Large-Scale Testing of Steel Reinforced Concrete (SRC) Coupling Beams

Christopher J. Motter, UC Los Angeles
John W. Wallace, UC Los Angeles

Ron Klemencic, John Hooper, Dave Fields
Magnusson, Klemencic Associates

Charles Pankow Foundation
ACI Pankow Foundation Student Fellowship

Los Angeles Tall Building Structural Design Council
May 2013, Los Angeles, CA

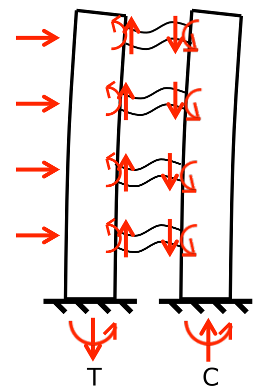
Presentation Outline

- Background
- Motivation
- Specimen Design
- Testing Program
- Test Results
- Backbone Modeling
- Conclusions & Recommendations

2

Background – Coupling Beams

- RC coupling beams
  - Diagonally-reinforced
  - Concrete-encased structural steel
- Primary functions
  - Added strength & stiffness
  - energy dissipation
- Primary issues
  - Detailing issues (ductility)
  - Modeling (e.g., backbone relation)

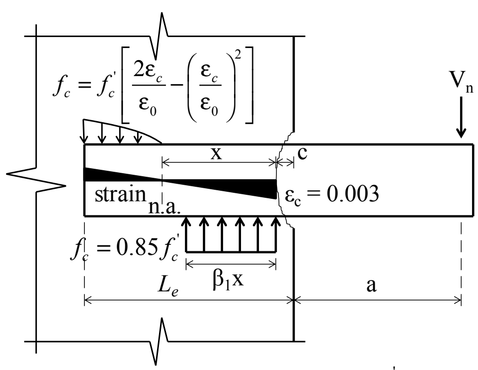


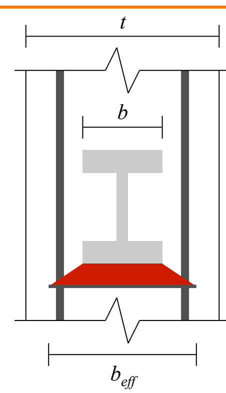
Diagonally-Reinforced

Concrete-Encased Steel

3

Embedment Model





Marcakis & Mitchell (1980) :*

$$V_n = \frac{0.85 f_c^{'} b_{eff} (l_e - c)}{1 + 3.6\left(\frac{e}{(l_e - c)}\right)}$$

Mattock & Gaafar (1982) :*

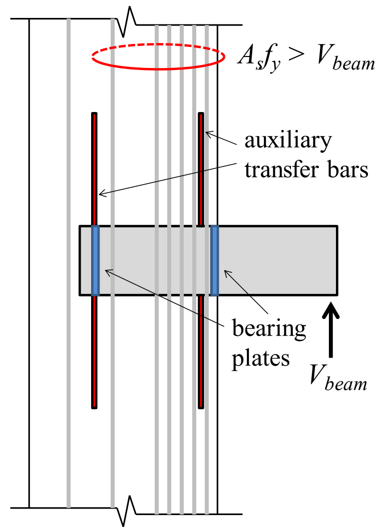
$$V_n = 4.5\sqrt{f_c^{'}}\left(\frac{t}{b}\right)^{0.66} \beta_1 b (l_e - c)\left(\frac{0.58 - 0.22\beta_1}{0.88 + (a + c)/(l_e - c)}\right)$$

**Modified to include interface spalling per Harries et al (2000)*

4

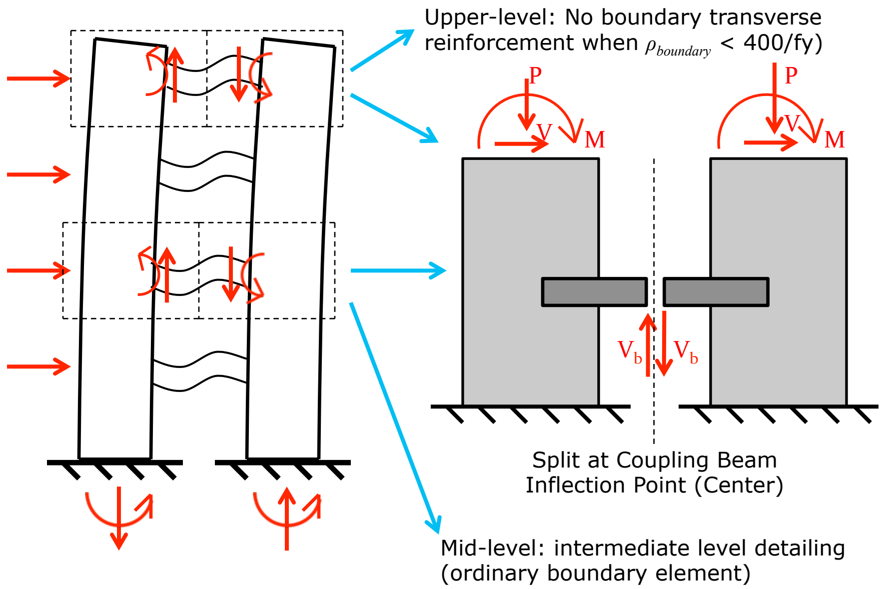
AISC 2010 Seismic Provisions

- Flexural capacity using strain compatibility or plastic analysis
- Shear capacity using $V_{comp} = 1.1 R_y V_{steel} + 1.56 V_{RC}$
- Initial stiffness using 0.35Ig
- Embedment length consistent with Mattock and Gaafar (1982)
- Transfer bars and bearing plates required
- Vertical boundary steel: $A_s f_y \geq V_{n,beam}$



5

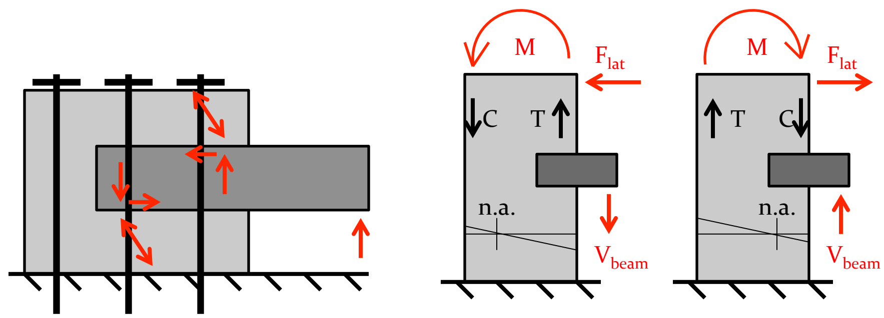
Test Sub-Assembly



6

Motivation

- Large-scale SRC beam
- Realistic boundary conditions (load paths)
  - Wall strain gradient across connection

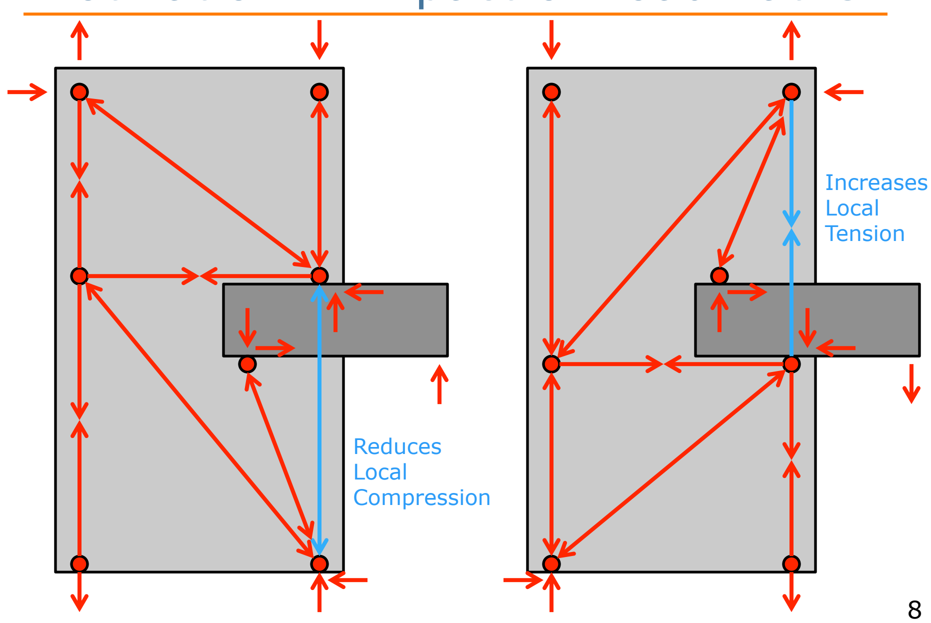


Embedment into reaction block:
- No strain gradient
- Load path satisfied

Embedment into wall boundary:
- Strain gradient at embedment
- Imposes demands on wall

7

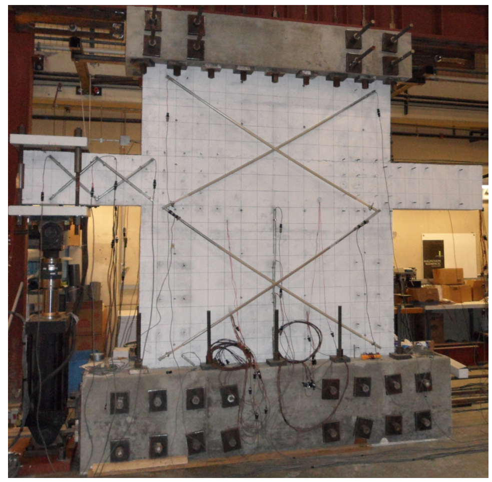
Motivation – Impact of Load Paths



8

Testing Program Overview

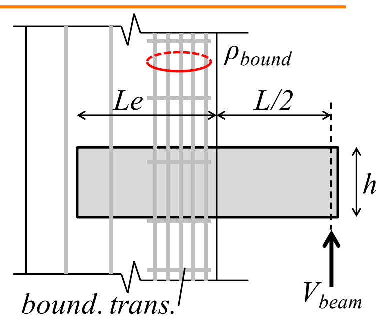
- Two test specimens
- Each specimen
  - One wall
  - Two coupling beams, one on each side
- Coupling beam tests
  - Individually with wall loads applied
- Second specimen designed after testing completed on first specimen



9

Summary of Test Variables

- Beam 1: Long embedment (conservative design)
- Beam 2: Shorter embedment
- Beam 3: Shorter aspect ratio
- Beam 4: No boundary confinement, $\rho_{bound} < 400/f_y$

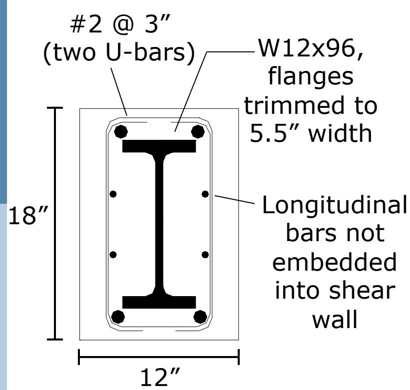


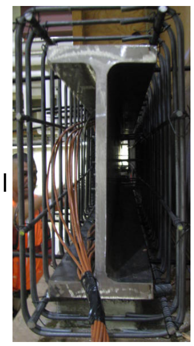
	$\alpha_{beam}=L/h$	L_e	ρ_{bound}	bound. trans.
Beam 1 (3.33-32-6C)	3.33	32”	0.024 (14#6)	#2@4"
Beam 2 (3.33-24-7C)	3.33	24”	0.033 (14#7)	#2@4"
Beam 3 (2.40-26-5C)	2.40	26”	0.017 (14#5)	#2@4"
Beam 4 (3.33-24-3NC)	3.33	24”	0.006 (14#3)	none

10

Coupling Beam

- Flexure-controlled
- ~1/2-scale W24x250

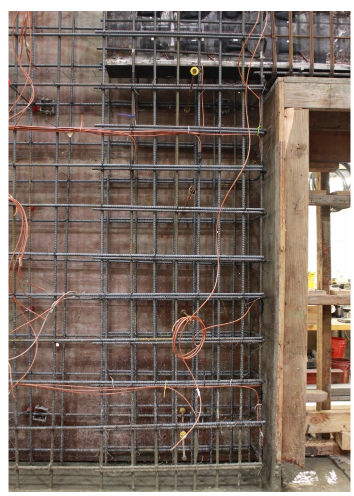




11

Shear Wall Boundary

Ordinary boundary element

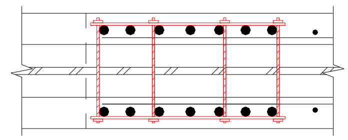


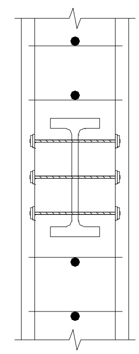
No boundary Confinement

12

Embedment Detailing

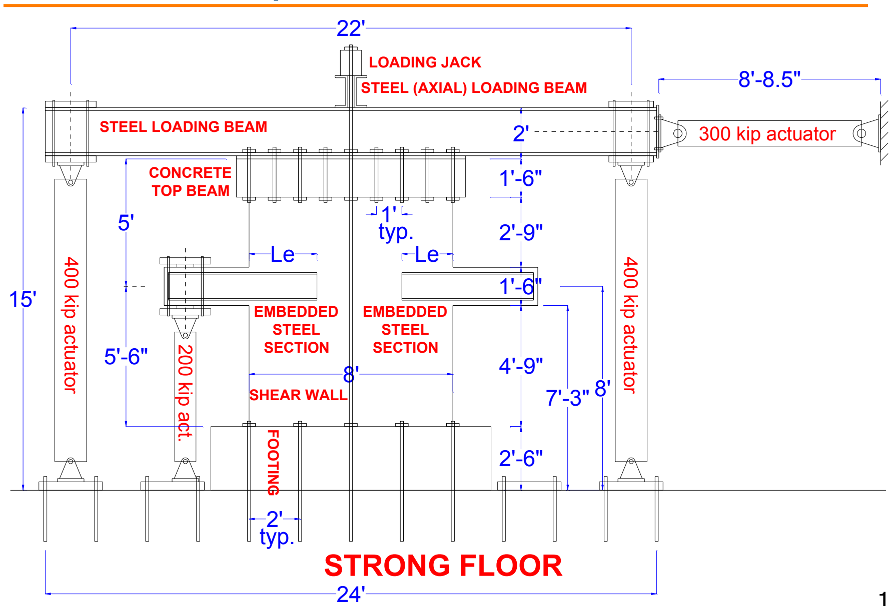
- Pre-drilled holes in web of steel section
- Threaded rods and side plates to maintain boundary confinement



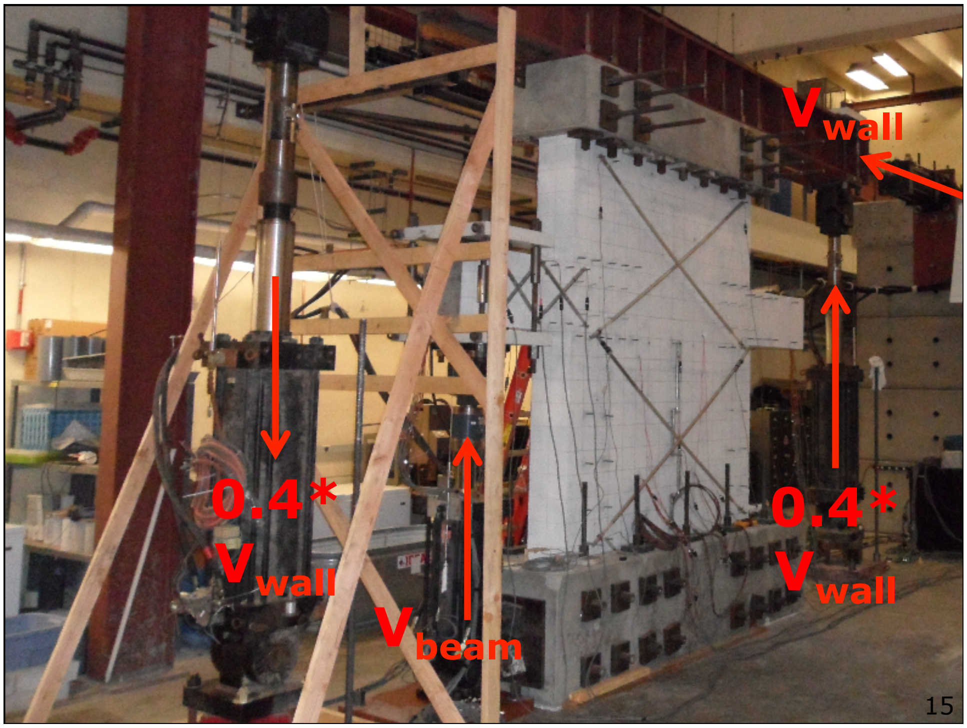


13

Test Set-Up



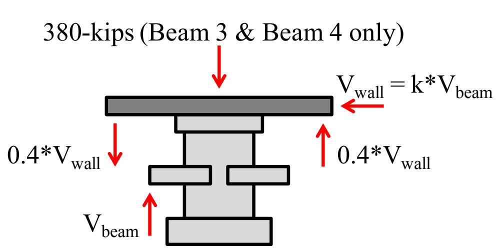
14



15

Wall Loading

- Proportional loading: Vu and Mu
- Wall moment demands at connection
  - Beam 1: Exceeded cracking moment (low moment, long Le)
  - Beam 2: Approached yield moment (high moment, short Le)
- Wall moment demands at connection
  - Beam 3 and Beam 4: Similar to Beam 2



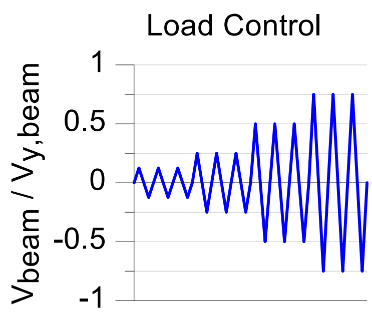
$k = V_{wall} / V_{beam} =$

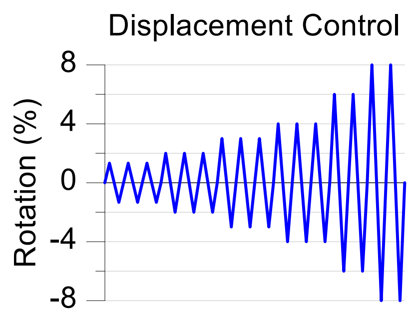
	(+), Up	(-), Down
Beam 1	0.5	0.5
Beam 2	1.25	1.25
Beam 3	1.0	0.5
Beam 4	1.0	0.5

16

Testing Protocol

- Reversed cyclic loading
- 3 cycles at each level up to 4%, then 2 cycles
- Load-controlled to (+/-) ¾*V_{yield}, then displacement- controlled





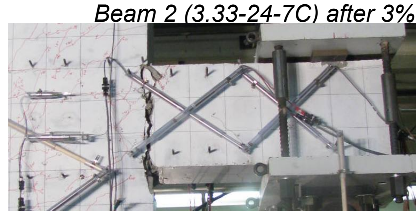
17

Observed Damage (Beams 1 & 2)

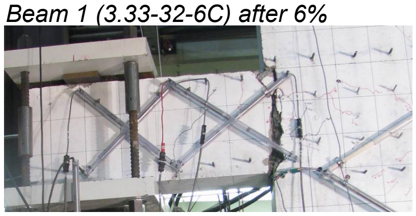
- Concentrated at beam-wall interface

Beam 1 (3.33-32-6C) after 3%

Beam 2 (3.33-24-7C) after 3%



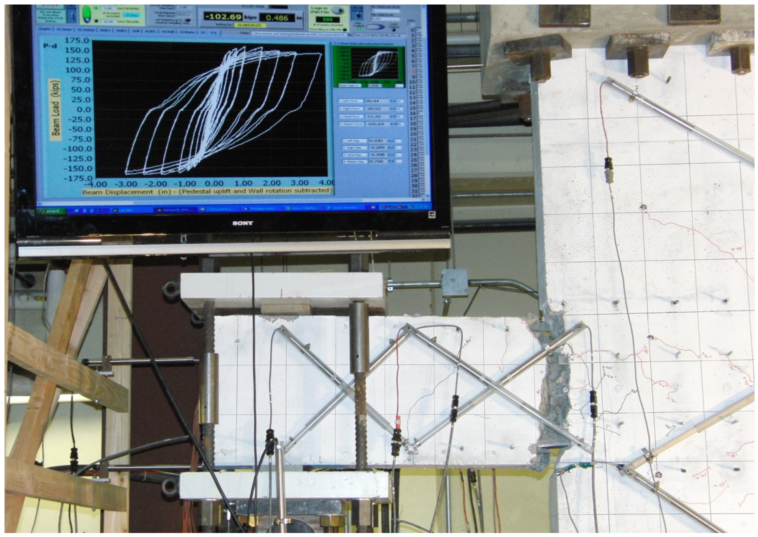
Beam 1 (3.33-32-6C) after 6%



Beam 2 (3.33-24-7C) after 6%

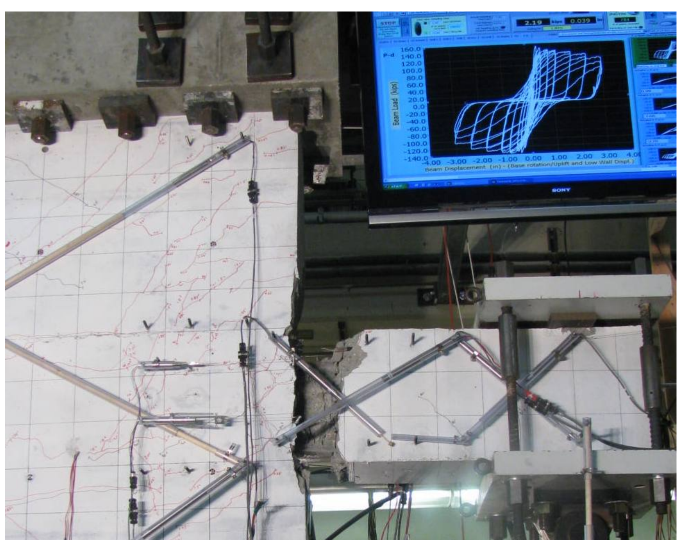
18

Beam 1: 3.33-32-6C (end of test)



19

Beam 2: 3.33-24-7C (end of test)

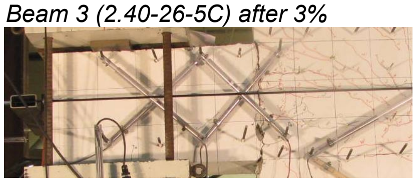


20

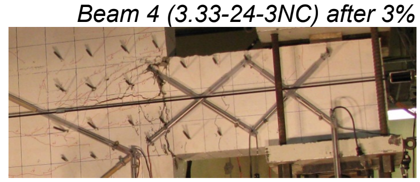
Observed Damage (Beams 3 & 4)

- Included embedment damage

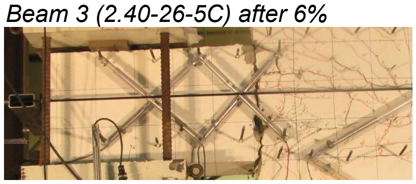
Beam 3 (2.40-26-5C) after 3%



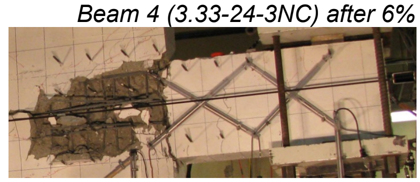
Beam 4 (3.33-24-3NC) after 3%



Beam 3 (2.40-26-5C) after 6%

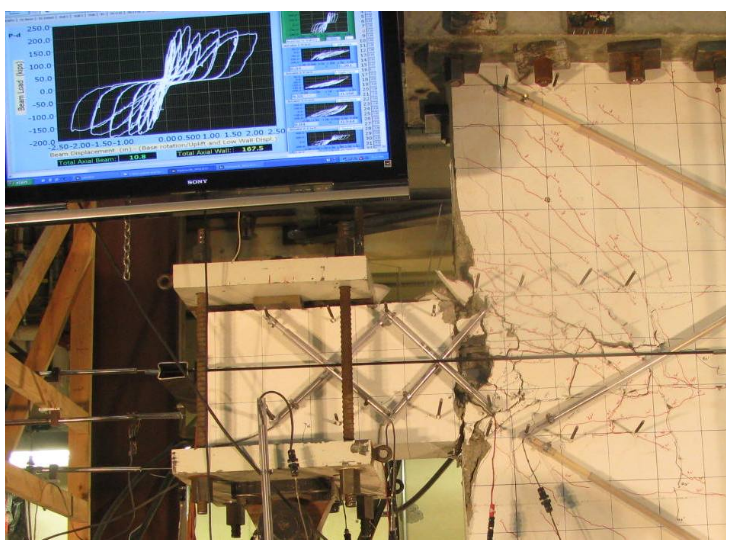


Beam 4 (3.33-24-3NC) after 6%



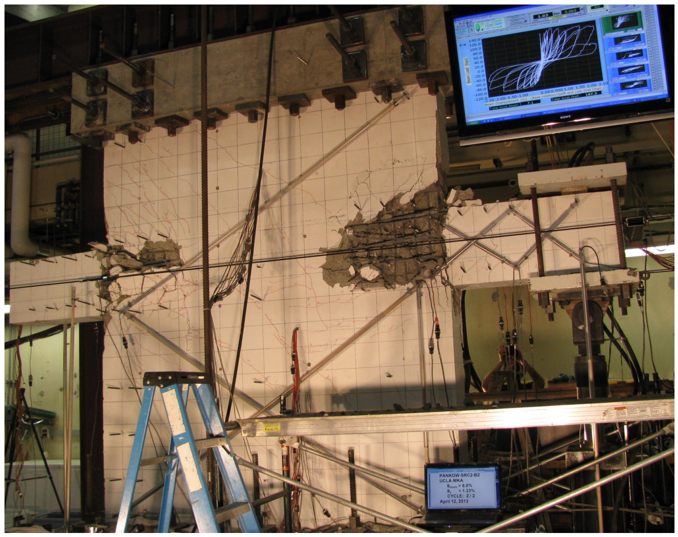
21

2.40-26-5C (end of test)



22

3.33-24-3NC (end of test)



23

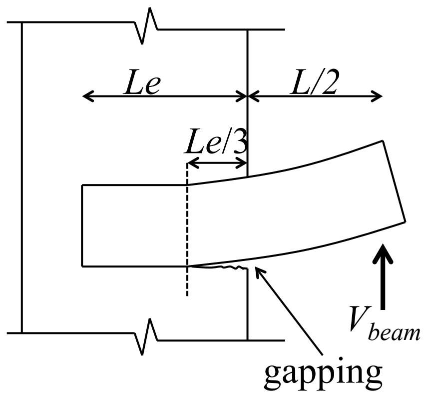
Observed Damage

Photo showing significant gapping between flange and concrete (3.33-24-7C)

24

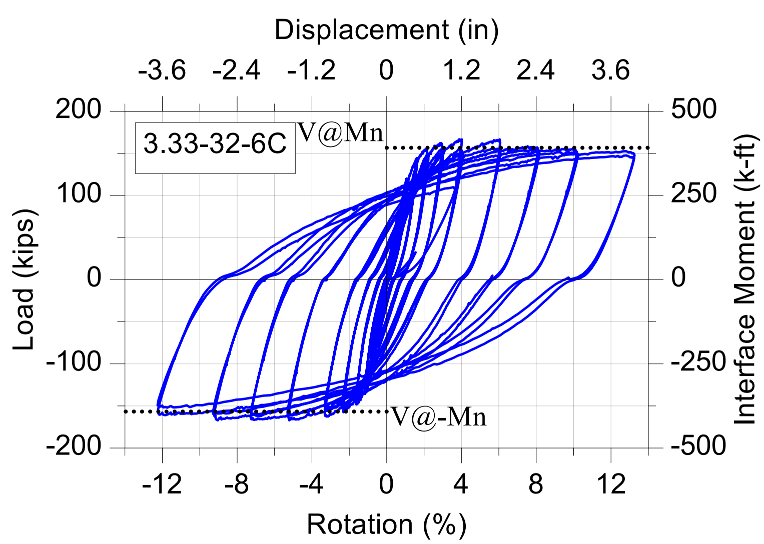
Modeling Recommendation

- Harris et al (2000) recommend taking the effective fixity point at *Le*/3 inside the beam-wall interface for modeling purposes



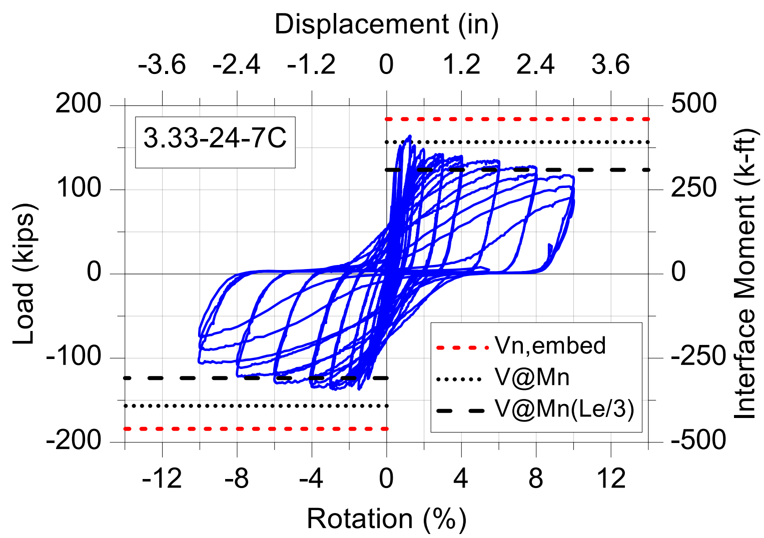
25

Load-Displacement



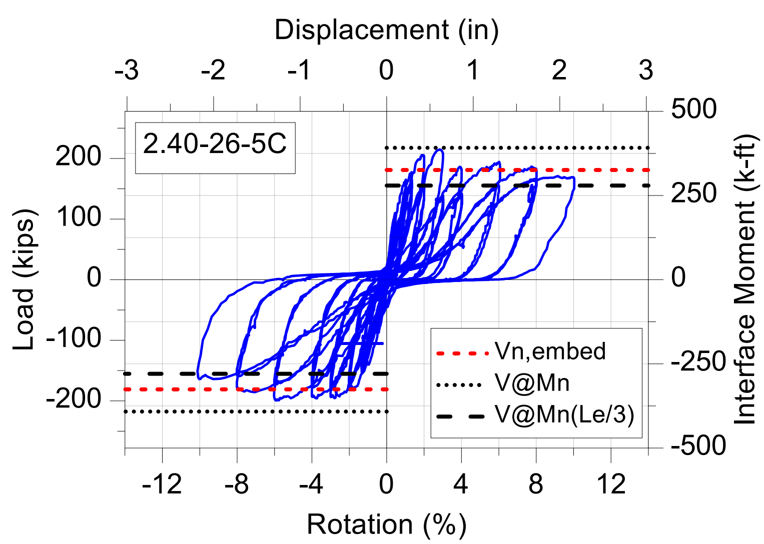
26

Load-Displacement



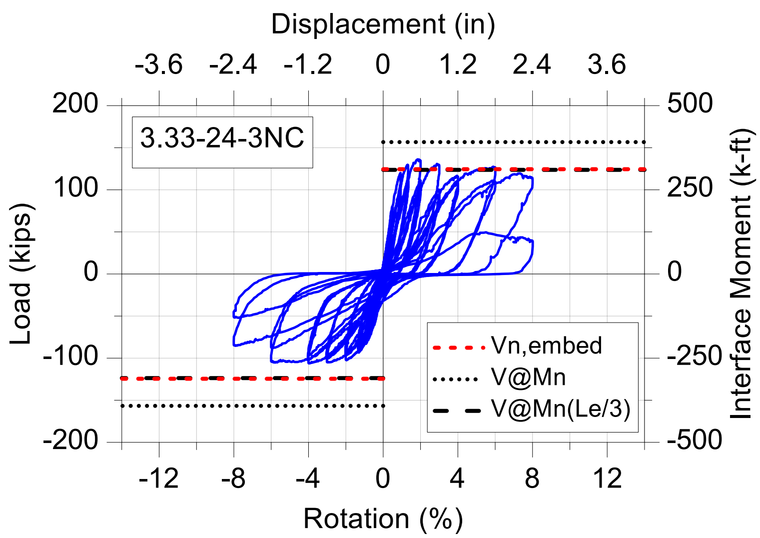
27

Load-Displacement



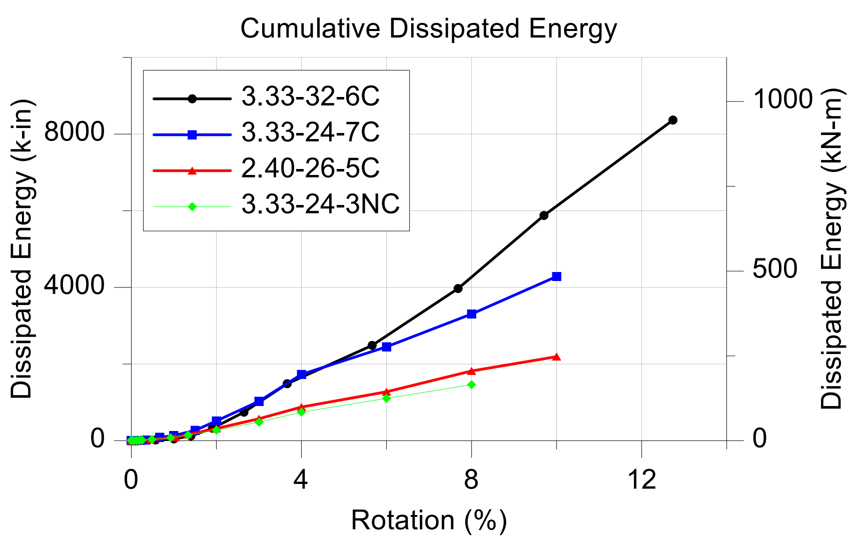
28

Load-Displacement



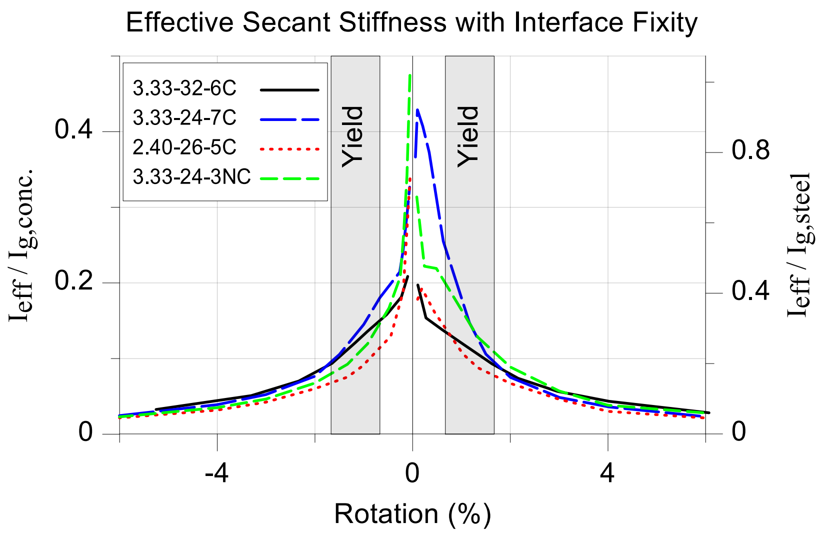
29

Test Results



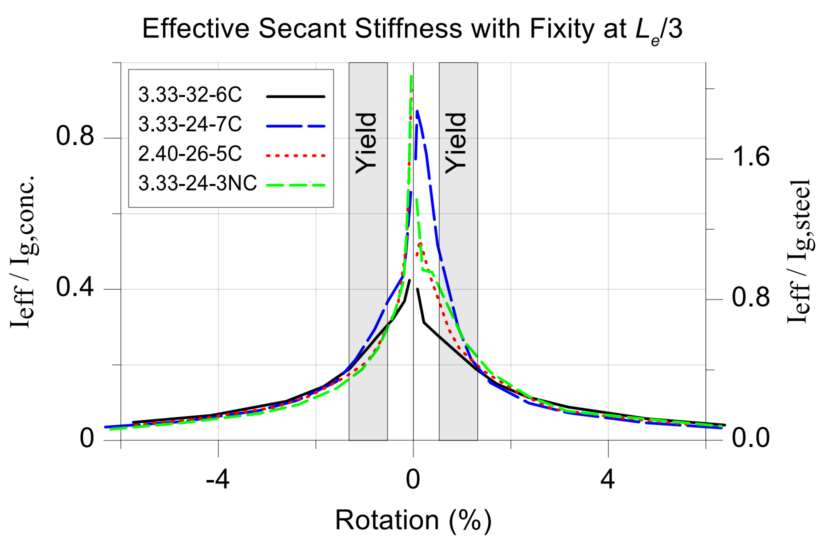
30

Test Results



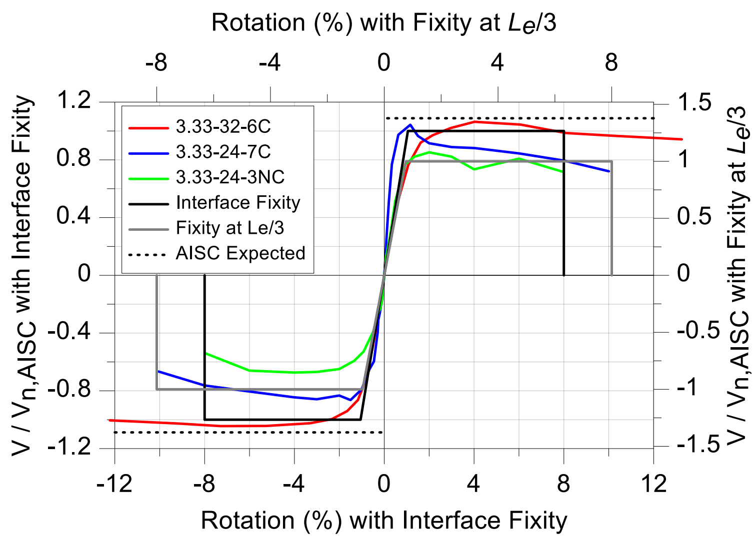
31

Test Results



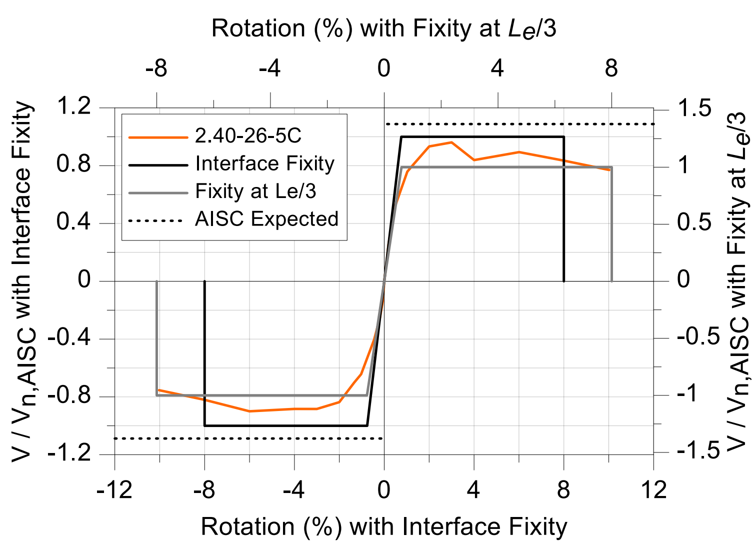
32

Backbone



33

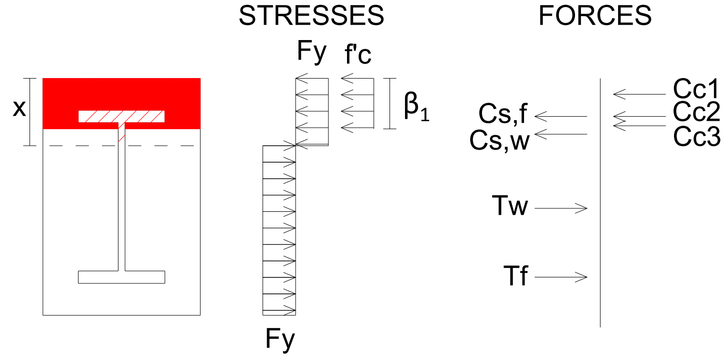
Backbone



34

Recommendation(1) - Capacity

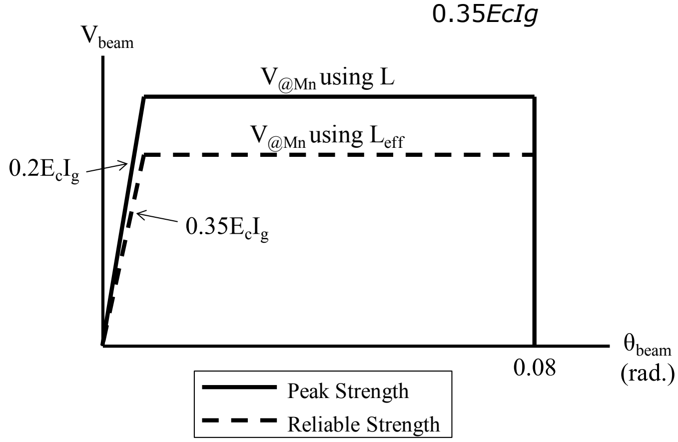
- Flexural capacity, Mn, determined using plastic section analysis with the design steel stress, Fy, and a Whitney stress block
- Probable flexural capacity for computing embedment length, Mn,pr, considers expected steel stress Ry*Fy



35

Recommendation(2) - Backbone

- For peak shear:
  - Interface fixity, use clear span, *L*
  - Use initial stiffness 0.2*EcIg*
- For reliable shear:
  - Effective fixity, use *Leff* = *L* + *Le*/3
  - Use initial stiffness 0.35*EcIg*



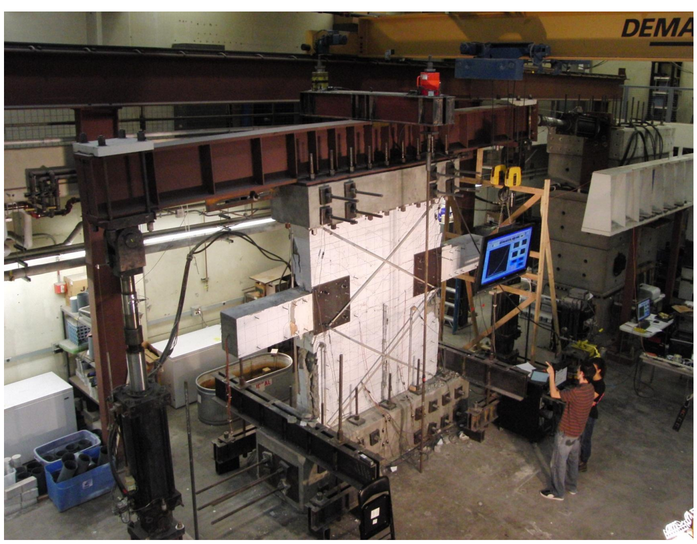
36

Recommendation(3) - Embedment

- Embedment length per Marcakis and Mitchell (1980), Mattock and Gaafar (1982), or AISC 2010 Seismic Provisions
  - Use design f'c
- Transfer bars and bearing plates
  - Not needed if sufficient quantity of wall boundary vertical reinforcement, i.e. Beam 1, Beam 2
  - May improve embedment performance if insufficient embedment length or wall boundary vertical reinforcement, i.e. Beam 3, Beam 4

37

Shear Wall Testing



38

Objectives

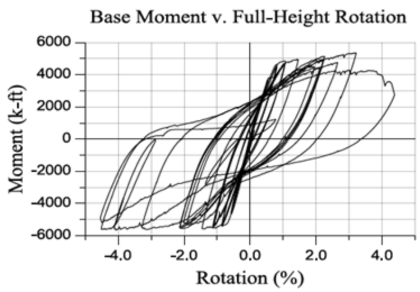
- Typical wall tests:
  - Thin walls, i.e. 6”
  - Special boundary elements, s=4”
- This specimen:
  - Thick wall
    - 12” test specimen, 24” thick full-scale
  - Intermediate confinement, i.e. ordinary boundary element
    - s=4” test specimen, s=8” full scale

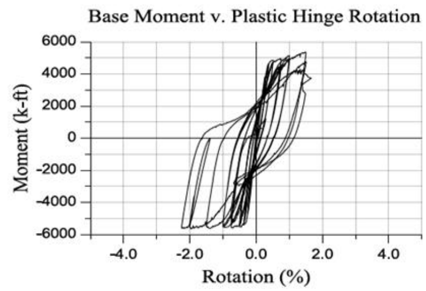
39

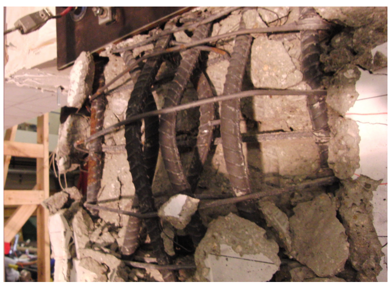
Shear Wall Testing

40

Shear Wall Testing







41

Thank you

- Questions?

42