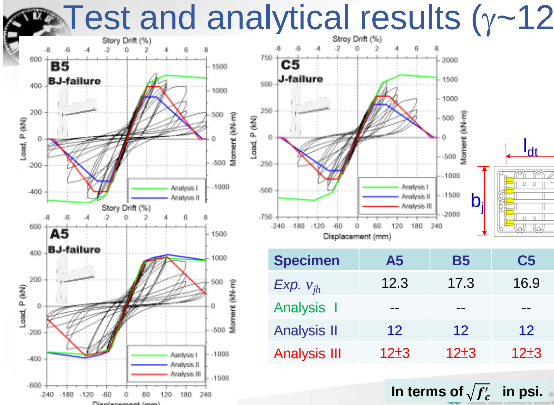
Test and analytical results (γ~12)



Specimen	A5	B5	C5
Exp. v_{jh}	10.2	14.4	14.0
Analysis I	--	--	--
Analysis II	12	12	12
Analysis III	12±3	12±3	12±3

In terms of $\sqrt{f'_c}$ in psi.

Test and analytical results (γ~12)



Specimen	A5	B5	C5
Exp. v_{jh}	12.3	17.3	16.9
Analysis I	--	--	--
Analysis II	12	12	12
Analysis III	12±3	12±3	12±3

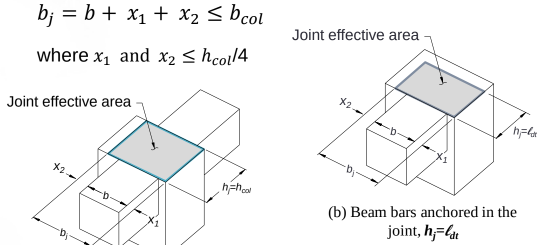
In terms of $\sqrt{f'_c}$ in psi.

Effective Joint Area $A_j = b_j \cdot h_j$

Effective joint width

$$b_j = b + x_1 + x_2 \leq b_{col}$$

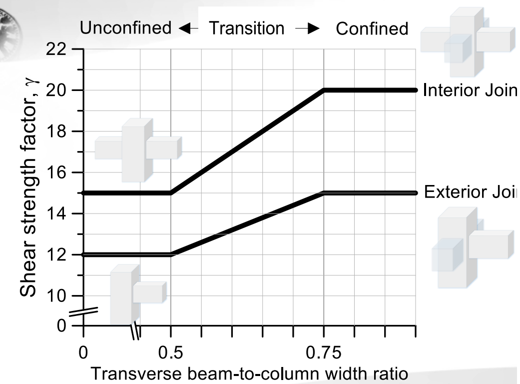
where x_1 and $x_2 \leq h_{col}/4$



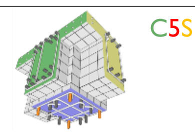
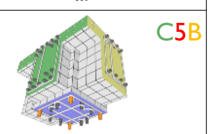
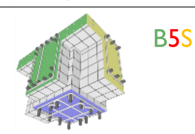
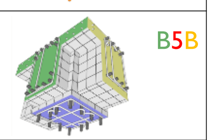
(a) Beam bars passing through the joint, h_j=h_{col}

(b) Beam bars anchored in the joint, h_j=ℓ_{dt}

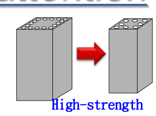
Unless the provided development length of the beam bars is not less than 3/4 of the column depth, h_j=h_{col}

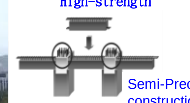


Test matrix in 2016, to be tested in June

Connection Parameters	$\frac{b_{b,tr}}{h_{col}} = 0.6$	$\frac{b_{b,tr}}{h_{col}} = 0.75$
$\sim 19\sqrt{f'c}\ psi$ 500x500mm Col. 12-D25 4-D32 400x600mm 9-D25 top 9-D25 bot	 C5S	 C5B
$\sim 15.5\sqrt{f'c}\ psi$ 500x500mm Col. 16-D25 400x600mm 7-D25 top 7-D25 bot	 B5S	 B5B

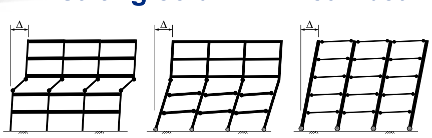
Thanks for your attention





Save labor, time, and materials
Total cost down!

Frame Mechanisms "strong column – weak beam"



- Avoid story mechanism
- Avoid joint failure

Inadequate confinement

Laboratory Specimen under Cyclic Deformation Loading