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Natural Hazards Engineering Research Infrastructure



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Structural Engineering

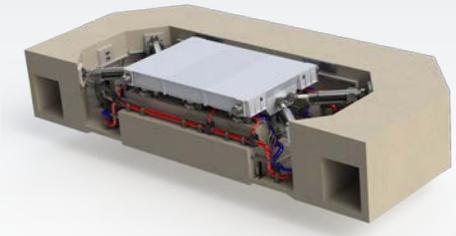
Example Uses of RAPID-Like Tools In Large-Scale Experimental Programs

Koorosh Lotfizadeh, UC San Diego

*Joint NHERI@UC San Diego – RAPID
Researcher Workshop*

December 14-15, 2020

University of California, San Diego



Outline:

- Brief overview of some recent experiments
 - Bar Development and Bond-Slip Tests
 - Bridge Column Extending into Type II Shaft
 - Exterior Column of Multi-Column Bridge Bent
 - Plastic Buckling-Straightening Fatigue of Grade 80 Reinforcement
- Technologies that can be incorporated in large-scale tests
 - DIC
 - GNSS/GPS
 - LiDAR
 - UAVs
- Available equipment and instrumentation at LHPOST6

Recent Experiments

1. Bar Development and Bond Slip Tests
2. Column Extending Into Type II Shaft
3. Exterior Column of Multi-Column Bridge Bent
4. Plastic Buckling-Straightening Fatigue of Grade 80 Reinforcement

1. Bar Development and Bond Slip Tests

- Assess if current AASHTO LRFD Specifications tensile development length equations are suitable for high-strength reinforcement
- Four test specimens built:
#18 and #14 bars
5 ksi and 8 ksi concrete
- Determine equivalent strain penetration of Grade 80 bars
- Provide recommendation for equivalent strain penetration term

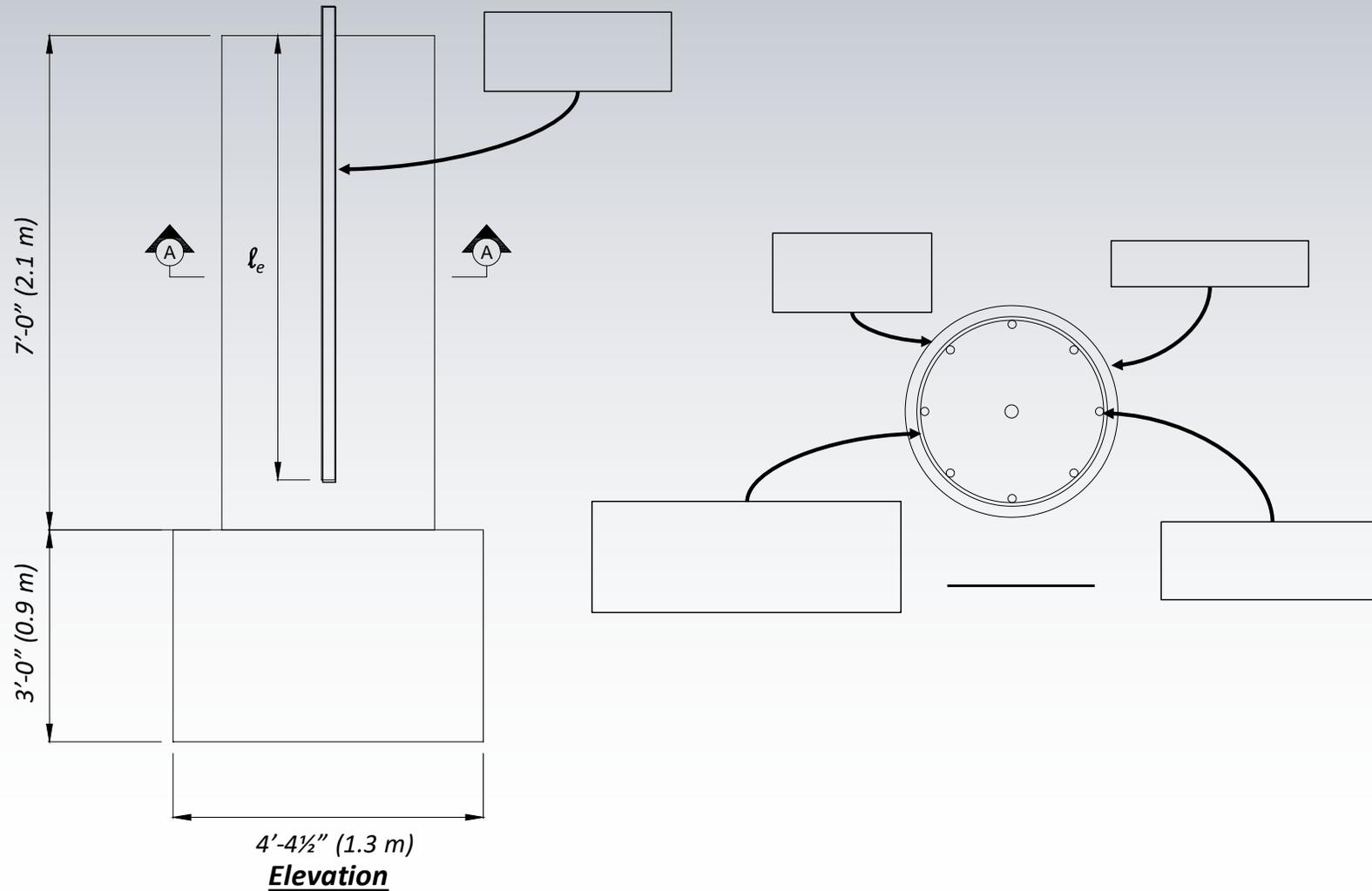


Specimen Design:

$$\rho_l = 1.22\%$$

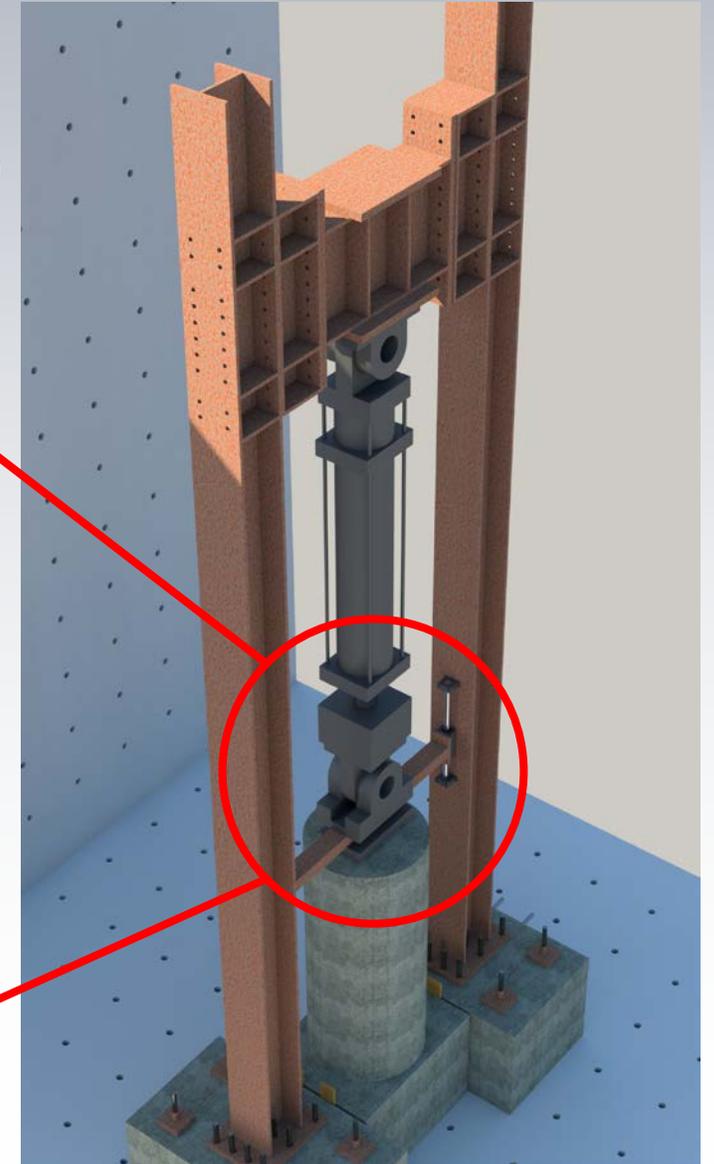
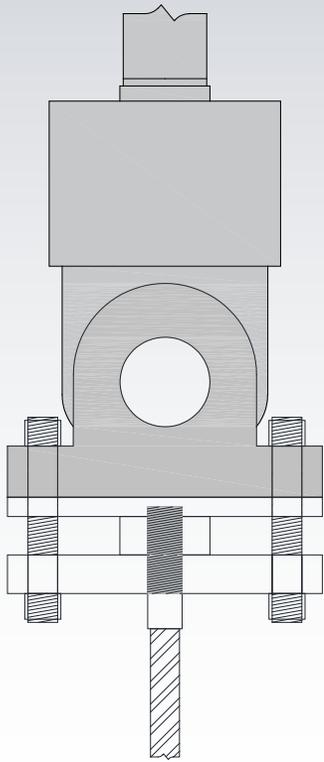
and

$$\rho_s = 0.79\%$$

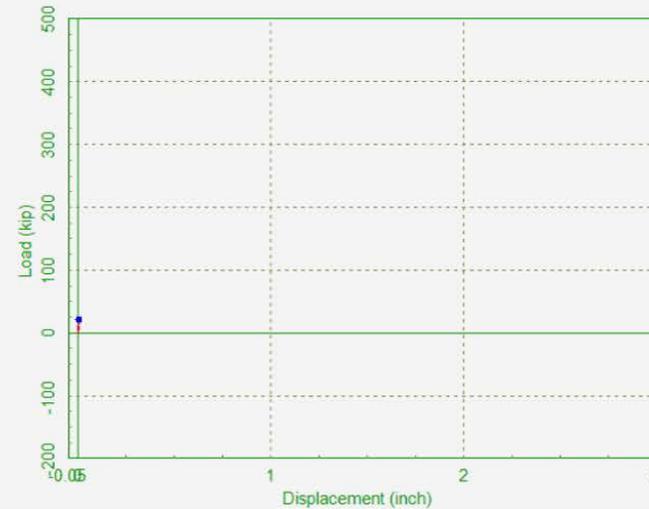
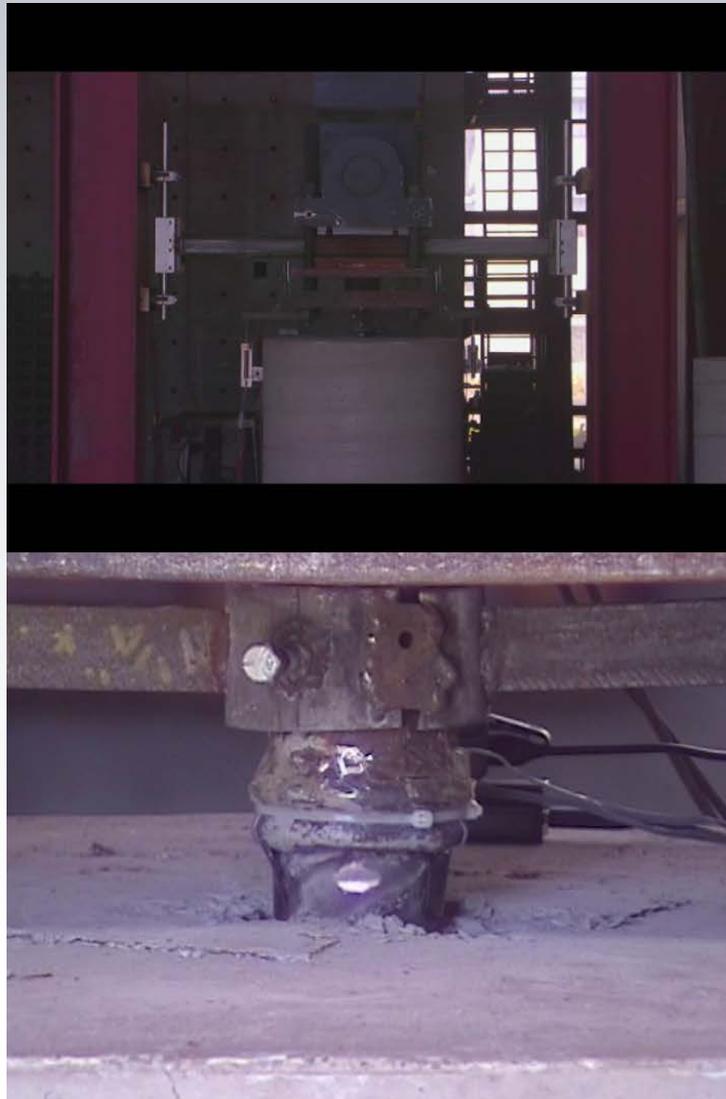


Specimen Design:

Guiding frame preventing instability during push (compression) loading cycles



Testing Procedure:



Bond Slip Specimen #1

#18 bar embedded in 4.5 ksi concrete
3/10/2017

GSR: Koorosh Lotfizadeh
PI: Jose Restrepo

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Structural Engineering



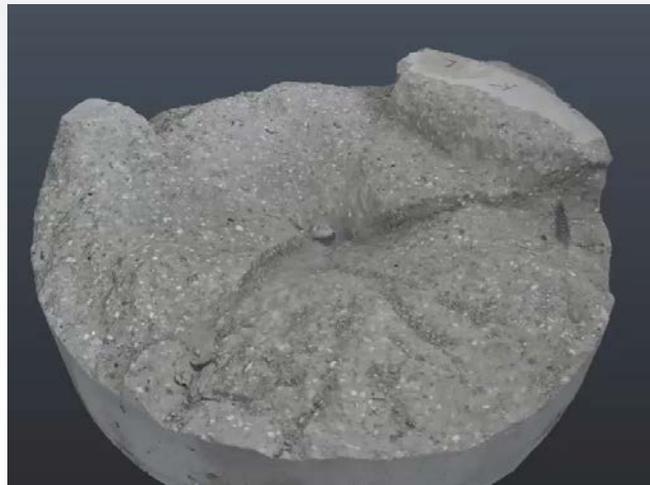
3D Point Cloud Models of Fracture Surfaces



Specimen 1: #18 bar, 5 ksi Concrete



Specimen 2: #14 bar, 5 ksi Concrete



Specimen 3: #18 bar, 8 ksi Concrete



Specimen 4: #14 bar, 8 ksi Concrete



Recent Experiments

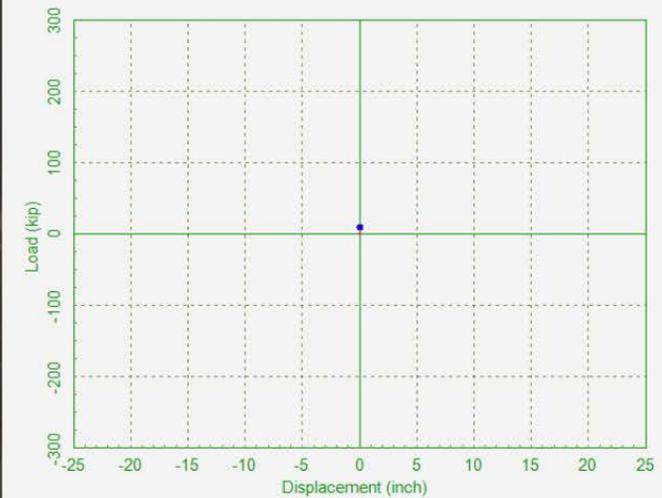
1. Bar Development and Bond Slip Tests
2. Column Extending Into Type II Shaft
3. Exterior Column of Multi-Column Bridge Bent
4. Plastic Buckling-Straightening Fatigue of Grade 80 Reinforcement

2. Full-Scale Column Extending into Type II Shaft

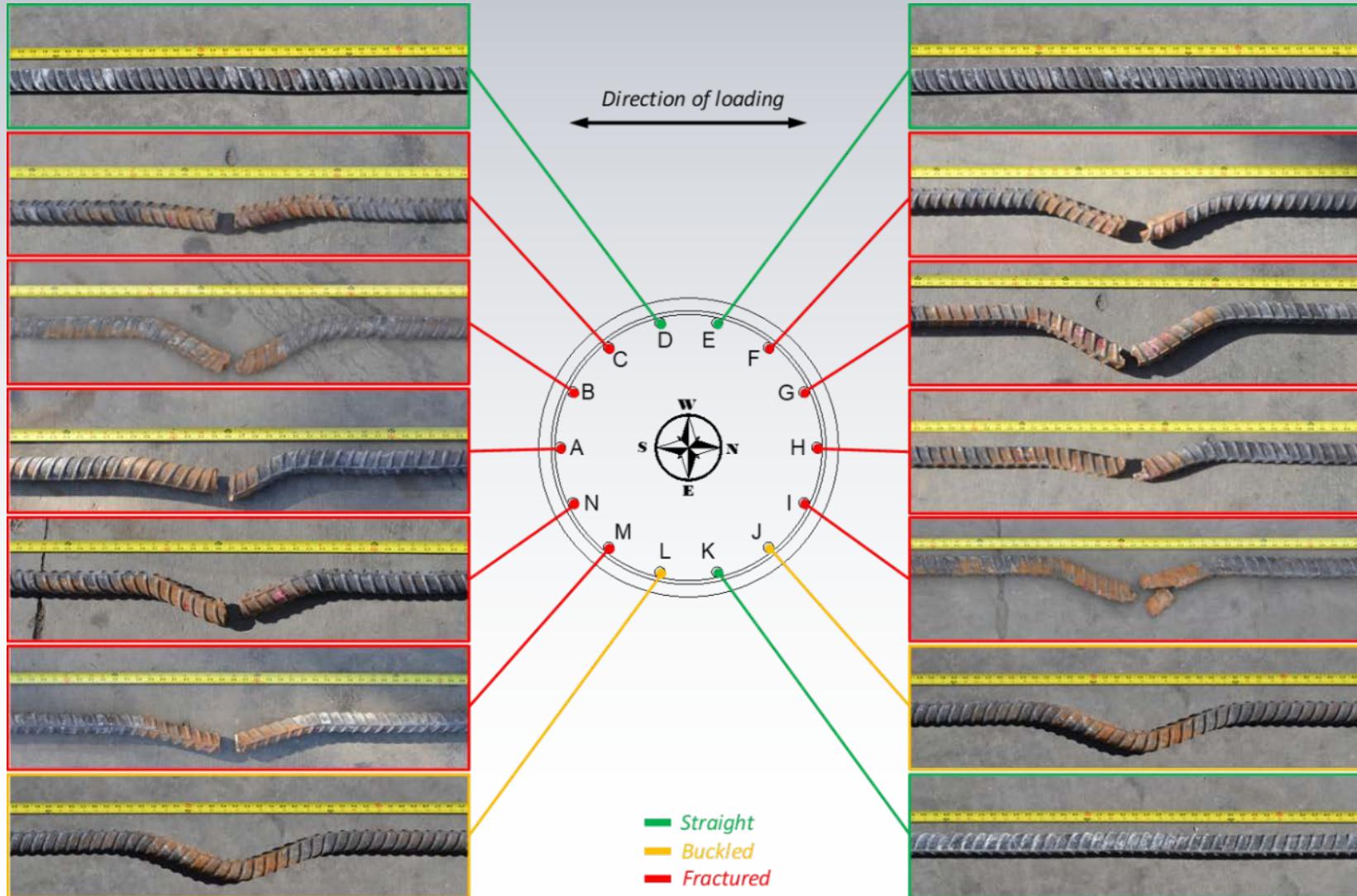
- Reinforced entirely with ASTM A706 Grade 80 bars
- Observe behavior of Grade 80 large-diameter bars in PH region and noncontact splice
- Validate the replacement of A706 Grade 60 bars in columns extending into Type II shafts



Testing Procedure:



Buckled and Fractured Bars:



Extent of Damage Post-Test:



Recent Experiments

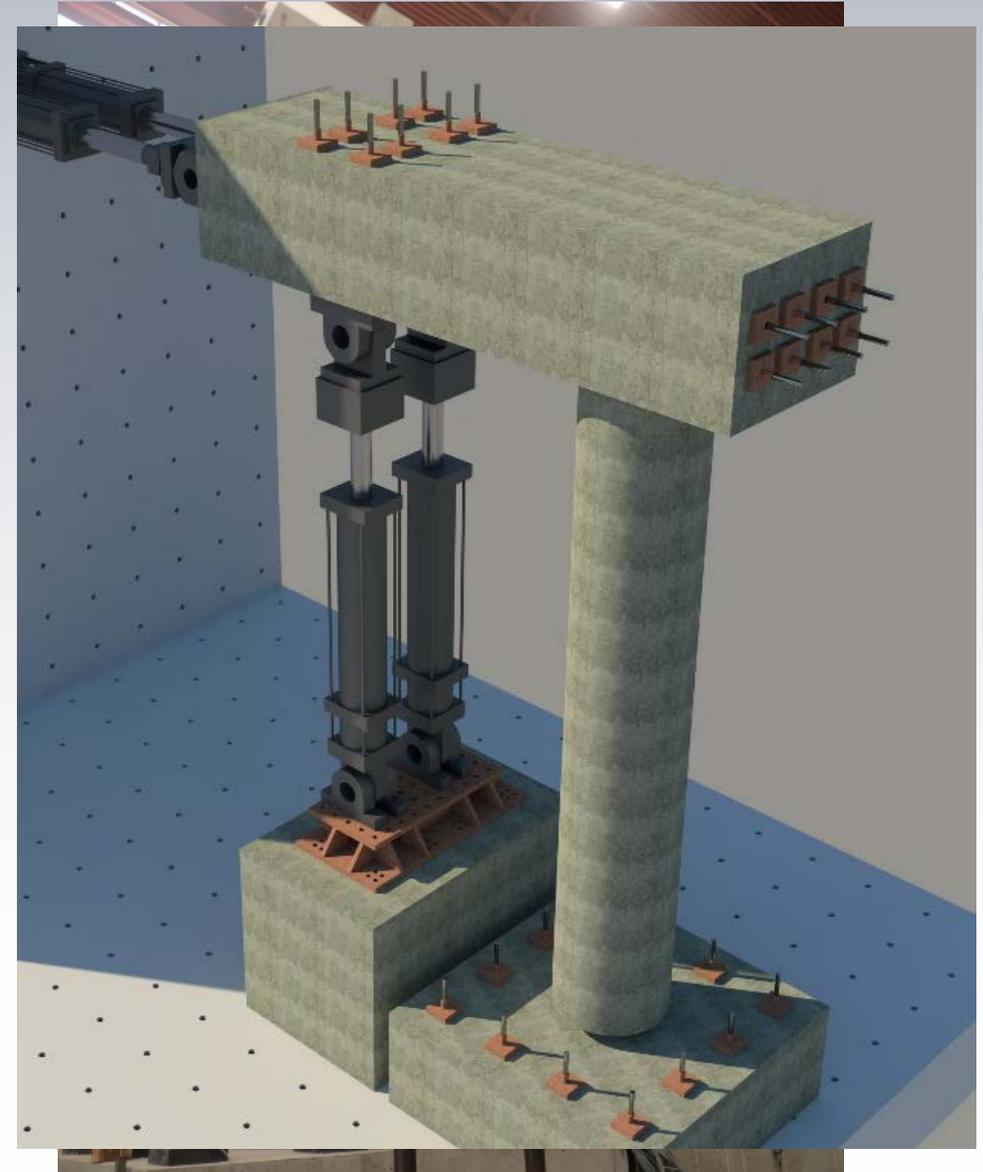
1. Bar Development and Bond Slip Tests
2. Column Extending Into Type II Shaft
- 3. Exterior Column of Multi-Column Bridge Bent**
4. Plastic Buckling-Straightening Fatigue of Grade 80 Reinforcement

3. $\frac{3}{4}$ -Scale Column-Bent Cap Connection:

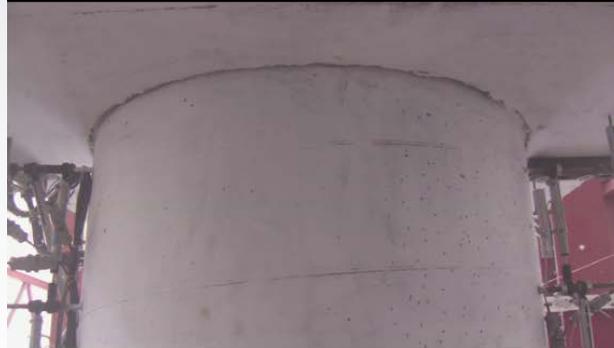
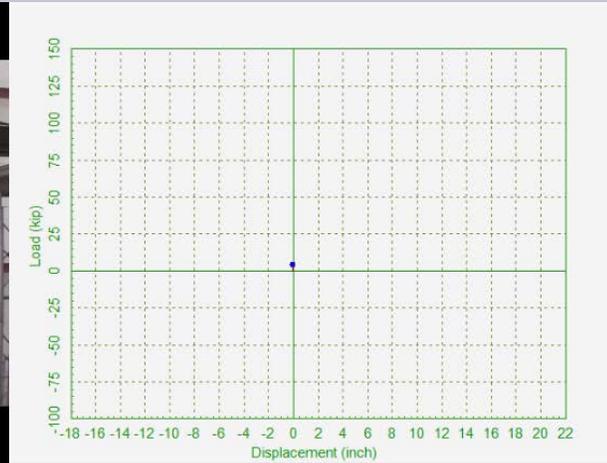
- Test model based on existing bridge in California (Massachusetts Ave Overcrossing)



- Reinforced entirely with ASTM A706 Grade 80 bars
- Observe behavior of Grade 80 bars in the bent cap connection joint
- Validate the replacement of A706 Grade 60 bars in bridge column-bent cap connections

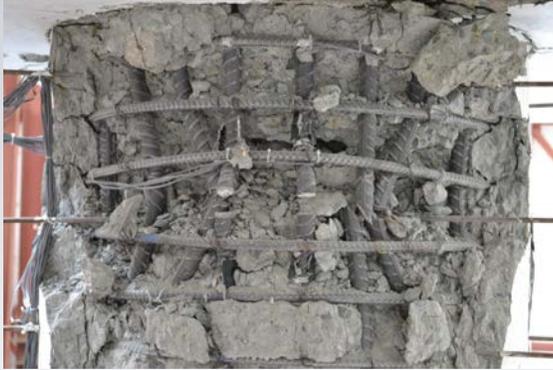


Testing Procedure:



Extent of Damage Post-Test:

Interior face plastic hinge region



Exterior face plastic hinge region



Recent Experiments

1. Bar Development and Bond Slip Tests
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4. Plastic Buckling-Straightening Fatigue of Grade 80 Reinforcement:

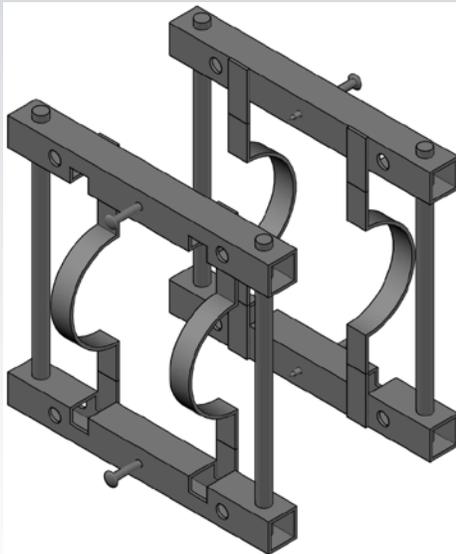
- Modify and use test apparatus by Duck et al. (2018)
- Conduct a series of buckling tests on ASTM A706 Grade 80 #14 bars
- Repeat tests for smoothed-rib-radii Grade 80 #14 bars
- Determine sensitivity of these bars to large strain amplitude cycles



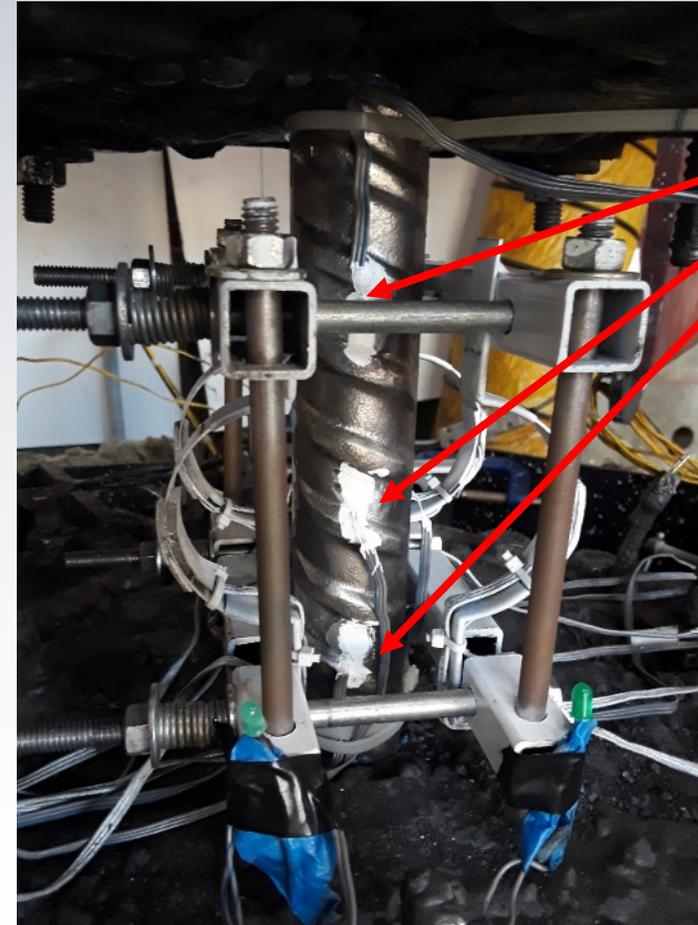
Photo Source: Duck (2018)

Instrumentation:

- Clip gage designed by Duck and Carreño (2018) used to measure smeared strains along buckled shape



- Series of strain gages on bar to measure local strains



Strain gages
on test bar

Bar Fracture Surface:

Normal A706 Grade 80 #14



Smoothed-rib-radii Grade 80 #14

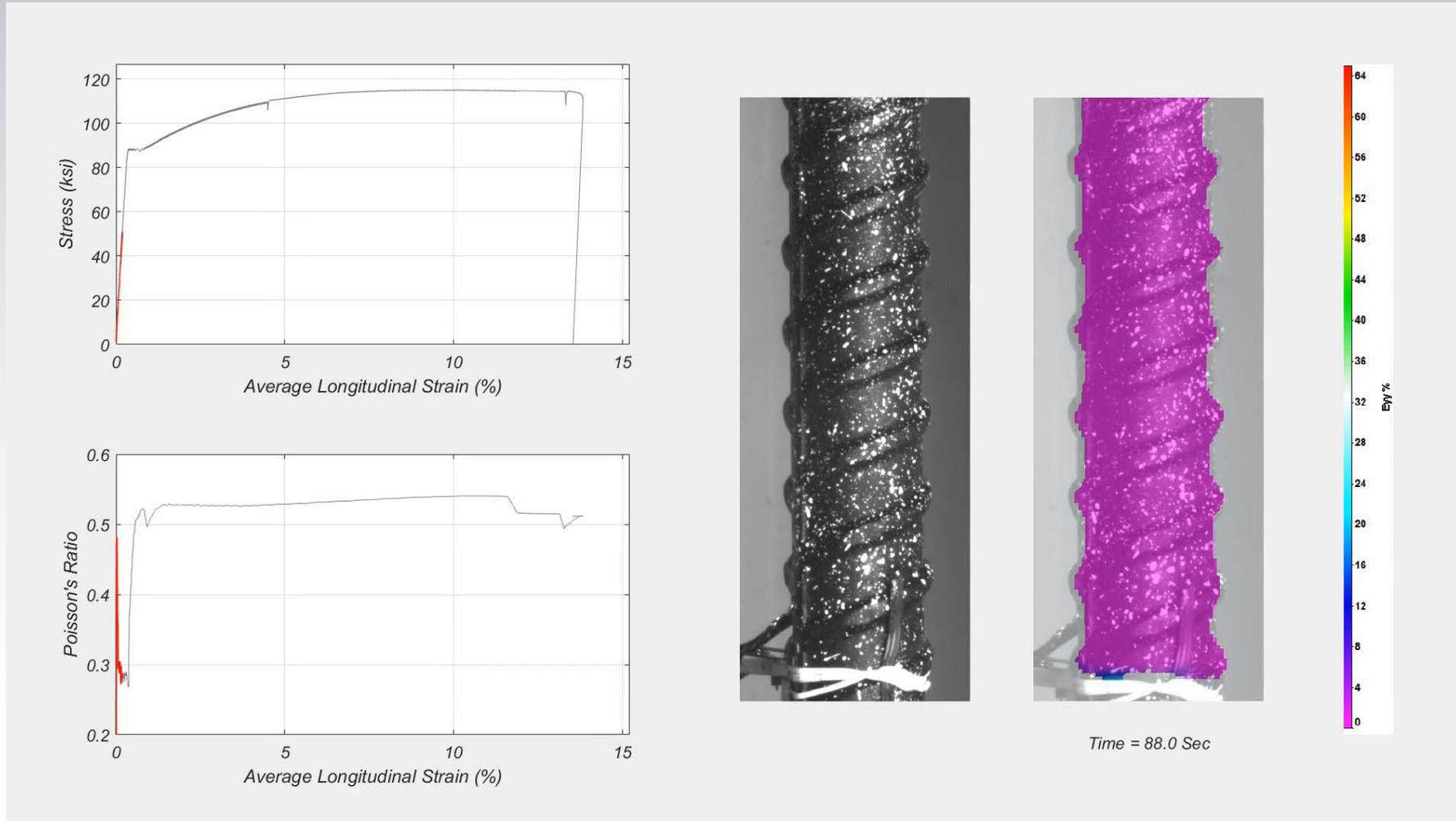


3D Point cloud model (smoothed-rib-radii)



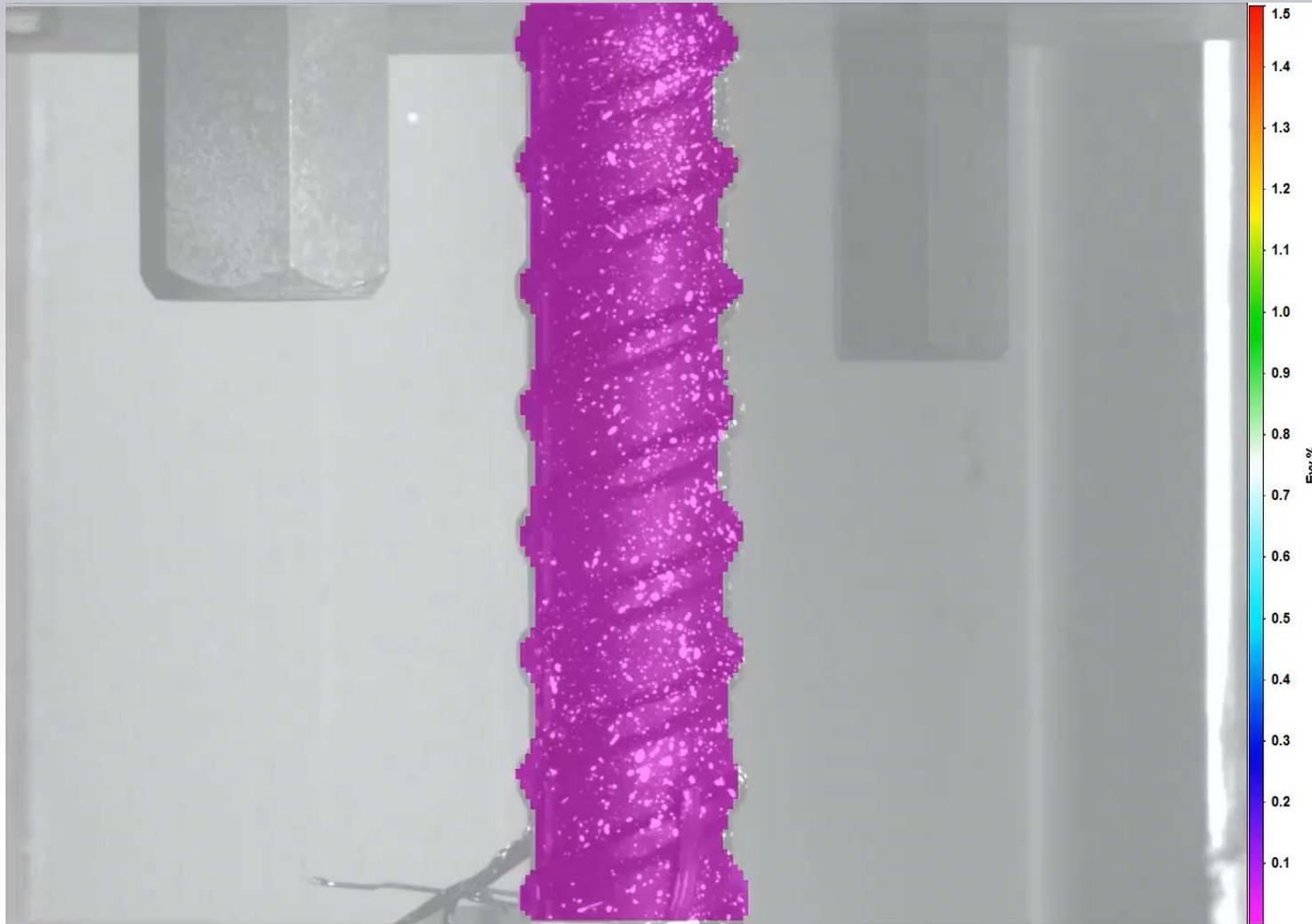
Available Technologies

1. DIC Applications in Tensile Testing:



Tensile test of ASTM A706 Grade 80 #14 bar:

1. DIC Applications in Tensile Testing:



Lüders bands in ASTM A706 Grade 80 #14 bar:

2. Use of Global Navigation Satellite System (GNSS) in Structural Engineering at UC San Diego and SIO

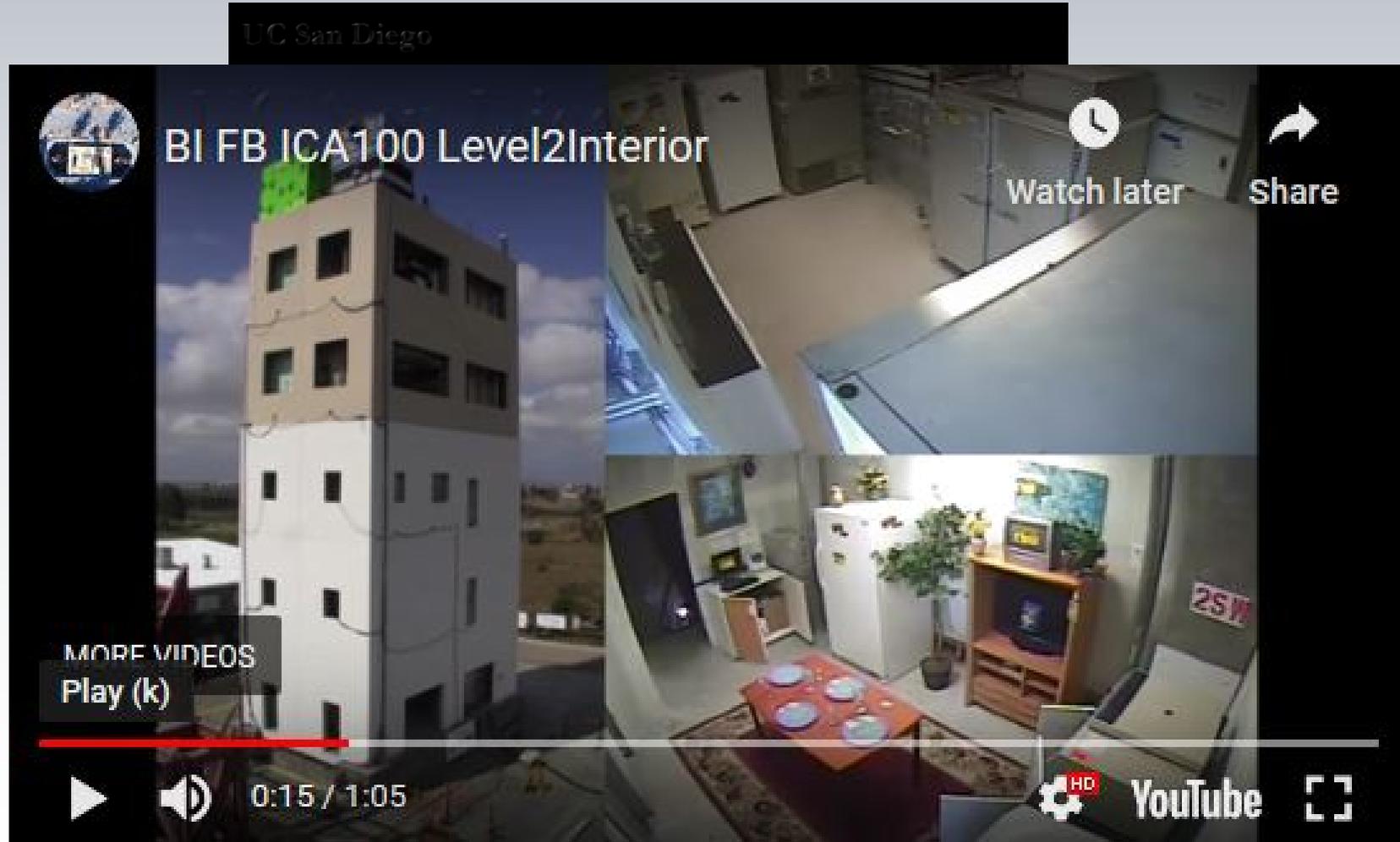
- GNSS provides mm-level precision measurements of dynamic and permanent displacements in three dimensions, as well as orientation with clusters of antennas
- High-rate (10-50 Hz.) GNSS instruments have been deployed as part of a series of LHPOST experiments and on the iconic UC San Diego Geisel Library
- Combining GNSS with accelerometers provides the full spectrum of displacement from the high-frequencies to the DC offset
- GNSS has been used to precisely geo-reference UAV and LiDAR measurements for creating digital surrogate models for structural health monitoring

LHPOST GPS Monitoring

2006–2007 full-scale seven-story reinforced concrete wall building
Prof. Jose Restrepo, PI



2012 Full-Scale Structural and Nonstructural Building System Performance during Earthquakes & Post-Earthquake Fire



UC San Diego

BI FB ICA100 Level2Interior

Watch later

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MORE VIDEOS
Play (k)

0:15 / 1:05

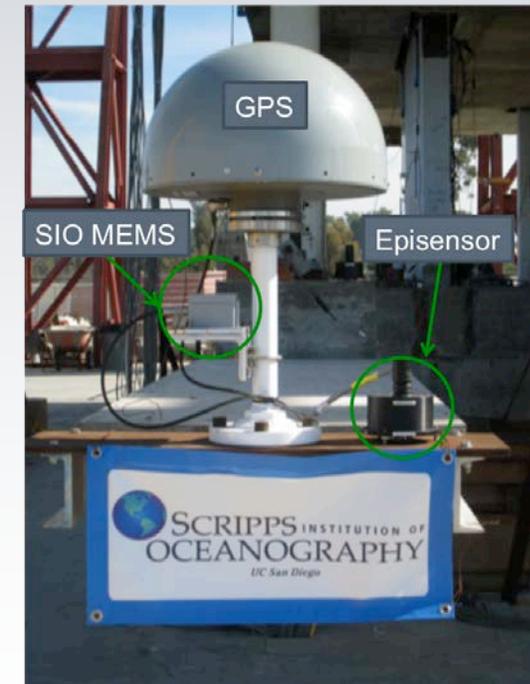
HD

YouTube

Foundation Displacements

Courtesy Dr. Yehuda Bock (2020)

2013 partially precast-concrete four-story structure constructed at half scale. Prof. Robert Fleischman, PI)



2016 Earthquake and Post-Earthquake Fire Performance of Mid-Rise Light-Gauge Cold-Formed Steel Framed Buildings, Prof. Tara Hutchinson PI

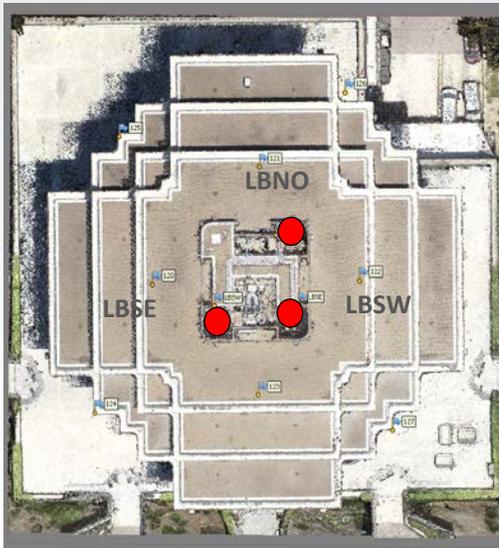
- (Left) 3D geometric model of the test building from UAV imagery including fire damage on the 3rd floor.
- (Right) Camera image of the building after the 1994 Mw6.6 Northridge earthquake simulation, with indication of tilt and residual displacements. The GPS displacements indicated a 1.4% tilt of the structure compounded by a 6% tilt at the 3rd floor after the fire tests.



UC San Diego Geisel Library Project (2017-present)



- Develop a nonlinear finite element model to predict the level of measured response (response thresholds) corresponding to various limit-states (cracking of concrete, crushing of cover concrete, yielding of steel reinforcement bars, etc.).
- Threshold values will be used in the structural health monitoring system by providing metrics for assessing damage based on ongoing observations of the library with GPS instruments on the roof of the structure and accelerometers throughout the structure. (Prof. Michael Todd, PI)



LBRF ●

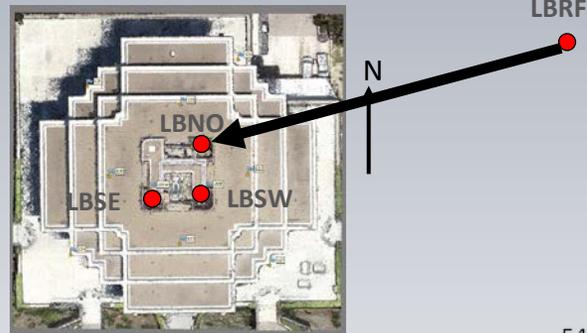


Reference Station

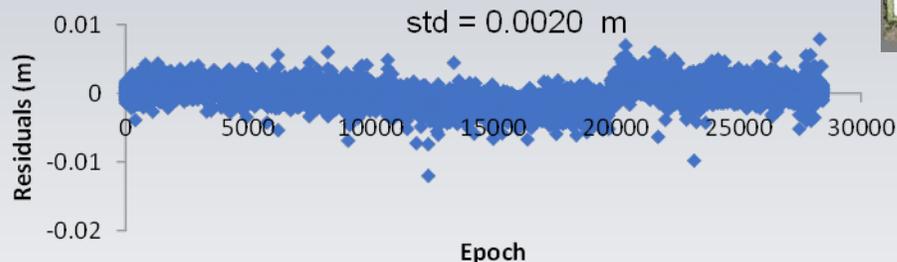


Courtesy Dr. Yehuda Bock (2020)

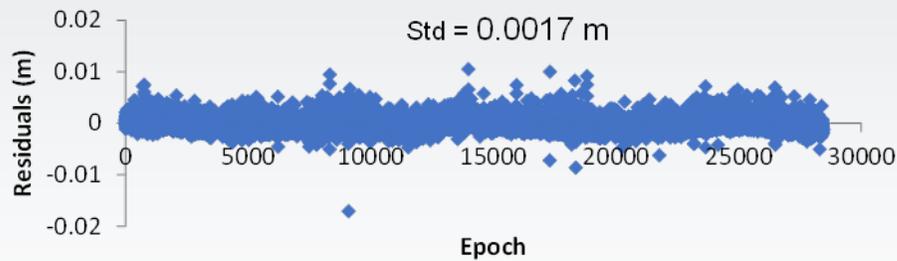
Geisel Library Hourly GPS Monitoring 9/17/2017 to 12/7/2020



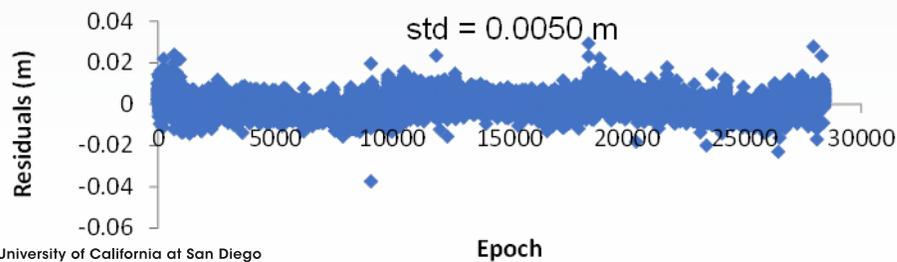
LBNO: North Residuals



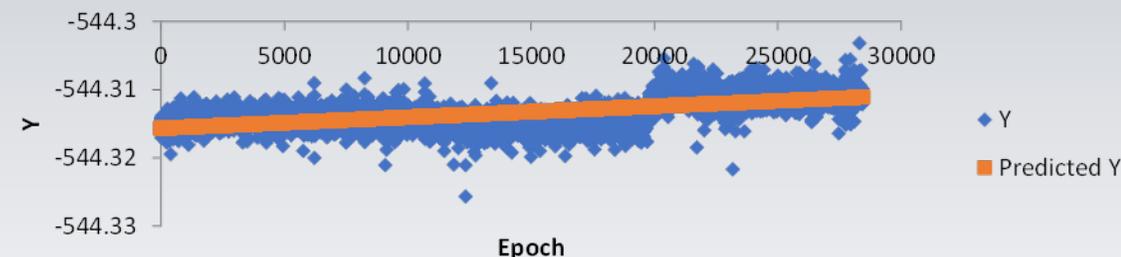
LBNO: East Residuals



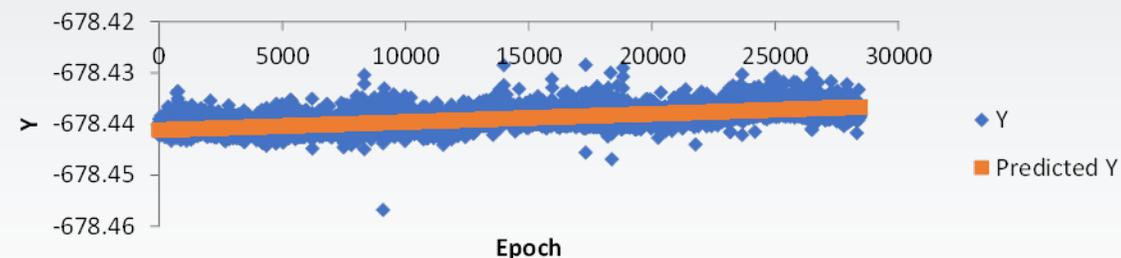
LBNO: Up Residuals



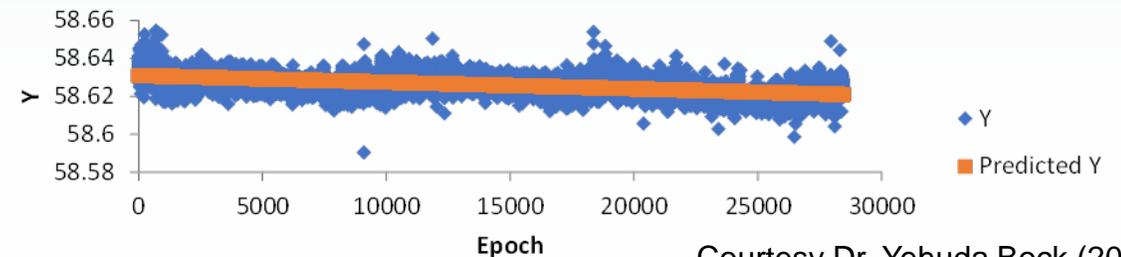
LBNO: North Line Fit



LBNO: East Line Fit



LBNO: Up Line Fit



Courtesy Dr. Yehuda Bock (2020)

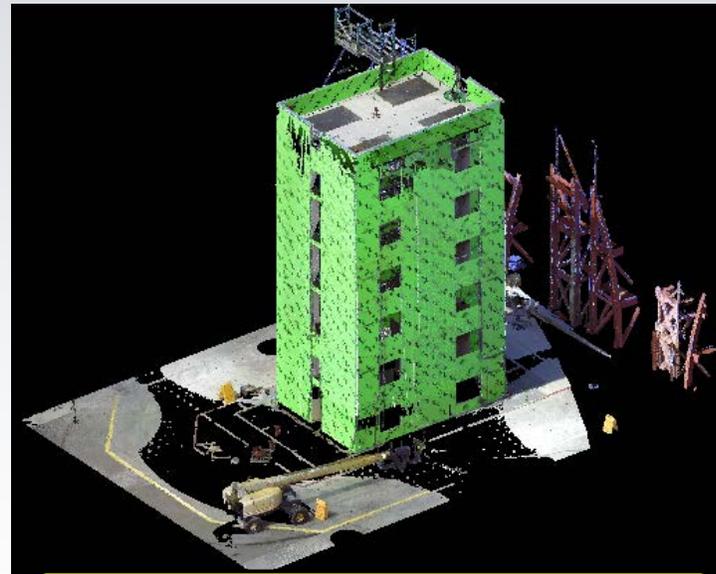
Looking to the future:

- The availability of multiple satellite constellations (U.S. GPS, Russian GLONASS, European Galileo and Chinese Beidou) collectively called Global Navigation Satellite Systems (GNSS) will provide increased sampling rates, more robust measures of displacement and orientation in real time and more precise georeferencing for UAV and lidar imagery
- Integration of GNSS with accelerometers through Kalman filters provides the full spectrum of precise displacement and velocity
- GNSS will provide an integrative tool for structural engineering applications such as structural health monitoring

3. LiDAR Point Cloud Analysis of Full-Scale Building During Earthquake and Fire Tests

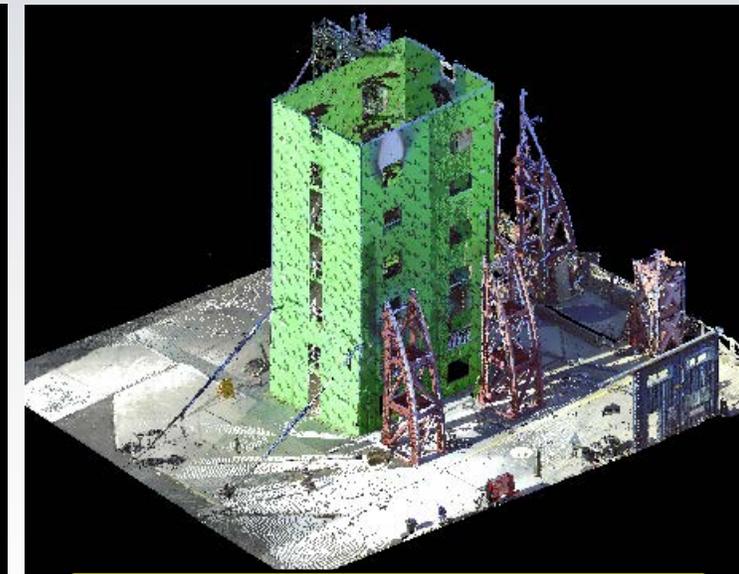
- Extract residual building displacements (baseline vs final)
- Characterize ground truth geo-information (building and test site)
- Fuse SfM-based imagery with LiDAR point clouds

Baseline Model



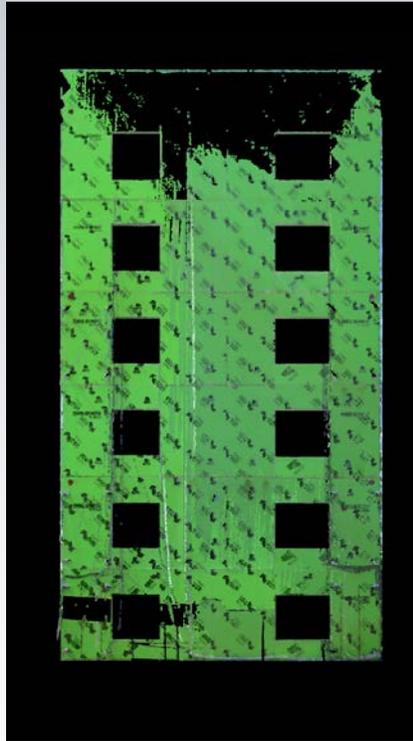
6 exterior scans & 2 roof scans

Final Model



9 exterior scans (no roof scan)

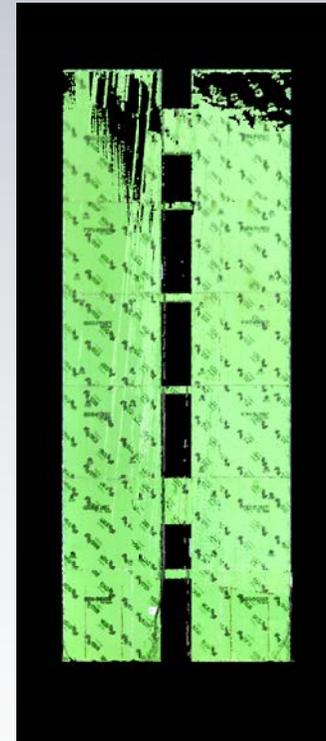
Elevation (Baseline)



South
1.2 M points



North
1.8 M points



West
0.8 M points



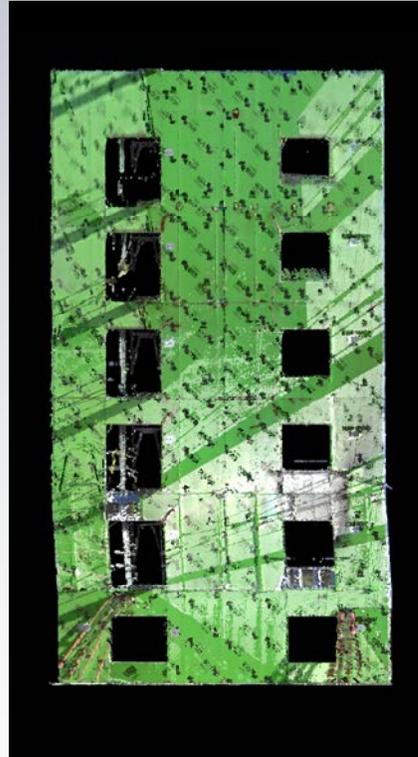
East
1.3 M points

Missing Points at the Top due to High Level of Reflection

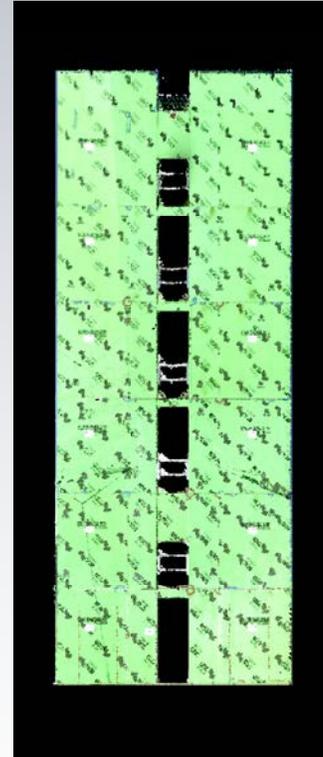
Elevation (Final)



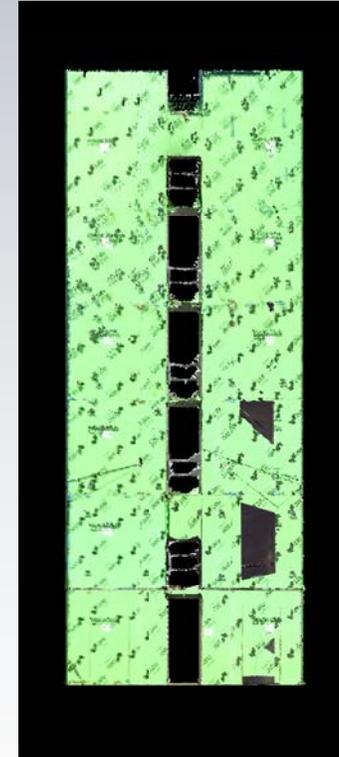
*South
4.5 M points*



*North
4.5 M points*

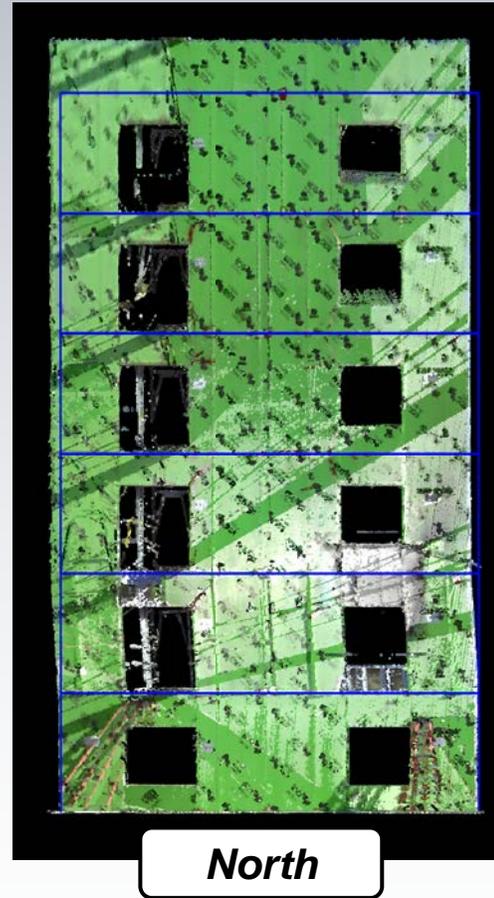
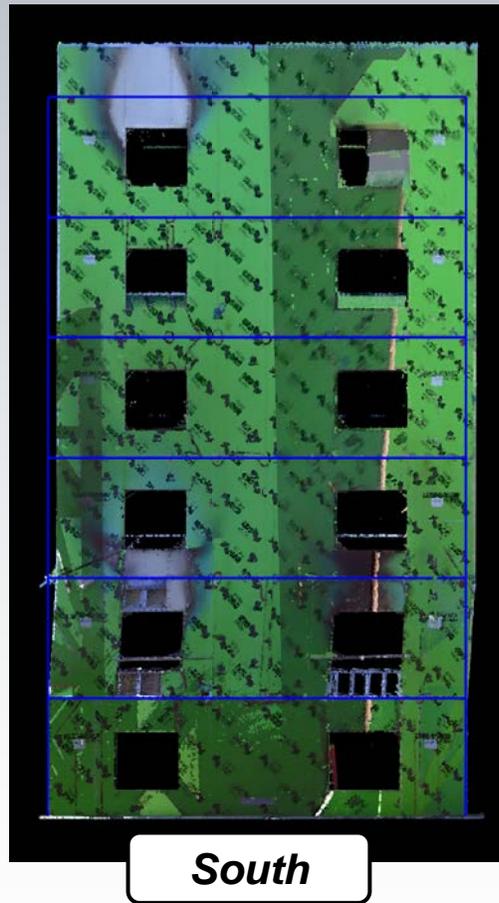


*West
4.4 M points*

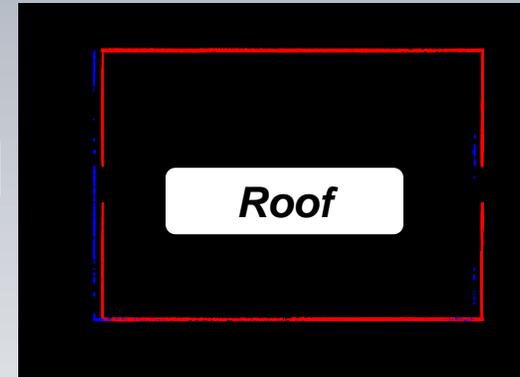


*East
6.1 M points*

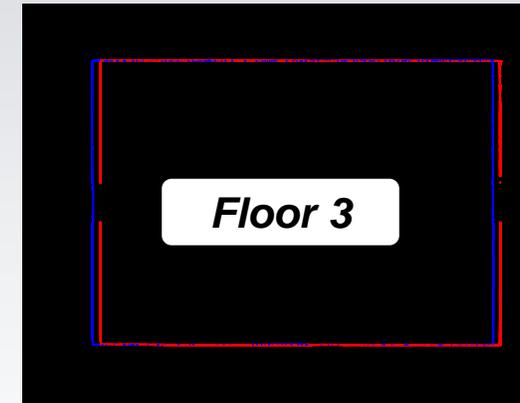
Much denser points (3~4 times)



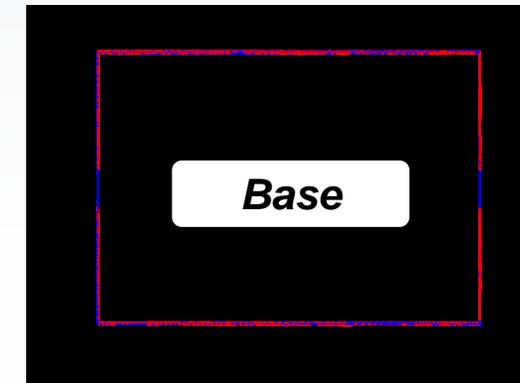
Roof



FL3

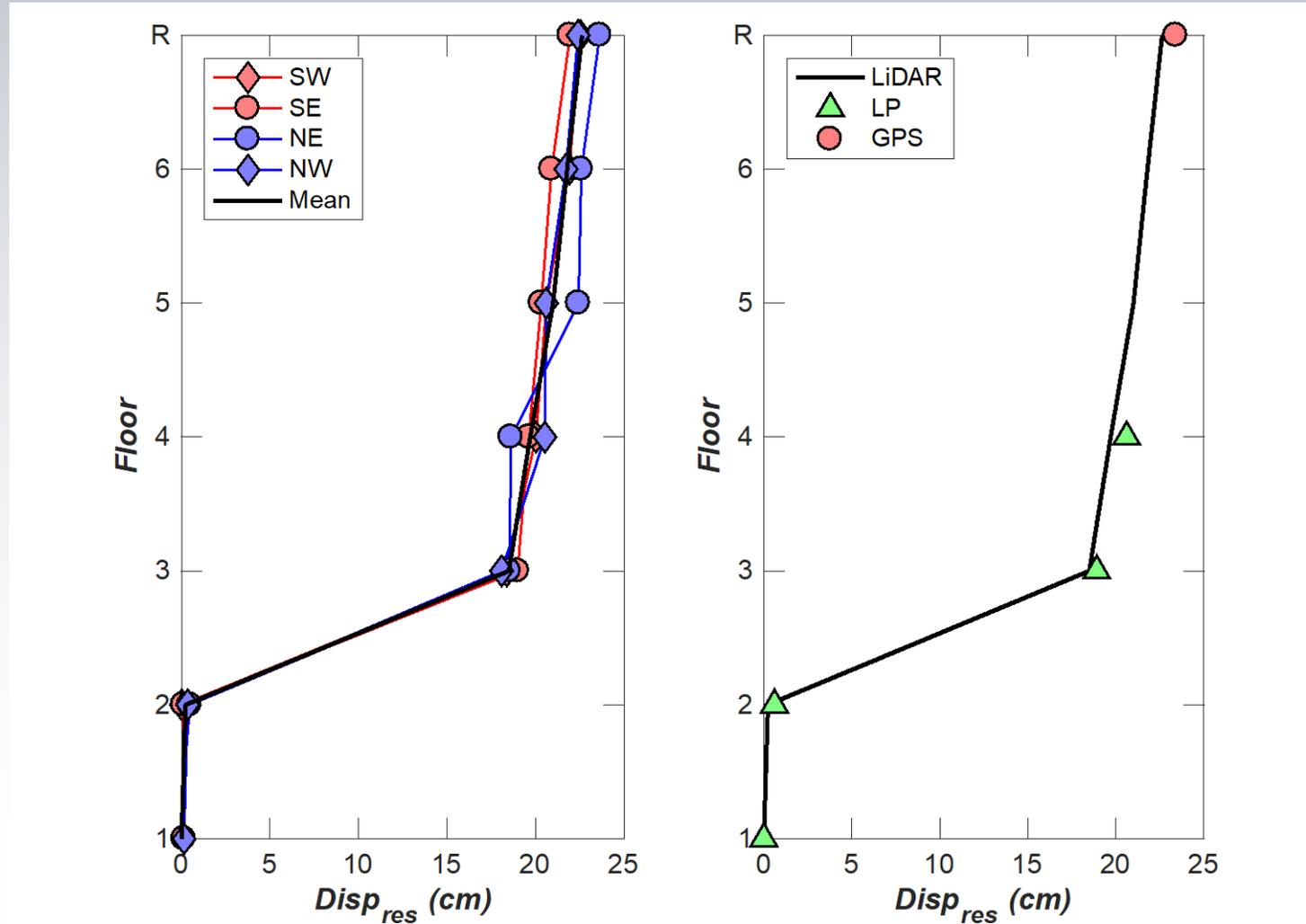


Base



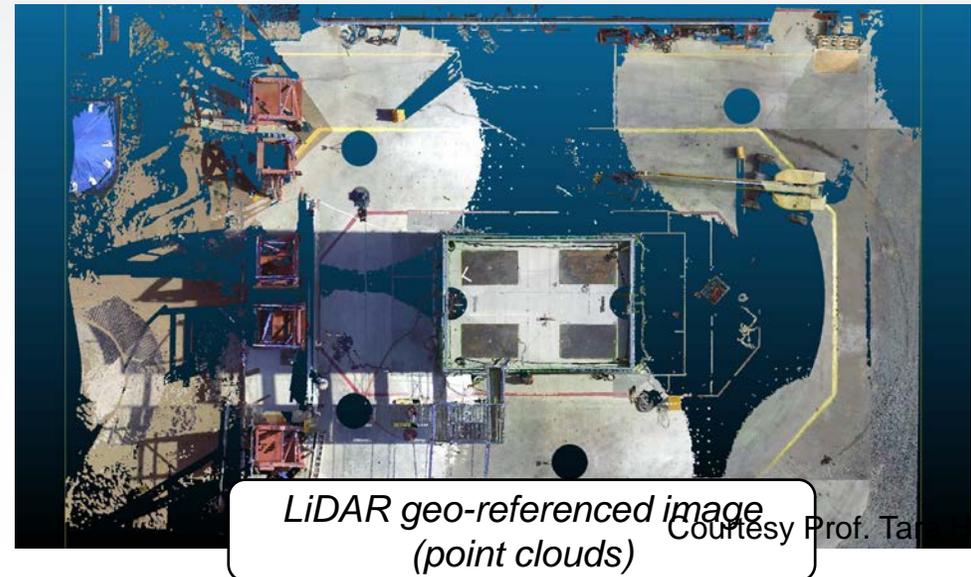
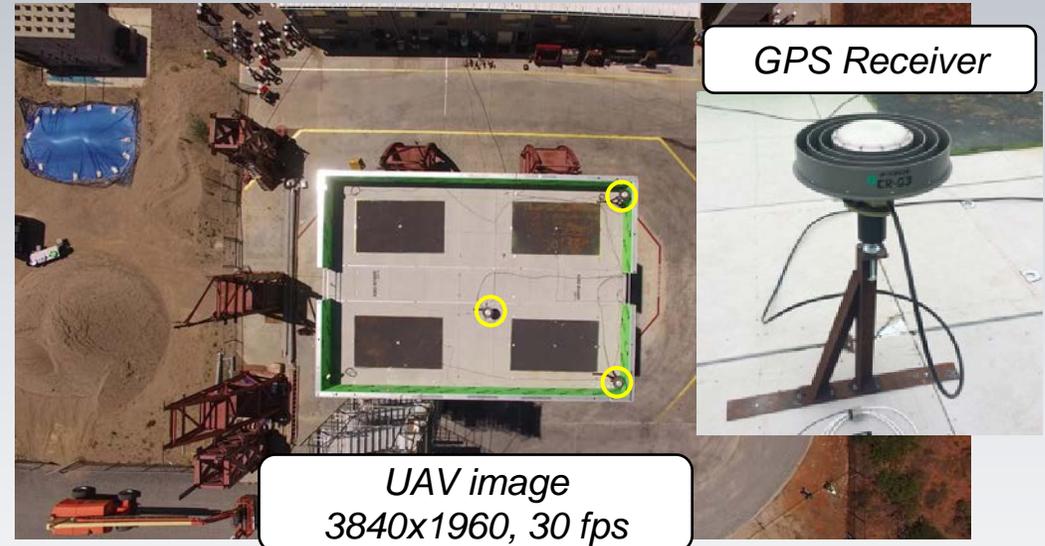
Base of building considered as fixed for model alignment

Validation of Residual Drifts

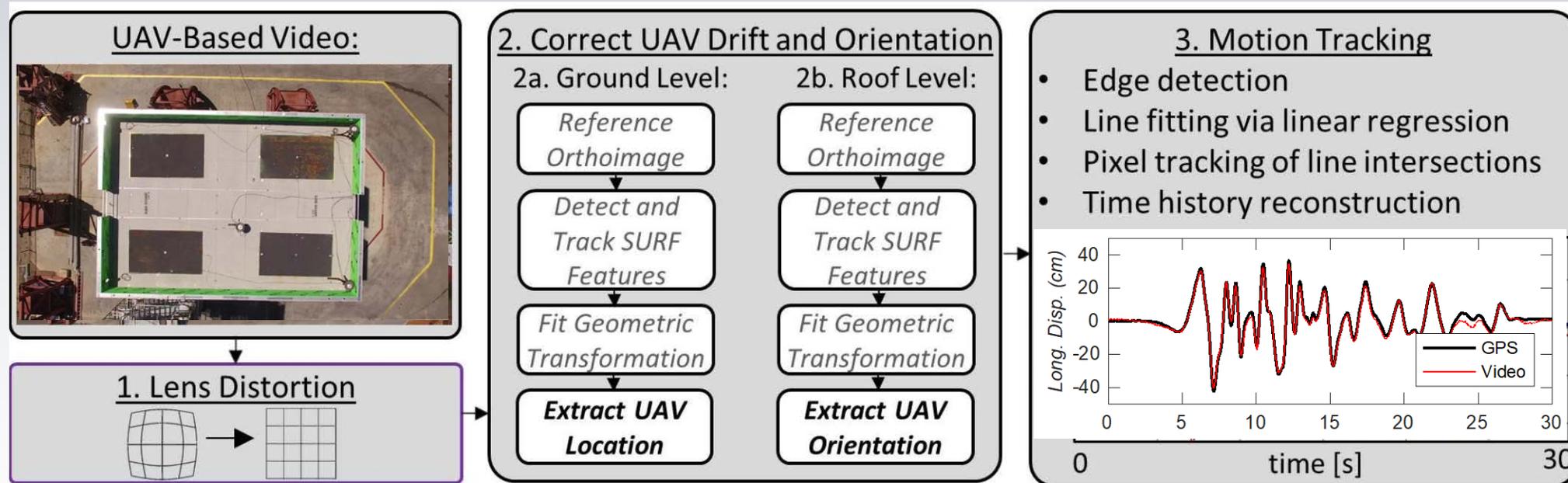


4. UAV-Based Motion Tracking of Full-Scale Building During Earthquake Shaking

- Responses of interest:
 - Absolute translational and rotational displacement histories of building roof
- Assumptions:
 - Roof moves as rigid body (no differential deformation)
 - Negligible vertical displacement of the roof (no overturning rotations)
- Available data:
 - Roof displacements measured by GPS (for validation)
 - Video footage from top taken by drones
 - LiDAR point cloud data of site and building (geo-referenced image)



Motion Tracking Methodology



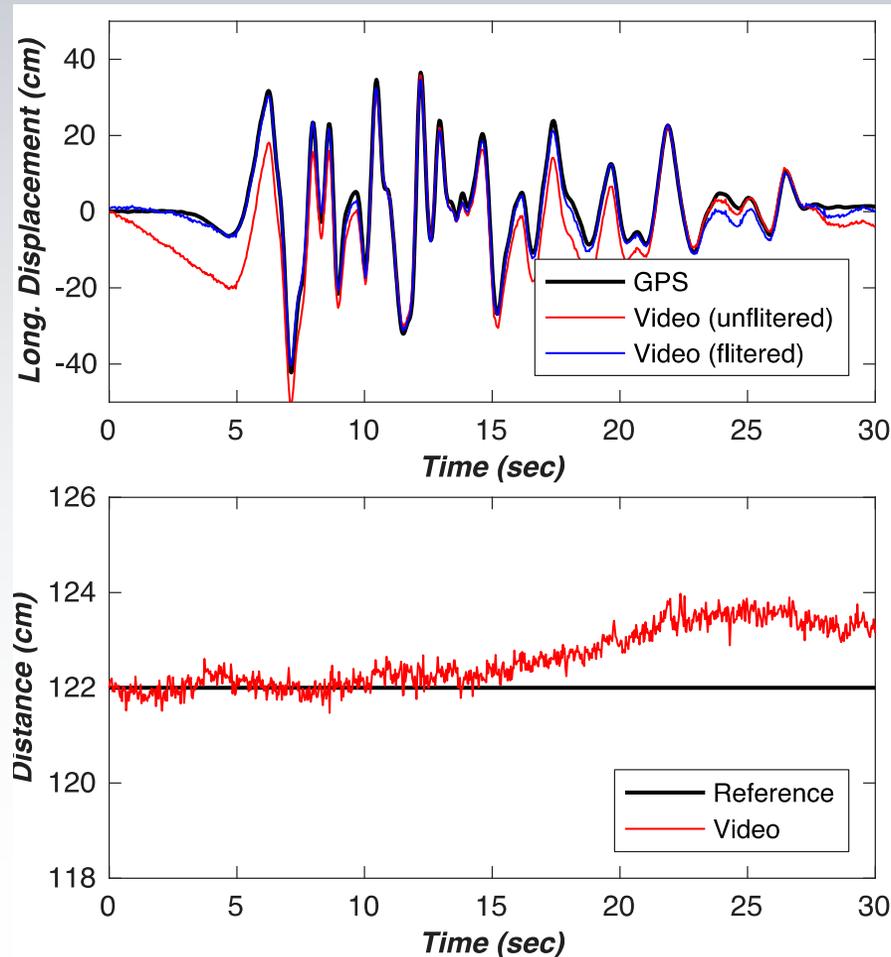
Result Validation – EQ7

**Reference Frame (Green) vs. Subsequent Frames (Magenta)
False Color Overlay**

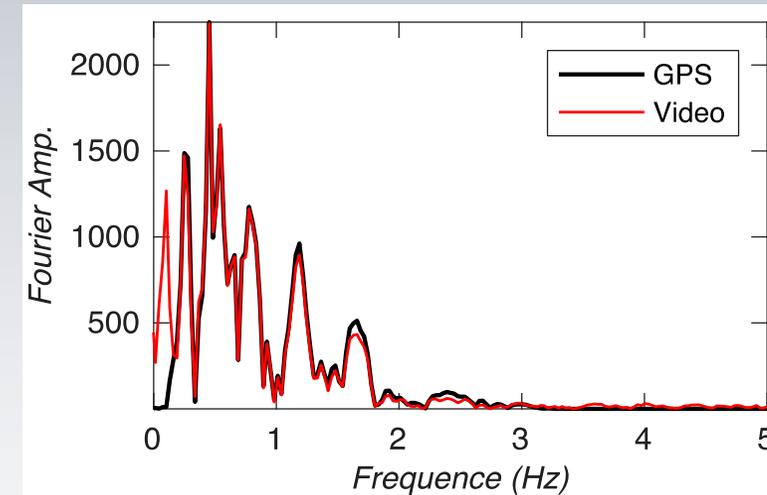


Result Validation – EQ7

Time histories



Fourier Amplitude

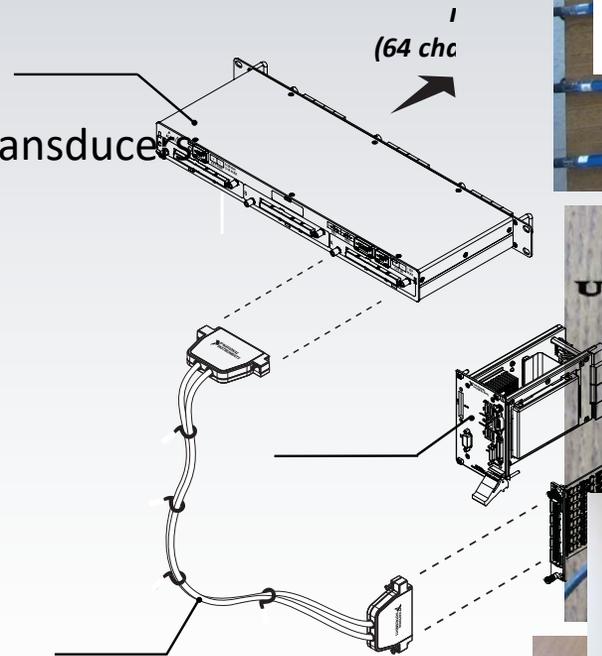


Remarks

- Video-based displacement involves accumulating static drift (red) that is significantly improved with the use of a high-pass filter (blue).
- Distance between the detected intersections nearly constant (difference < 2%)

Equipment and Sensors Presently Available at LHPOST6

- Data Acquisition System:
 - 12 DAQ “Nodes”
 - 64 channels in each node
 - 25 kS/sec, 24-bit, simultaneous sampling per channel
- Instrumentation:
 - 205 MEMS-Based Accelerometers
 - 142 Linear Displacement Transducers
 - 119 String Potentiometer Displacement Transducers
 - 4 Load Jacks
 - 31 Load Cells
 - 32 Soil Pressure Transducers
- GPS System:
 - 3 Receivers Operating at 50 Hz
 - RTD_NET Software by Geodetics
- Cameras:
 - Drones (DJI Phantom 4 Pro)
 - GoPro Cameras (4K and 1080p)
 - End-to-end Live Video Streaming Production System



Thank You