Performance of Steel Fiber-Reinforced Concrete (SFRC) Coupling Beams under Simulated Wind Loading

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Performance-based Wind Design

- Implementation of performance-based wind design would allow some degree of inelastic deformations during extreme wind events

- While inelastic deformation demands would be significantly less than those for a strong ground motion, loading duration and number of loading cycles is a concern

- There is thus need to evaluate the behavior of critical structural members under loading histories representative of extreme wind events

Coupled-Wall Systems

- Coupled wall systems are commonly used in high-rise construction because of their lateral stiffness and strength
- Coupling beams connecting walls are typically subjected to high shear stresses and deformations
- In non-seismic regions, coupling beams are designed either as slender or deep beams

Motivation

- Results from recent research at UCLA have indicated stable behavior of RC coupling beams under simulated wind loading when subjected to shear stresses up to ≈ $7.5\sqrt{f_c'}$ (psi)
- Behavior of coupling beams under much larger shear stresses induced by a severe windstorm is not known
- Use of steel fiber reinforced concrete may lead to improved behavior of coupling beams under severe wind loading while allowing a simplification in reinforcement detailing

Steel Fiber-Reinforced Concrete (SFRC)

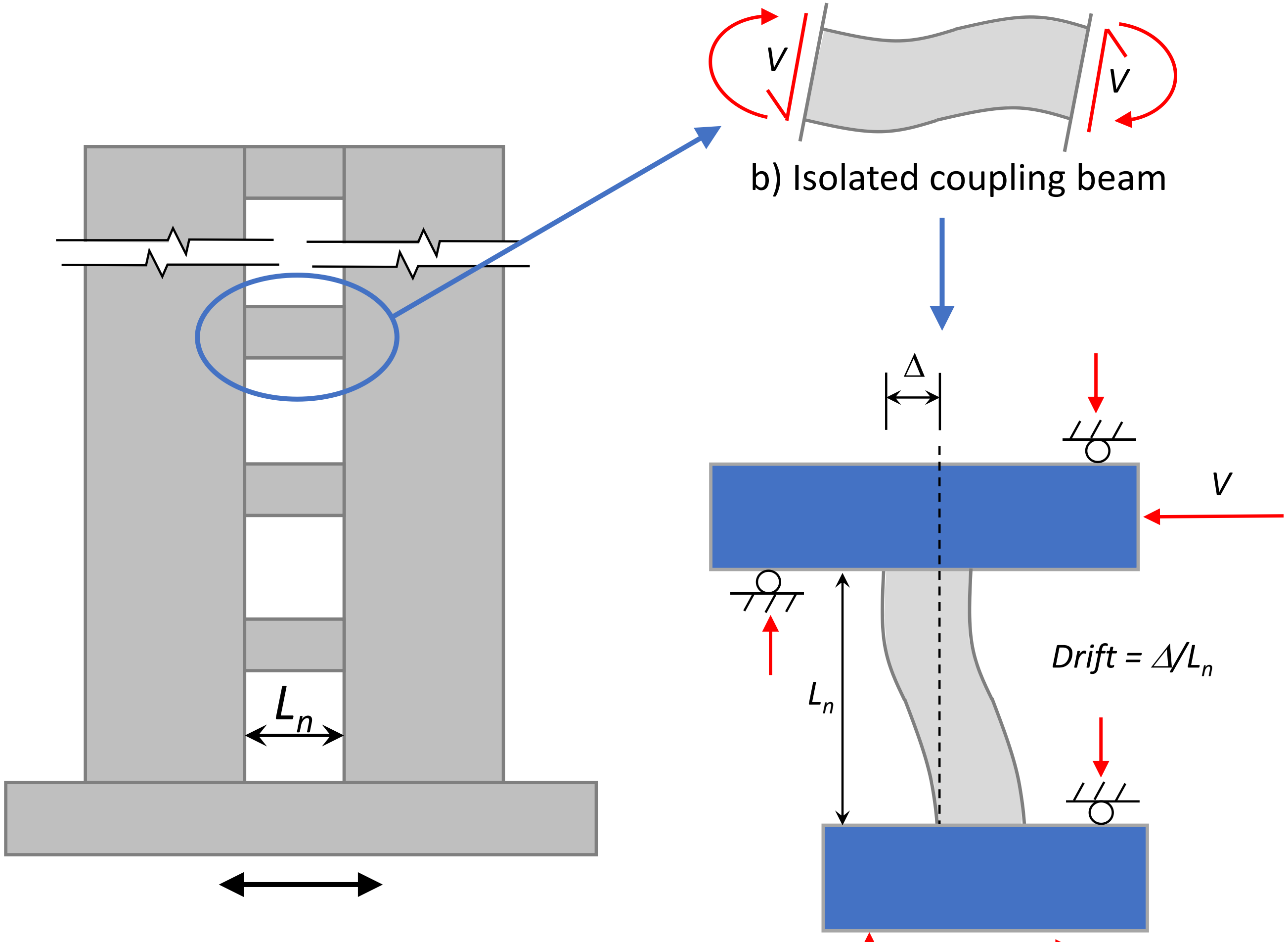
- Most steel fibers have deformations for better anchorage
- Steel fiber length typically ranges between 1.2 and 2.4 in., with length-to-diameter ratios between 50 and 80. Fiber tensile strength ranges between 160 and 330 ksi.
- Maximum practical dosage ≈ 200 lb/yd^3

SFRC Coupling Beams

- Use of SFRC in earthquake-resistant coupling beams with aspect ratio between 2.0 and 3.0 allowed elimination of diagonal reinforcement and reduction of transverse reinforcement detailing (Parra-Montesinos et el., 2017)

(Parra-Montesinos et el., 2017)

Experimental Program



b) Isolated coupling beam

a) Coupled wall

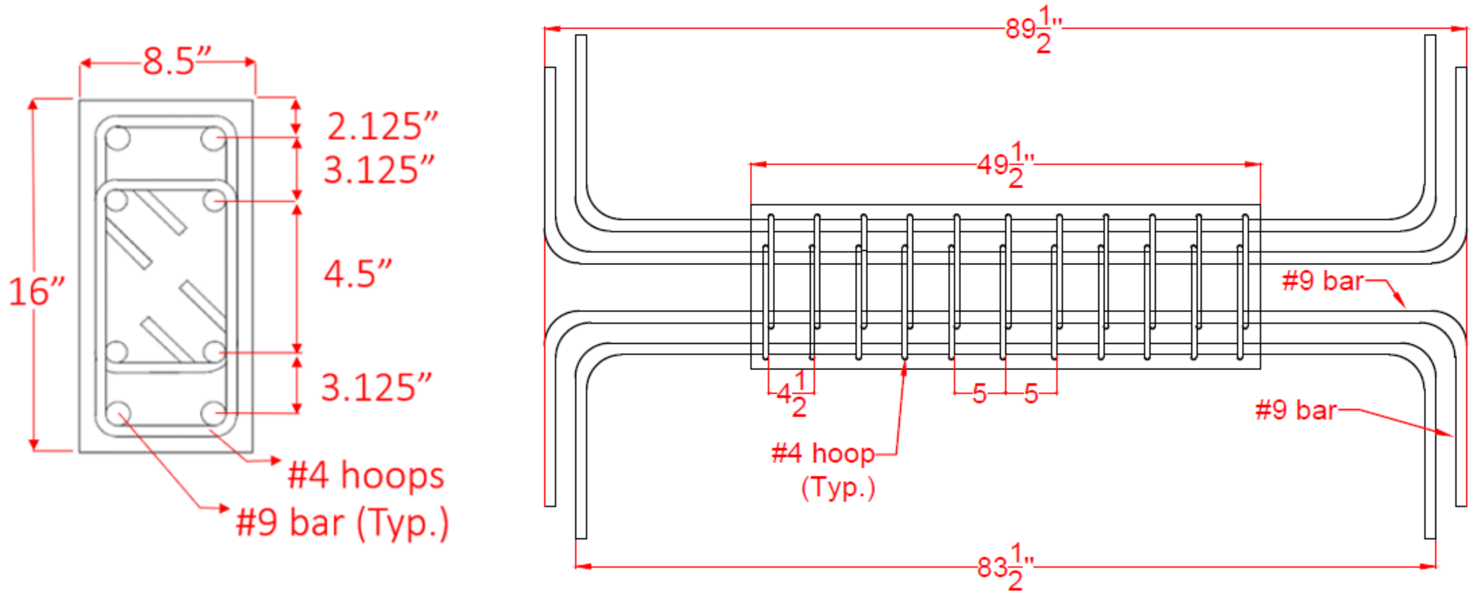
c) Test configuration

Experimental Program

Specimen ID	CB1	CB2	CB3	CB4
b x h x l_n (in.)	8 x 16 x 48	8.5 x 16 x 48		
Target Stress, v_u (psi)	$15\sqrt{f'_c}$	$10\sqrt{f'_c}$		
Aspect Ratio (l_n/h)	3.0			
Target f'_c (psi)	8000			
Fiber Volume Fraction, V_f (%)	0.65			0.50

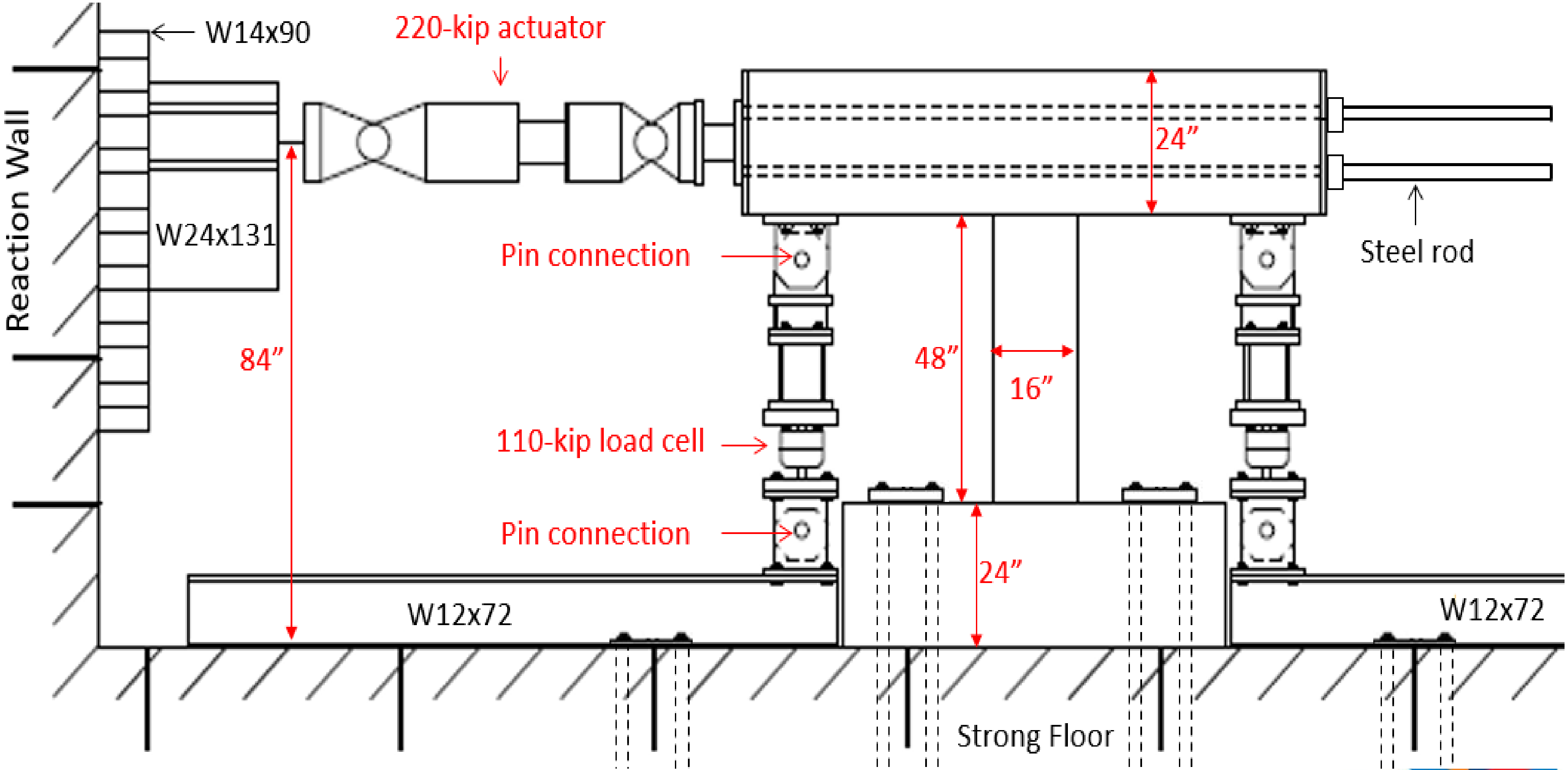
Coupling Beam Design

- $V_u = 10 \text{ or } 15\sqrt{f'_c}\, b\, d$
- $V_c = 5\sqrt{f'_c}\, b\, d$
- $V_s = V_u - V_c$
- $s \leq \frac{A_v f_{yt} d}{V_s}$
- $P = 0.05 f'_c A_g$



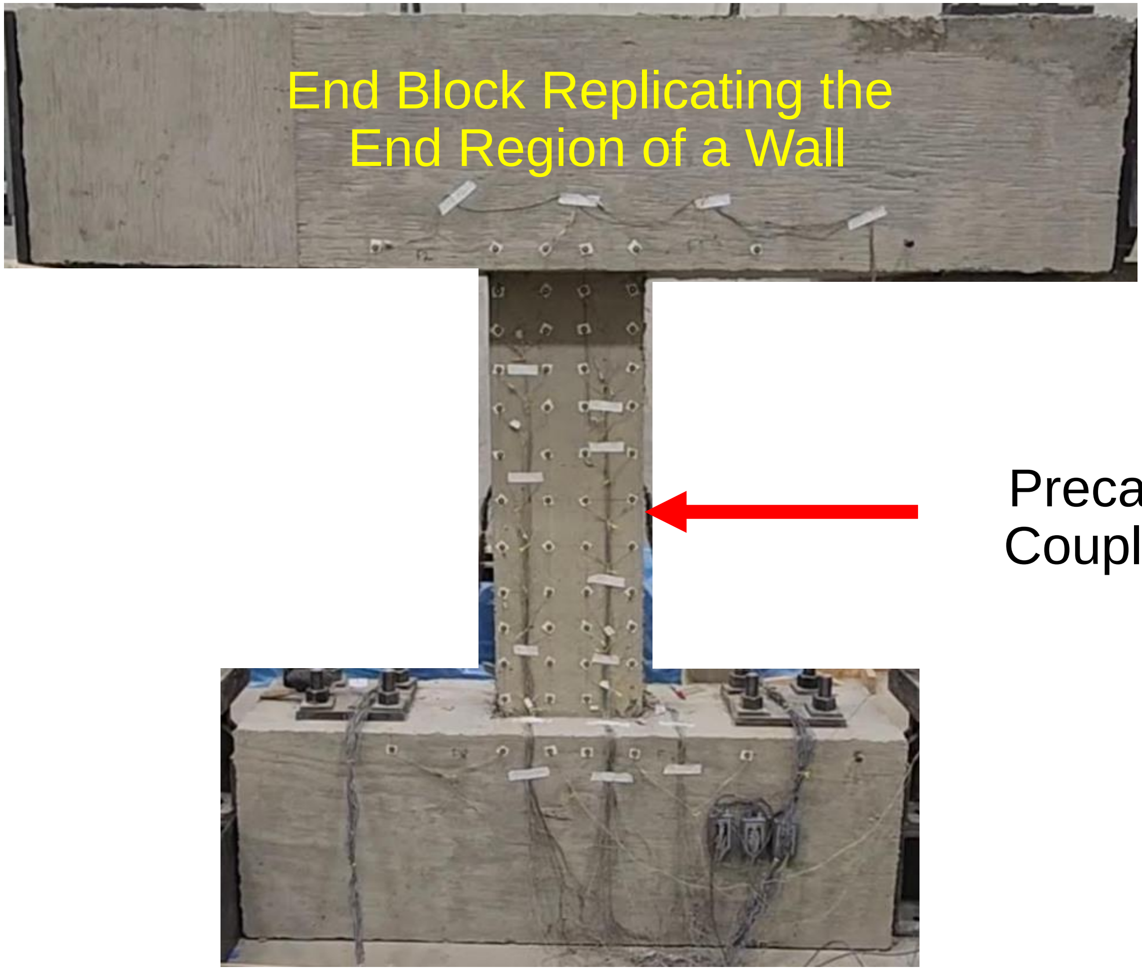
Specimens CB3 and CB4

Test Setup



W14x90
220-kip actuator
Reaction Wall
W24x131
24"
Steel rod
Pin connection
84"
48"
16"
110-kip load cell
Pin connection
24"
W12x72
W12x72
Strong Floor

Coupling Beam Specimen



Precast SFRC
Coupling Beam

Wind Loading Protocol

Ramp-up

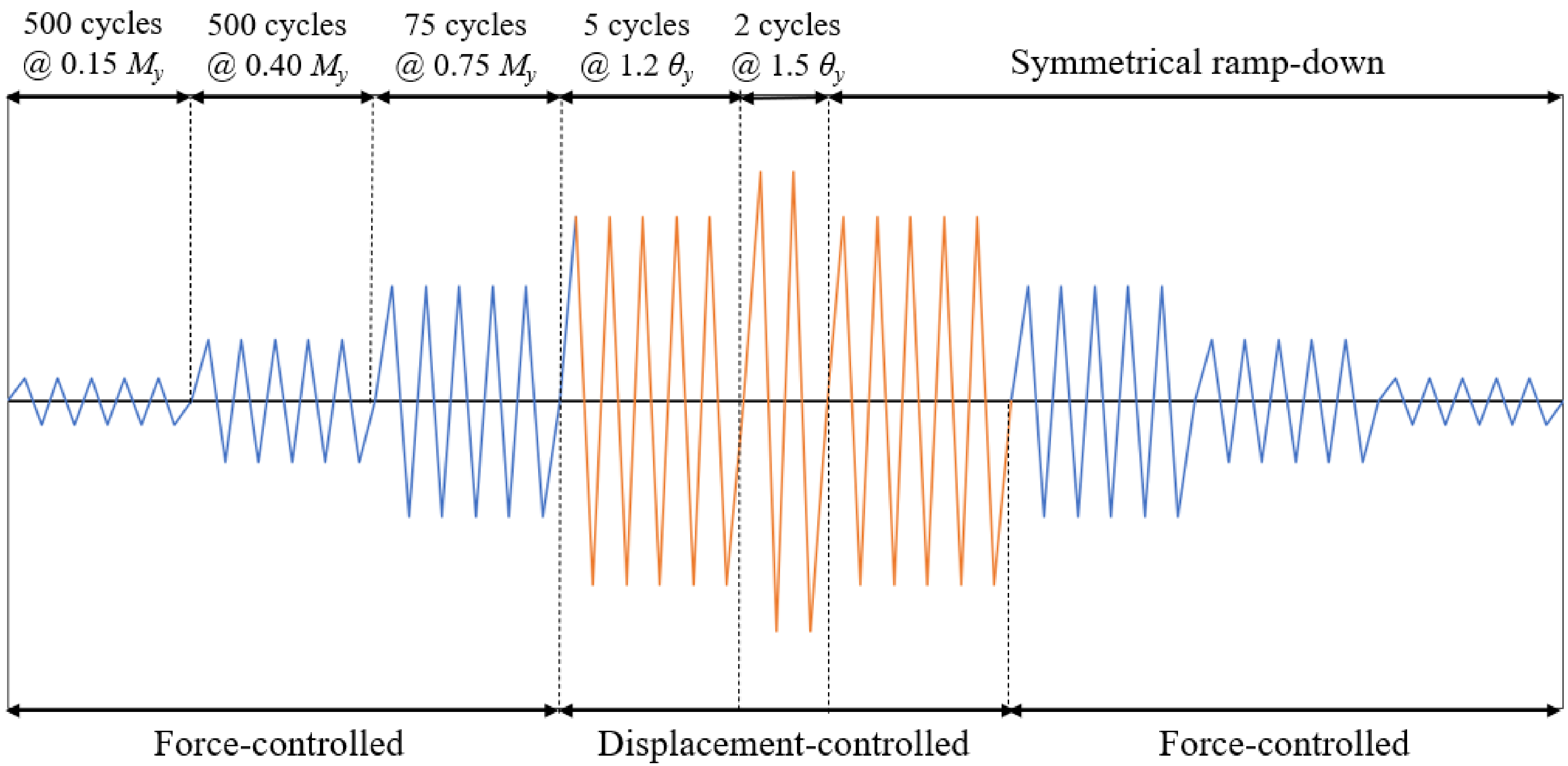
Ramp-down

Loading Stages	No. of Cycles	Load Type
$0.15M_y$	500	Force-Controlled
$0.4M_y$	500	
$0.75M_y$	75	
$1.2\theta_y$	10	Displacement-Controlled
$1.5\theta_y$	2	
$1.2\theta_y$	10	
$0.75M_y$	75	Force-Controlled
$0.4M_y$	500	
$0.15M_y$	500	

where; M_y = nominal moment at yield and θ_y = rotation at yield

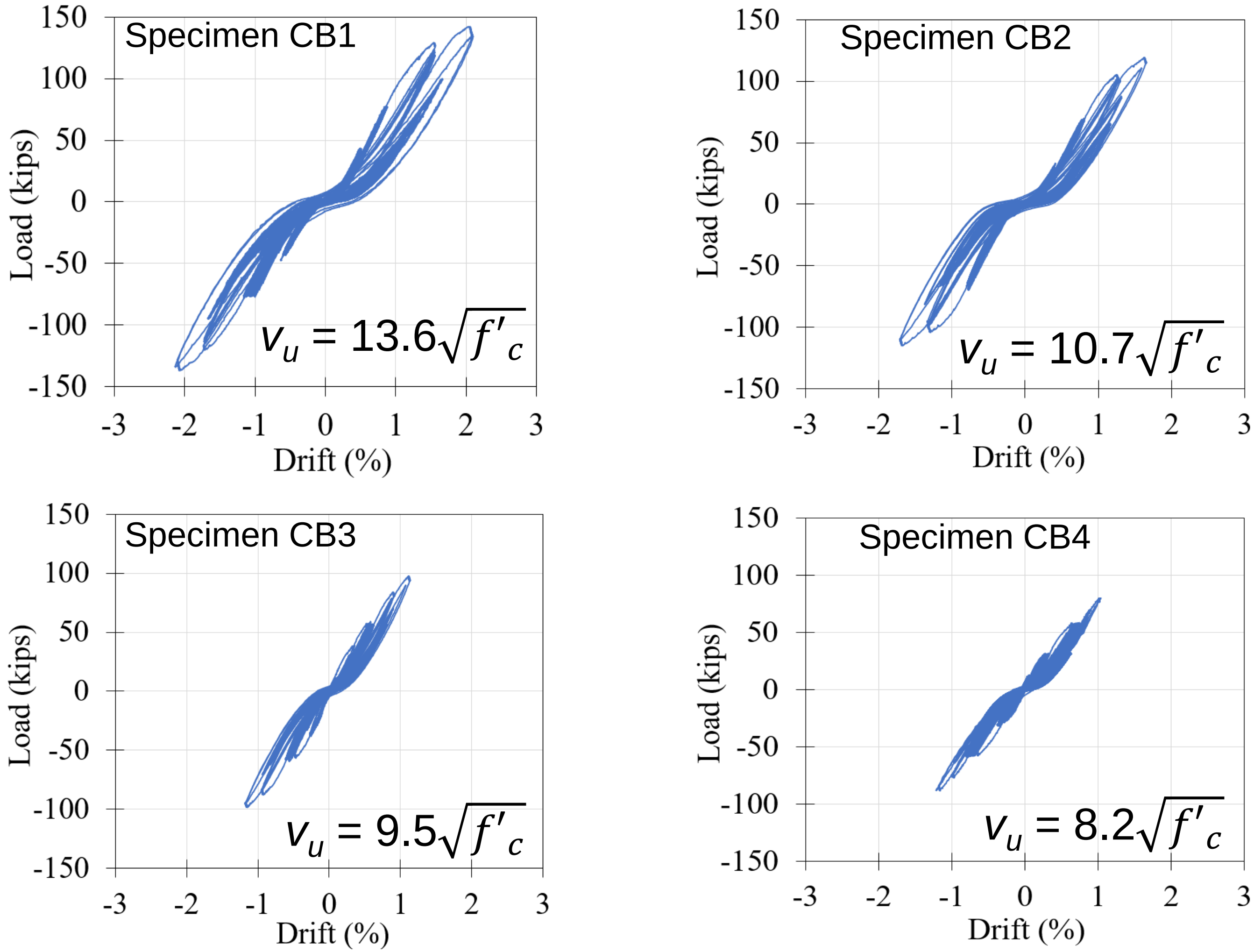
Source: Mr. John Hooper (MKA)

Wind Loading Protocol



where; M_y = nominal moment at yield and θ_y = rotation at yield

Hysteresis



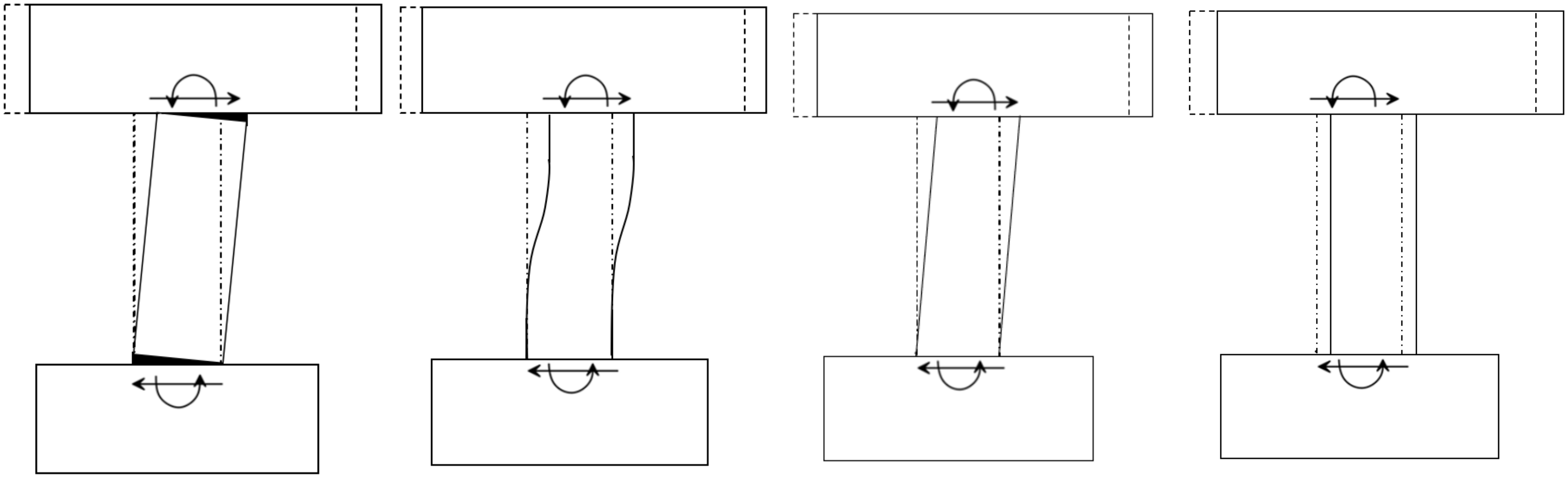
Specimen CB1
$v_u = 13.6\sqrt{f'_c}$
Specimen CB2
$v_u = 10.7\sqrt{f'_c}$
Specimen CB3
$v_u = 9.5\sqrt{f'_c}$
Specimen CB4
$v_u = 8.2\sqrt{f'_c}$
Load (kips)
Drift (%)
150
100
50
0
-50
-100
-150
-3
-2
-1
0
1
2
3

Overall Behavior

- Similar cracking pattern in all specimens.
- Maximum residual flexural crack width of 1/24 in.
- Maximum residual diagonal crack width of 1/64 in.
- Minor spalling at the bottom end of the beams
- No yielding in transverse reinforcement

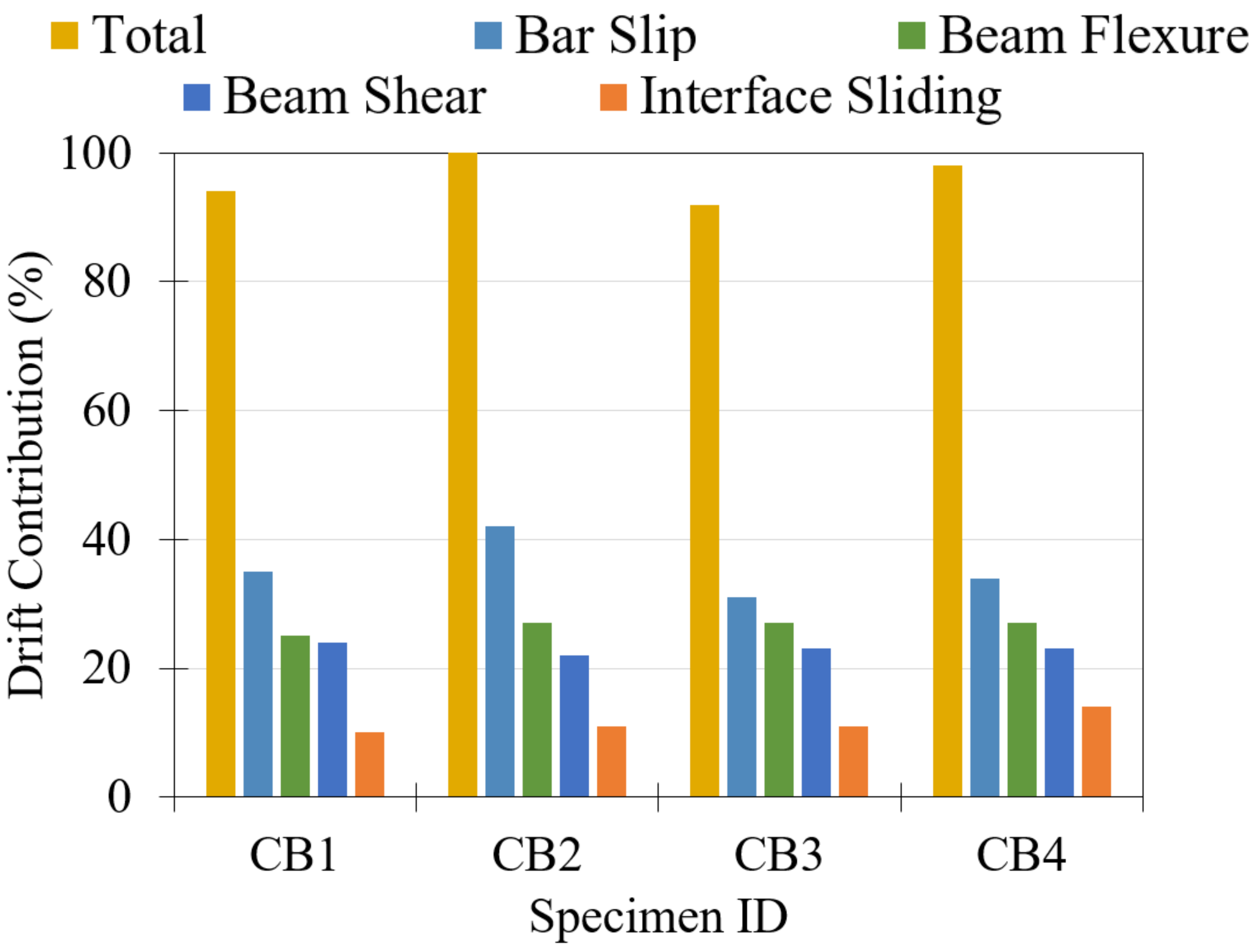
Drift Components

- Drift contributions from bar slip, flexural deformations, shear deformations, and interface sliding



Bar slip — Flexural deformations — Shear deformations — Interface sliding

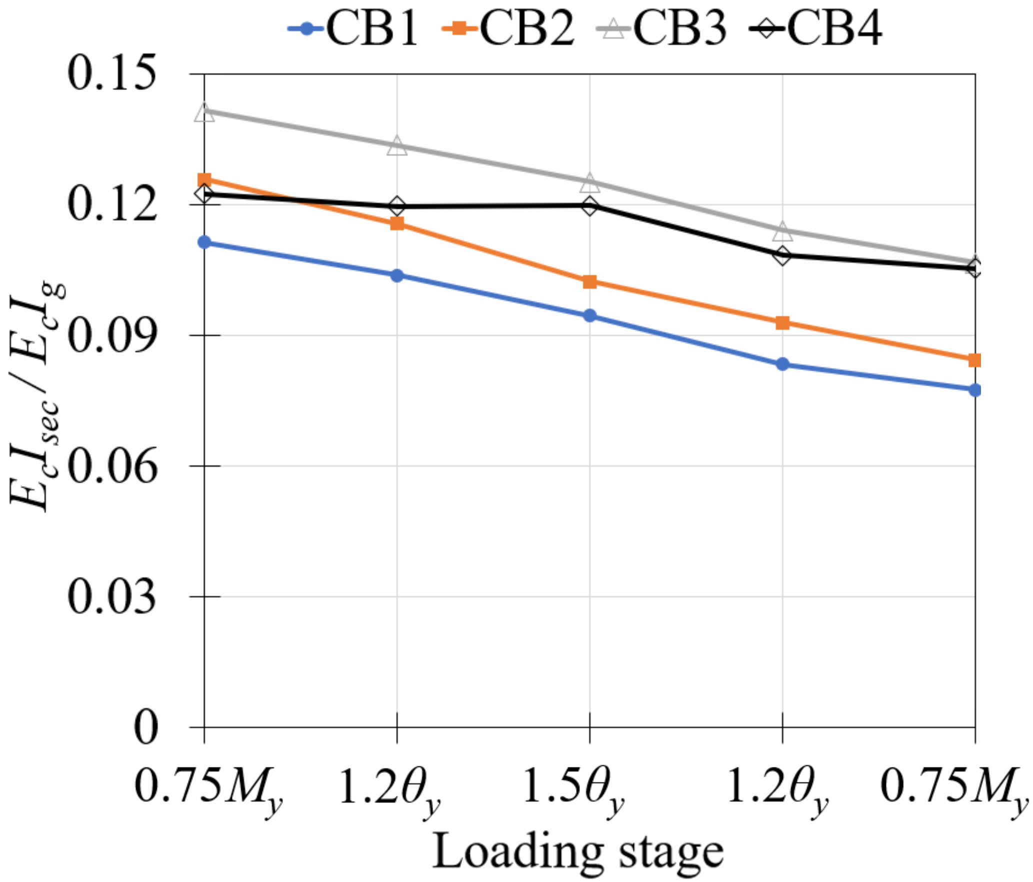
Contribution of Drift Components



Drift Contribution at $1.5\theta_y$

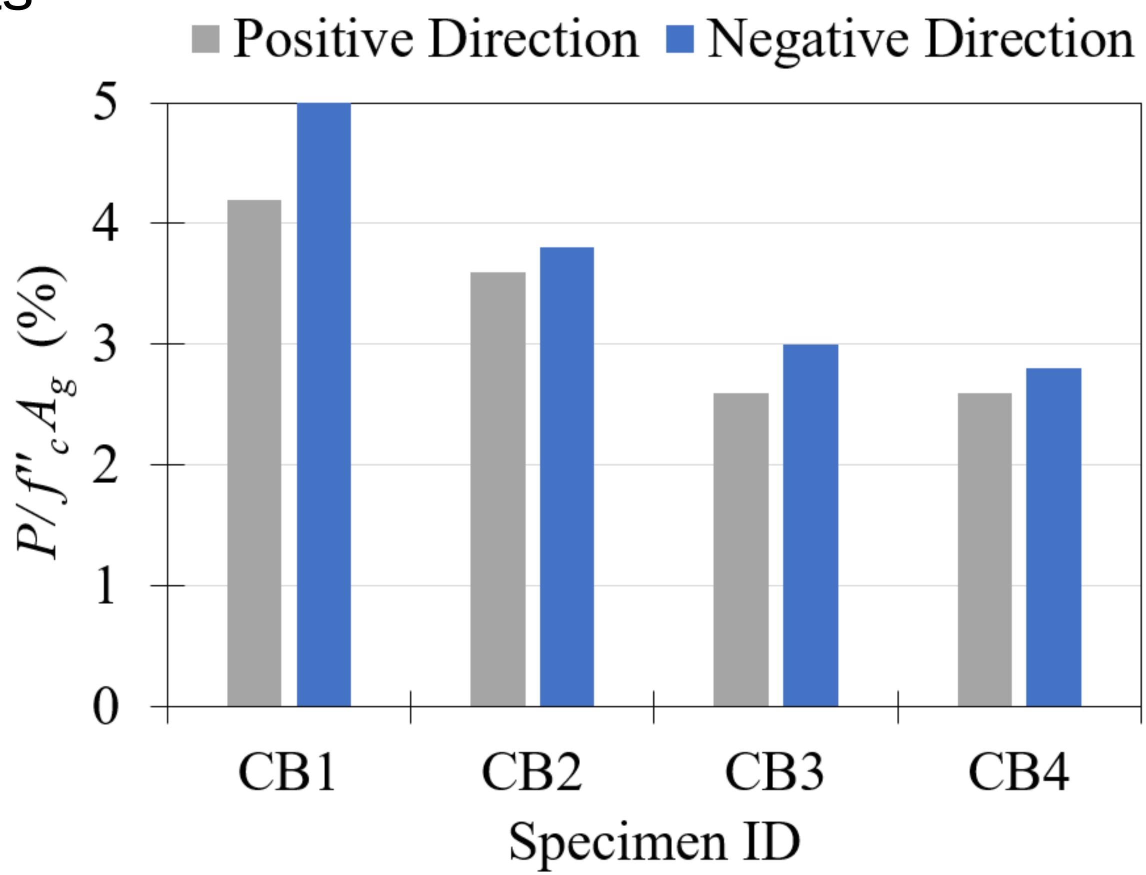
Normalized Average Stiffness

Specimen ID	E_cI_{sec}/E_cI_g at $1.5\theta_y$
CB1	0.10
CB2	0.10
CB3	0.13
CB4	0.12



Axial Compression

- Restraint against beam axial expansion due to cracking and reinforcement yielding led to axial compressive forces during tests



Axial compression at $1.5\theta_y$

Conclusions

- SFRC coupling beams with traditional beam reinforcement exhibited only minor damage during simulated wind loading and shear stresses as high as $14\sqrt{f_c'}$ (psi)
- Rotation demand of 1.5θ_y resulted in moderate yielding of longitudinal reinforcement, but no yielding in transverse reinforcement
- Drift due to flexural deformations and concentrated rotations at the beam-wall interface ranged between approximately 60 and 70% of applied drift. Shear deformations accounted for most of the remaining drift
- Normalized stiffness ranged between 0.11 and 0.14 of the gross stiffness during ramp up phase at 0.75M_y, and between 0.08 and 0.11 during ramp-down loading phase

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Thank you for your attention!