American Concrete Institute

Seismic Performance of an Innovative Concrete Pier Reinforced with Titanium Alloy Bars

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Outline

- Background
- Titanium Alloy Bars (TiABs)
- Cantilever Pier Reinforced with Normal Rebar
- Cantilever Pier Reinforced with TiABs
- Comparison
- Conclusions

Background

- ASCE Infrastructure Report Card (2017)

  614387 bridges in United States

  40% are 50 years or older

  9.1% US Bridges are structurally deficient

  39% of bridges already past service life

- ASCE Infrastructure Report Card (2021)

  617000 bridges in United States

  42% are 50 years or older

  Reduction of deficient bridges for past two years-slowed down 0.1% annually

  Number of bridges slipping from good to fair condition is increasing annually

Titanium Alloy Bars

- New Advanced Materials for Civil Engineering Industry

  Titanium Alloy
- Widely used Grade of Titanium: Grade 5 (Ti6Al4V)
- Advantages

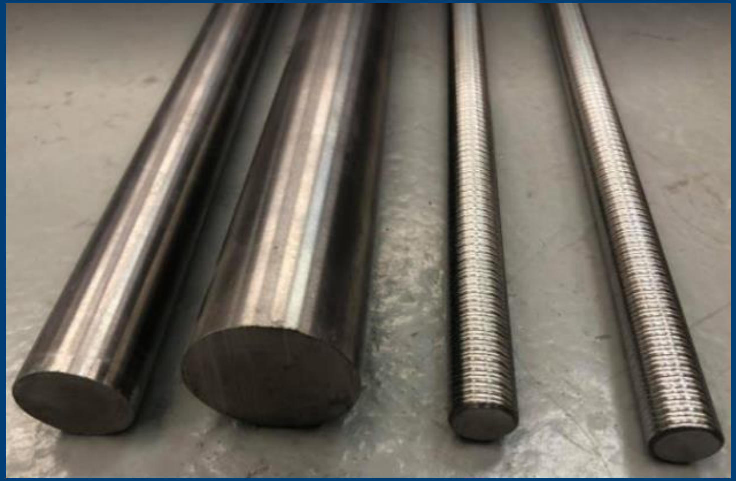
  Great corrosion resistance

  High strength to weight ratio

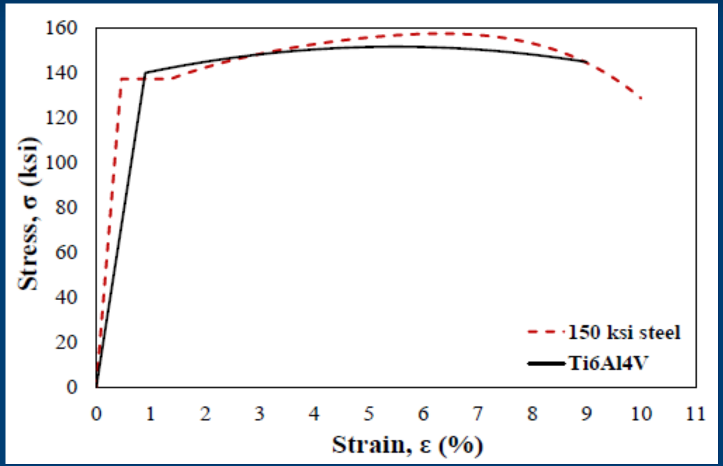
  Flexibility

  Ductility
- Disadvantage

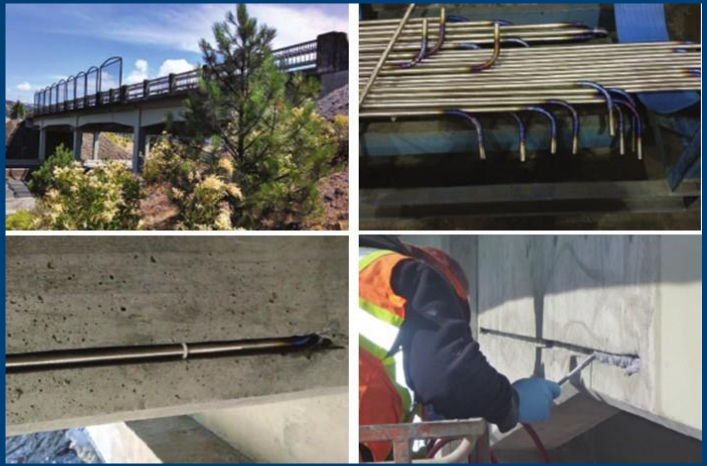
  Expensive material



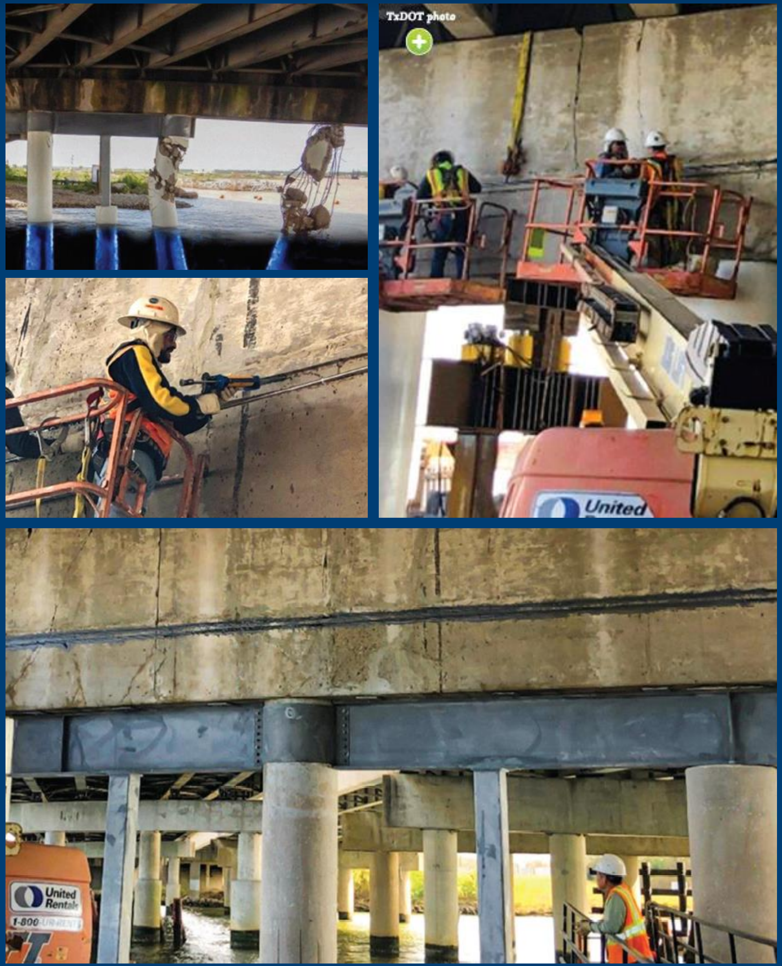
Literature



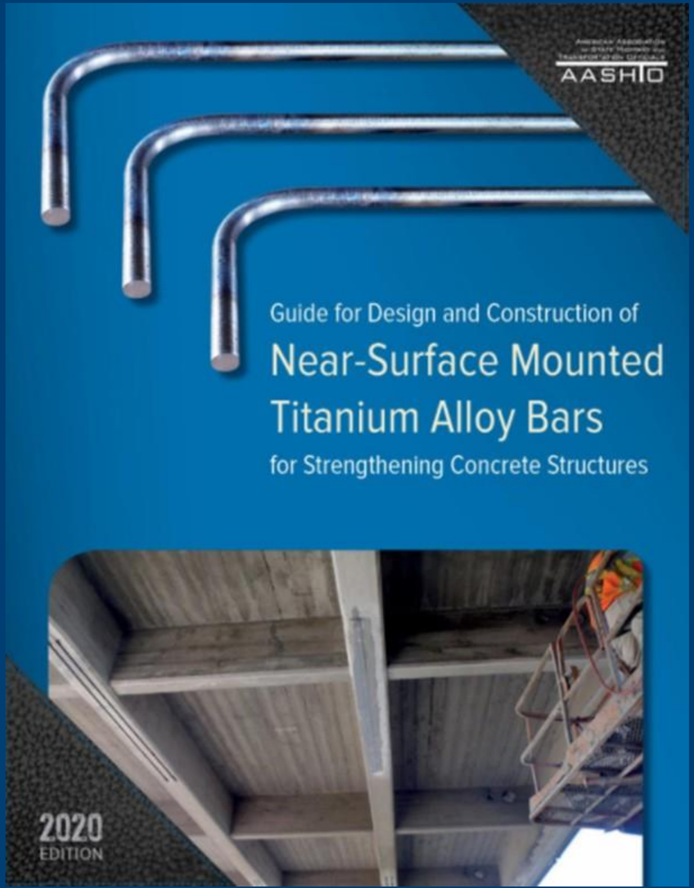
Stress-Strain Plot for Ti6Al4V and 150 ksi Steel Specimen



NSM TiABs Technology Used in Mosier Bridge by ODOT

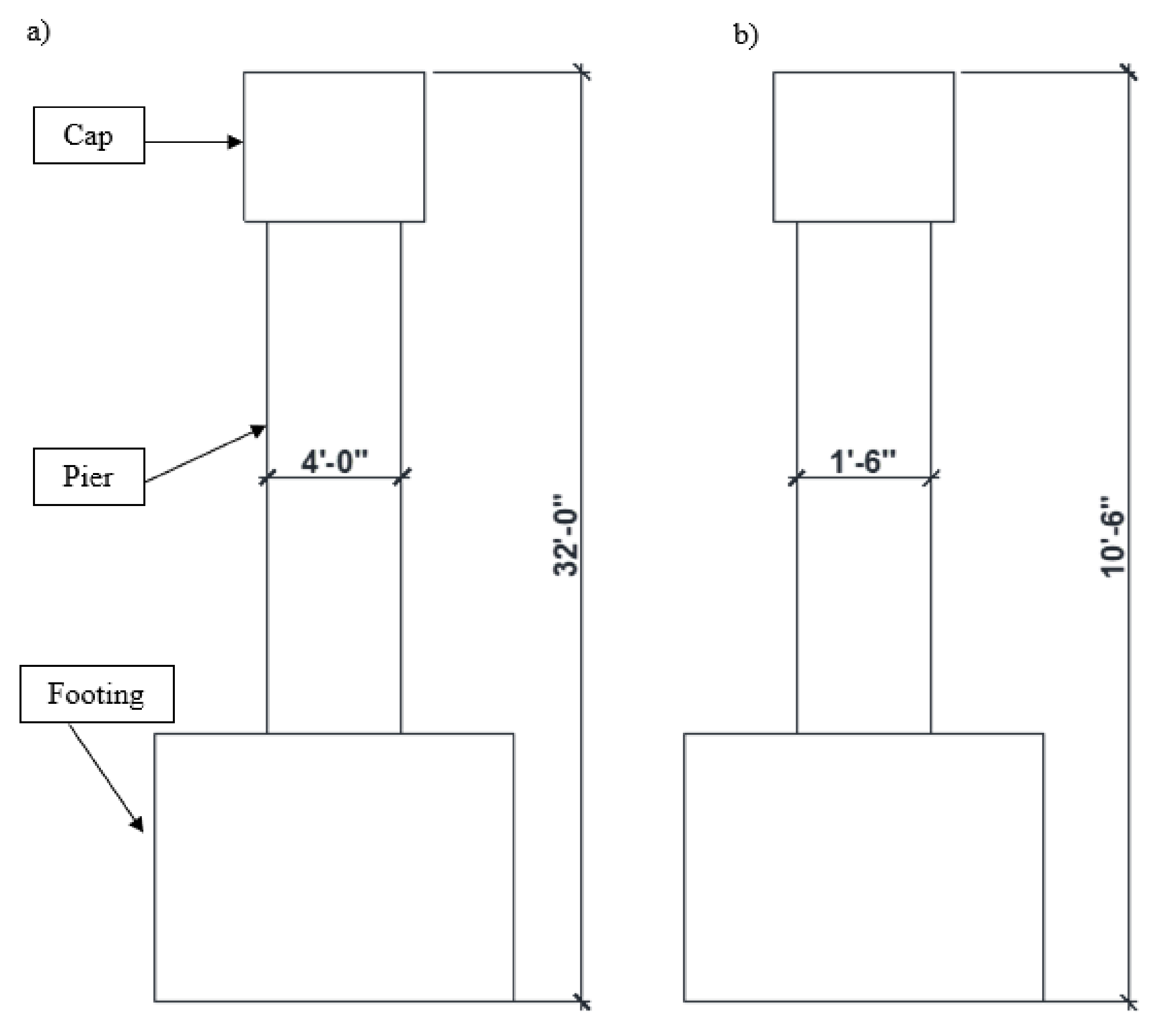


NSM TiABs Technology Used in San Jacinto River Bridge by TxDOT



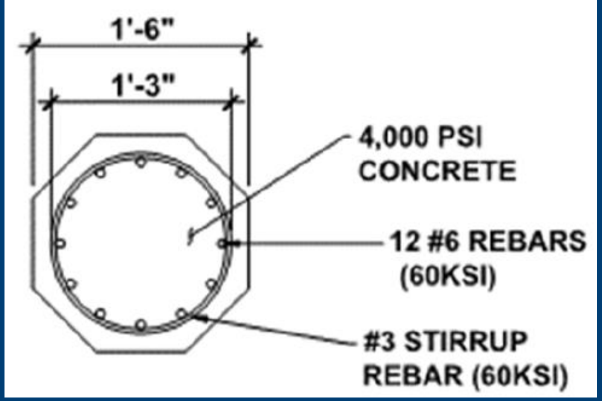
1st Edition, AASHTO Publication

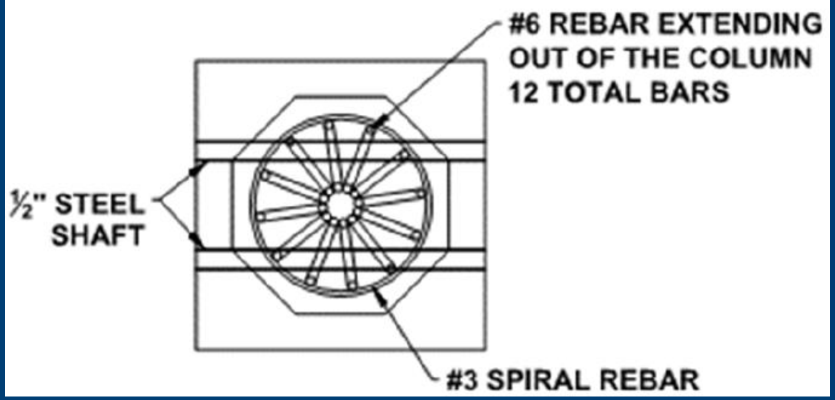
Prototype Structure

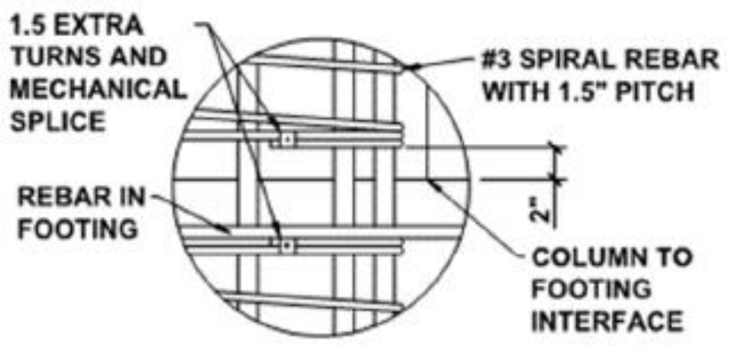


CIP Pier Reinforced with Normal Rebar

- Design moment capacity: 150 k-ft
- Octagonal column; Diameter: 18”
- Longitudinal reinforcing: 12#6 Steel
- Spiral: #3 steel w/1.5” pitch

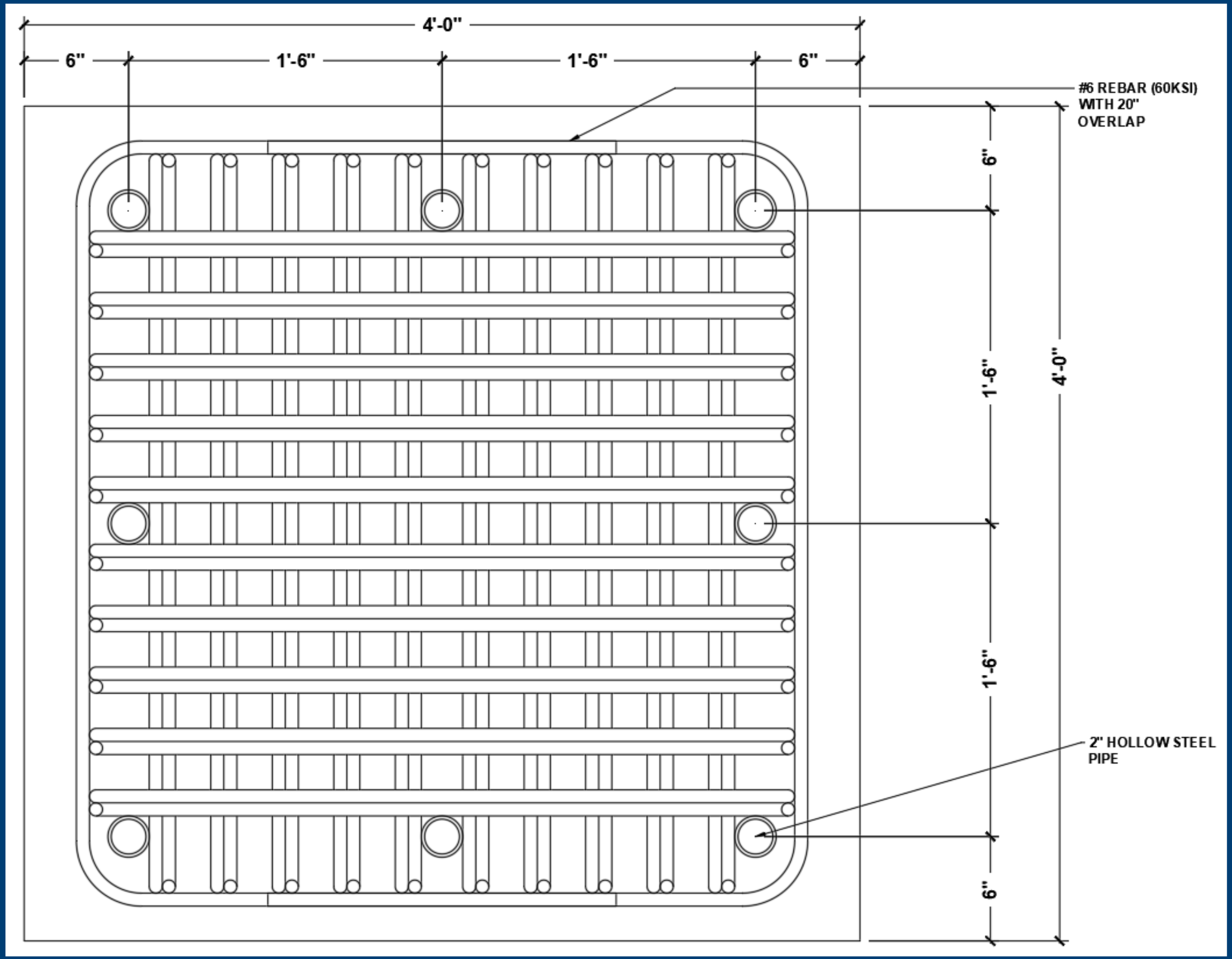






CIP Pier Reinforced with Normal Rebar

- Moment capacity: 1000 k-ft (to let column reach ultimate before footing yields)
- Dimension: 4ft × 4ft × 3ft w/ 2” cover
- 10#6 bars on top and bottom in both directions
- 8 hollow steel pipe (dia. 2”)



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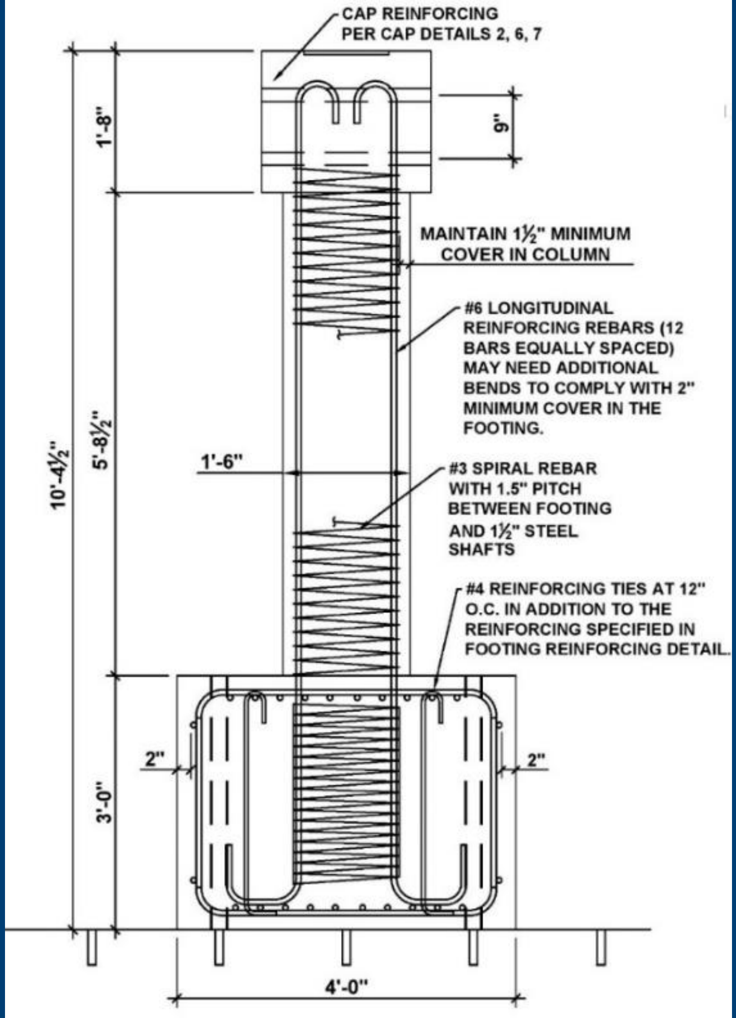

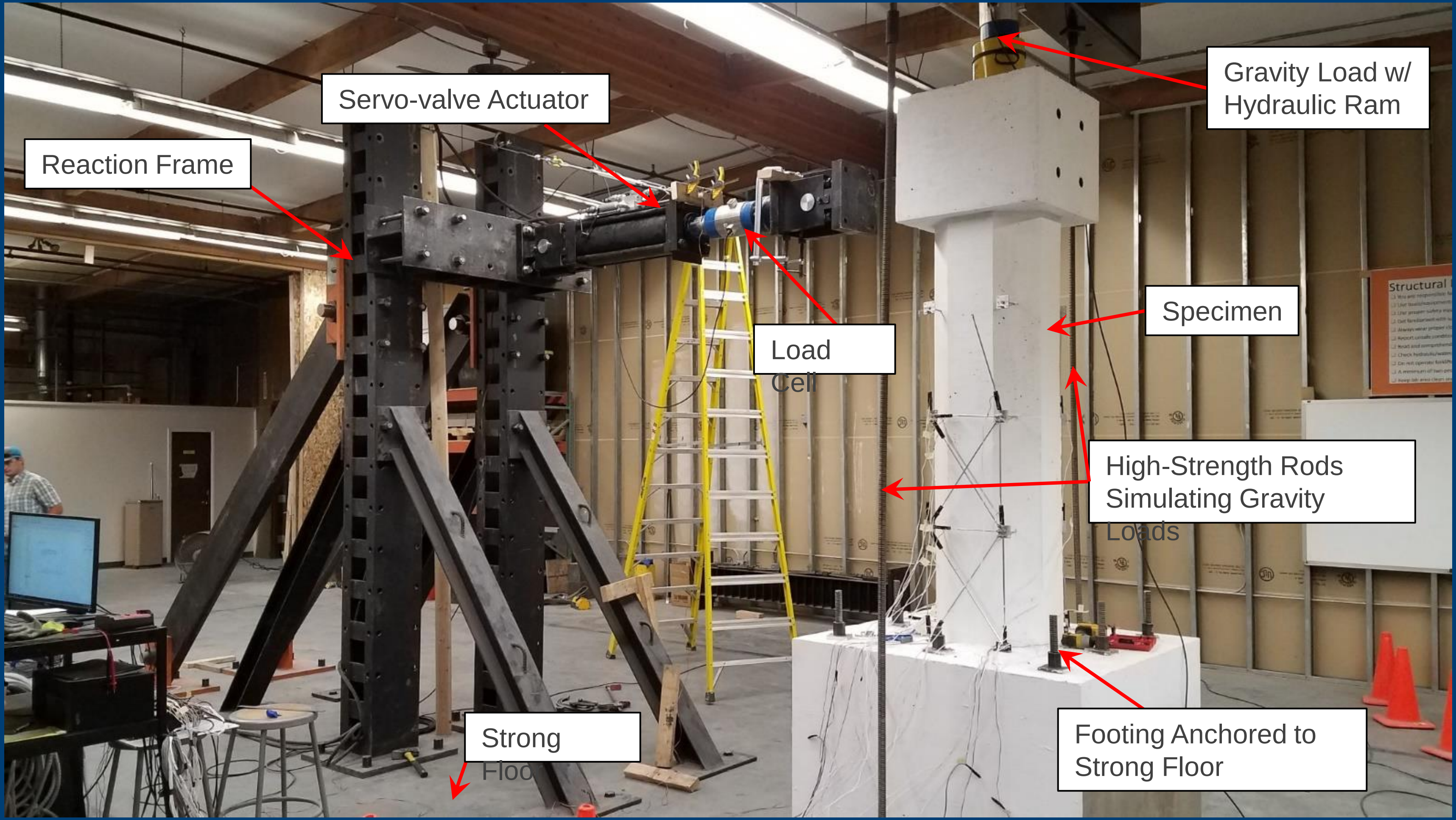

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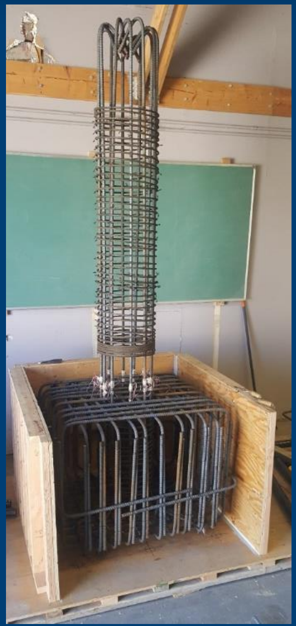
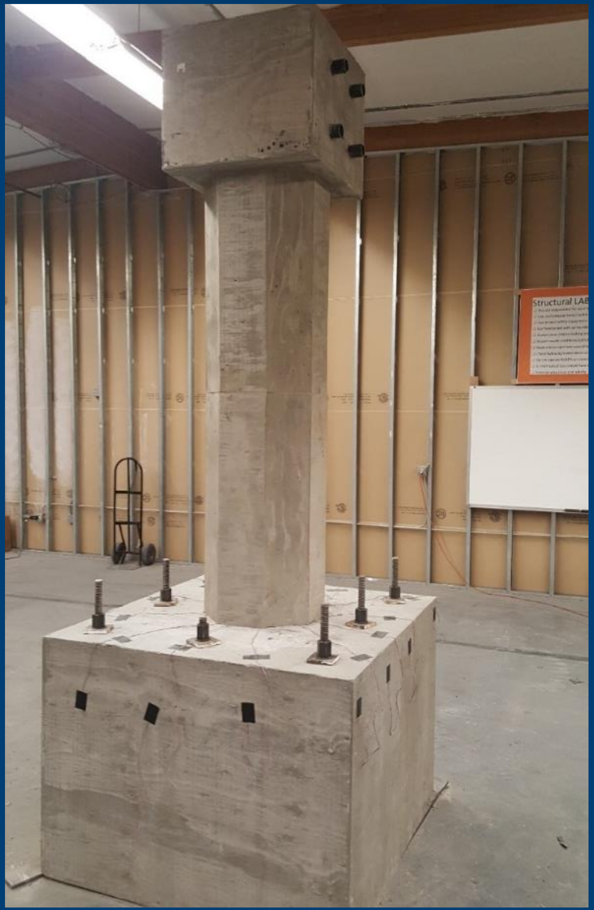
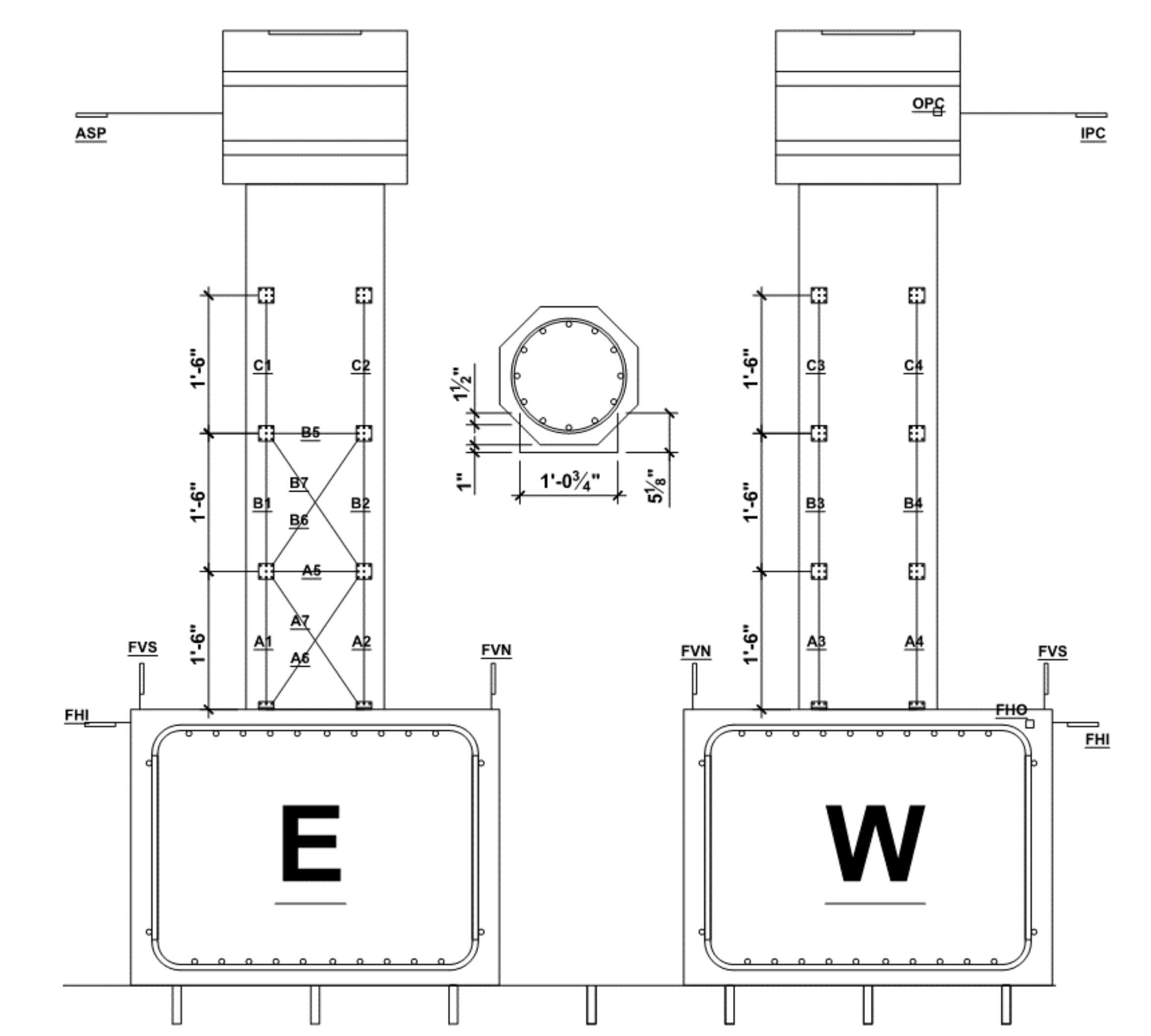




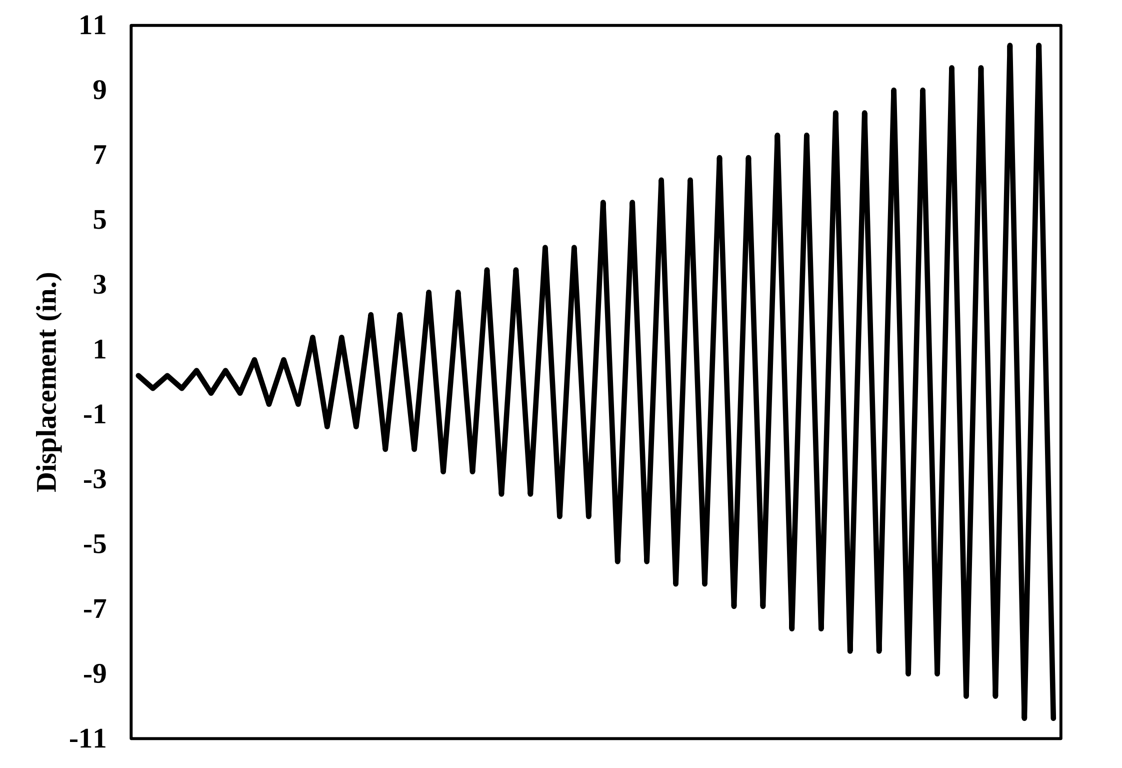
Construction photos

CIP Pier Reinforced with Normal Rebar



CIP Pier Reinforced with Normal Rebar

- Guide for Testing Reinforced Concrete Structural Elements under Slowly Applied Simulates Seismic Loads (ACI 374.2R-13)
- Quasi-Static Cyclic Loading Protocol
- Loading rate: 1 mm/s



Cast-in-place
cantilever specimen

CIP Pier Reinforced with Normal Rebar

2.2% Drift Ratio

3.8% Drift Ratio

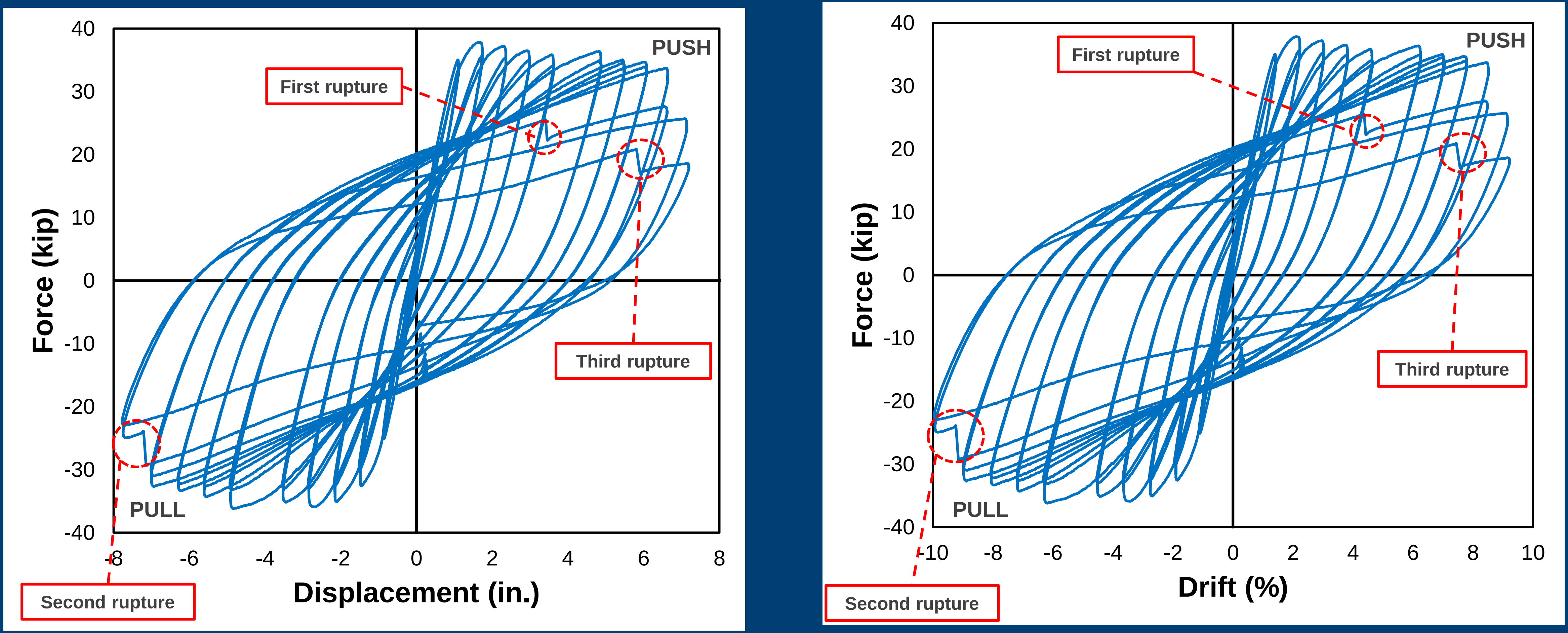
9.0% Drift Ratio

9.0% Drift Ratio (1^{st} Rebar Rupture)

10.0% Drift Ratio (2^{nd} Rebar Rupture)

10.0% Drift Ratio (3^{rd} Rebar Rupture)

CIP Pier Reinforced with Normal Rebar



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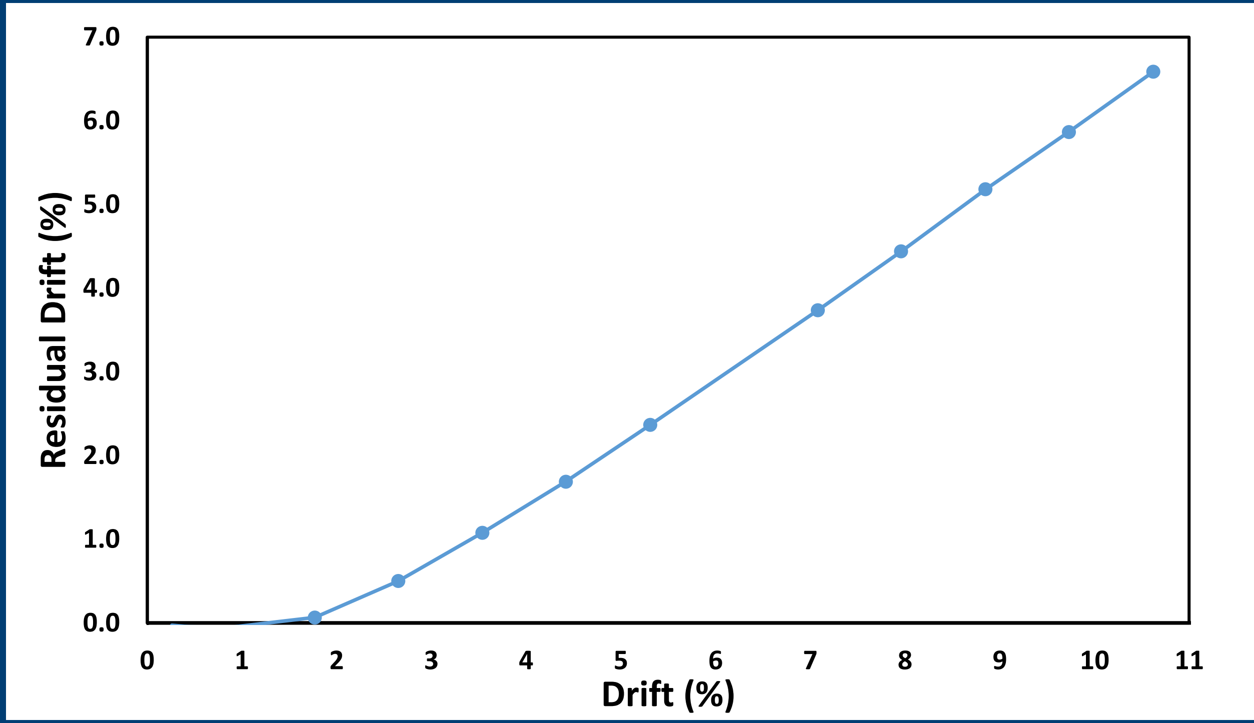
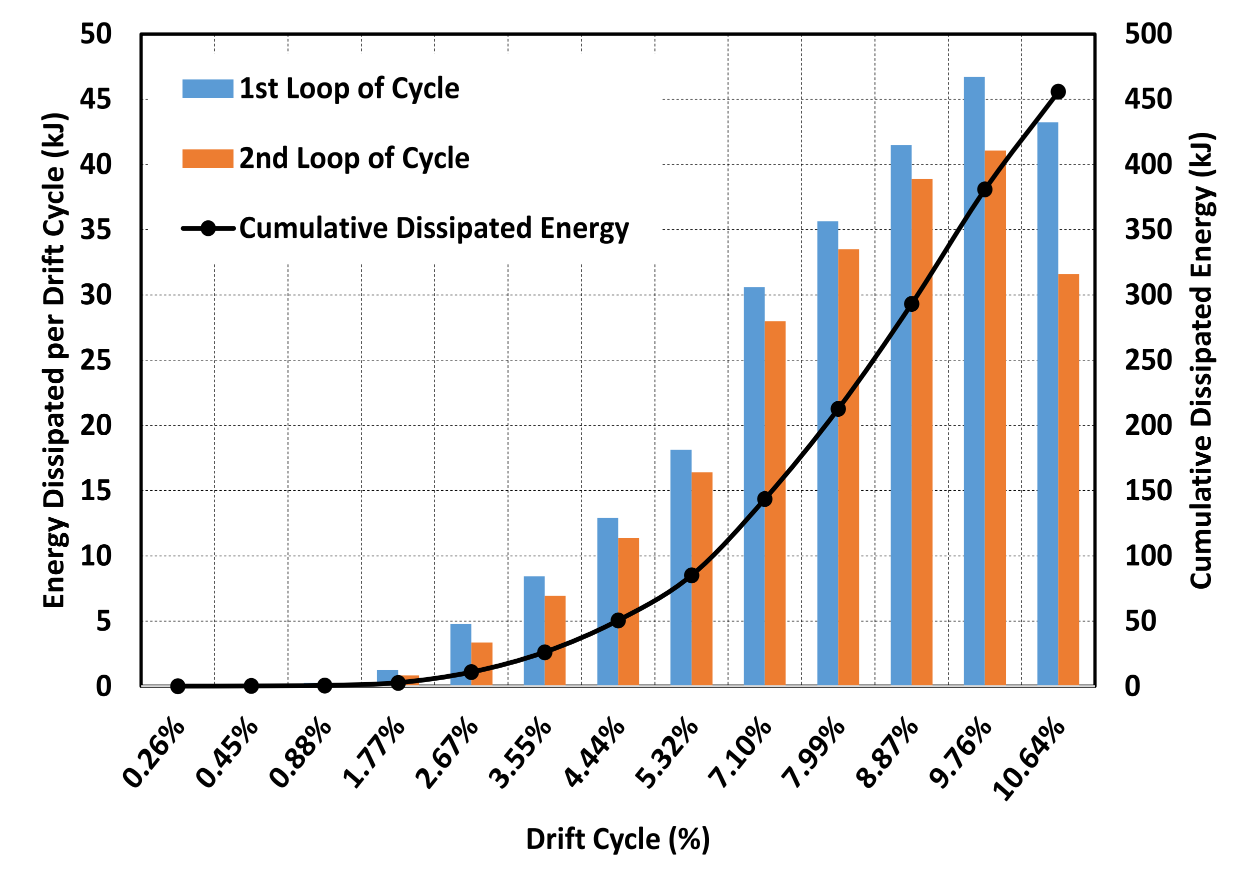
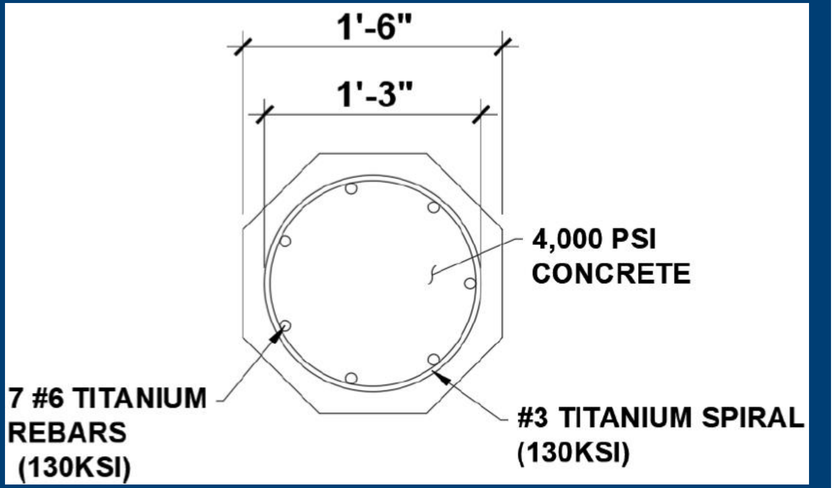
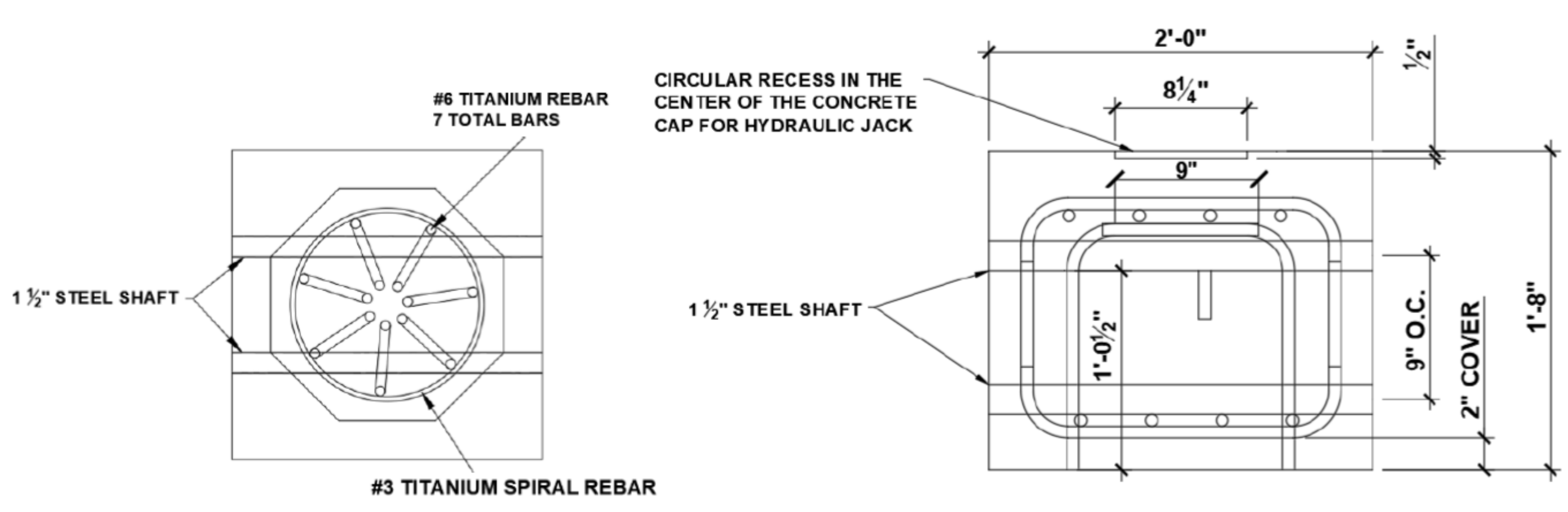




CIP Pier Reinforced with TiABs

- Design moment capacity: 150 k-ft
- Octagonal column; Diameter: 18”
- Longitudinal reinforcing: 7#6 smooth TiABs
- Spiral: #3 TiABs w/3” pitch





CIP Pier Reinforced with TiABs

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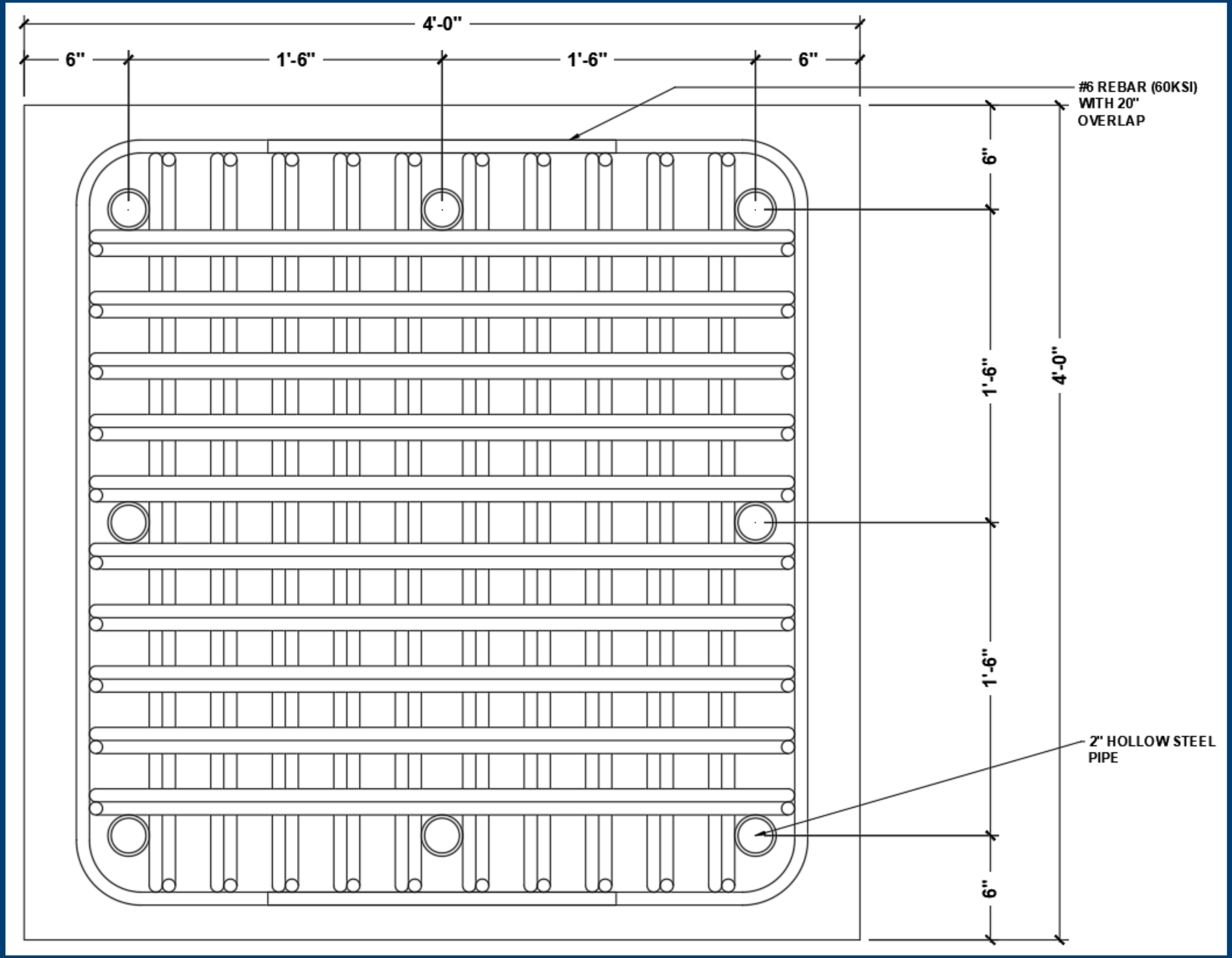
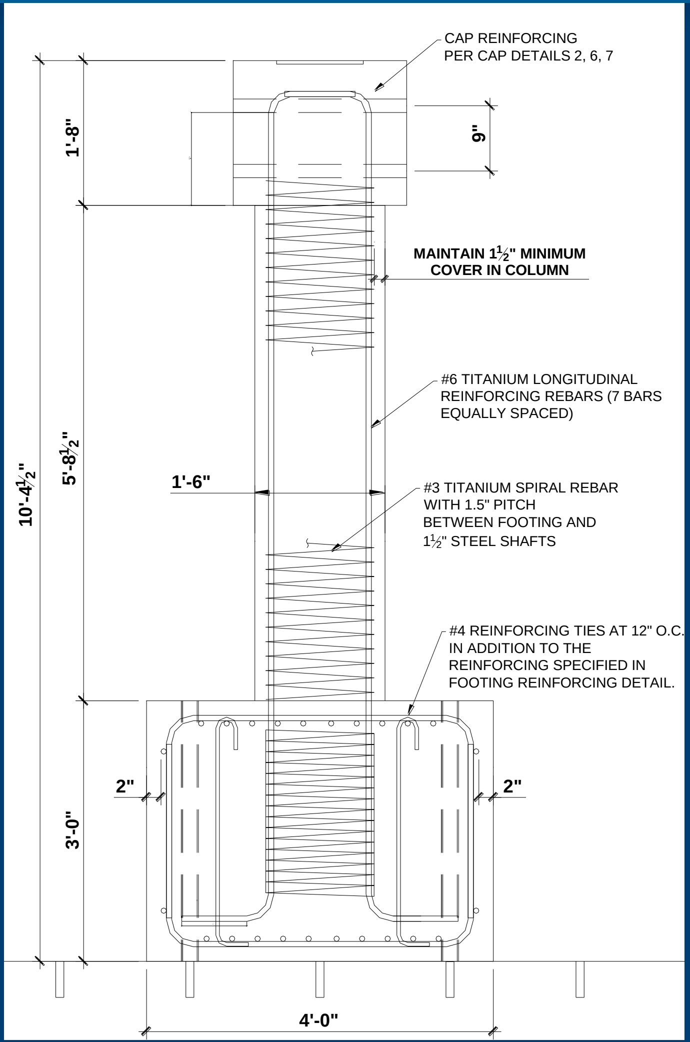
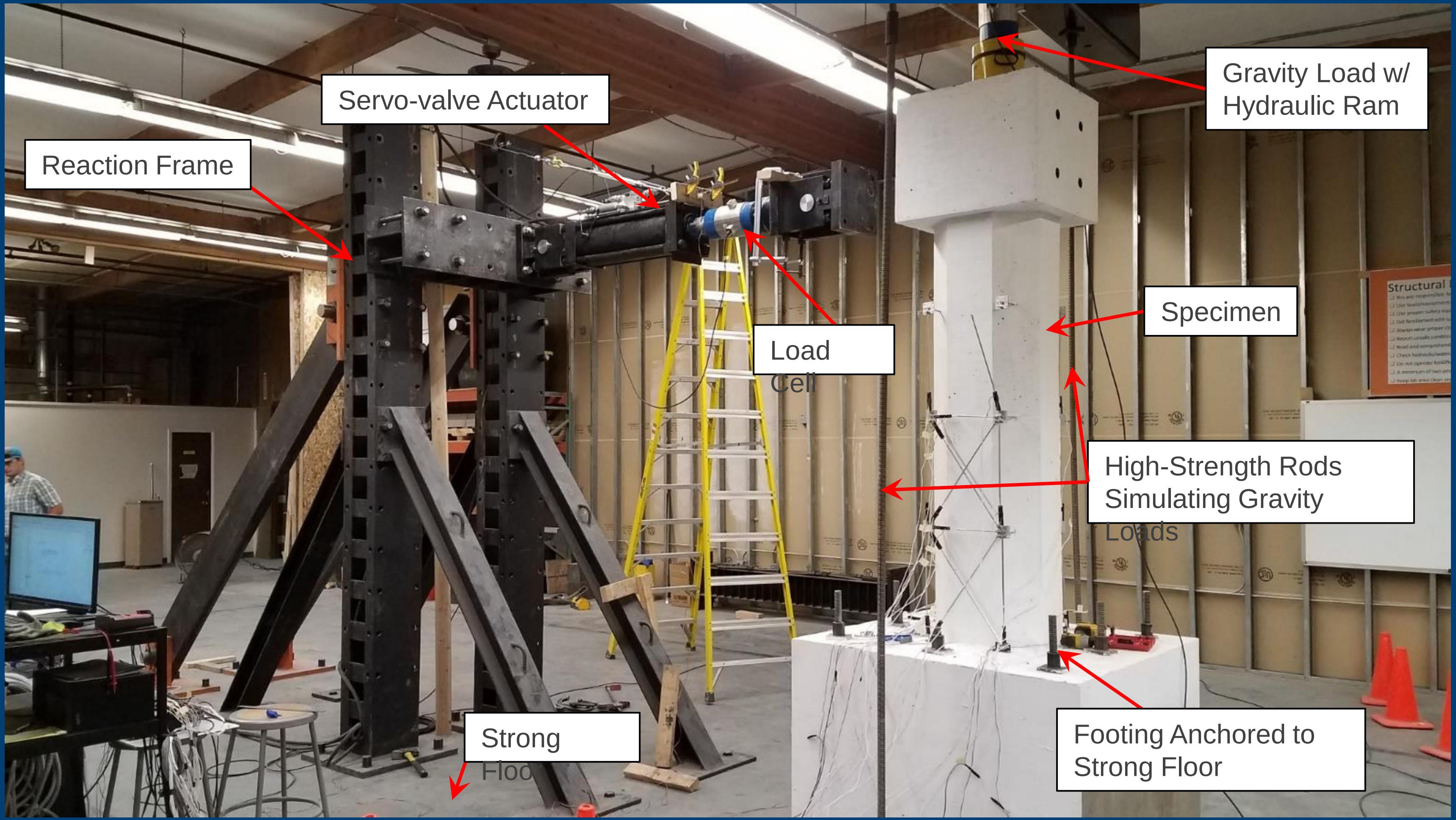


CIP Pier Reinforced with TiABs

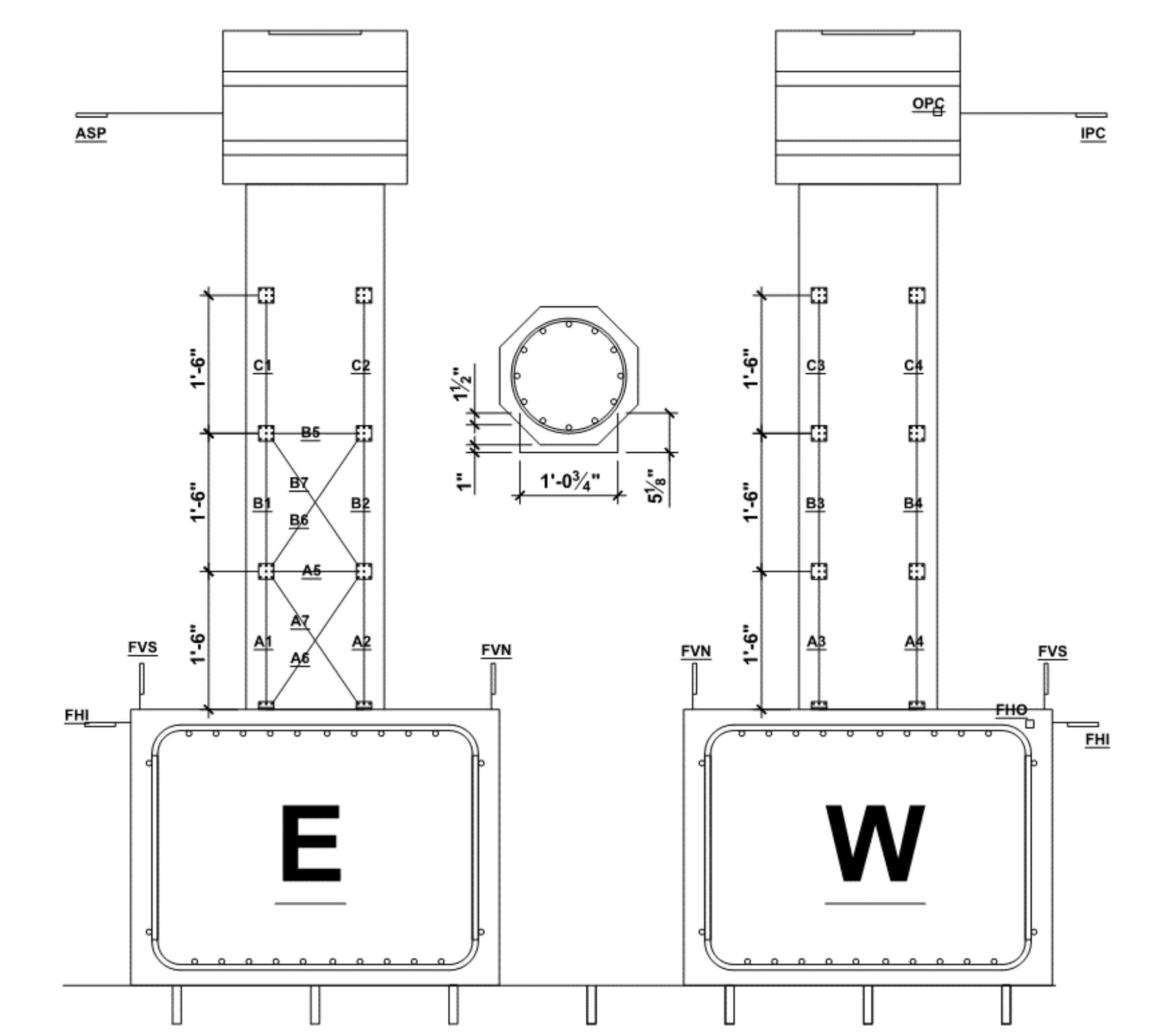




CIP Pier Reinforced with TiABs

Construction photos

CIP Pier Reinforced with TiABs



CIP Pier Reinforced with TiABs

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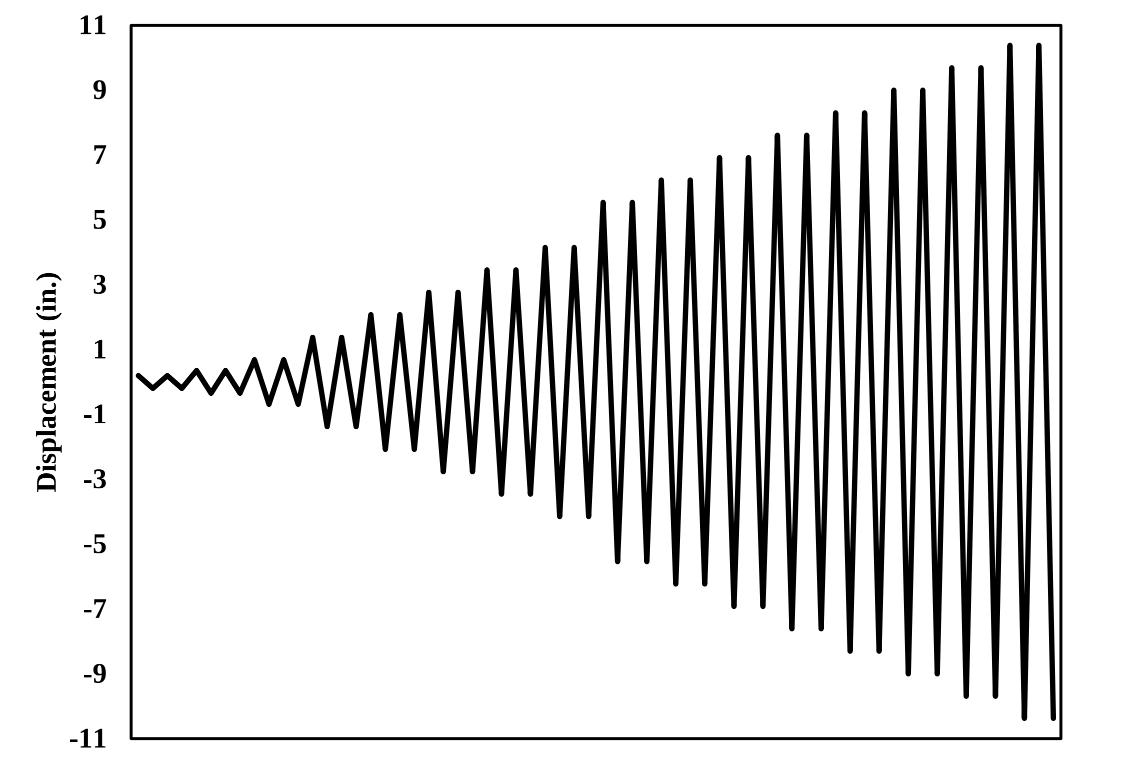
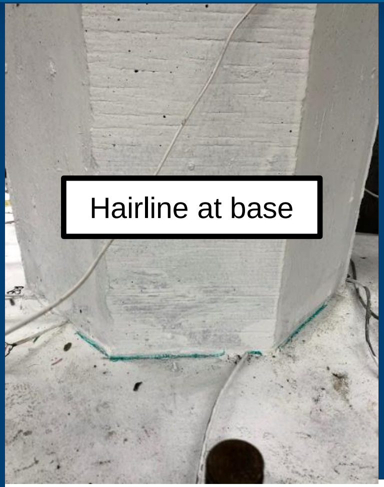
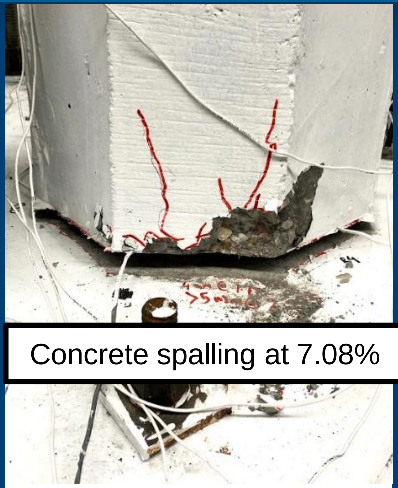



TITANIUM
CANTILEVER SPECIMEN
0 26 DRIFT
10 17 2019
ISU SLAB

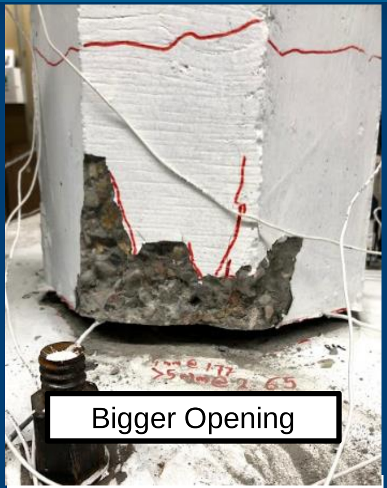
CIP Pier Reinforced with TiABs



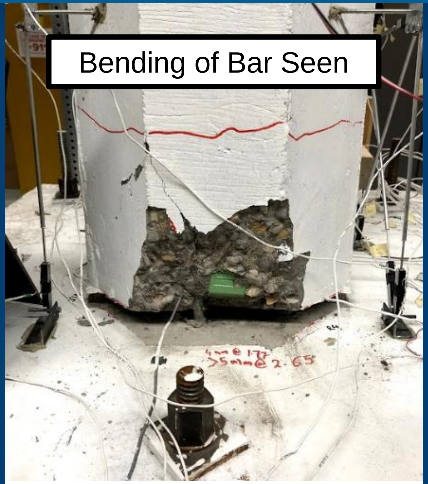
0.44% Drift Ratio



7.08% Drift Ratio



7.96% Drift Ratio



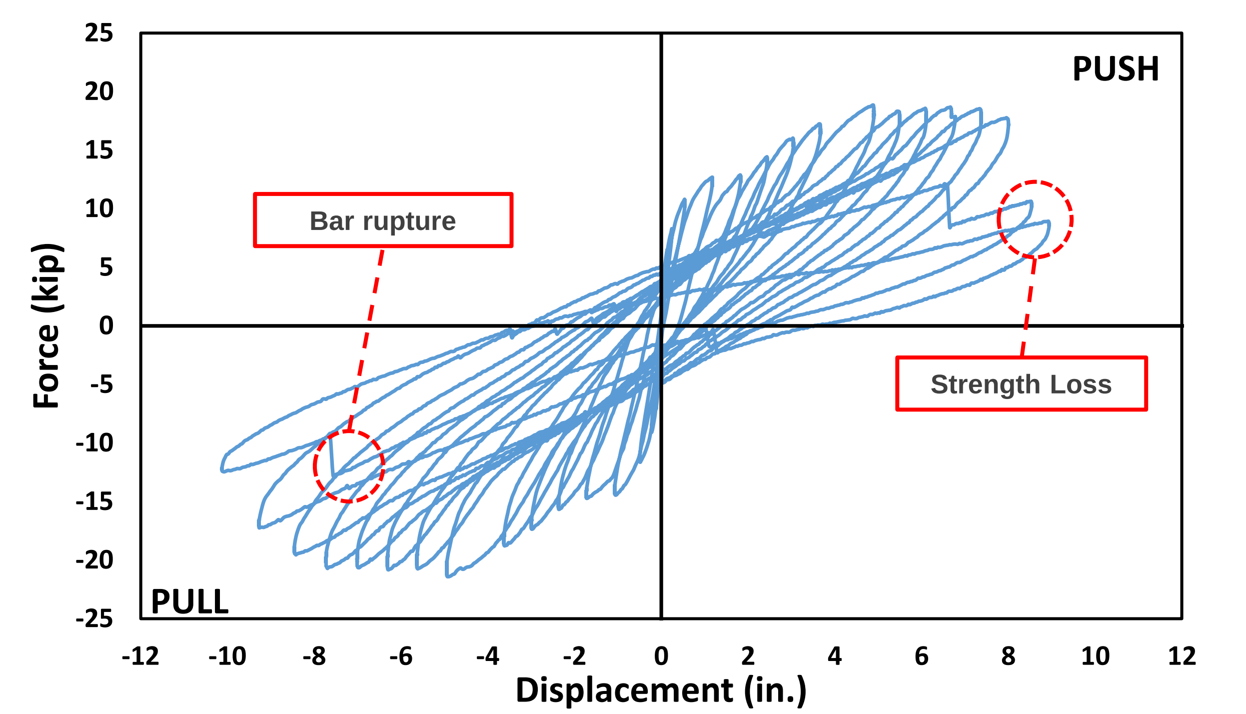
10.62% Drift Ratio

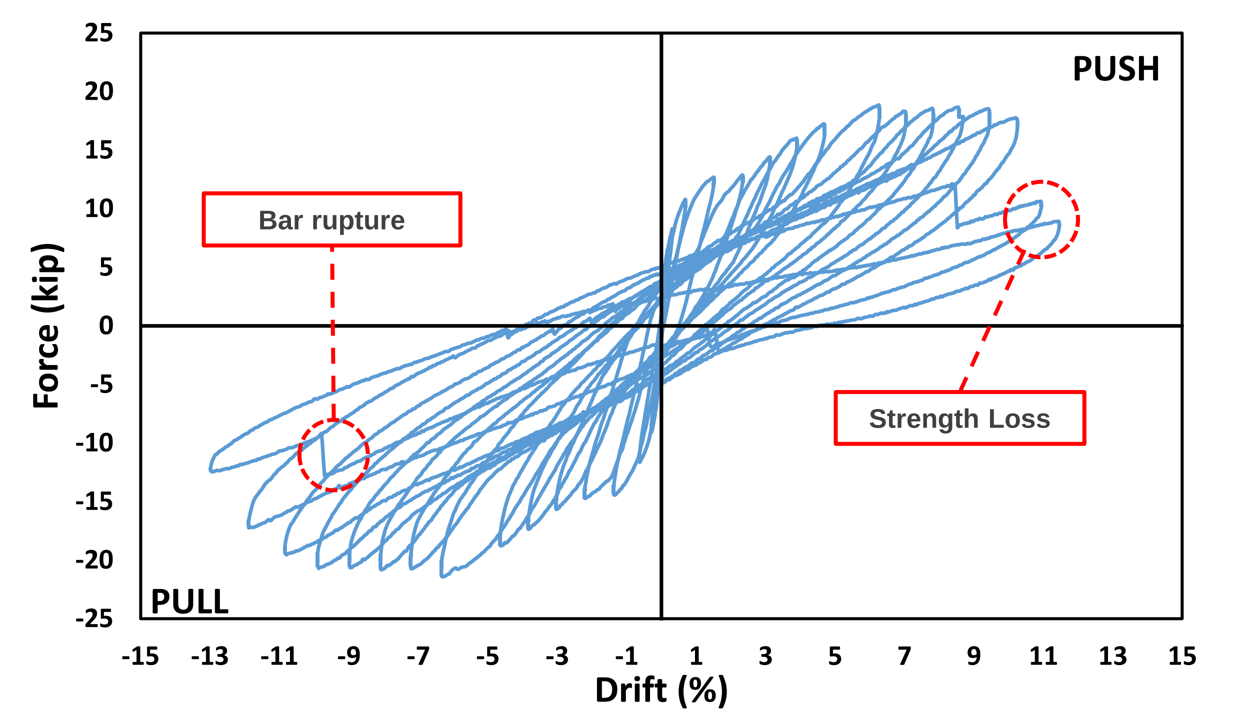
11.5 % Drift Ratio

12.38% Drift Ratio (Bar Rupture)

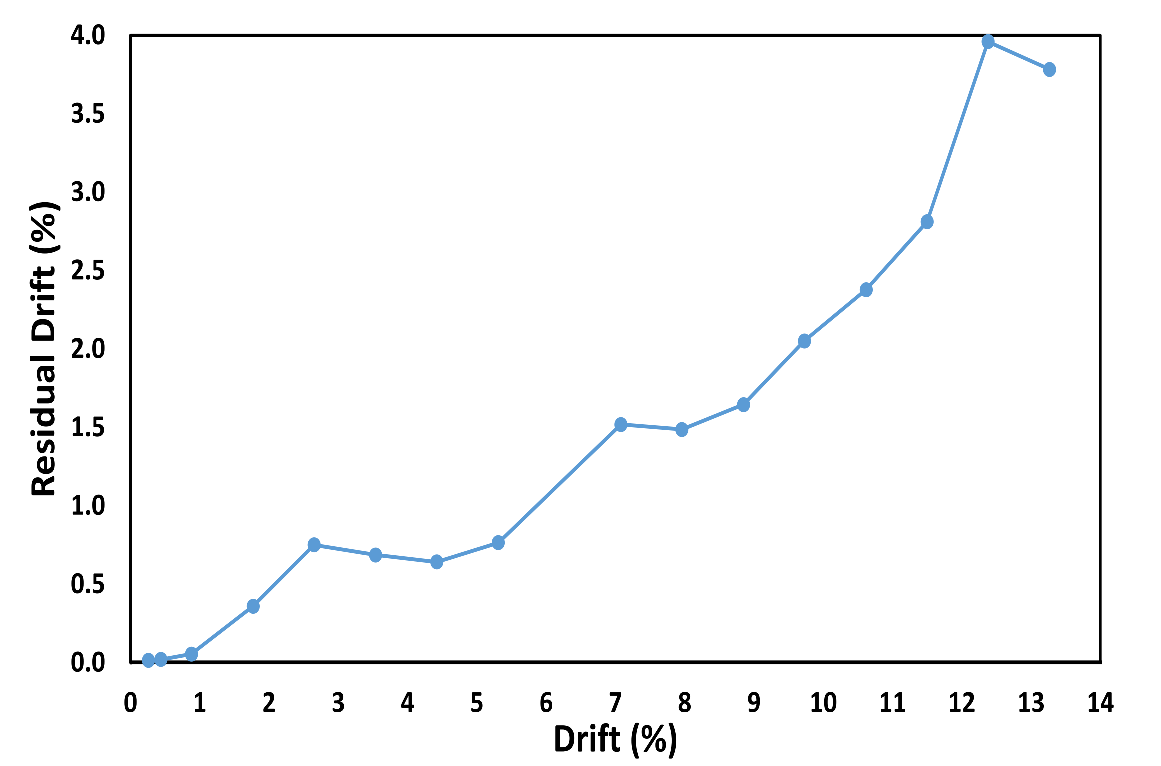
13.27% Drift Ratio

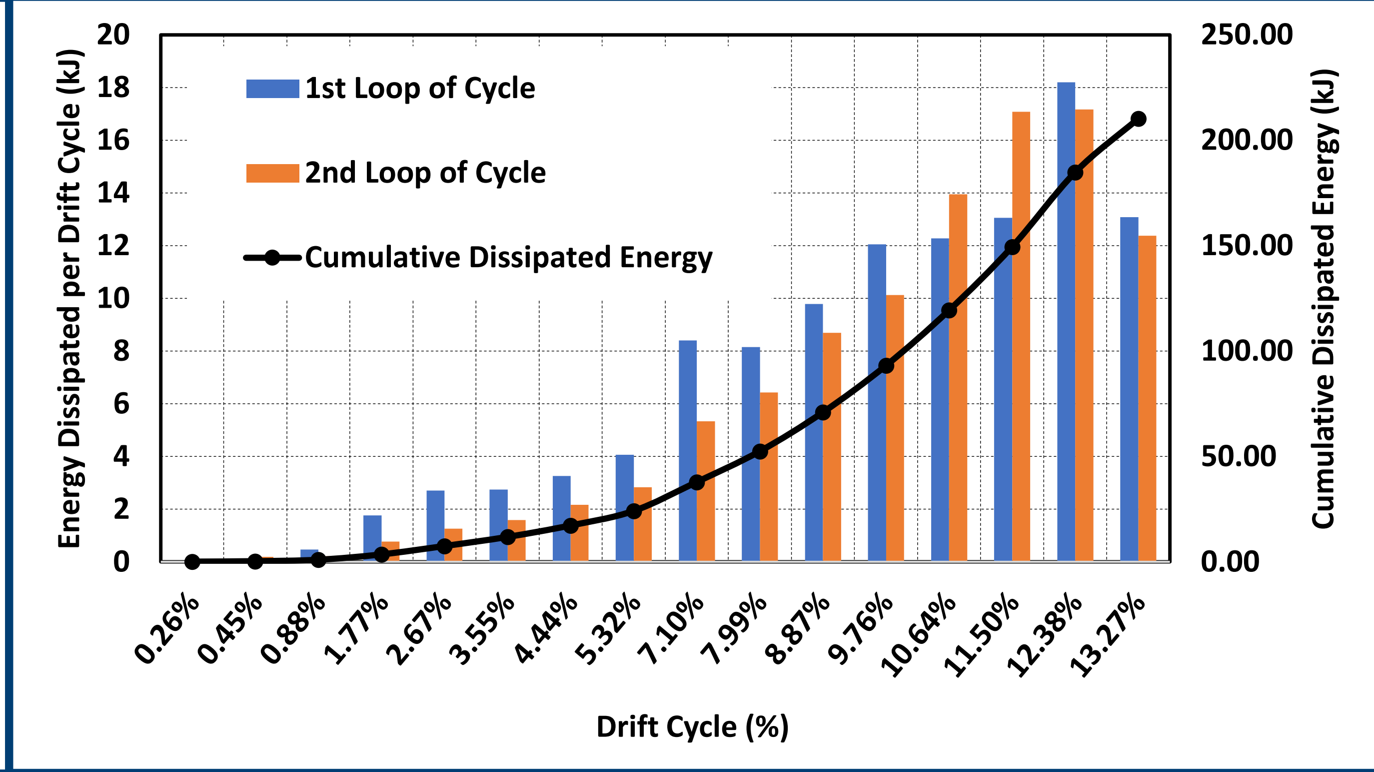
CIP Pier Reinforced with TiABs



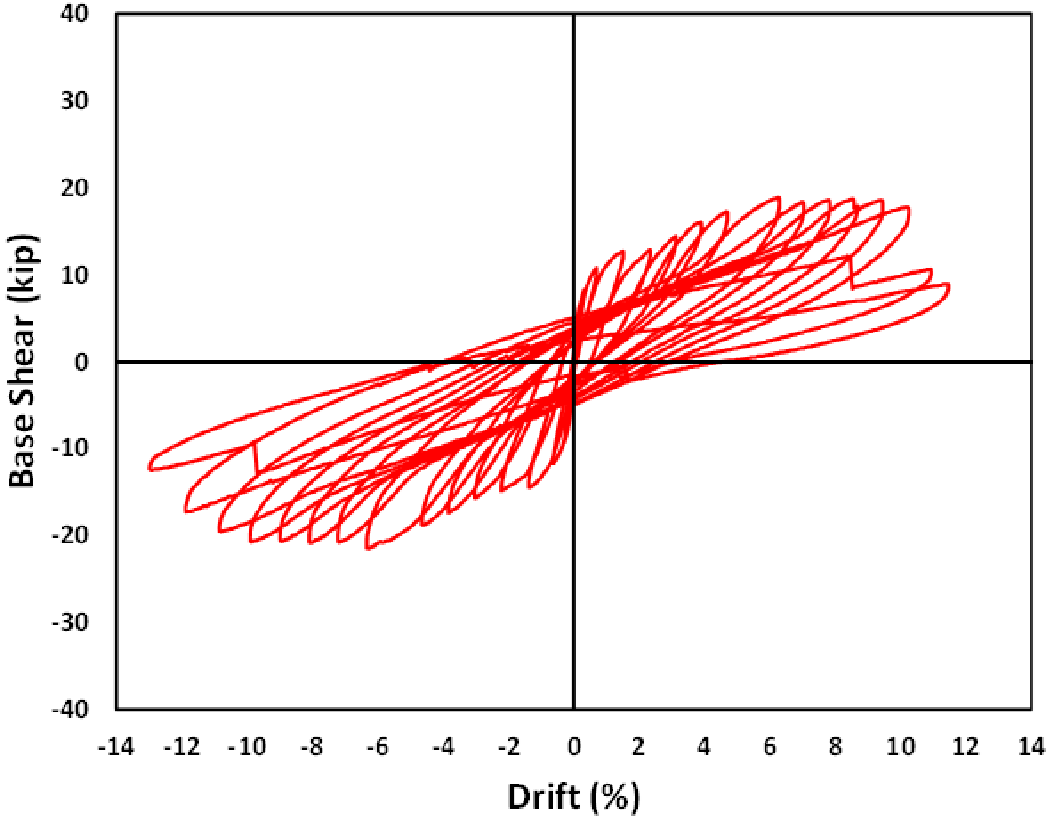


CIP Pier Reinforced with Normal Rebar

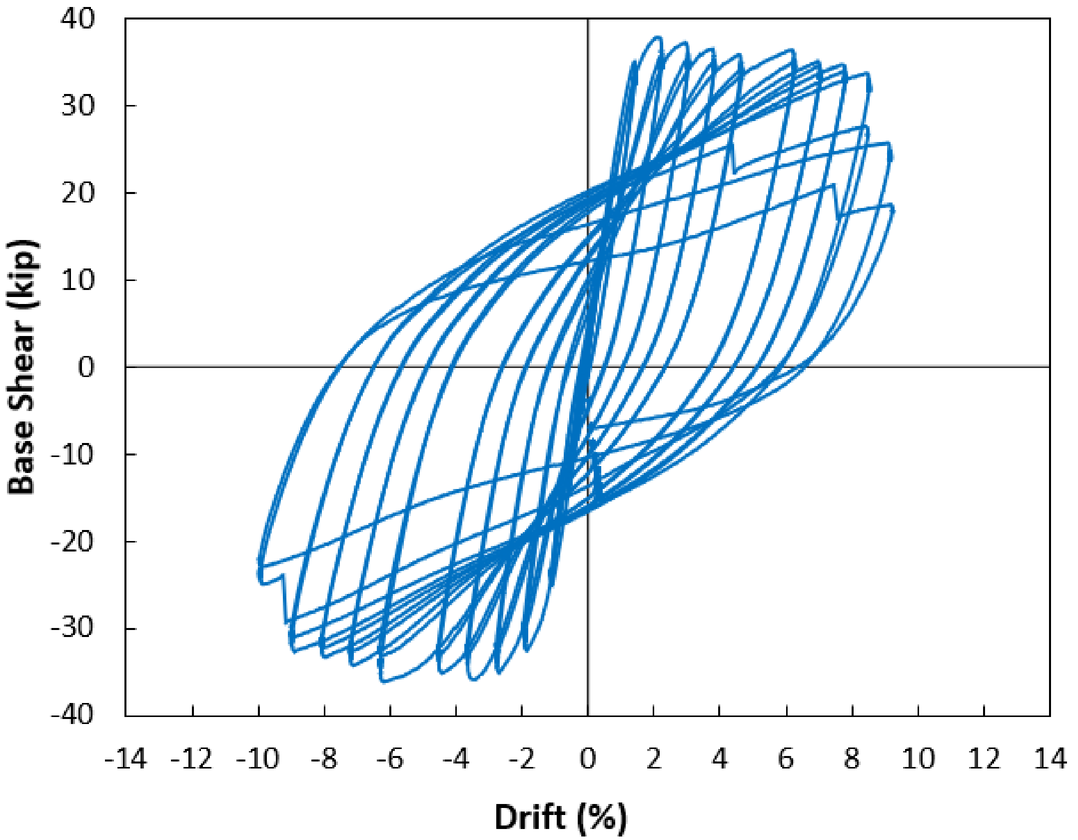




Comparison

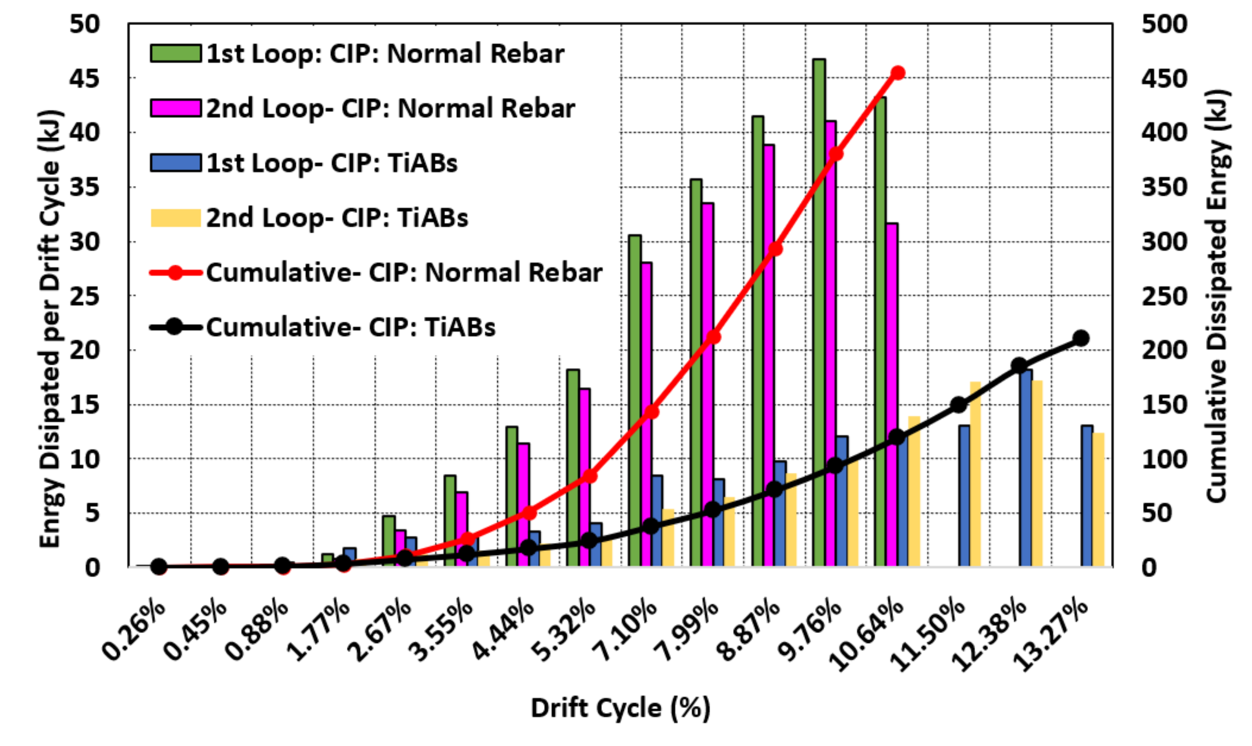


CIP Pier reinforced w/ TiABs

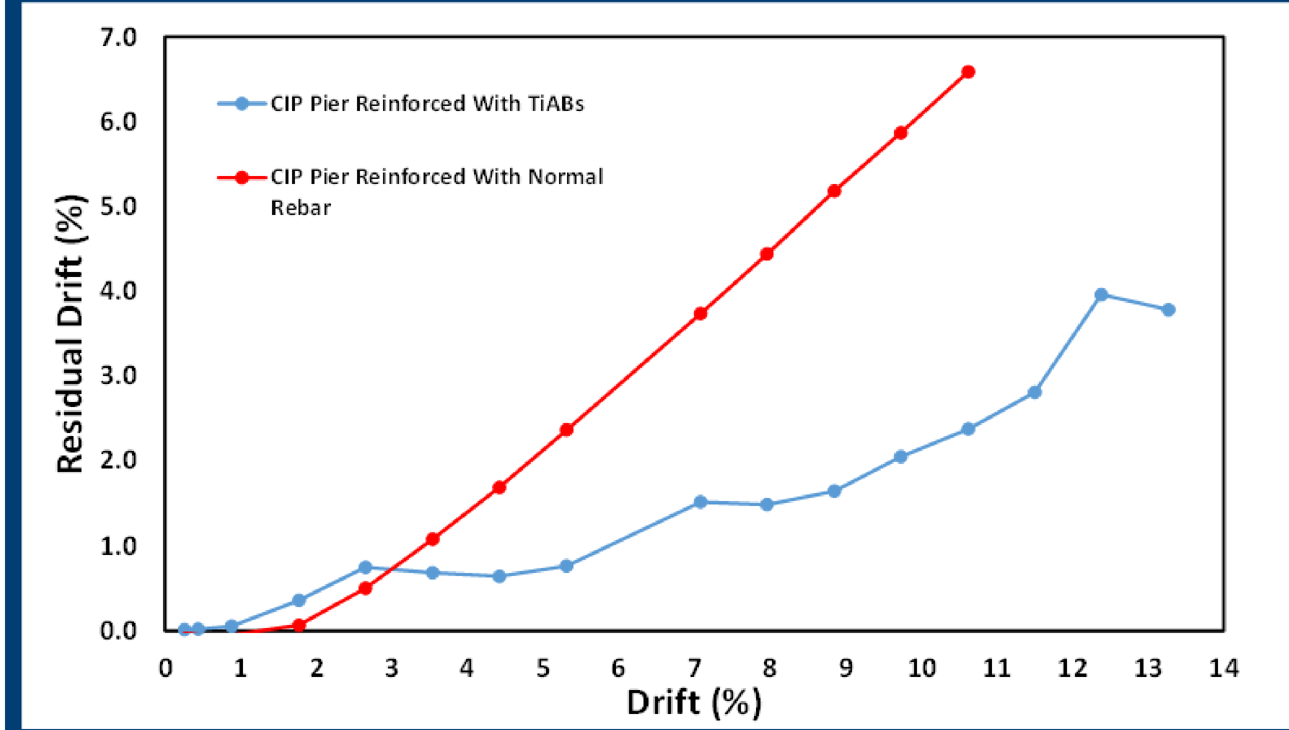


CIP Pier reinforced w/ Normal Rebar

Comparison



1st Loop: CIP: Normal Rebar
2nd Loop- CIP: Normal Rebar
1st Loop- CIP: TiABs
2nd Loop- CIP: TiABs
Cumulative- CIP: Normal Rebar
Cumulative- CIP: TiABs
Enrgy Disipated per Drift Cycle (kJ)
Cumulative Dissipated Enrgy (kJ)
Drift Cycle (%)
0.26%
0.45%
0.88%
1.77%
2.67%
3.55%
4.44%
5.32%
7.10%
7.99%
8.87%
9.76%
10.64%
11.50%
12.38%
13.27%



CIP Pier Reinforced With TiABs
CIP Pier Reinforced With Normal Rebar
Residual Drift (%)
Drift (%)

Conclusions

- A cantilever pier reinforced with titanium alloy bars (TiABs) is proposed
- The system aims to achieve seismic performance and durability.
- The proposed piers reinforcement of TiABs offers advantages such as good ductility, better fatigue performance and excellent corrosion resistance compared to piers reinforced with normal rebar.
- Uni-directional quasi-static cyclic tests were conducted on a large-scale cantilever pier specimen to validate the concept and compare performance with pier reinforced with normal rebar.
- TiABs can reduce the number of rebars to almost half and can prevent from rebar congestion. This reduces the labor cost as well.

Conclusions

- Displacement at yield and ultimate for TiABs pier is higher compared to steel pier, however base shear at yield and ultimate, is lower.
- Overstrength factor (Ω_0) of the pier reinforced with TiABs is 1.32 and ultimate ductility (μ_T) is 8.52. This overstrength factor load is due to elastic perfectly plastic behavior of TiABs.
- Pier Reinforced with TiABs exhibited less energy dissipation, however it was more ductile compared to an equivalent pier with normal rebars.
- Distribution of curvature along height of piers showed yielding occurred in plastic hinge region of pier, and height above it approached but never reached yield point.

Conclusions

- The cracks, spalling of concrete and non-linear deformation occurred mostly at the plastic hinge region for both piers.
- Large-scale testing showed less residual displacement of the pier reinforced with TiABs after yielding (about 40% less)
- Based on testing results, TiABs has lot of potential for civil infrastructure.
- The research at ISU on the use of TiABs for construction of new structures in seismic zone is an on-going effort.

Acknowledgements

- Idaho State University
- Idaho State Board of Education
- Perryman Company, PA
- Idaho Transportation Department, ID
- Premier Technology, Inc., ID

Thank you

For the most up-to-date information please visit the American Concrete Institute at:
www.concrete.org

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