American Concrete Institute
Always advancing

Unconventional Reinforced Concrete Bridge Columns

ACI Spring 2014 Convention
March 23 - 25, Reno, NV

David H. Sanders, ACI Member, is a Professor at the University of Nevada, Reno. He received his BS from Iowa State University, and MS and PhD from University of Texas, Austin. He is a member of ACI 318, and chair of 318E. He has been a member of ACI Board of Direction. chair of the ACI Technical Activities Committee, chair of ACISEI 445, Shear and Torsion, and ACI 341, Earthquake Resistant Concrete Bridges. His research interest includes concrete structures with an emphasis in seismic performance of bridges.

American Concrete Institute *Always advancing* WEB SESSIONS

USE OF POST-TENSIONING AND PRETENSIONING IN COLUMNS TO MITIGATE EARTHQUAKE DAMAGE

David H. Sanders
Professor
University of Nevada, Reno

NEVADA DOT, NSF, nehrp, NEES, SCDOT, Caltrans

Lots of Help and Sponsors

- Graduate Research Assistants, University of Nevada, Reno
  - Mark Cukrov, Alex Larkin, Sarira Motaref,
- Professors
  - David Sanders and M. Saiid Saiidi
    University of Nevada, Reno
  - John Stanton and Marc Eberhard (Travis Thonstad)
    Univ. of Washington
  - Paul Ziehl (Aaron Larosche)
    University of South Carolina

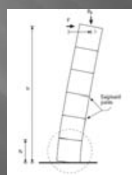
Benefits of Post-Tensioning

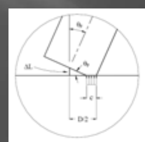
- Re-centering capabilities
- Reduced damage
- Unbonded post-tensioned tendons have shown reductions in residual displacement
- Localized inelastic straining can be avoided by using unbonded tendons as opposed to a bonded system

Issues of Post-Tensioning

- Initial prestress force must be carefully selected to prevent tendon yielding at large drift ratios
- Previous work anchored the tendons in the base of the footing, making it nearly impossible to gain access to replace them following an earthquake
- Long-term durability is a concern for unbonded tendons

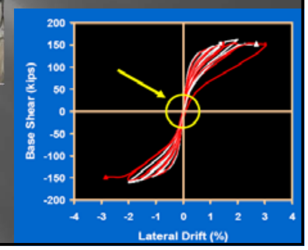
Precast Post-Tensioned Column





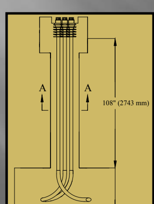
7

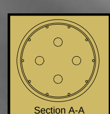
Precast Post-Tensioned Column



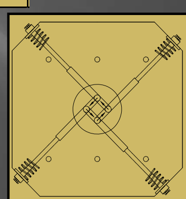
Column Parameters

Column	ρ_l	ρ_s
PT-LL	0.685% (10 #5's)	1.00%
PT-HL	1.33% (10 #7's)	1.00%





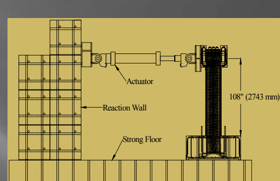
Diameter = 24″
Aspect Ratio = 4.5
Axial Load = 10%f'_cA_g
Dead load = 6%f'_cA_g

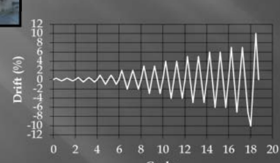


Column Design

- Four tendons pass through ducts, centered around column cross section
- Full-scale column of 60” (1524 mm) diameter would require 100 strands, unreasonable for one tendon

Test Setup

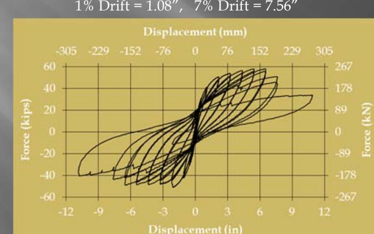




PT-LL Results

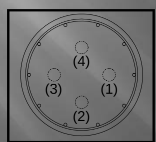
- Longitudinal reinforcement=10 #5′s, compared to 10 #7′s
- PT-LL failed at 7%, went from -7% drift right to -10%, then to +10%
- Ductility at first fracture = 6.9

1% Drift = 1.08″, 7% Drift = 7.56″

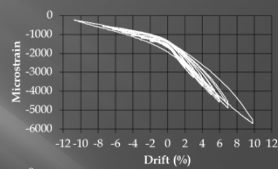


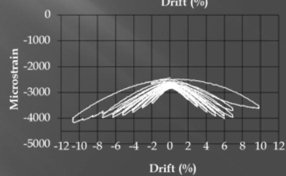
PT-LL Results

- Tested material properties show that tendons yield at 8600με
- Column rotated about axis running through tendons 2 and 4



Column Cross Section

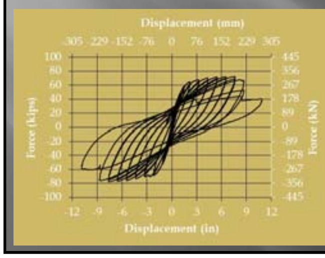




PT-HL Results

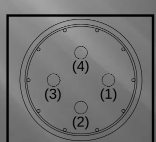
- Longitudinal reinforcement = 10 #7's, compared to 10 #5's
- Ductility at first fracture = 6.0

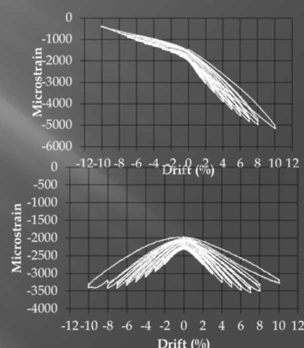
1% Drift = 1.08″, 7% Drift = 7.56″



PT-HL Results

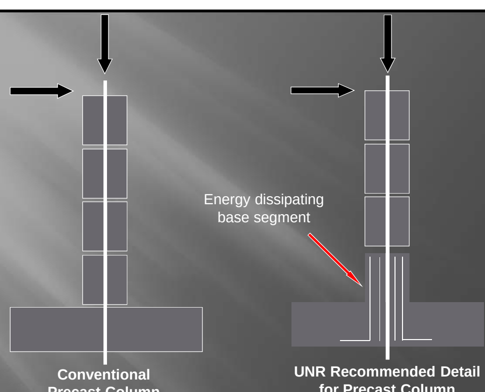
- Tested material properties show that tendons yield at 8600με
- Column rotated about axis running through tendons 2 and 4





Conclusions

- Both columns provide re-centering
- Tendons do not yield, even at a large drift ratio of 10%
- Longitudinal reinforcement ratio plays significant roll for re-centering
  - Average residual displacement of PT-LL at 7% drift = 2.94" (74.6 mm)
  - Average residual displacement of PT-HL at 7% drift = 3.94" (100 mm)
- Tendons exiting the corners of the footing (diamond configuration), do not display any negative effects
- Similar damage to each column, PT-LL showing slightly more at 3% and 7% drifts



Using Advanced Materials in Plastic Hinges

ECC "Bendable Concrete"

(Engineered Cementitious Composite)

FRP (Fiber Reinforced Polymer) Wrapping

Elastomeric Bearing

Construction and Assembly

Time for column assembly= 3 Hours!!!

Elastomeric Bearing

- First studied in Japan w/ partial success
- Second generation pad was developed at UNR
- Works in flexure NOT Shear
- A steel pipe at the center to restrain shear
- Holes to allow passing longitudinal reinforcement
- Steel shims to prevent buckling of the longitudinal reinforcement

SC-2 (Segmental with Concrete)
Bench mark

- Base segment was connected to the footing via the longitudinal bars
- All segments were made out of **conventional concrete**
- An unbonded tendon rod at the center to connect all segments

SBR-1(Segmental with Built in Rubber pad)

- Base segment used a combination of rubber pad and concrete
- Two reasons for using the rubber pad
  - Minimizing the damage
  - Increasing energy dissipation

SF-2 (Segmental with FRP)

- Base segment and second segment were wrapped with FRP
- Dissipation of EQ energy by yielding longitudinal bars at base segment
- Three reasons for using the FRP
  - Improving the concrete strength
  - Minimize the damage
  - Improving the concrete ductility

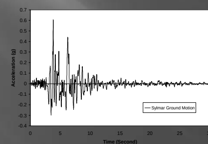
SE-2 (Segmental with ECC)

- Base segment and second segment made out of ECC material
- Three reasons for using ECC
  - Improving ductility
  - Minimizing damage
  - Increasing energy dissipation

Loading Protocol

- Columns were tested on the shake table at UNR
- Series of Sylmar ground motion were applied
- Full Sylmar max. acceleration = 0.61g

Run	Input Ground Motion
A	White noise
1	Sylmar X 0.1
B	White noise
2	Sylmar X 0.25
C	White noise
3	Sylmar X 0.5
D	White noise
4	Sylmar X 0.75
E	White noise
5	Sylmar X 1.00
F	White noise
6	Sylmar X 1.25
G	White noise
7	Sylmar X 1.50

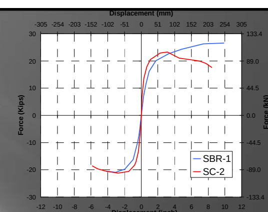


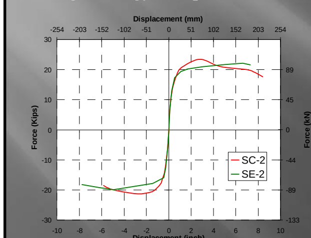
SBR-1, Run 6 (Sylmar X 1.25), 7% Drift ratio

Level of Damage at Run 7 Sylmar X1.5

SBR-1 (Rubber) vs. SC-2 (Conventional

- Higher capacity
- No drop in lateral load capacity
- Minimal damage at plastic hinge area
- Larger energy dissipation



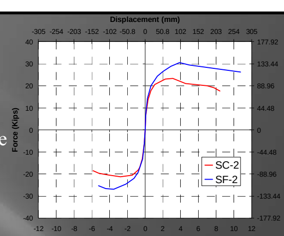


SE-2 (ECC) vs. SC-2 (Conventional

- No drop in lateral load capacity
- Minimal damage at plastic hinge area

SF-2 (Fiber) vs. SC-2 (Conventional)

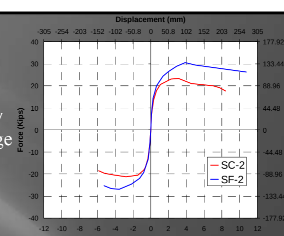
- Higher capacity
- No drop in lateral load capacity
- Minimal damage at plastic hinge area
- Minimal damage at joint
- Larger energy dissipation



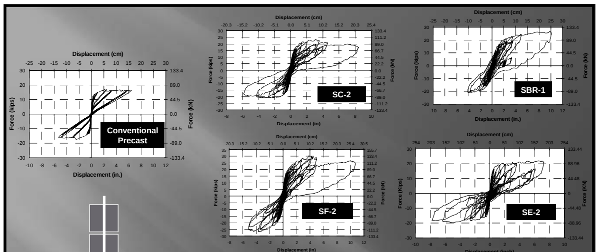
Specimen	Energy Dissipation (Kip-inch)	Increase compared to SC-2
SC-2	539	0
SBR-1	616.3	14.3%
SF-2	788.4	46%
SE-2	637.4	18.2%

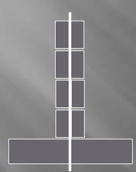
SF-2 (Fiber) vs. SC-2 (Conventional)

- Higher capacity
- No drop in lateral load capacity
- Minimal damage at plastic hinge area
- Minimal damage at joint
- Larger energy dissipation



Specimen	Energy Dissipation (Kip-inch)	Increase compared to SC-2
SC-2	539	0
SBR-1	616.3	14.3%
SF-2	788.4	46%
SE-2	637.4	18.2%



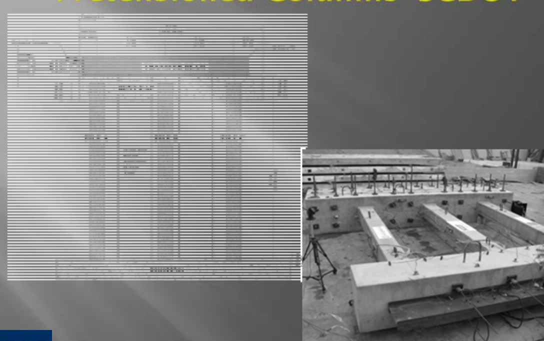


Specimen	Energy Dissipation (Kip-inch)	Increase compared to **Conventional precast**
SBR-1	616.3	244%
SC-2	539	200%
SF-2	788.4	340%
SE-2	637.4	250%
SC-2R	790	340%
Conventional Precast segmental	179	0%

Conclusions

- **Plastic hinges incorporating advanced material experienced minimal damage**
- **Residual displacement was negligible until very large motions**
- **Energy dissipation in innovative details were larger than SC-2**
- **Energy dissipation in all columns (with base segment connected to footing) was much larger than conventional precast column**
- **Amongst four columns detail, the one with lower segments wrapped by FRP had the best performance.**

Pretensioned Columns -SCDOT



Experimental Results

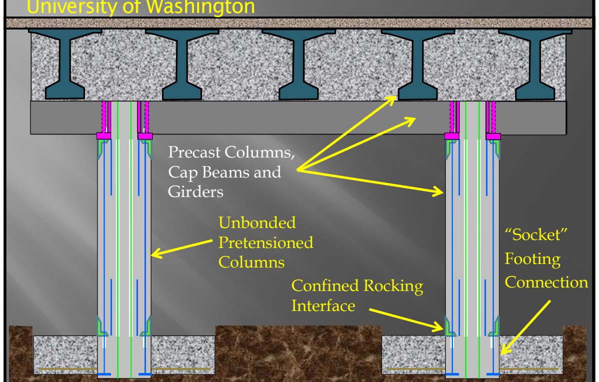
0.5*Josh-T

1.0*Josh-T

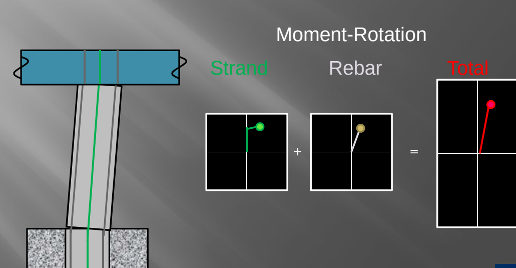
2.0*Josh-T

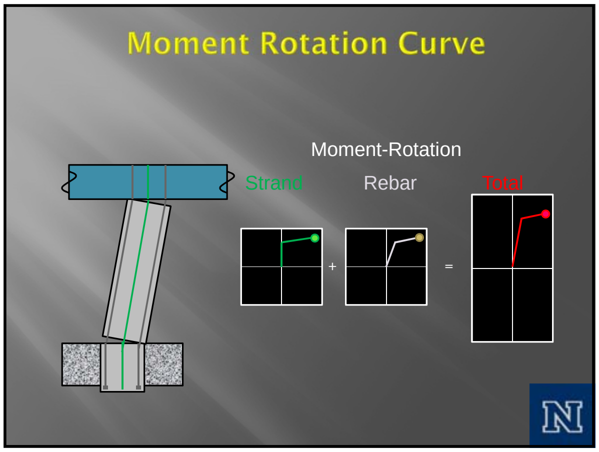
34

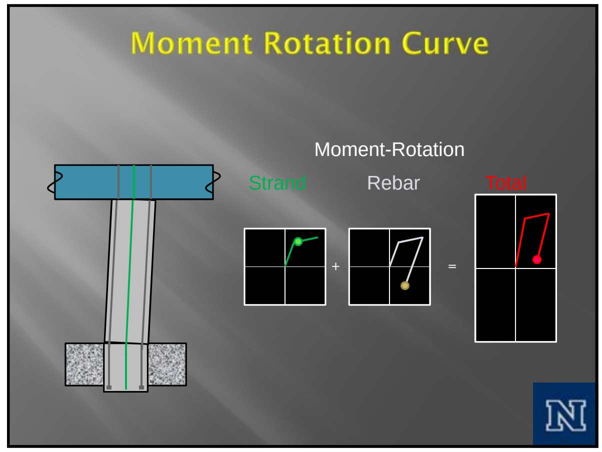
Pretensioned Columns and Unbonded Reinforcement-University of Washington

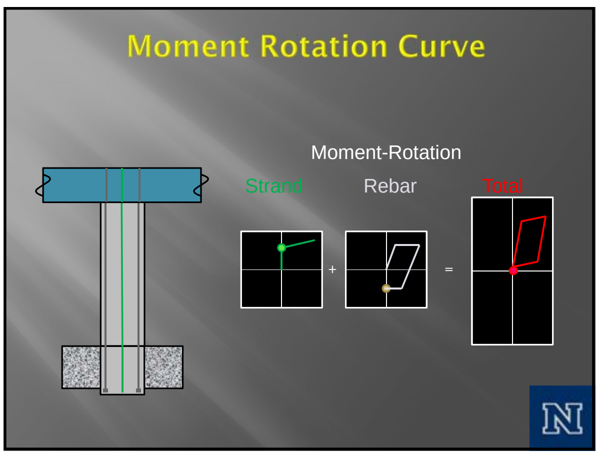


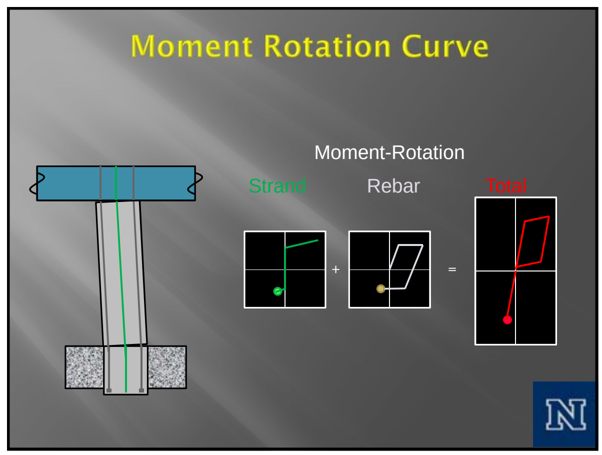
Moment Rotation Curve

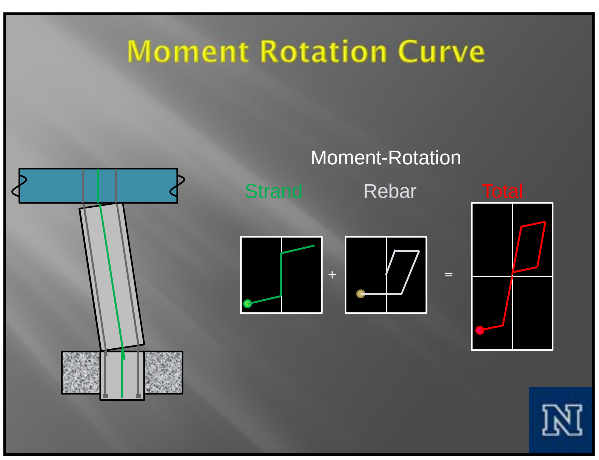


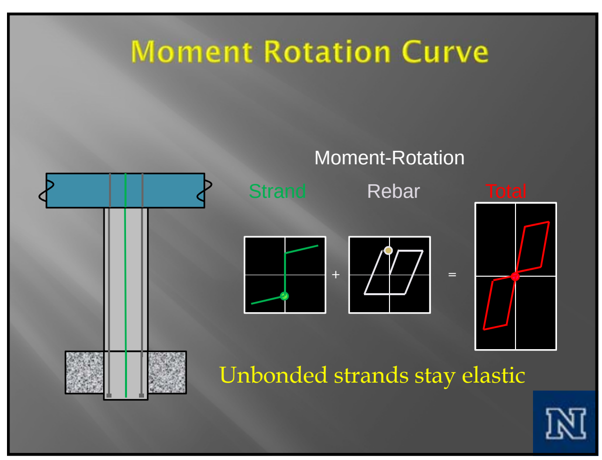

Moment Rotation Curve
Moment-Rotation
Strand
Rebar
Total
+
=


Moment Rotation Curve
Moment-Rotation
Strand
Rebar
Total
+
=

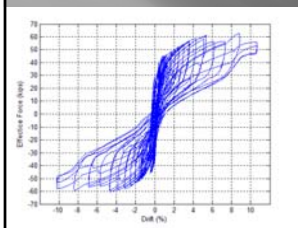

Moment Rotation Curve
Moment-Rotation
Strand
Rebar
Total
+
=


Moment Rotation Curve
Moment-Rotation
Strand
Rebar
Total
+
=

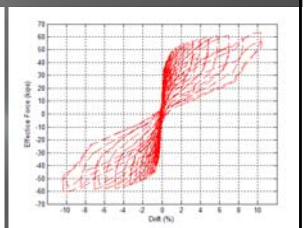

Moment Rotation Curve
Moment-Rotation
Strand
Rebar
Total
+
=


Moment Rotation Curve
Moment-Rotation
Strand
Rebar
Total
+
=
Unbonded strands stay elastic

Sub Assembly Curves



Connection to Spread Footing



Connection to Cap Beam

Shake Table Model-1/4 scale

Need to do Better