Use of NHERI Facility to Understand the Behavior of Seismic Collectors in Steel Building Structures

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Multi-University Research Project

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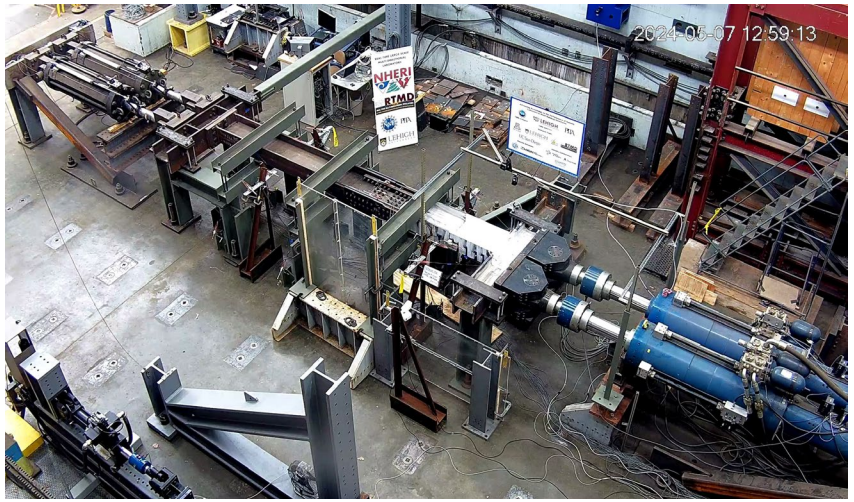
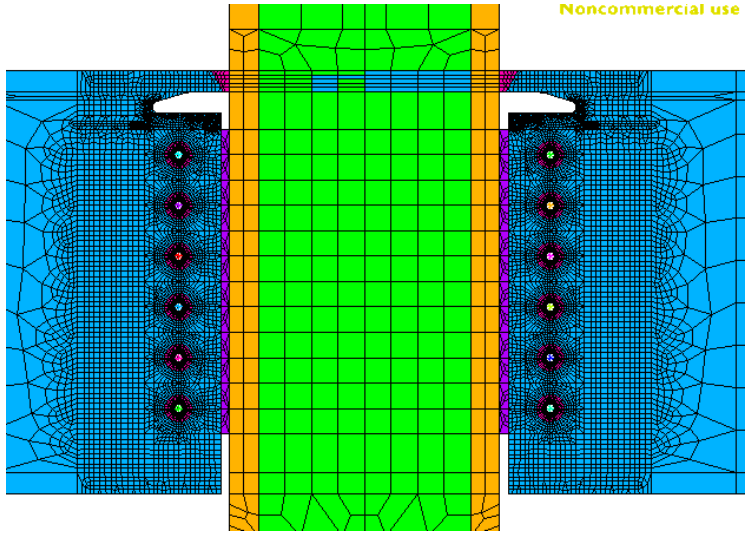
Multi-University Research Project

LEHIGH UNIVERSITY

ARIZONA

UC San Diego





Acknowledgment

Industry Partners

Professional Collaborators

James O. Malley,
Senior Principal

Rafael Sabelli, S.E.

Chris Tokas
Roy Lobo
Ali Sumer

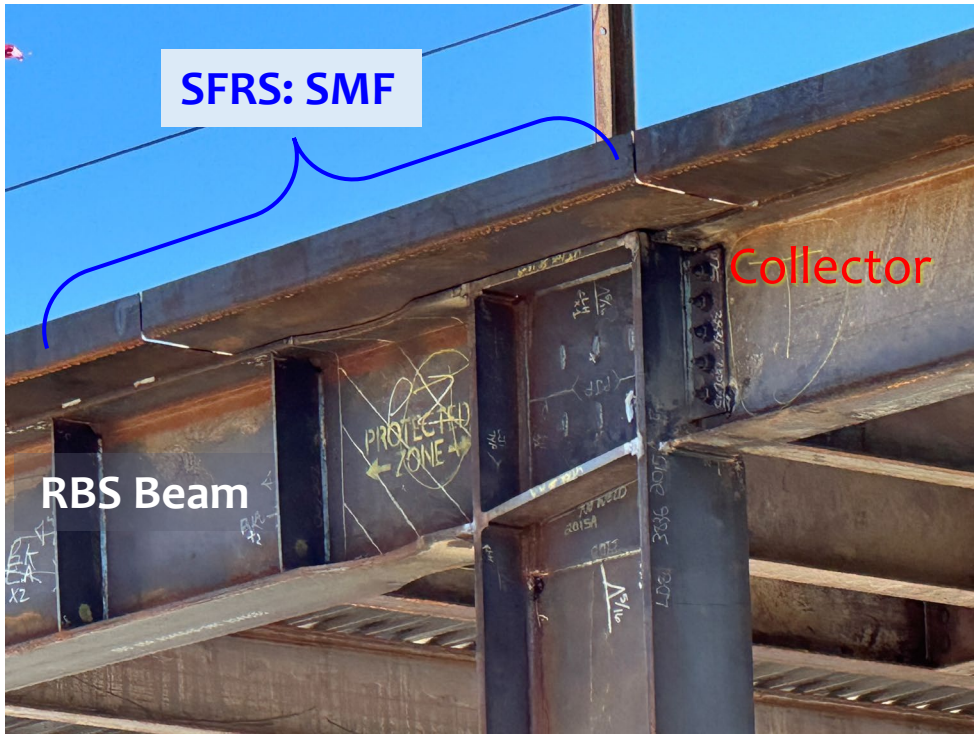
Collectors

In past research most of the focus is on the Vertical elements of the SFRS

Research on collectors is limited so far. Associated code clauses and deign guidelines are very few.

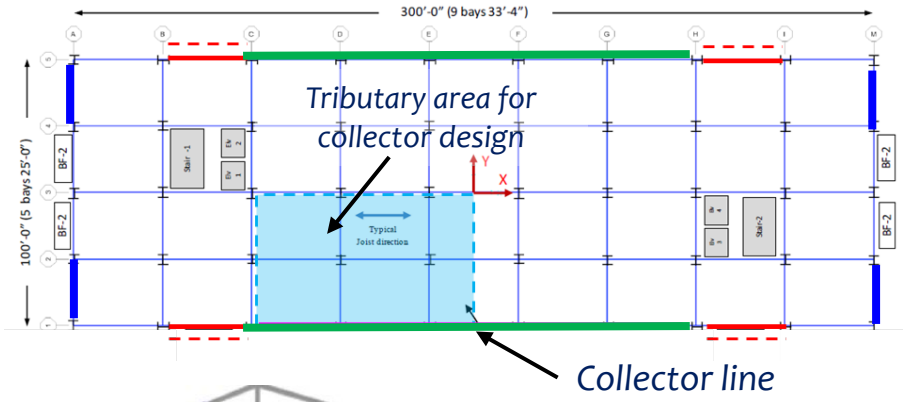
SFRS: SCBF
(Specially Concentrically Braced Frame)

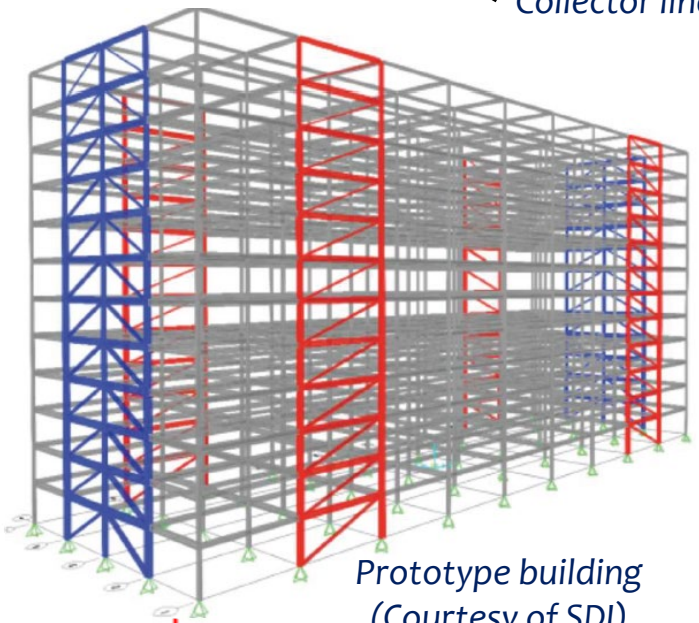
SFRS: SMF
(Special Moment Frame)



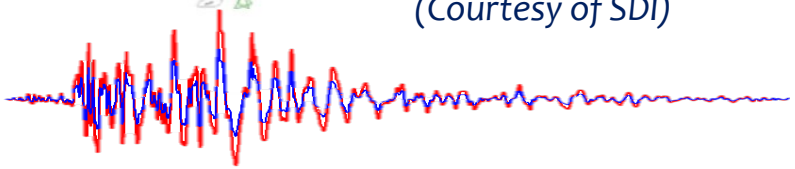
Collector at the SFRS

Background: Inertial Force Transfer Mechanism



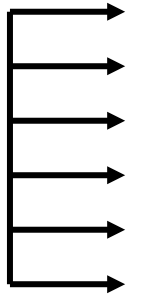


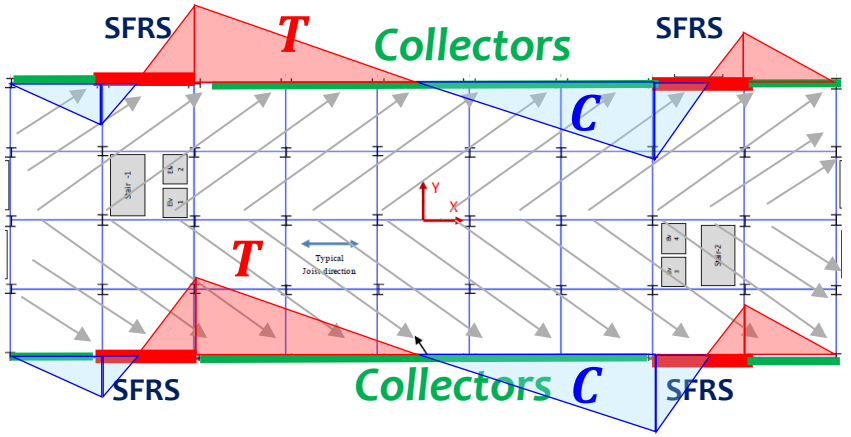
Prototype building (Courtesy of SDI)

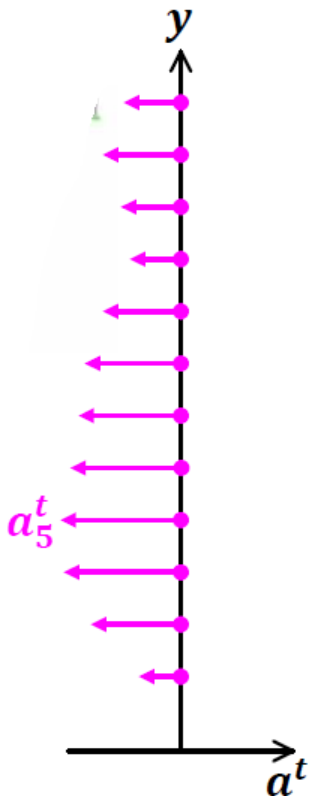


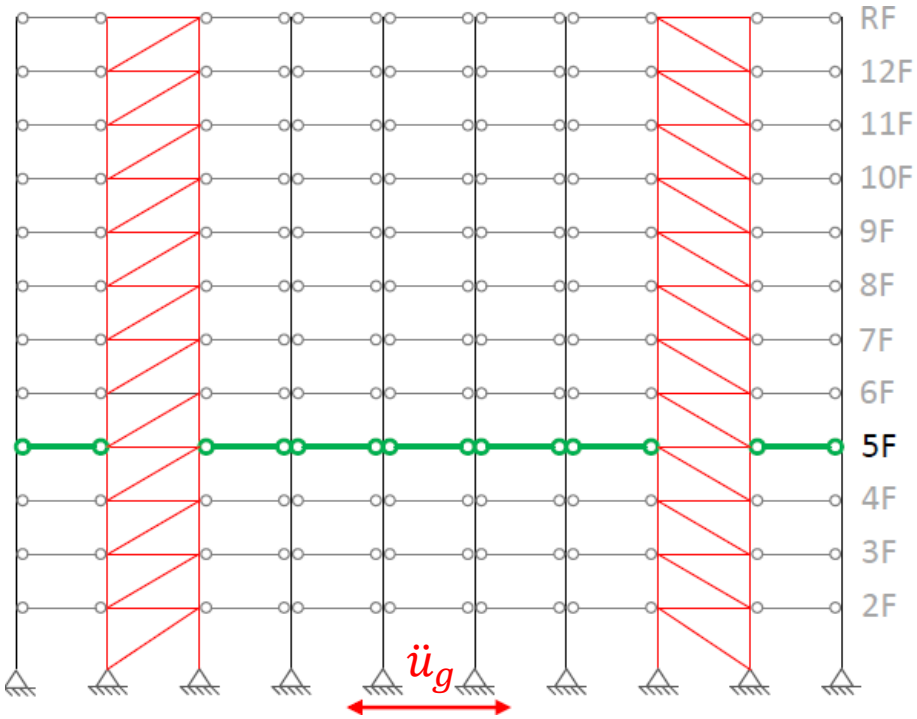
Earthquake ground motion

$$F_{i5} = -M_5 a_5^t$$

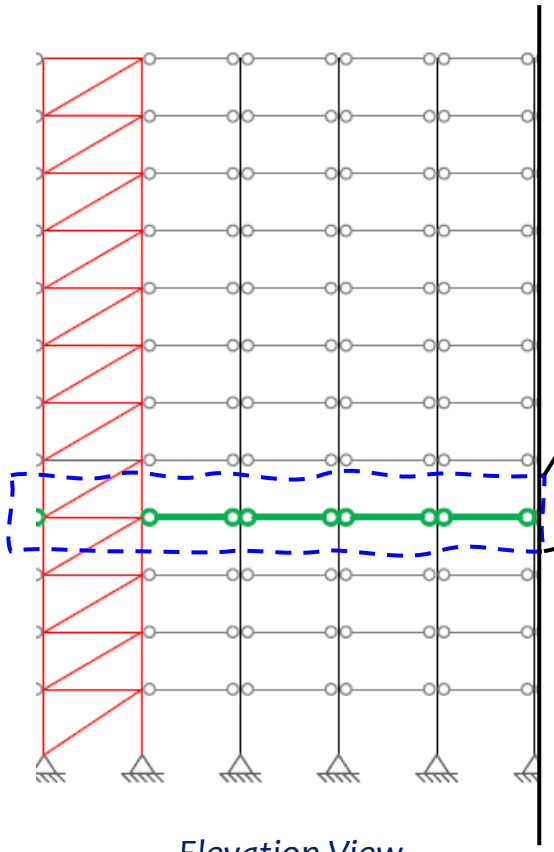






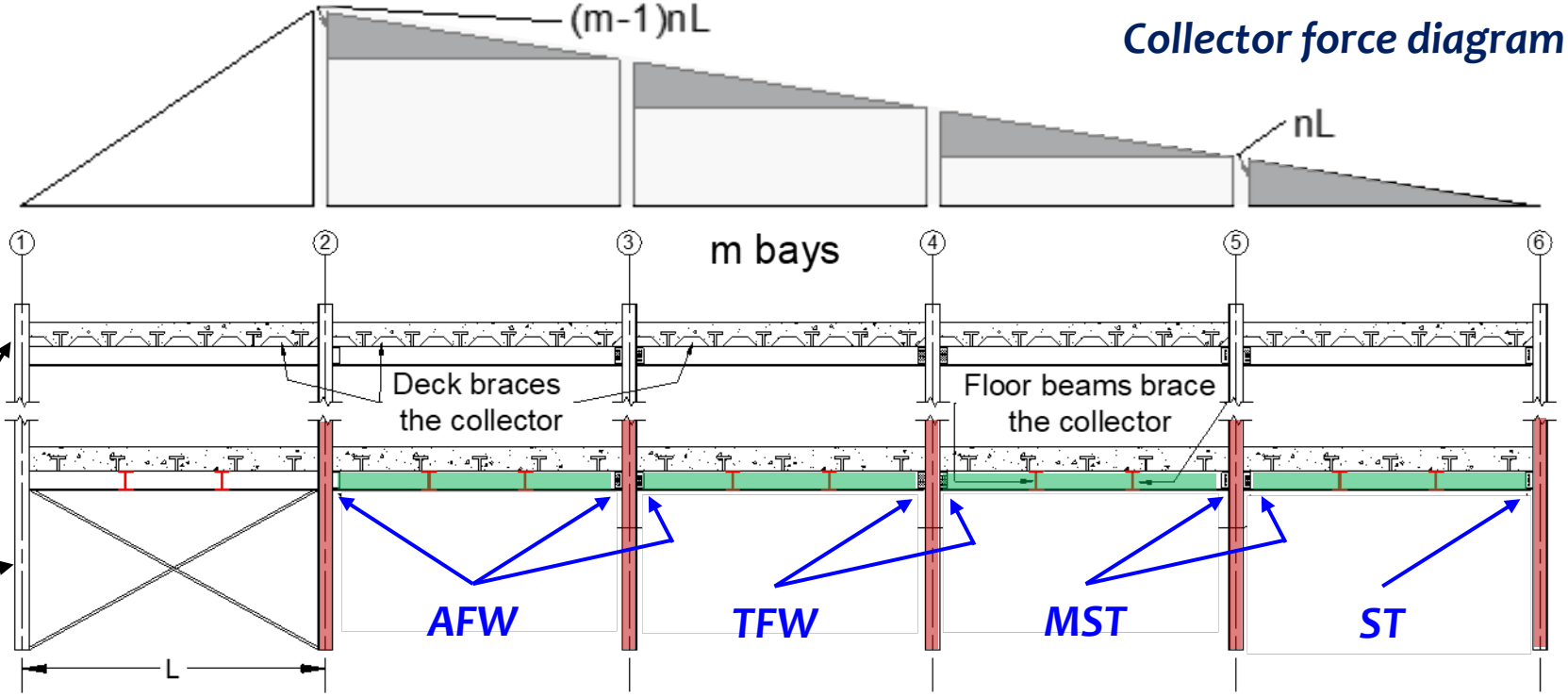


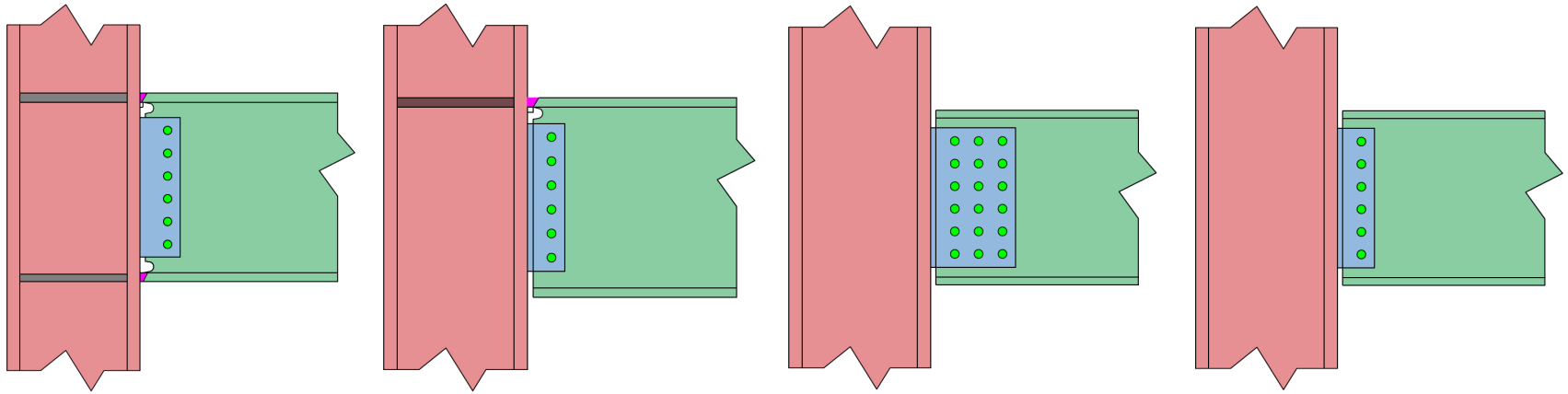
Collector Connection



Elevation View

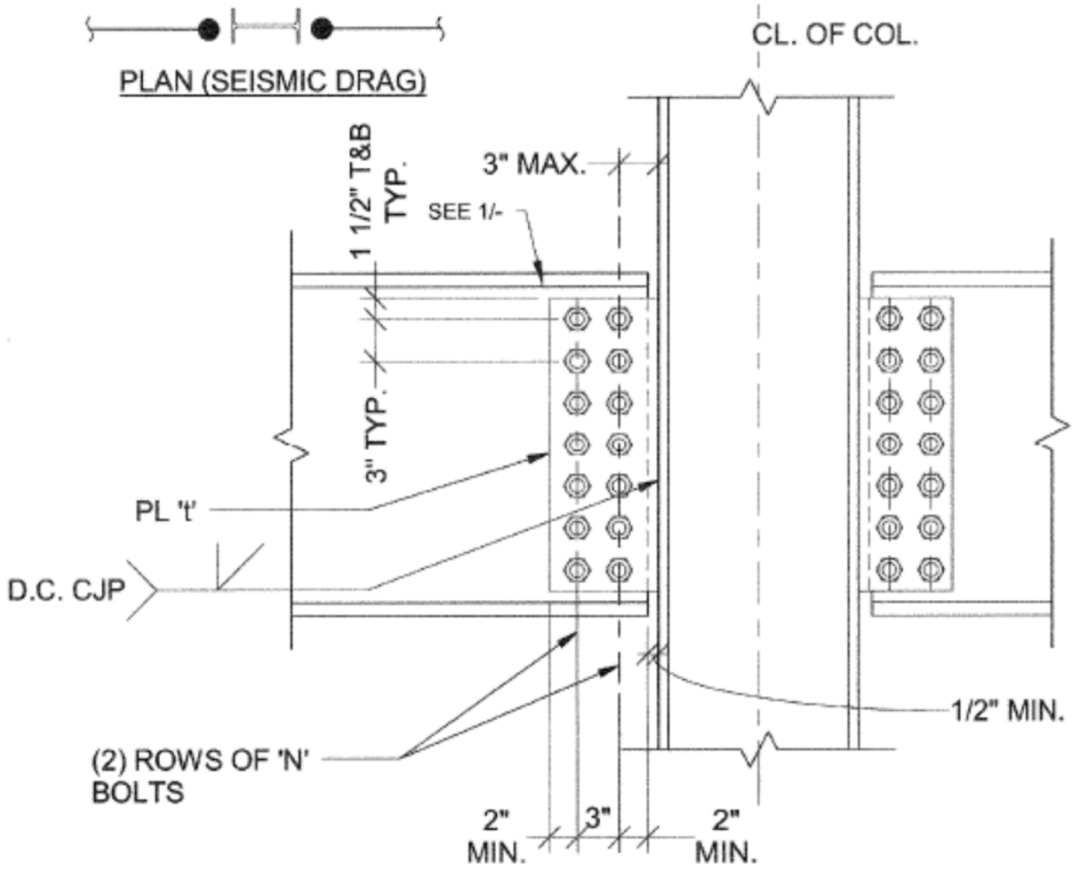
Collector force diagram





Collector Connection

Multiple Bolt Row Shear Tab (MST) Connection

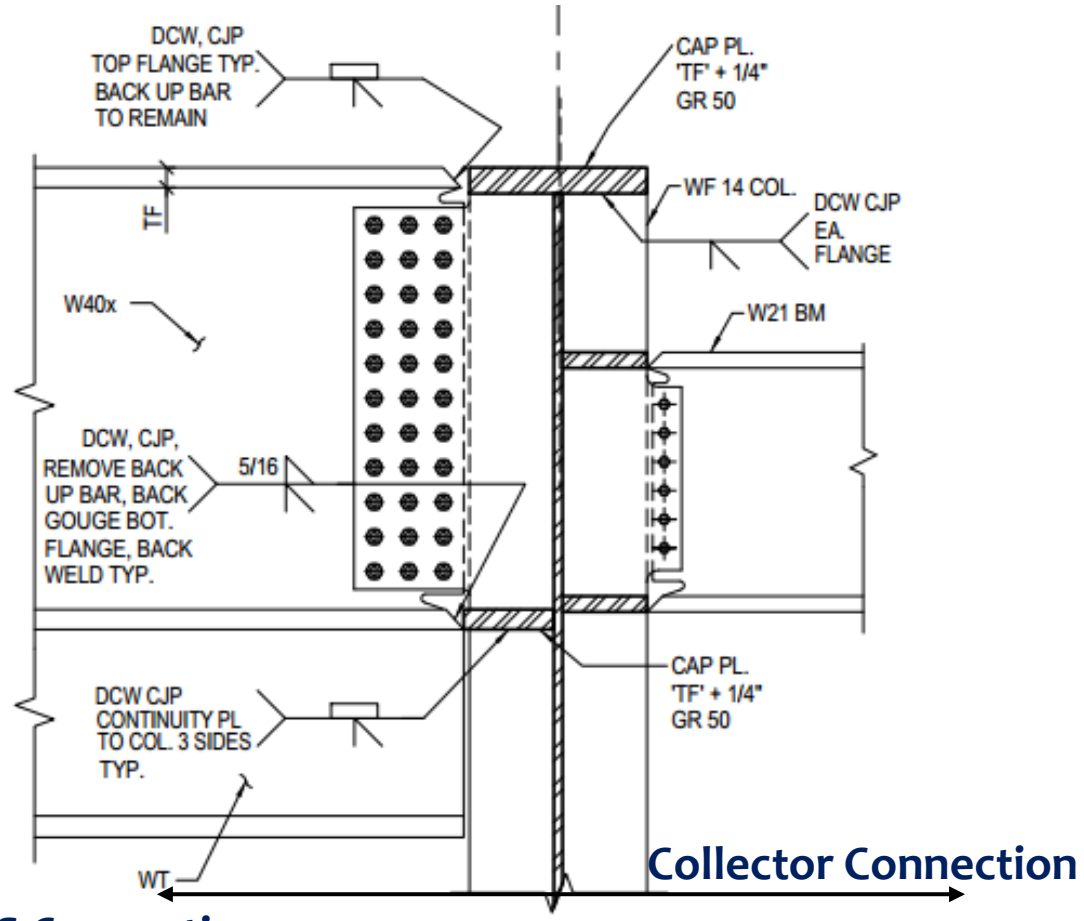


(Courtesy of Herrick)

(Courtesy of Chao-Hsien Li)

Collector Connection

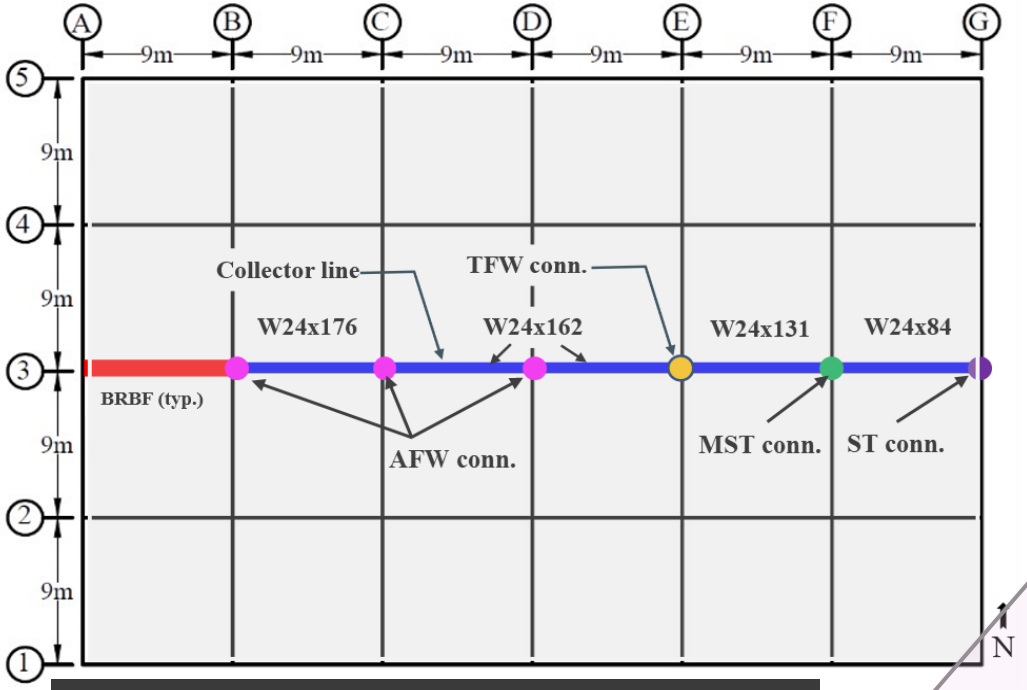
All Flange Welded (AFW) Connection



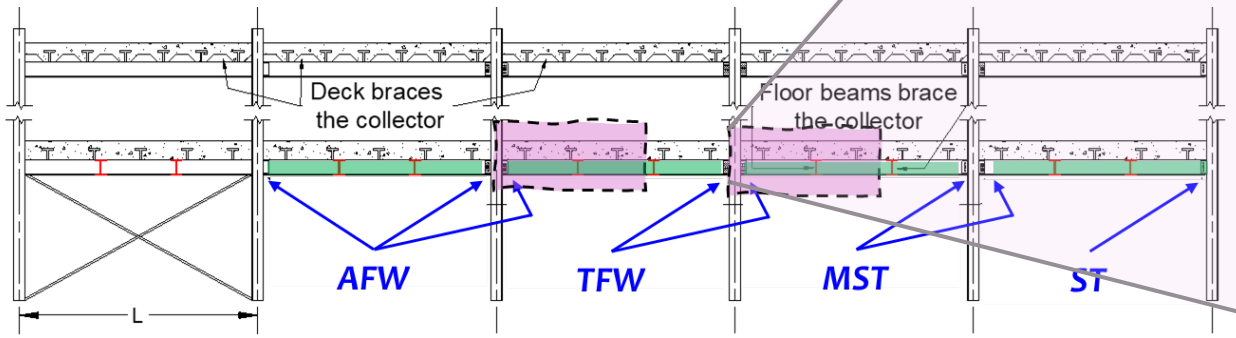
(Courtesy of Dr. Fleischman)

All flange welded (AFW) Connection

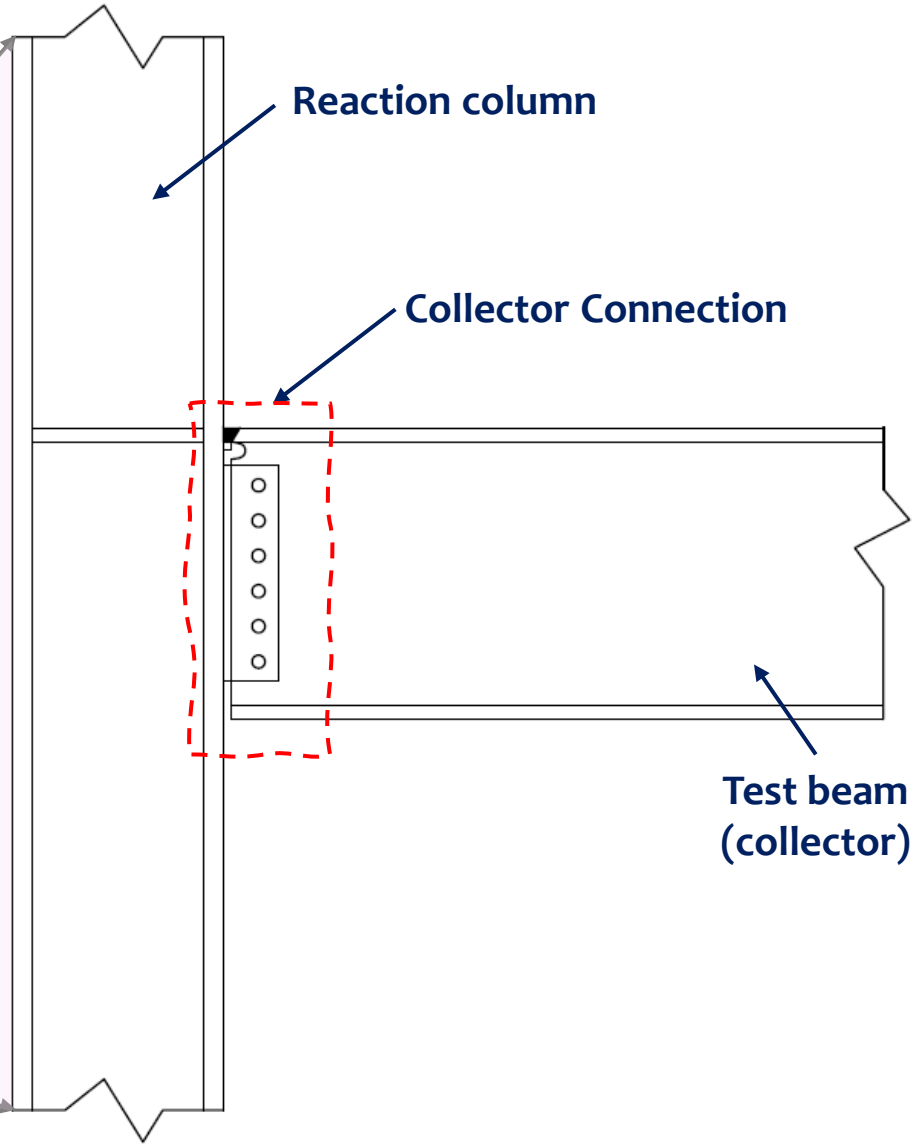
Prototype Structure



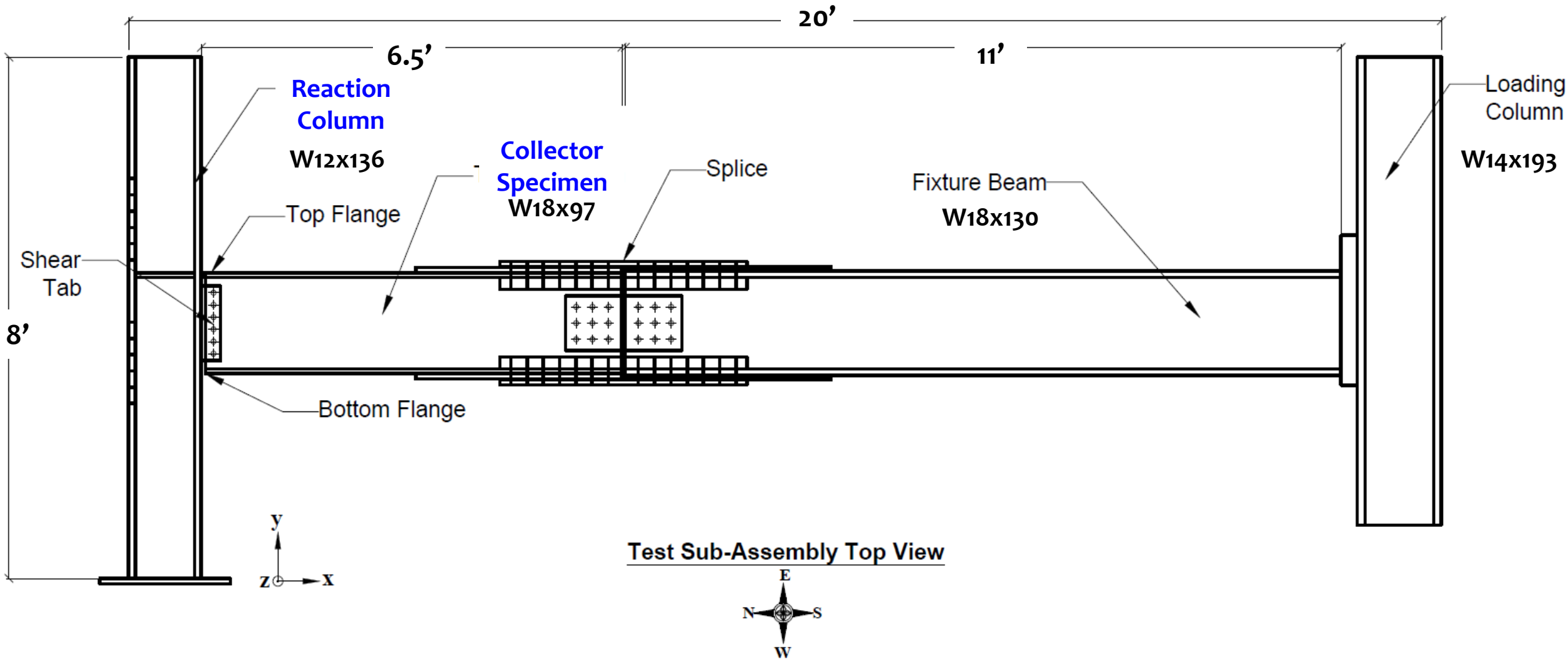
Plan (only showing quarter area, tributary to a collector line)



Elevation

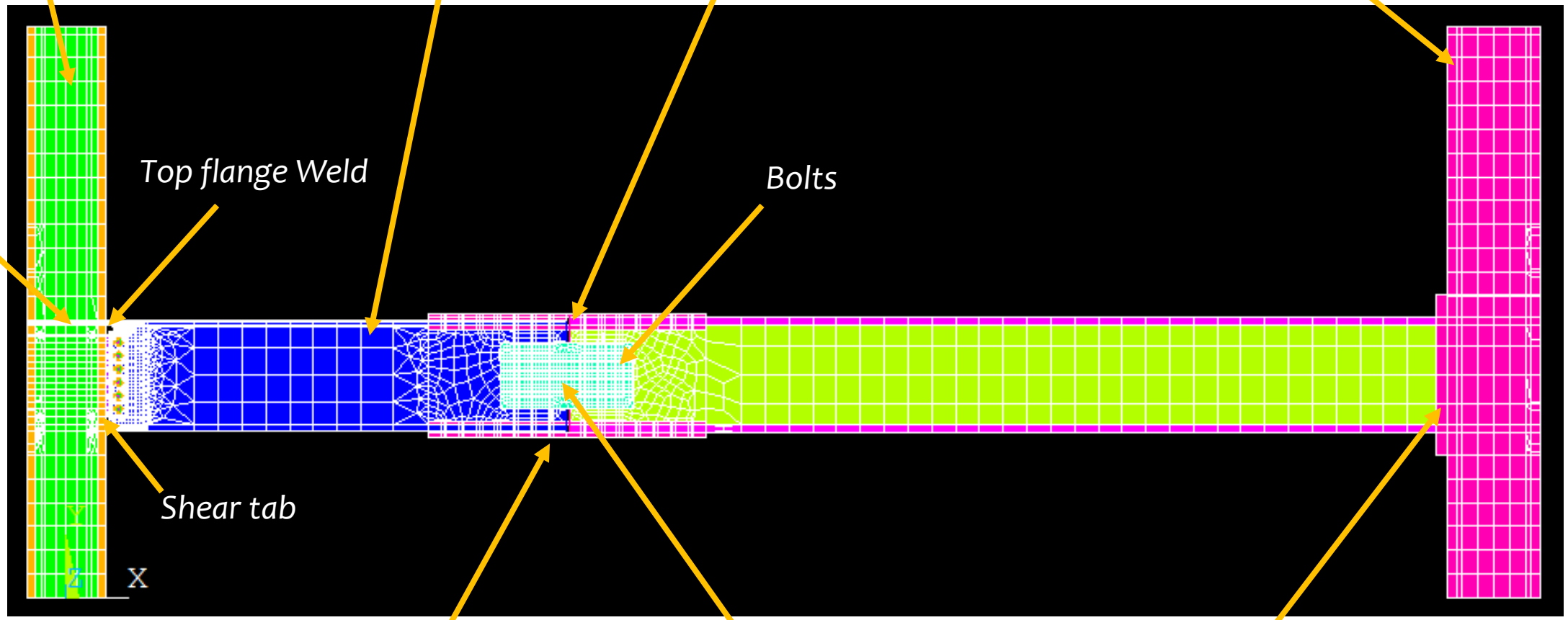


Test Sub Assembly

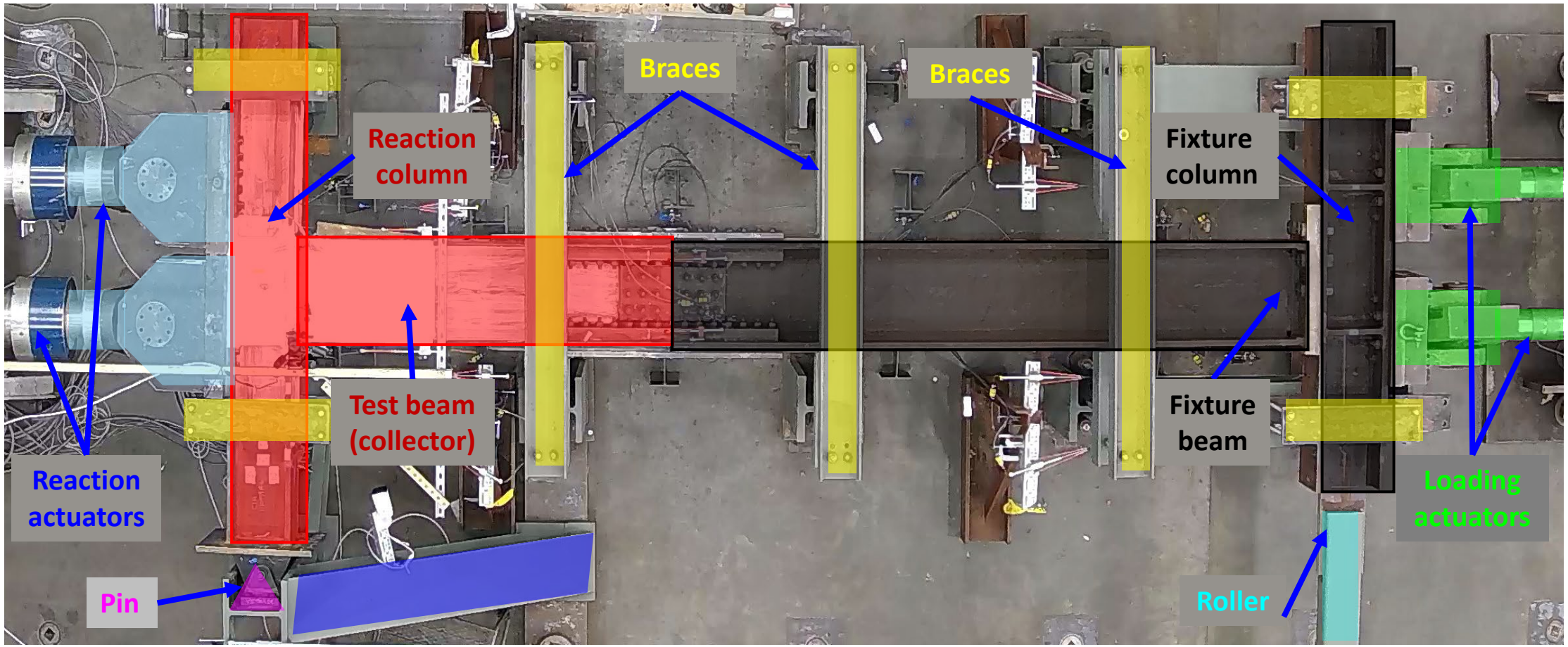


Test Sub-Assembly Top View

FE Model of Test Sub Assembly



Test Setup



Test specimens

Fixture

Reaction actuators

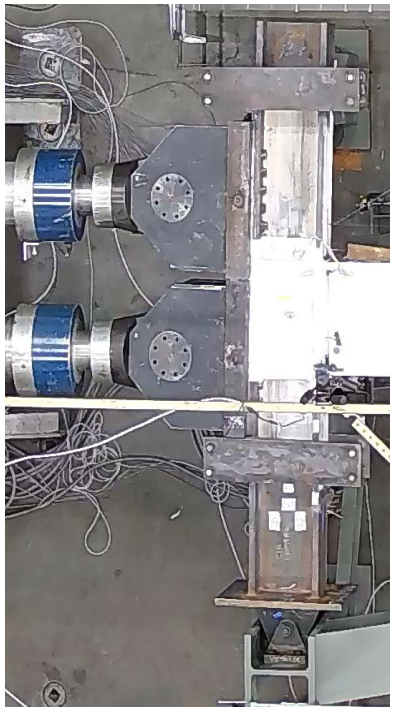
Loading actuators

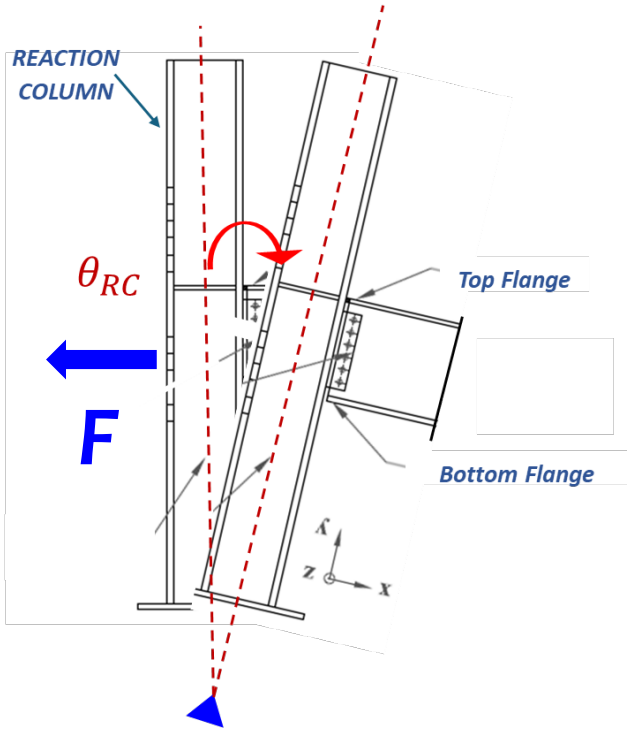
Pin support

Roller support

Braces

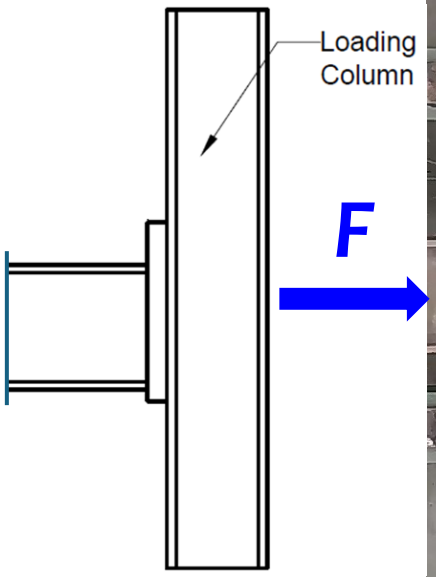
Actuators

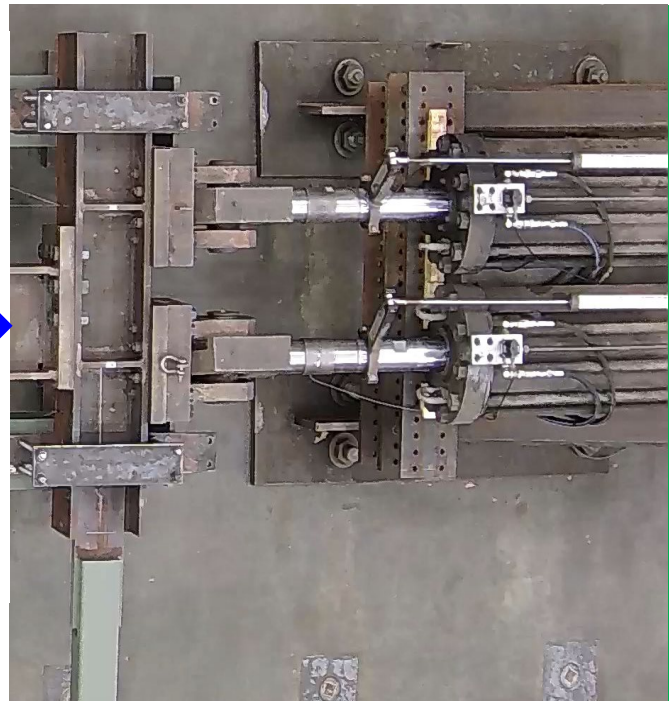




NHERI Actuators (Rotation actuators)

- *Support the reaction force*
- *Imposed a rotation on the reaction column*





NAVY Actuators (Loading actuators)

- *Apply the cyclic collector force*

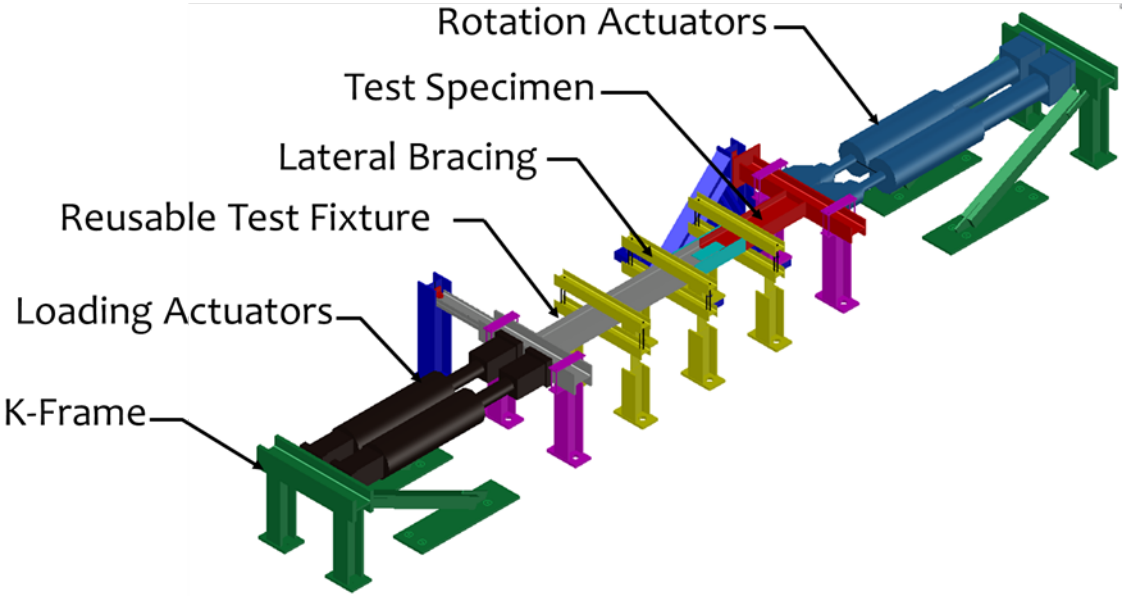
- *Each actuator has a loading capacity of 550 kips*
- *Loading capacity of 2 million pounds*

Test Fixture Design

Lehigh team designed a reusable test fixture

Key Design Features

- ***Reusable fixture beam and loading column***
- ***Splice plates and Filler plates***
- ***K-Frames***
- ***Lateral Bracing***
- ***Column Support, Pin and Roller Support***

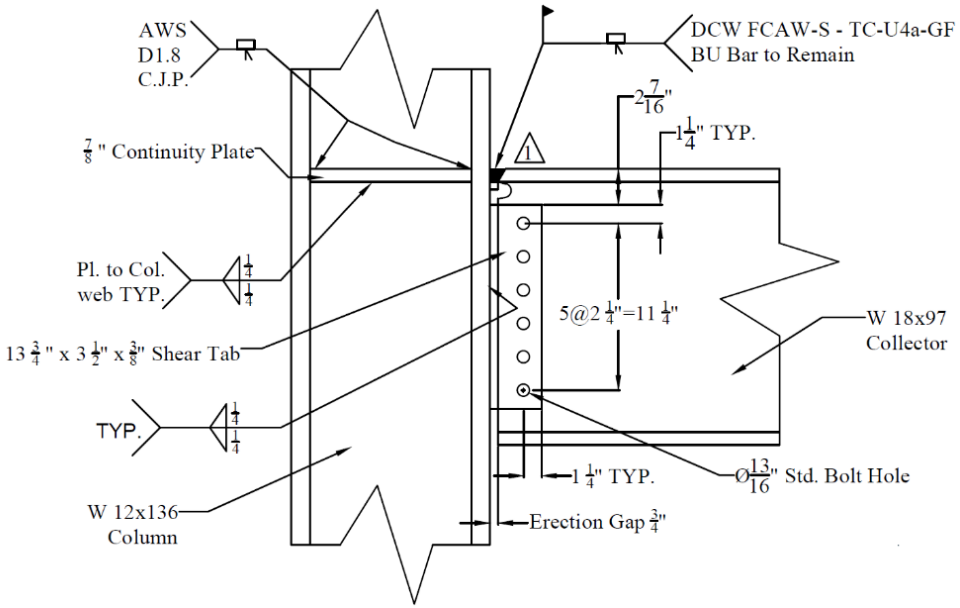


(Max Beedle 2020, Jessica Duke, 2021)

Large-Scale Collector Connection Experimental Testing

Test Collector Connection

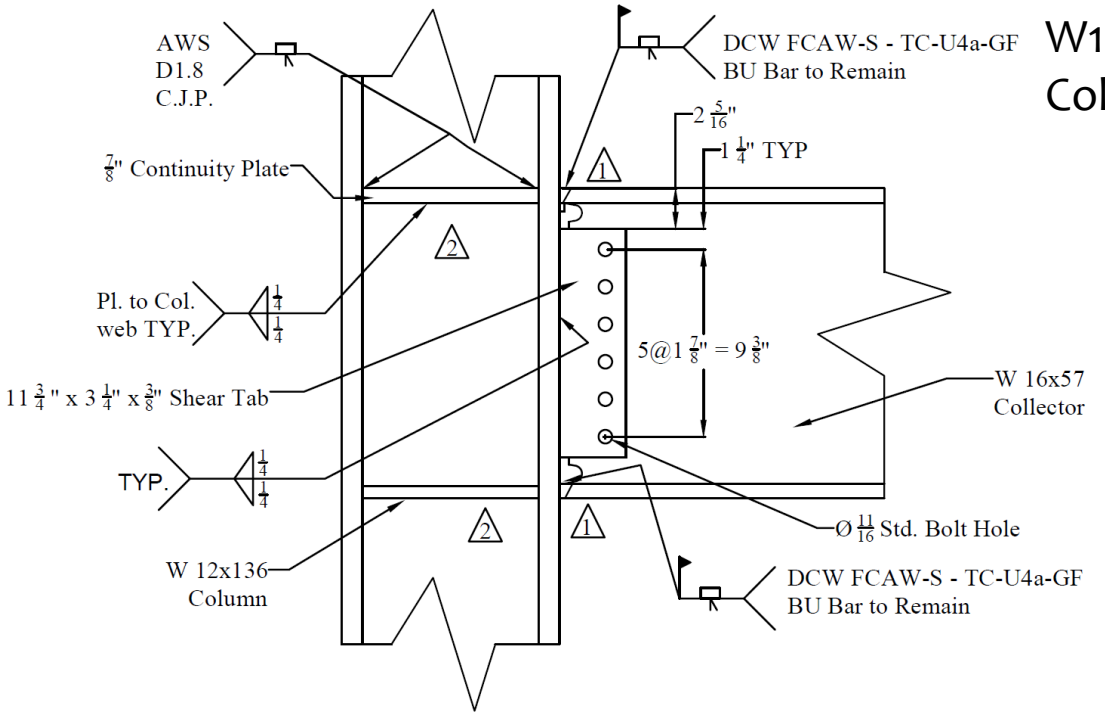
Top Flange Weld (TFW)



The TFW is a 3/4-scale test specimen based on a Full-Scale Prototype

Test Collector Connection

All Flange Weld (AFW)

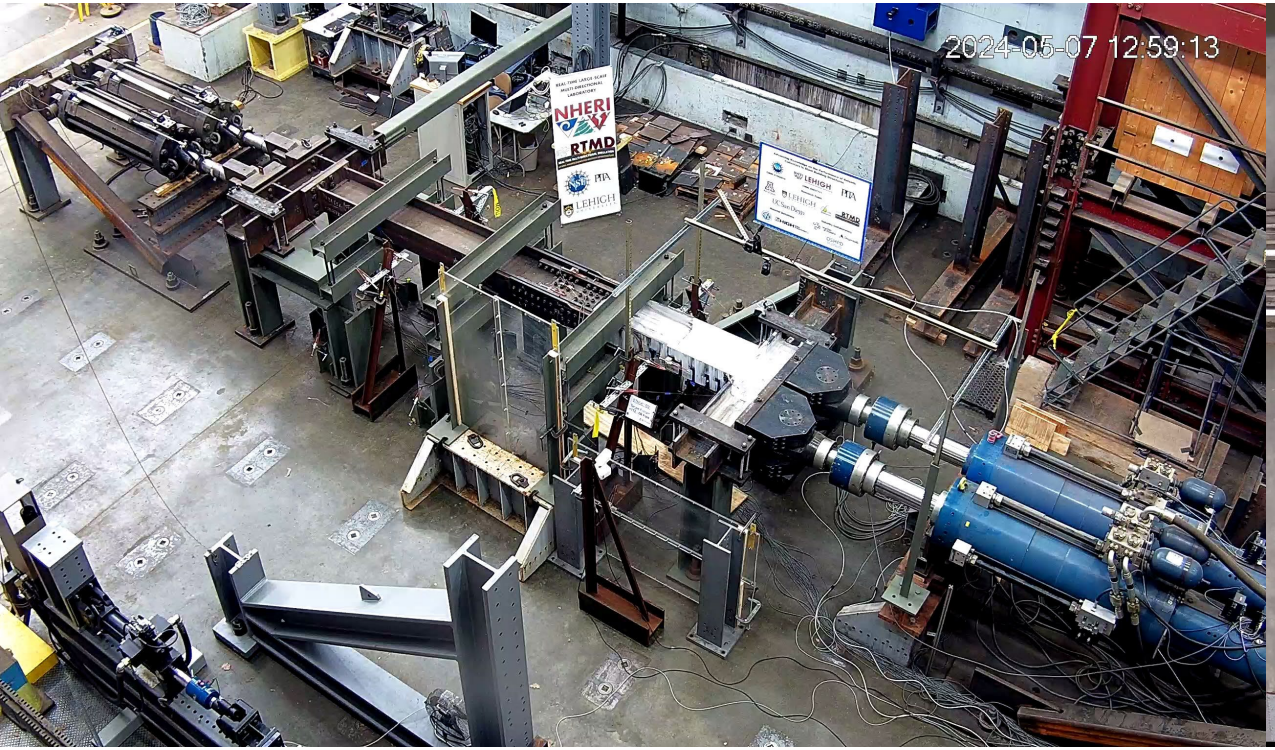


W12x136 Column

W16x57 Collector

The AFW is a 2/3-scale test specimen based on a Full-Scale Prototype

Videos/Photos Recording

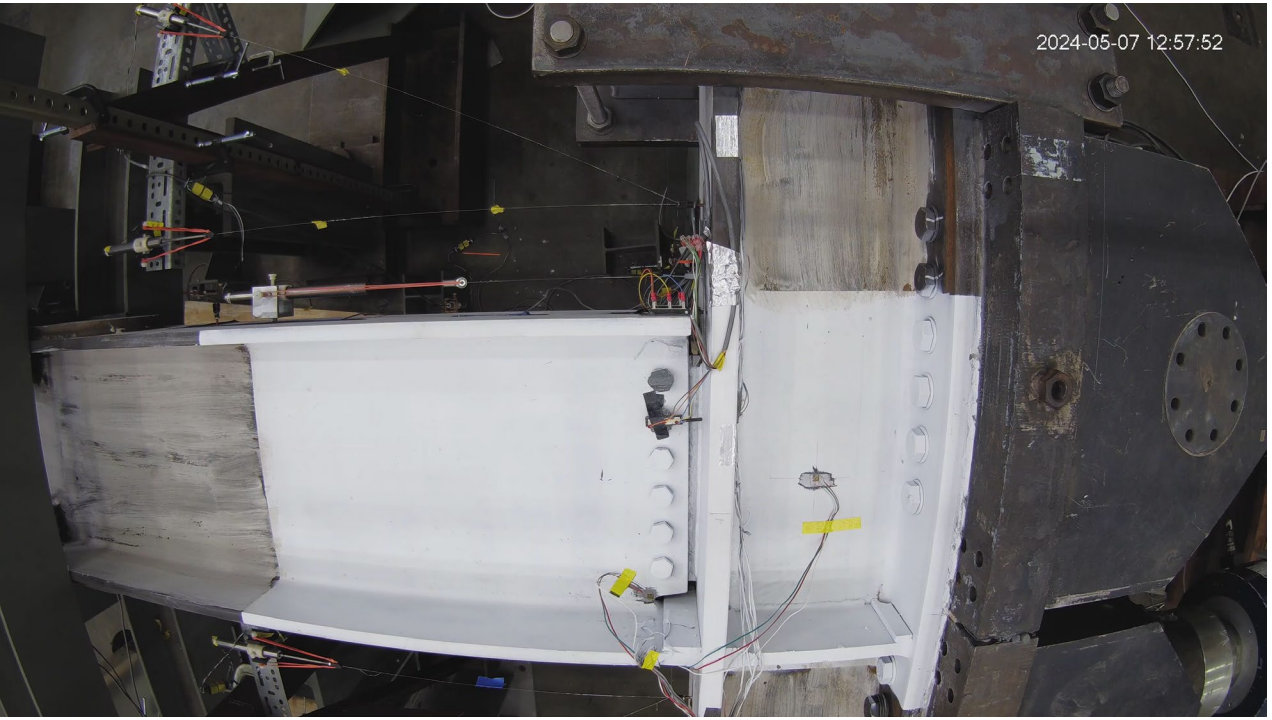


Perspective View

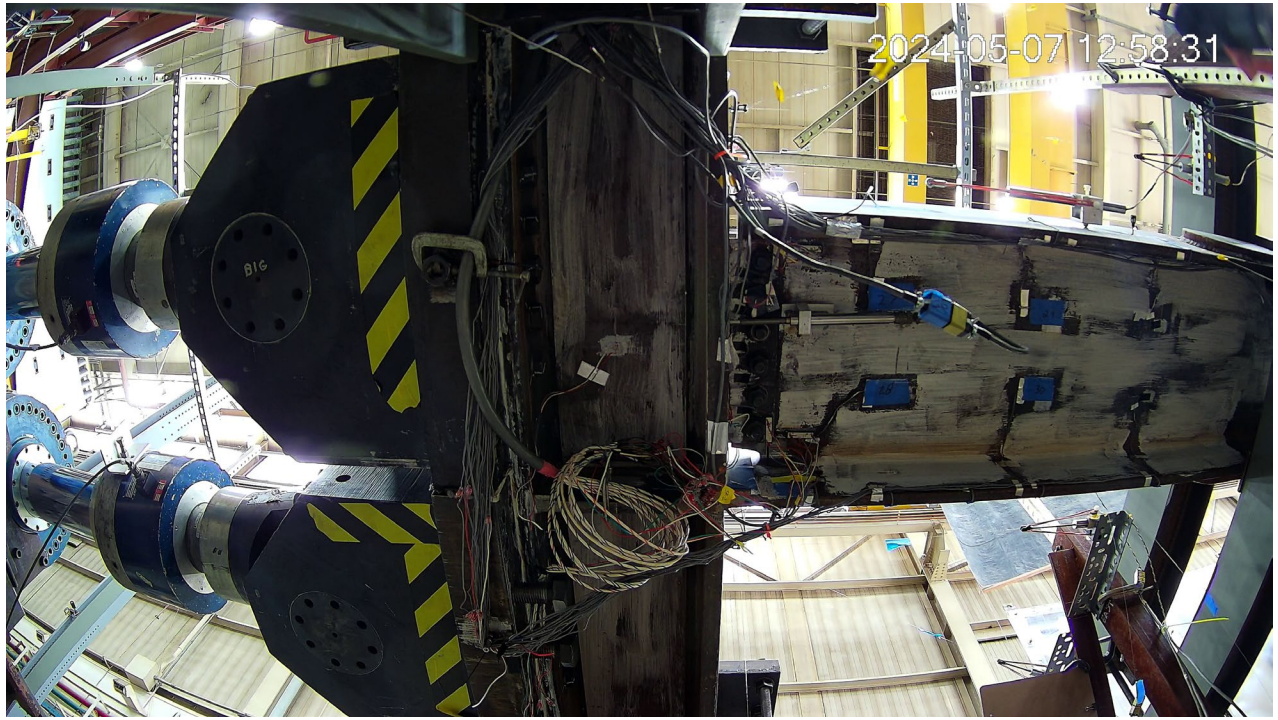
Birds Eye View

All camera feeds were streamed live in real time for remote observation and monitoring.

Videos/Photos Recording



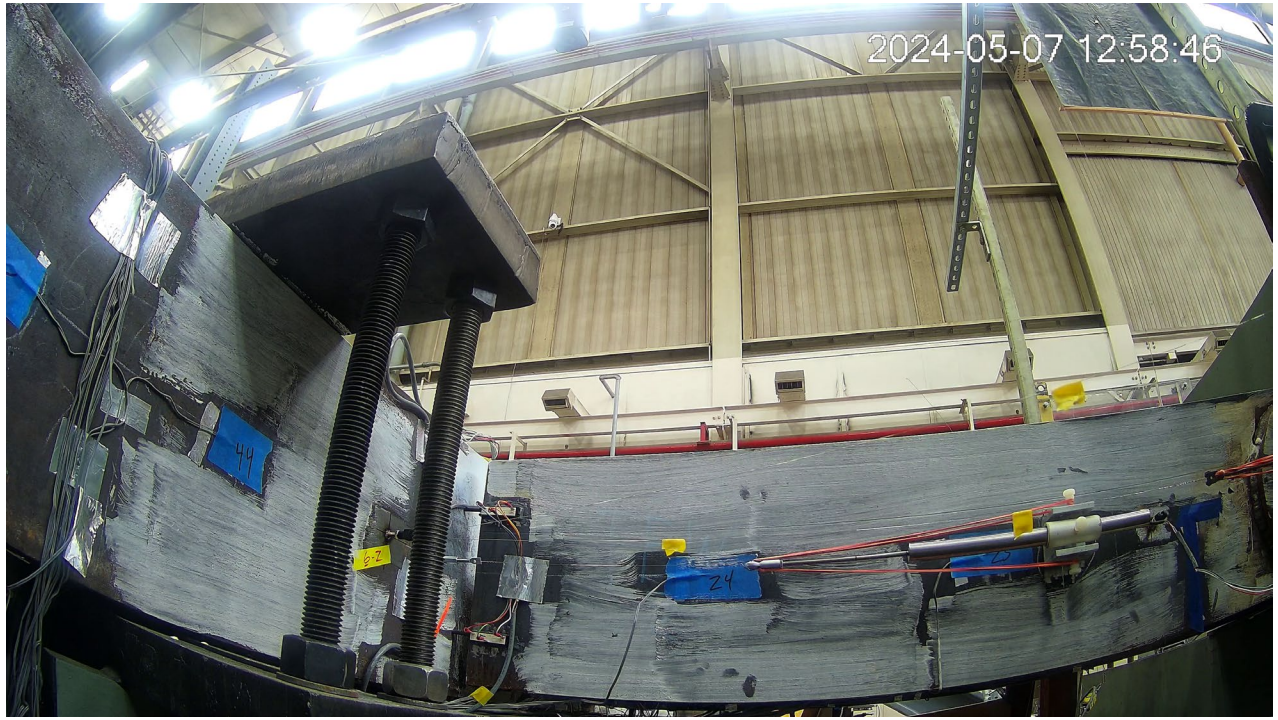
Connection Region (Top-side)



Connection Region (Bottom side/ST side)
(Whitewashed region)

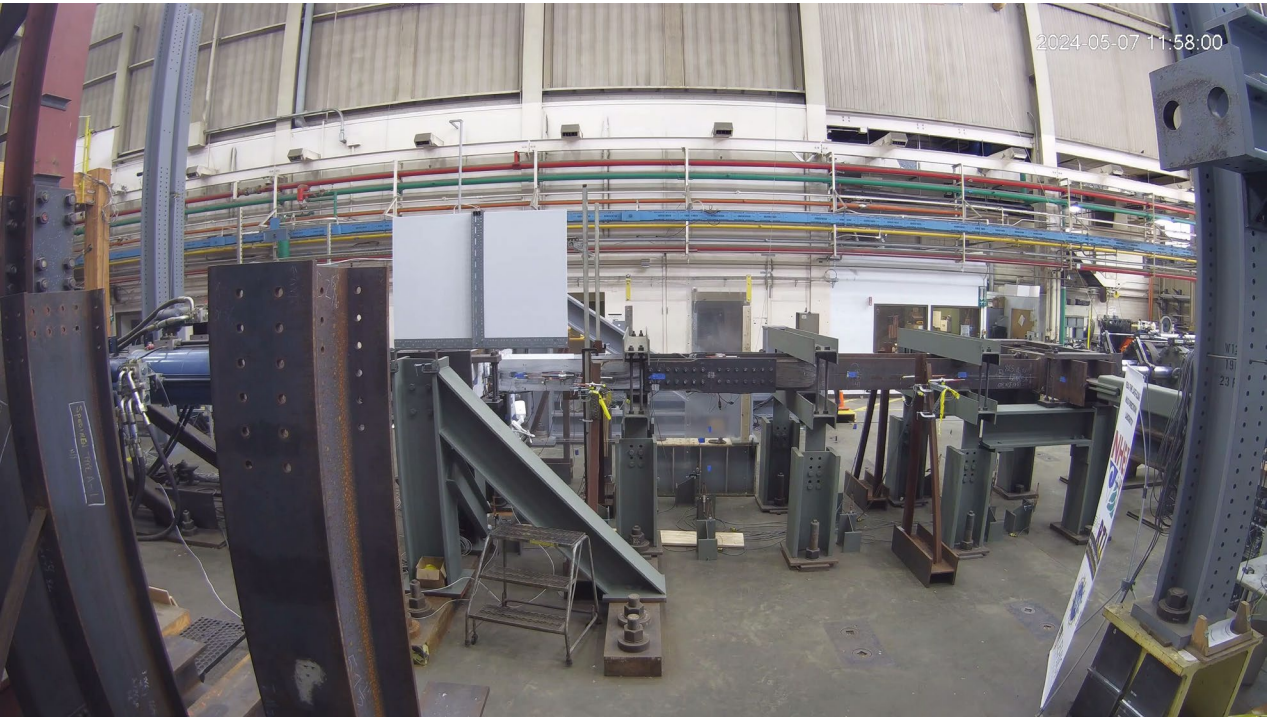
Videos/Photos Recording

Top flange View



Bottom flange view

Videos/Photos Recording

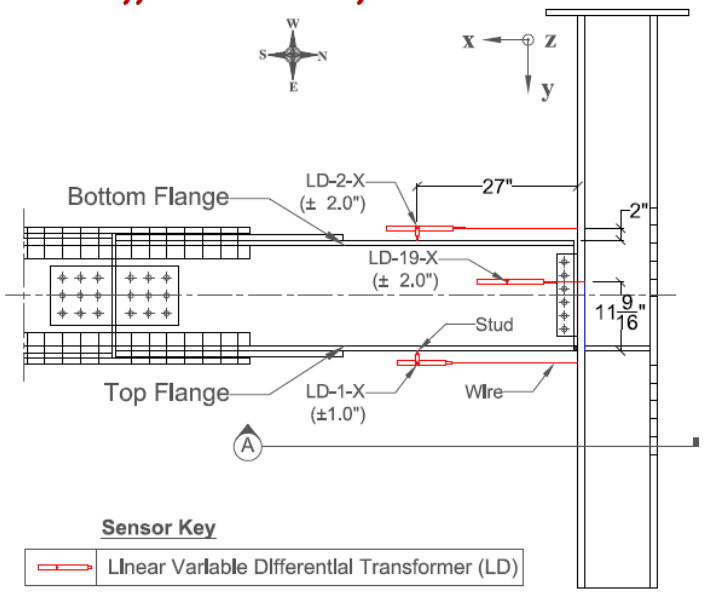


Side View (Wide)

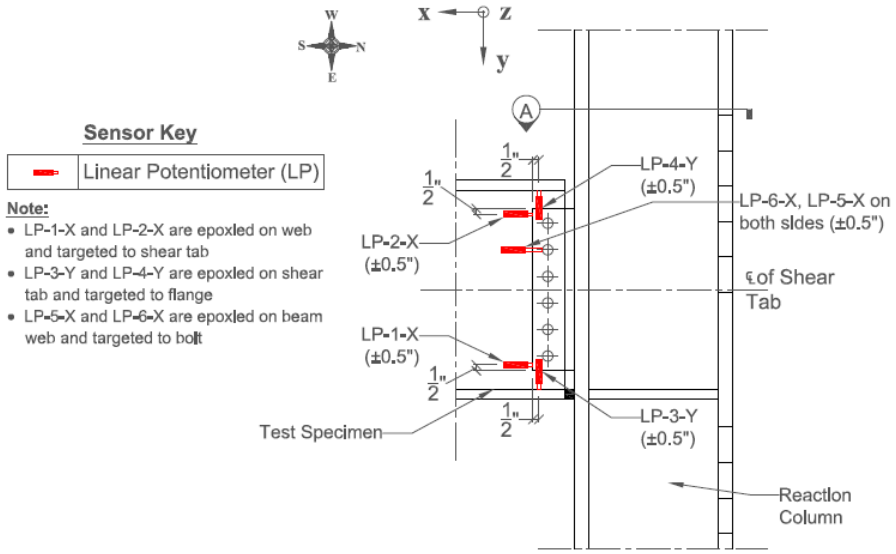
Side View (Wide)

Instrumentation

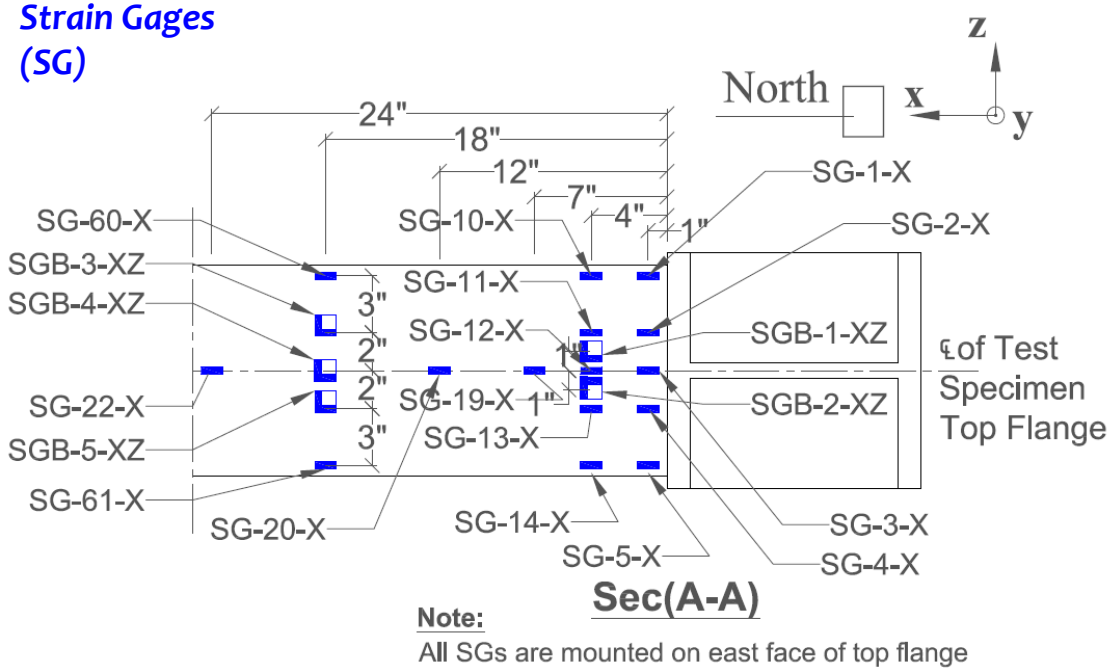
Linear variable differential transformer (LVDT)



Linear potentiometer (LP)



Strain Gages (SG)

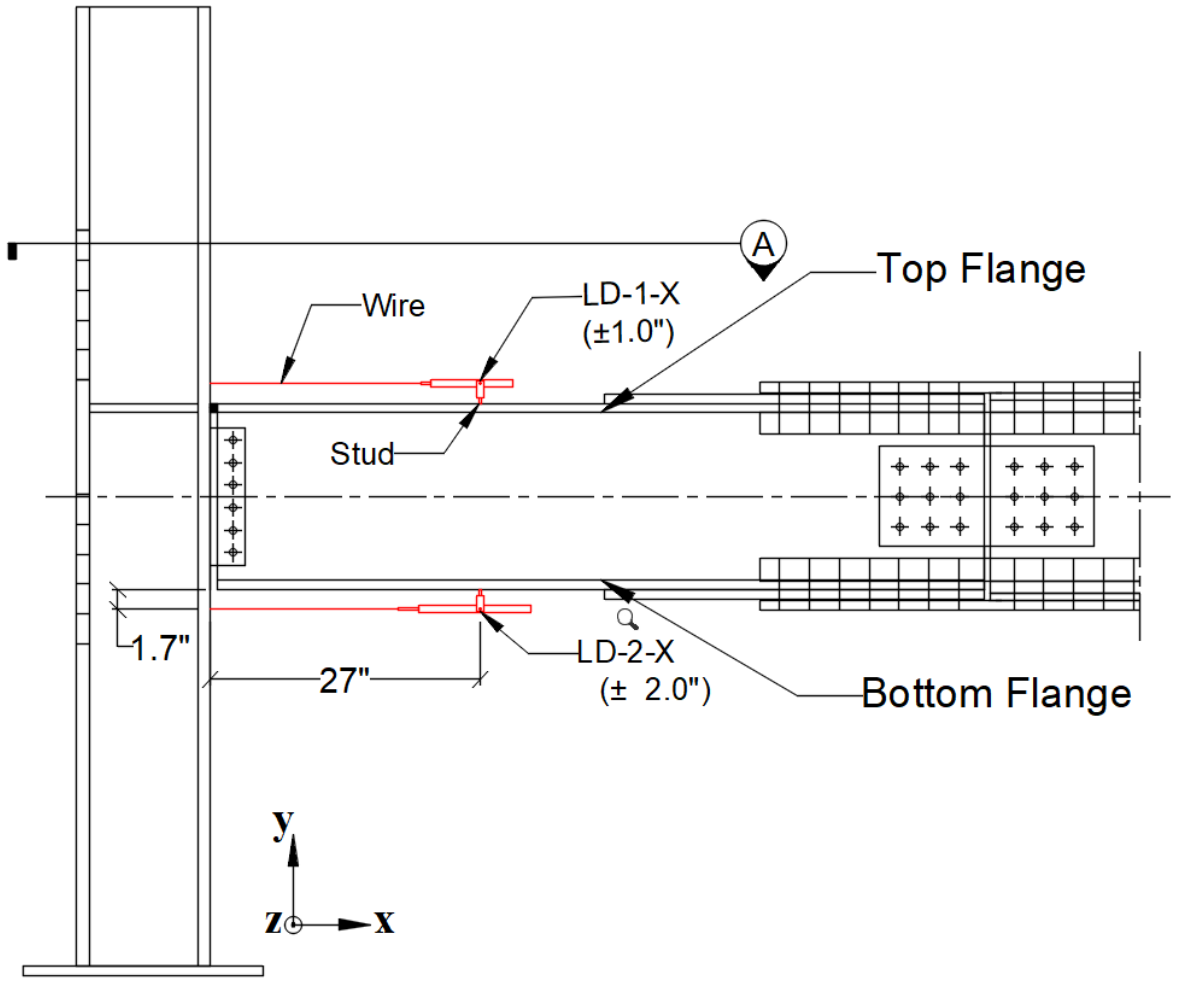


Note:
All SGs are mounted on east face of top flange

Instrumentation plan per test (varies)

Instrument	Count
LVDT	*33*
LP	*7*
Axial strain gage	*55*
Rosette gage	*5*
Biaxial gage	*6*

Calculated Responses



LVDT's to measure the deformation

Axial Deformation at girder centroid

$$\delta_c = \frac{LD1_X + LD2_X}{2}$$

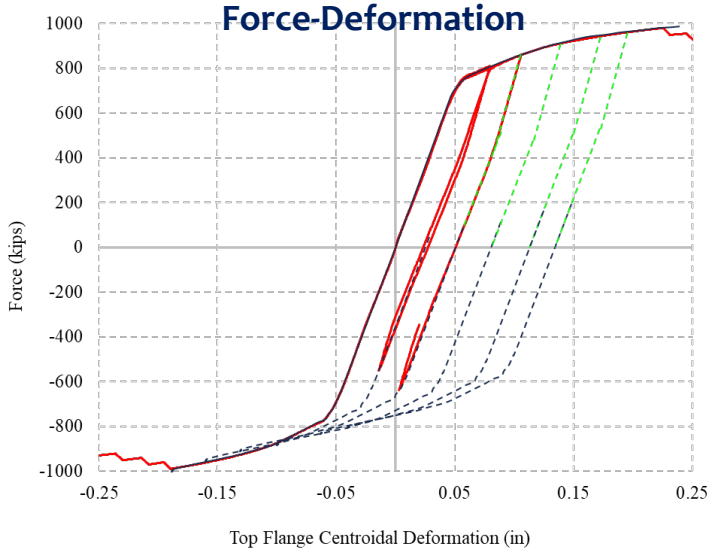
Rotation of the girder cross section (positive when bottom flange open)

$$\theta_c = \frac{LD2_X - LD1_X}{h'}$$

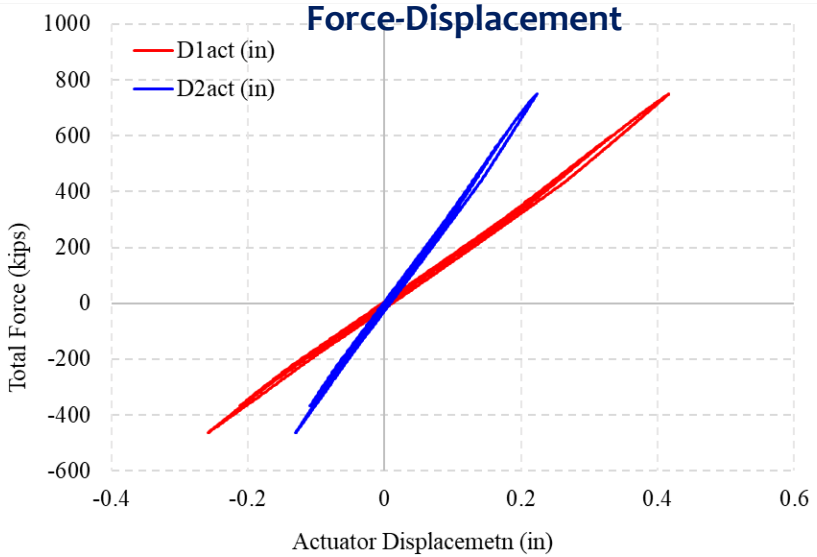
h' = vertical distance between LD 1-X and LD 2-X = 18.6 +1.7*2 = 22"

Test Day Display Board

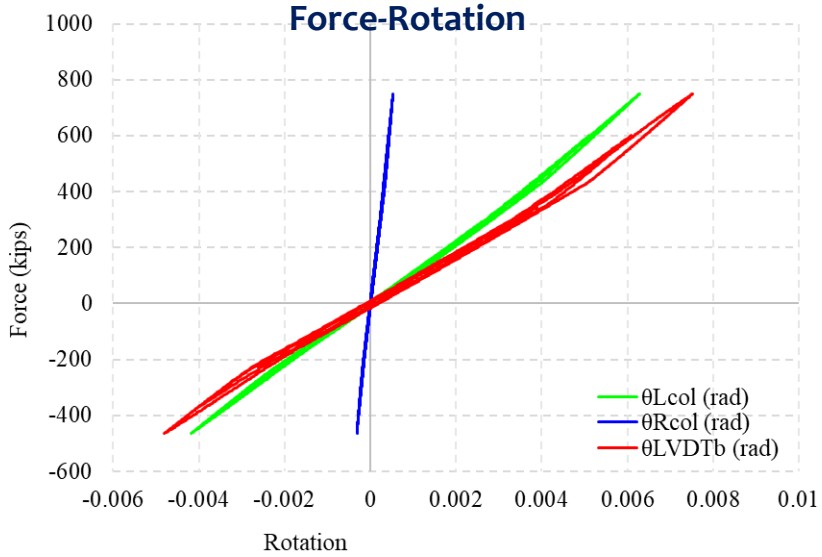
Force-Deformation



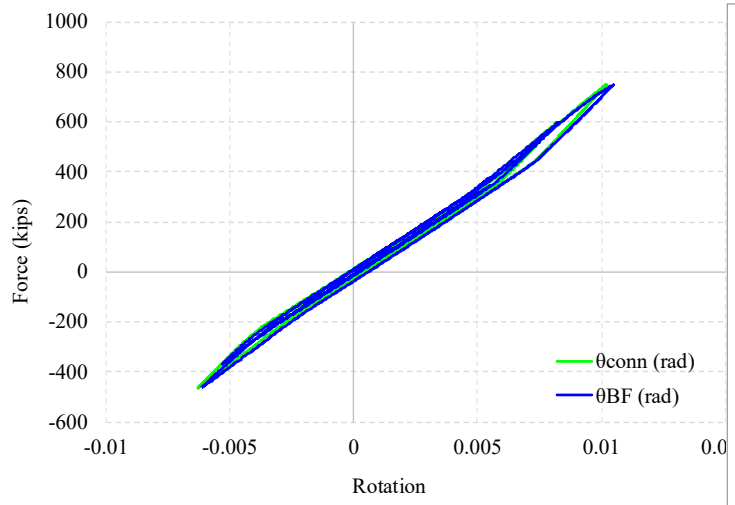
Force-Displacement



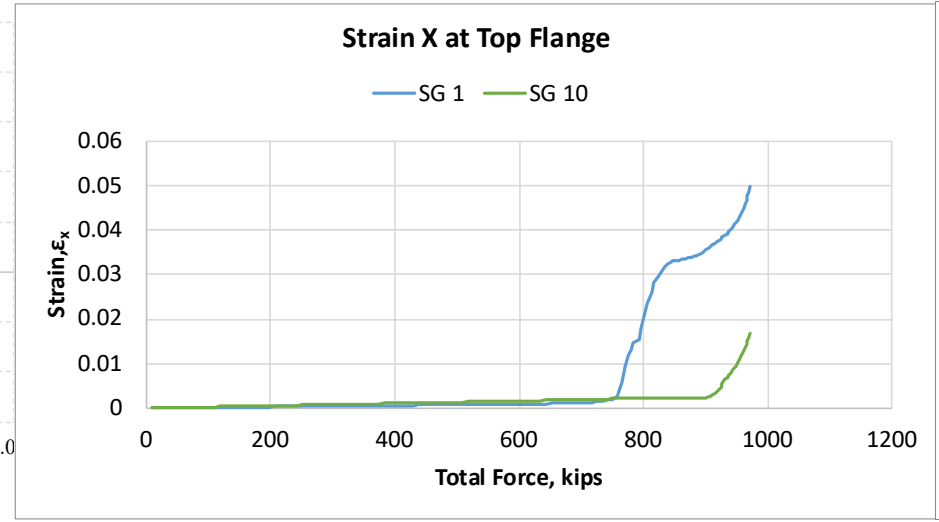
Force-Rotation



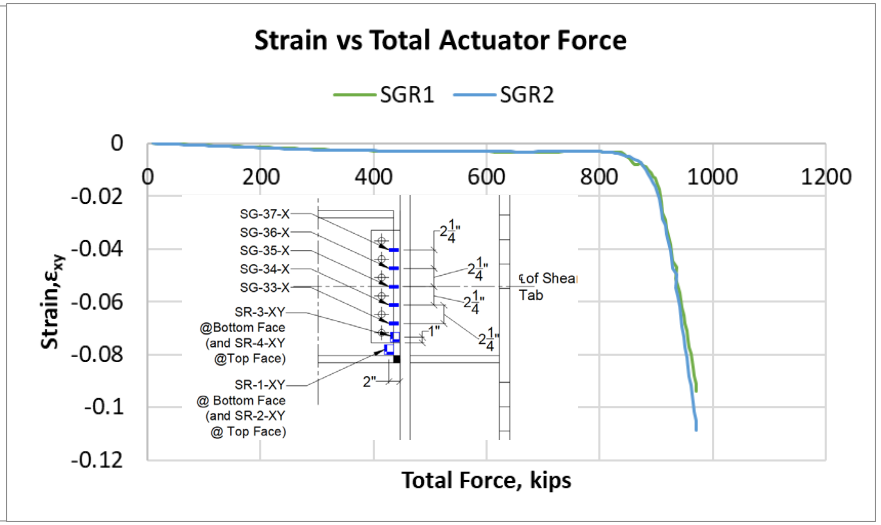
Force-Connection Rotation



Strain X at Top Flange



Strain XY in Weld Access Hole

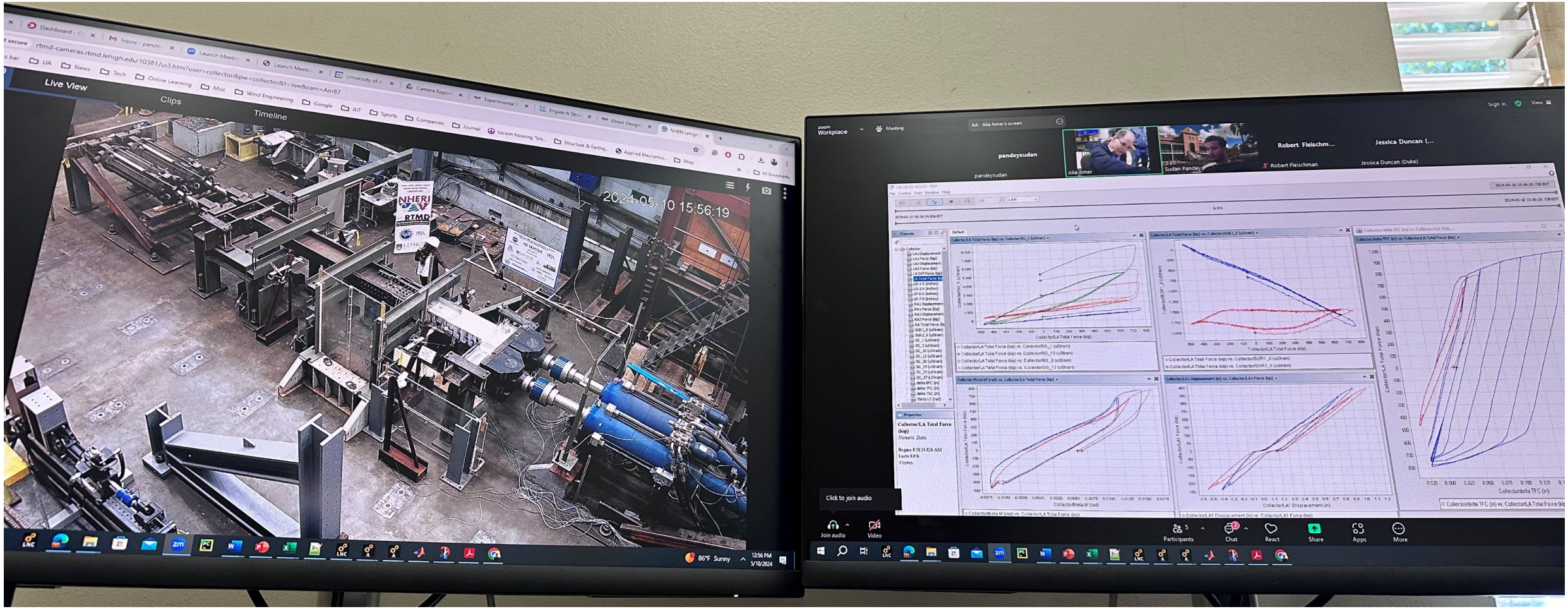


Control Room

Virtual Participation

Real time live-streamed feed

Live display board (via Zoom)



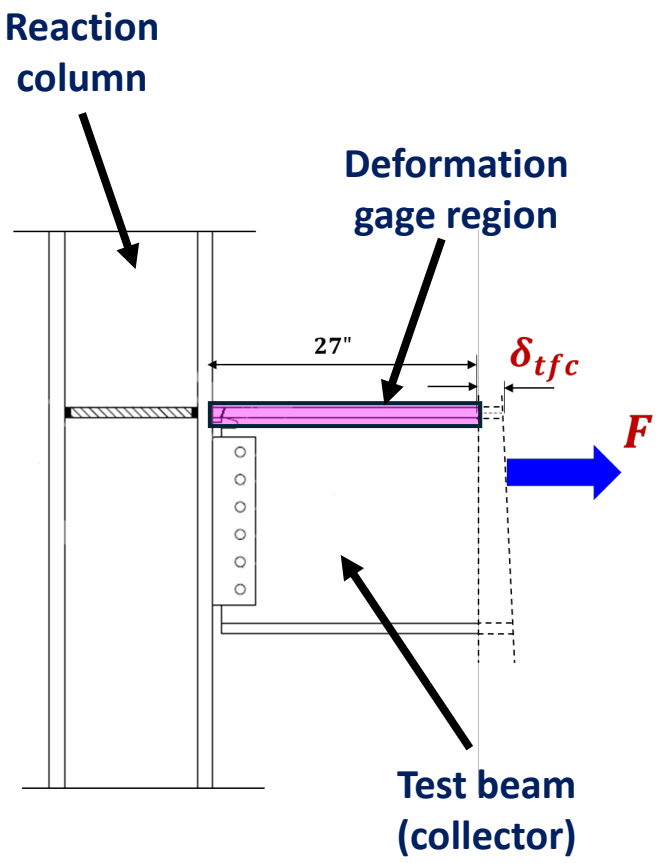
Challenges

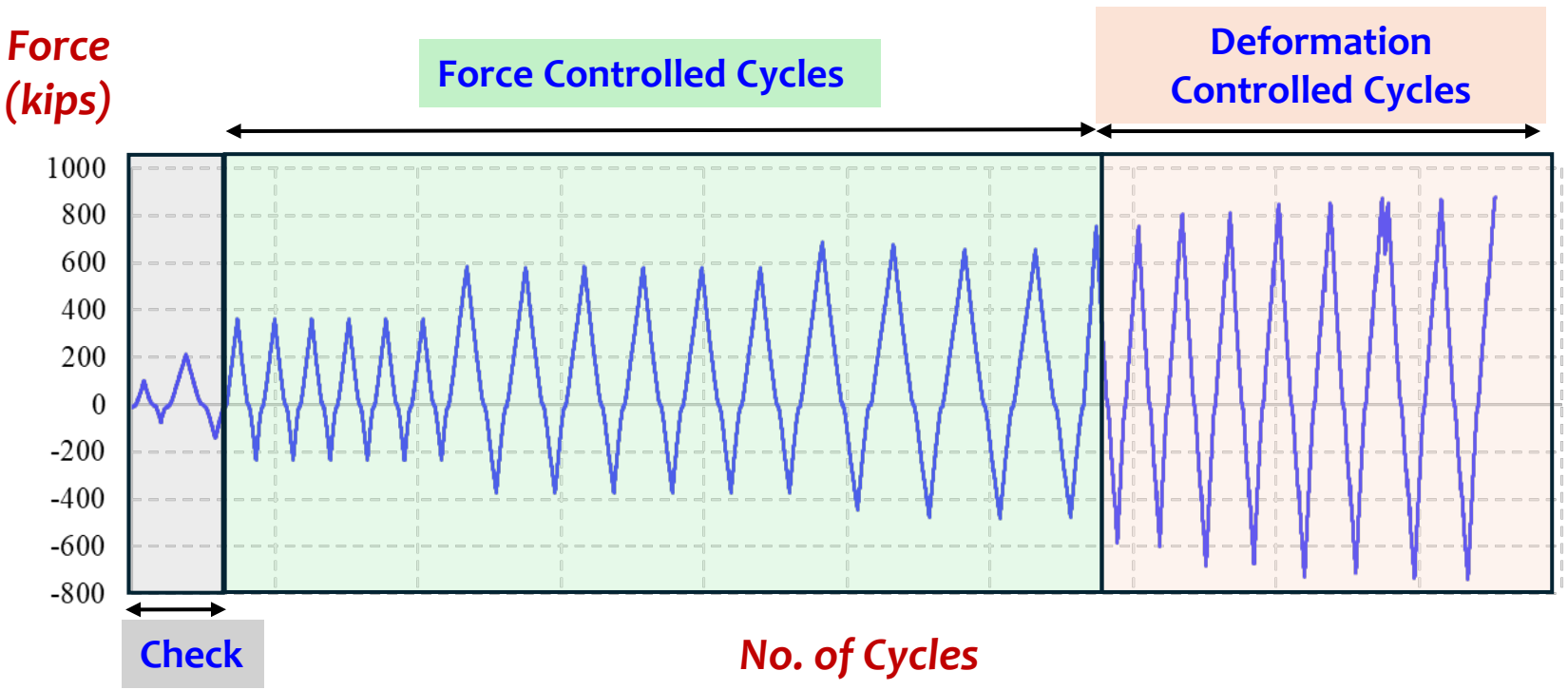
- *Control of two pairs of actuators*
- *Force Controlled vs Displacement (or Deformation) Controlled*
- *Cyclic loading (Force/Displacement controlled) in presence of imposed rotation on the reaction column*
- *Loading with predetermined histories of force and rotation*

Loading Protocols

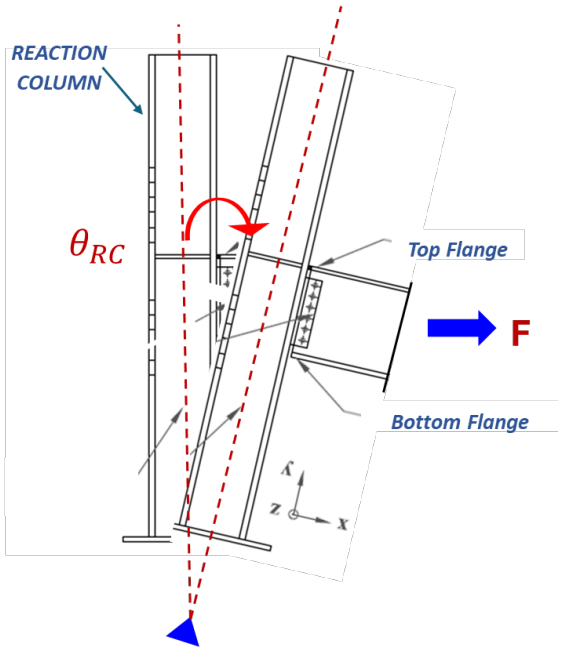
- Cyclic Collector Force w/o Column Rotation
- Cyclic Collector Force w/ Column Rotation
- Collector Seismic Demands

Loading Protocol: Cyclic Collector Force

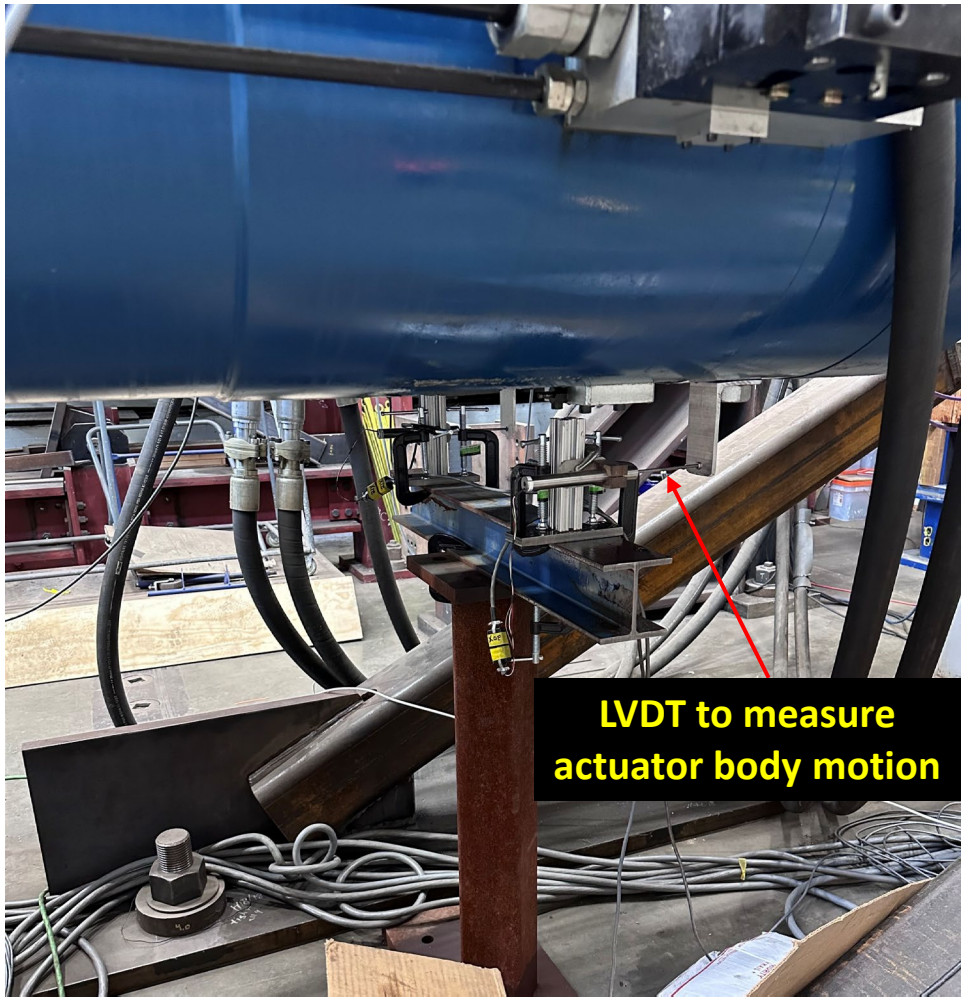




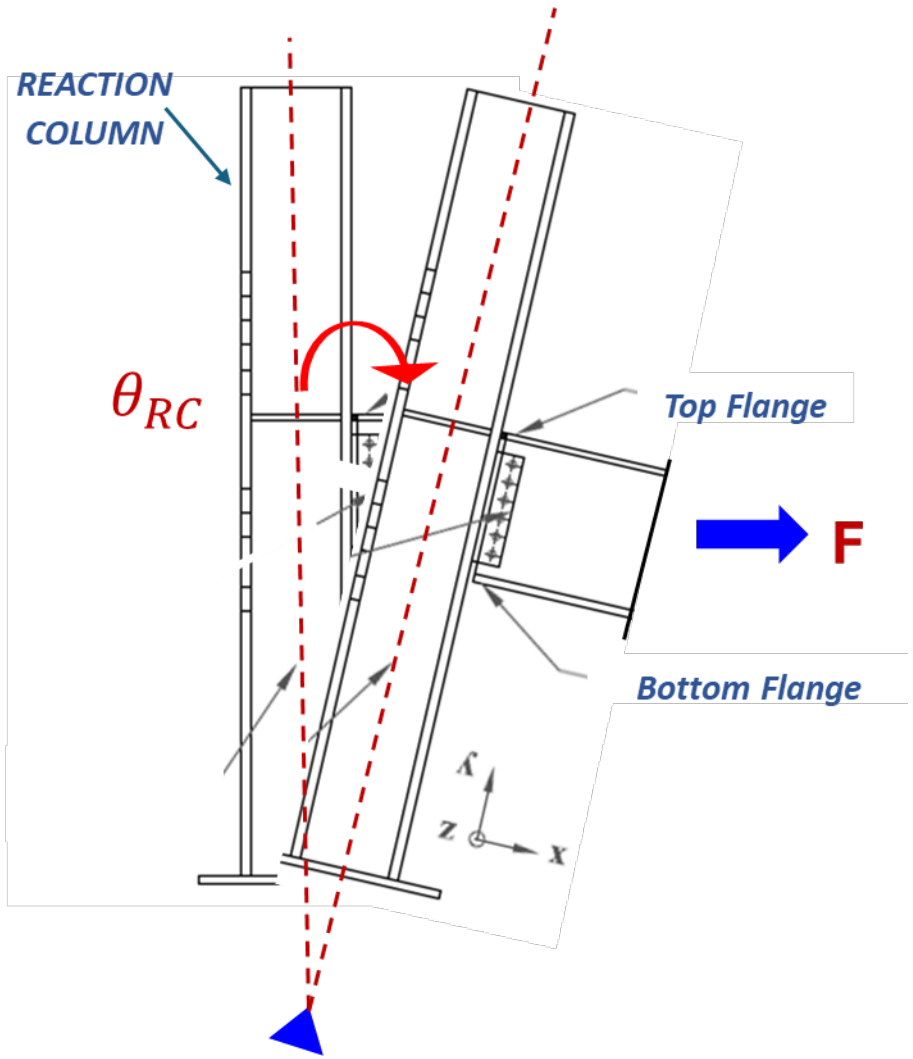
Imposing Column Rotation

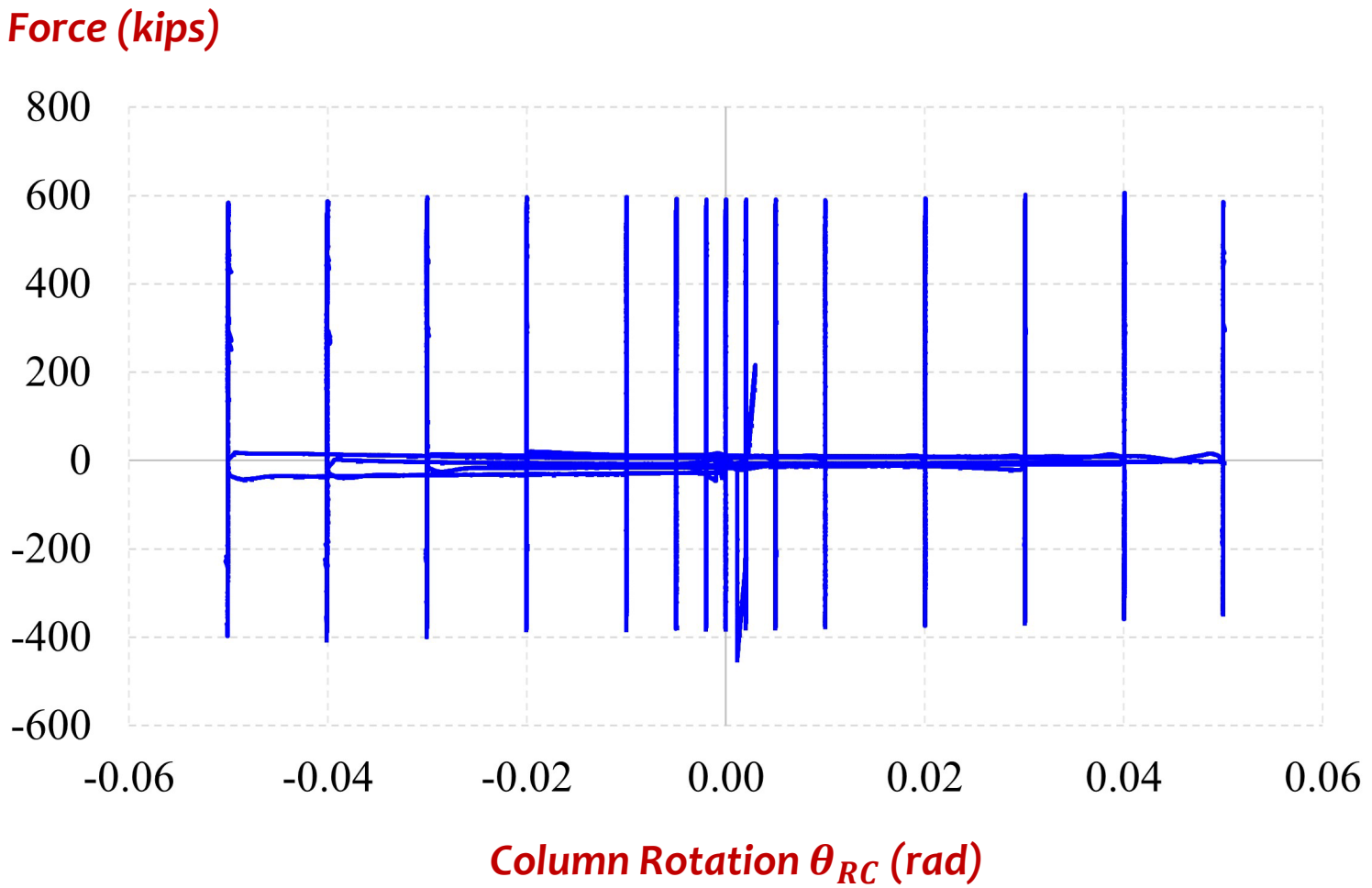


- *Assuming rigid body rotation, reaction column rotation was computed using measurements from two locations on the reaction column*
- *The application of large forces led to measurable displacement in the actuator bodies*
- *Actuator body motion was compensated for in rotation calculations.*

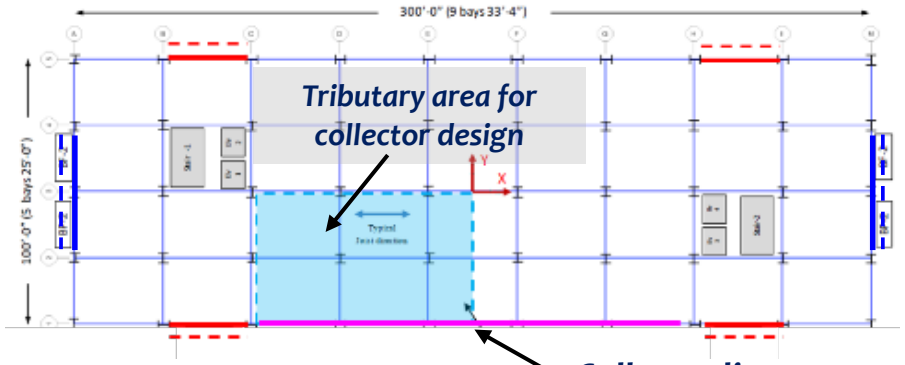


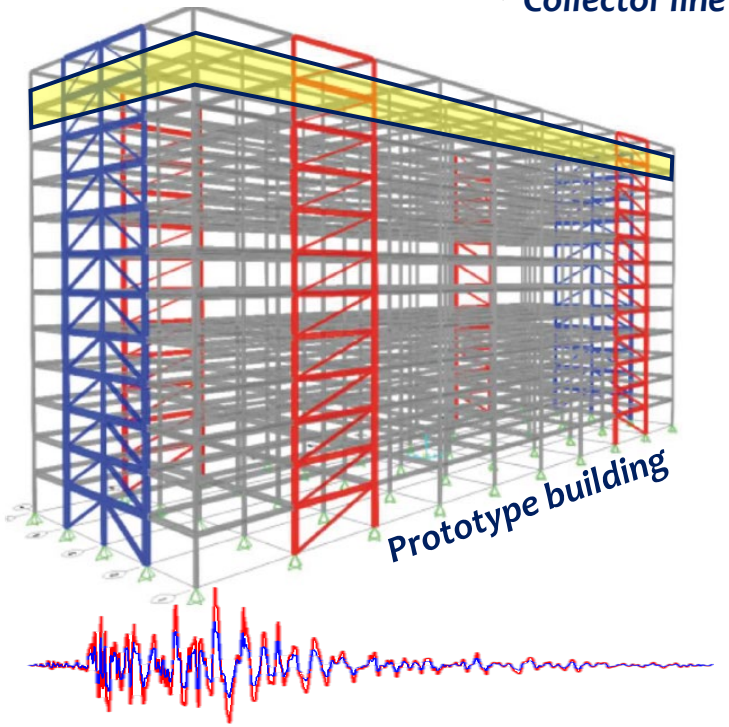
Loading Protocol: Cyclic Collector Force w/ Rotation



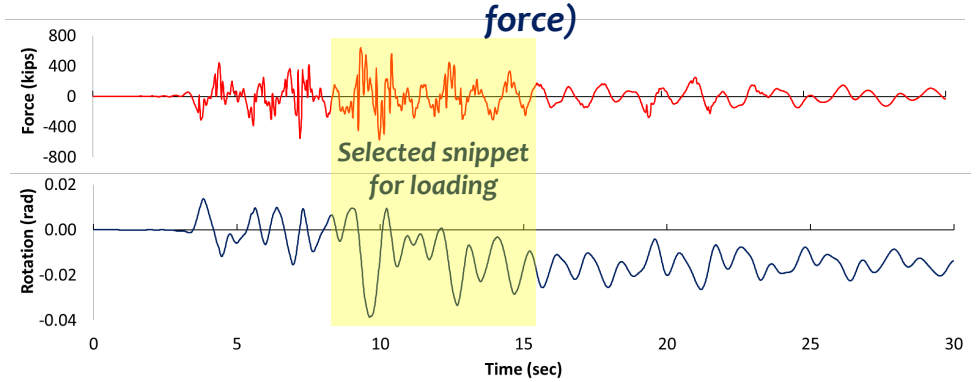


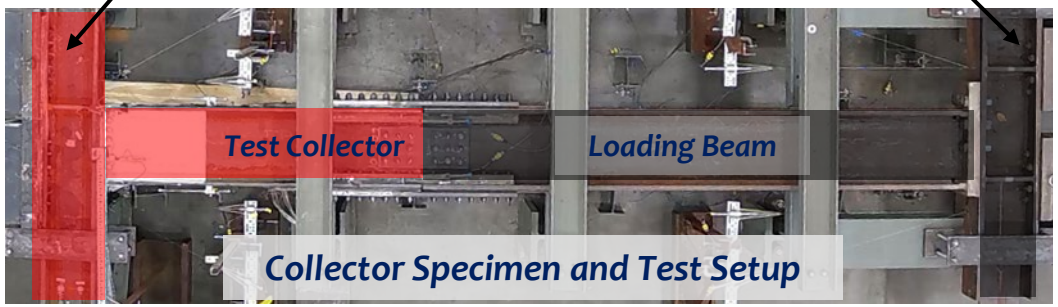
Loading Protocol: Collector Seismic Demand

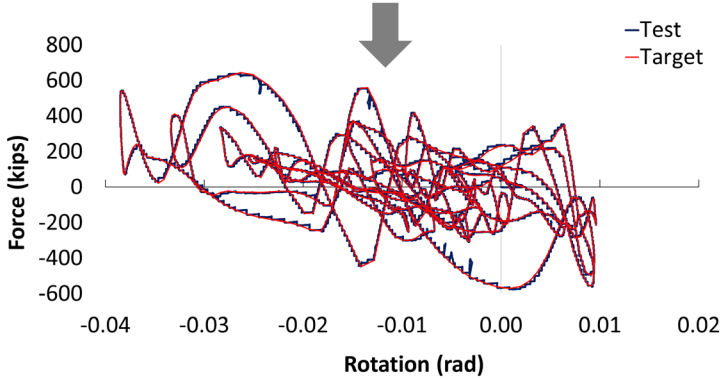




Collector force and frame rotation at the 12th floor (scaled force)

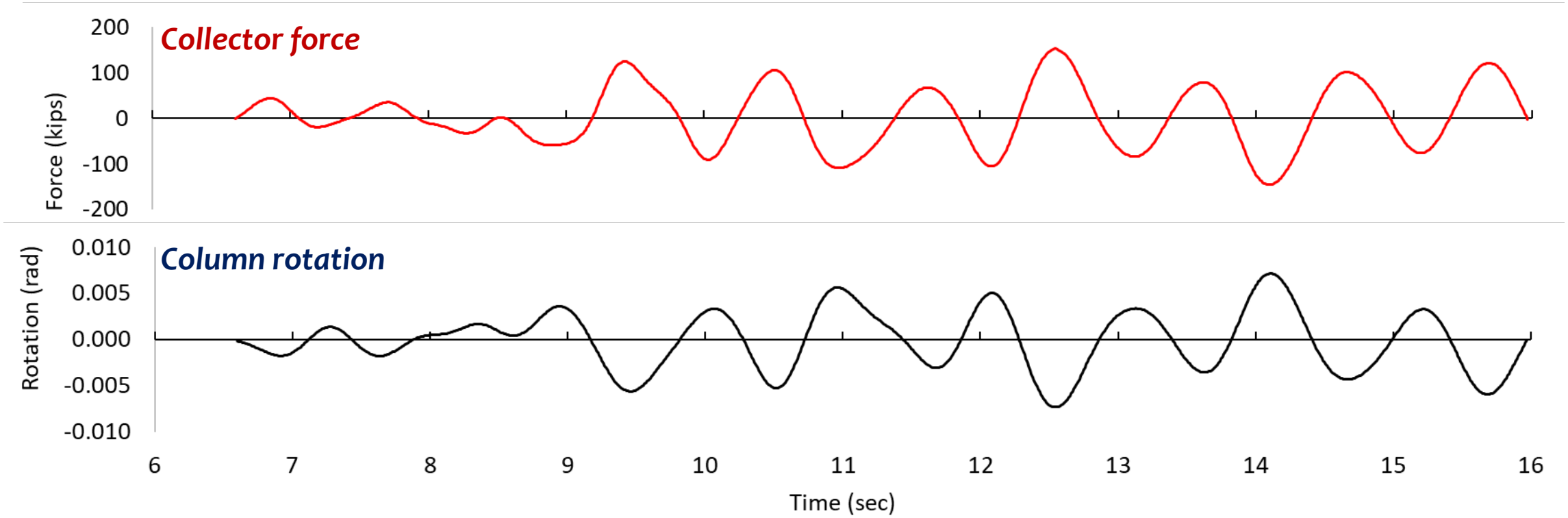




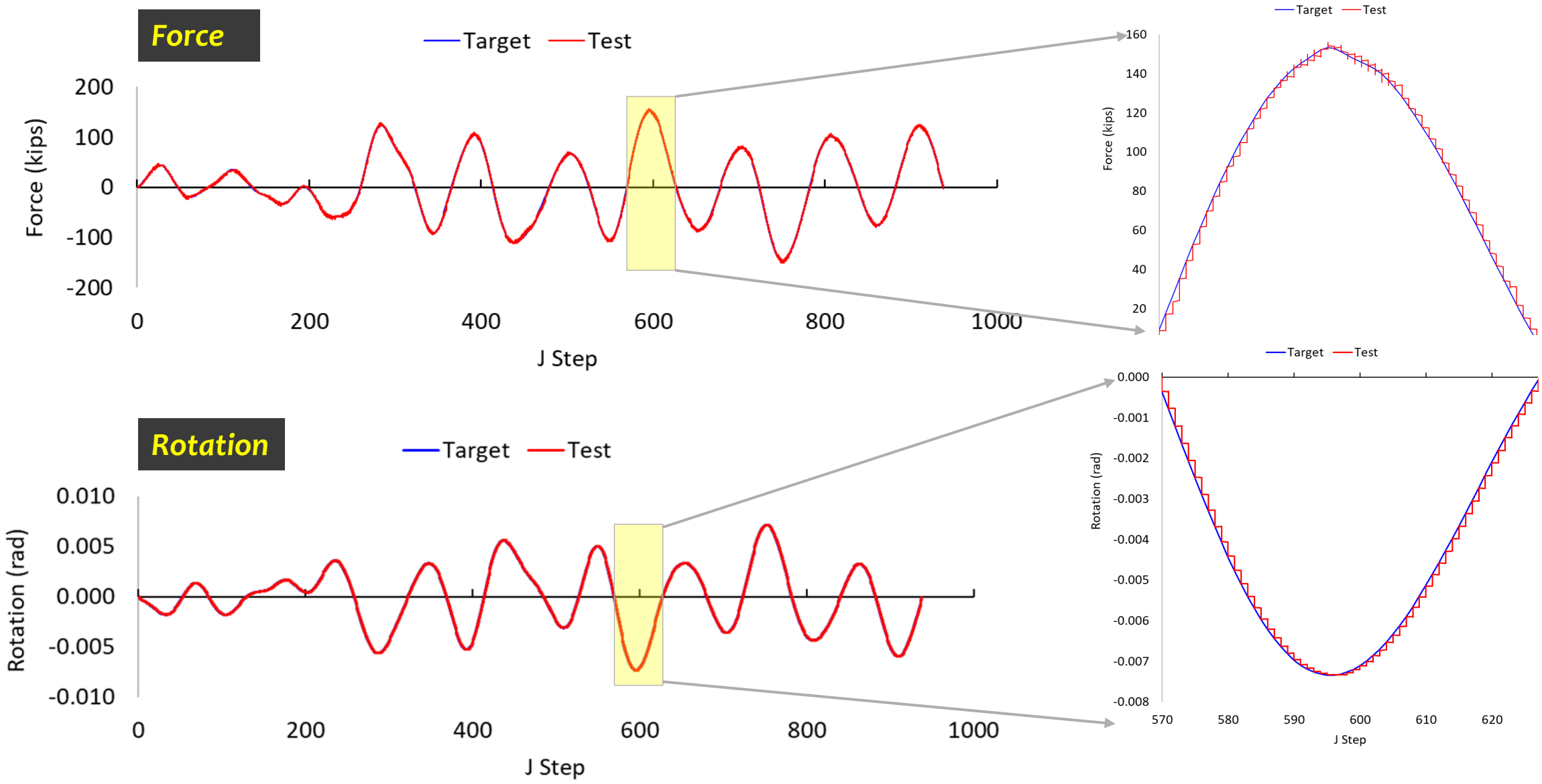


Development of Loading Control

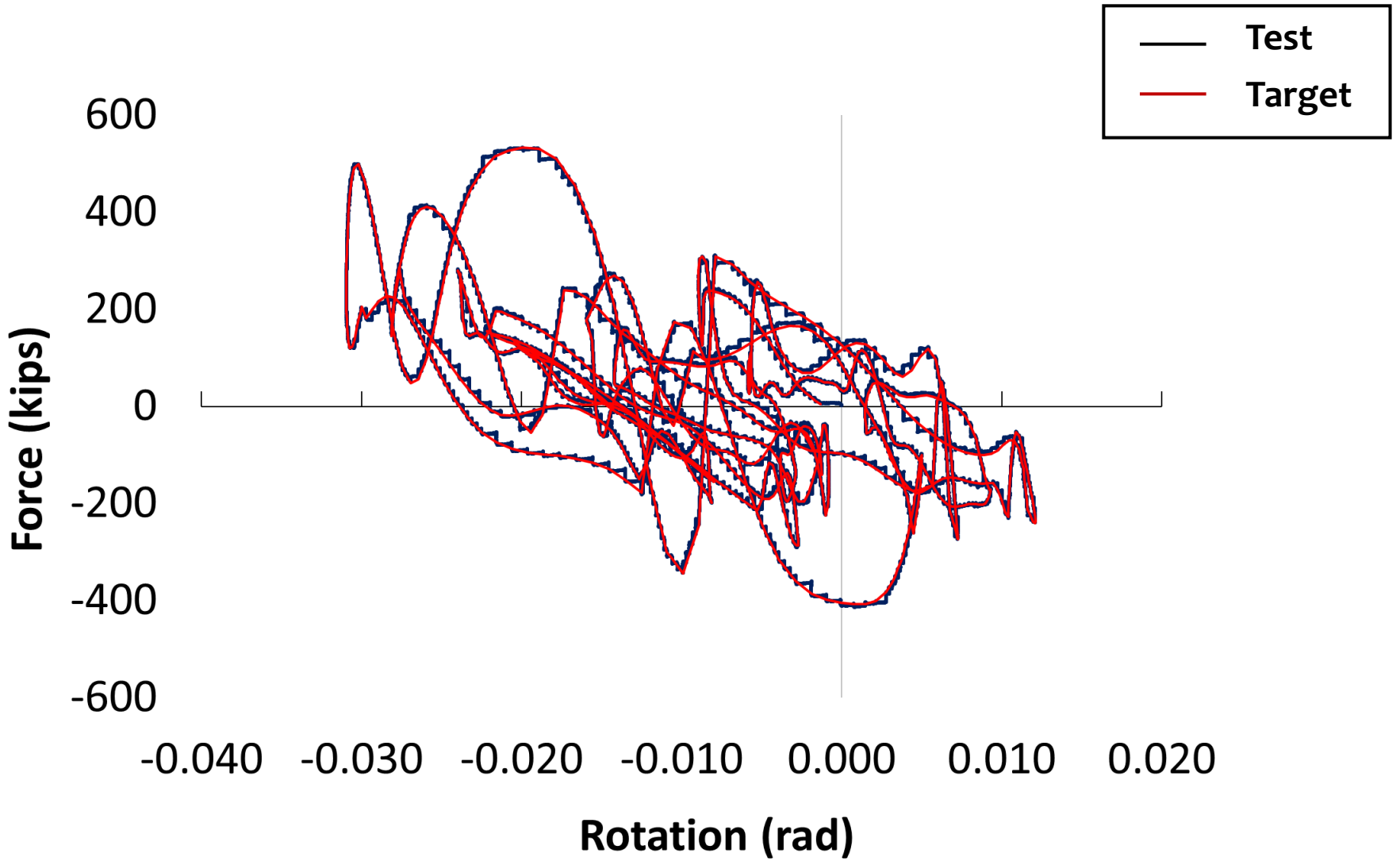
- *Loading of predetermined time histories*
- *Simultaneous loading: Imposing rotation on the reaction column and applying collector force on the loading column*



Comparison of Target and Test Responses



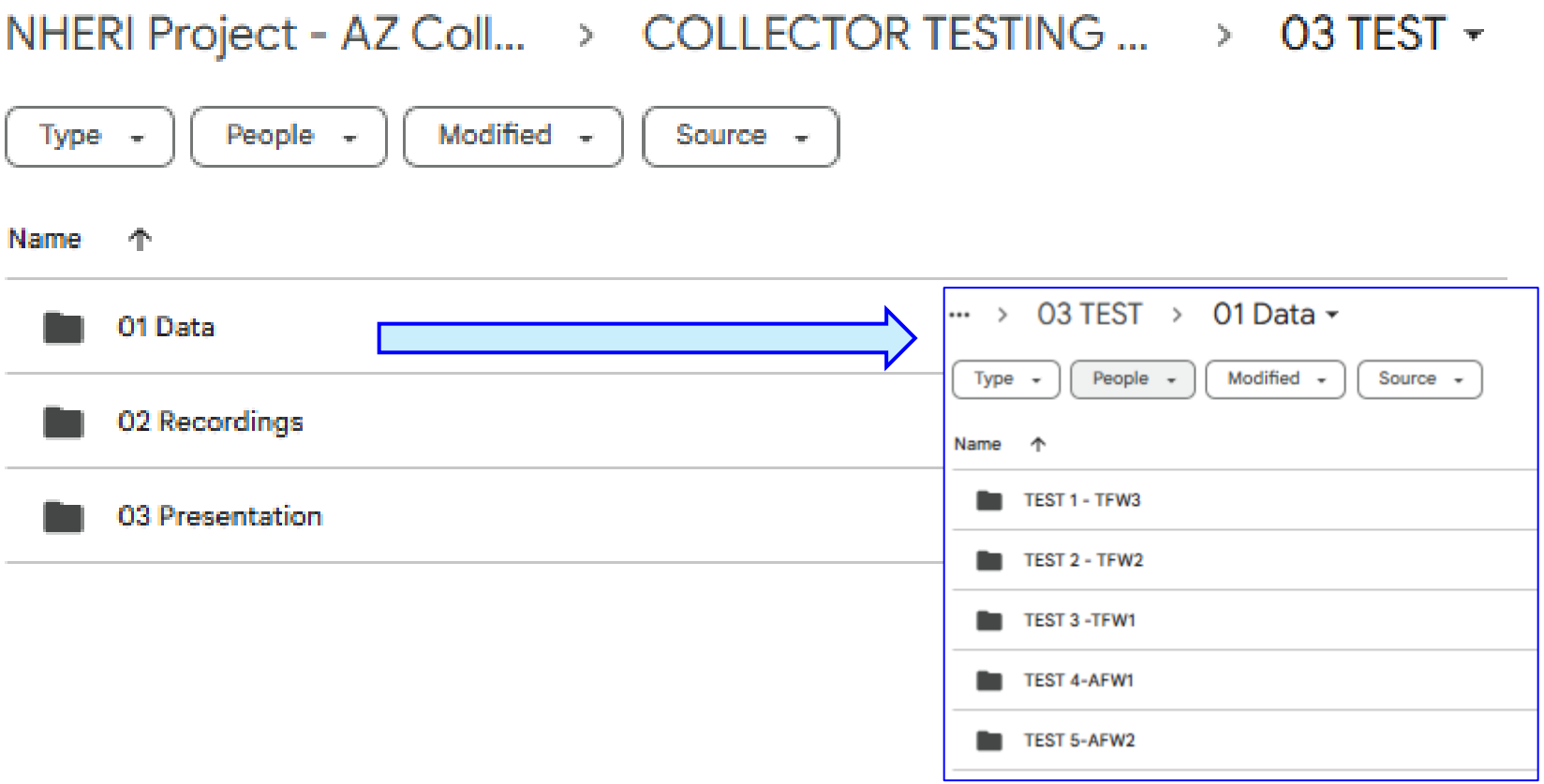
Comparison of Hysteretic Orbit



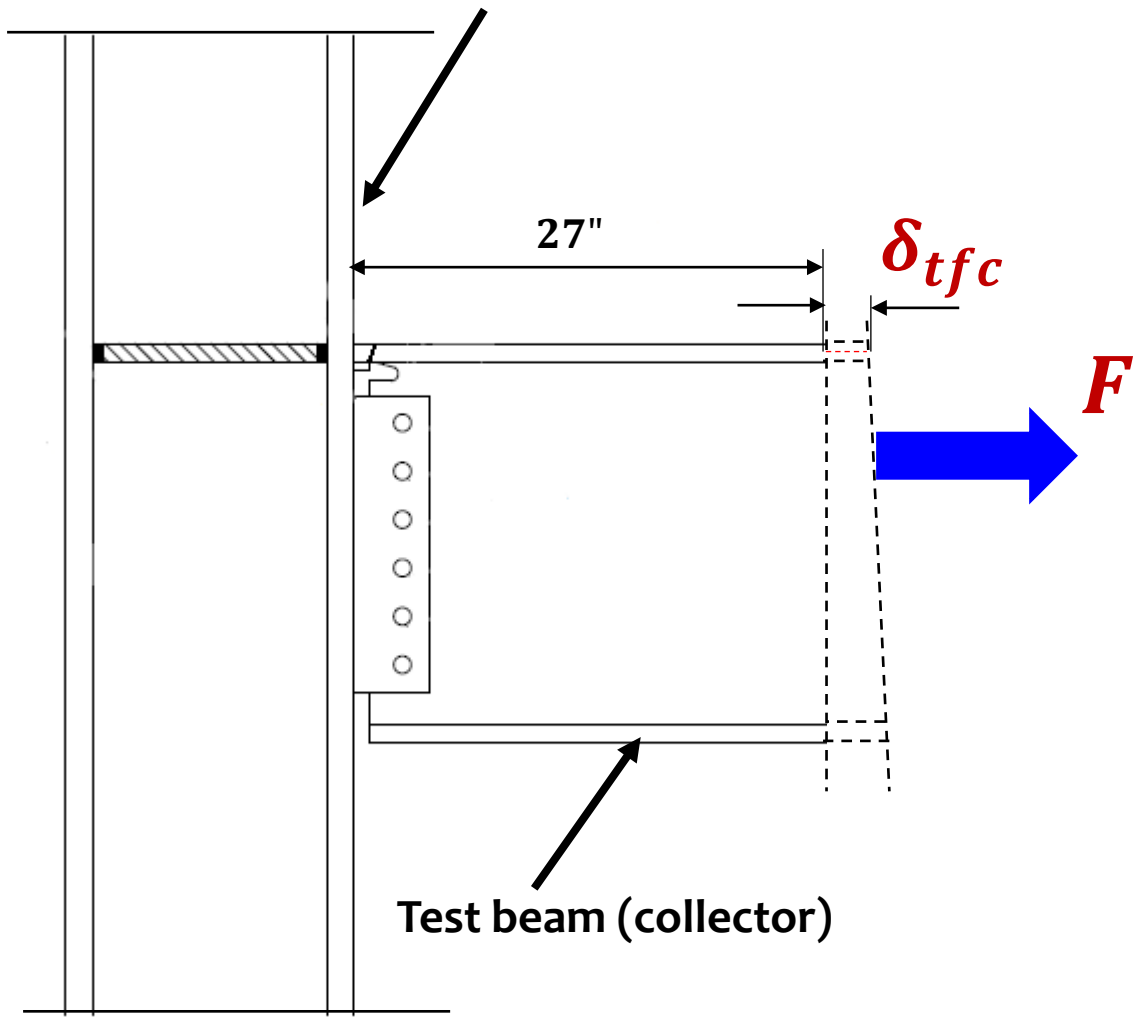
Videos

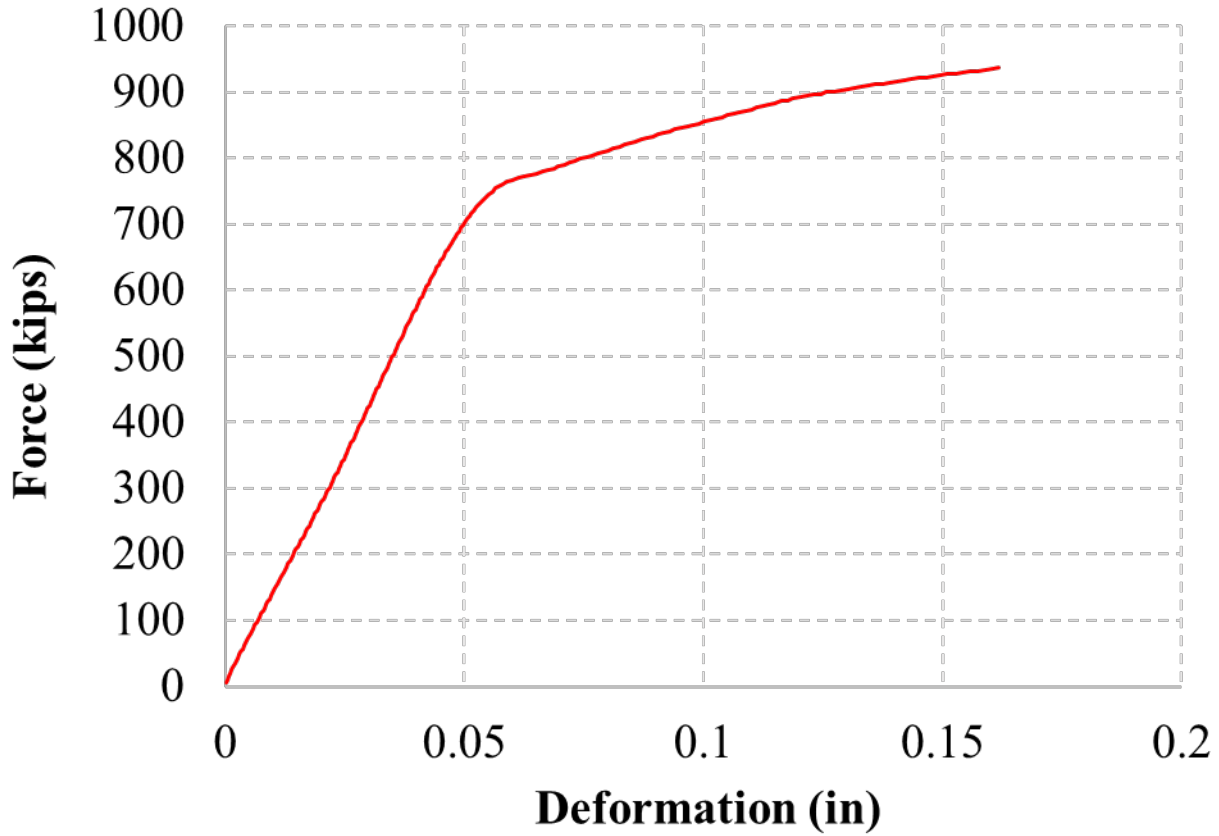
Test Data and Recordings

Test data and recording are distributed via shared drive



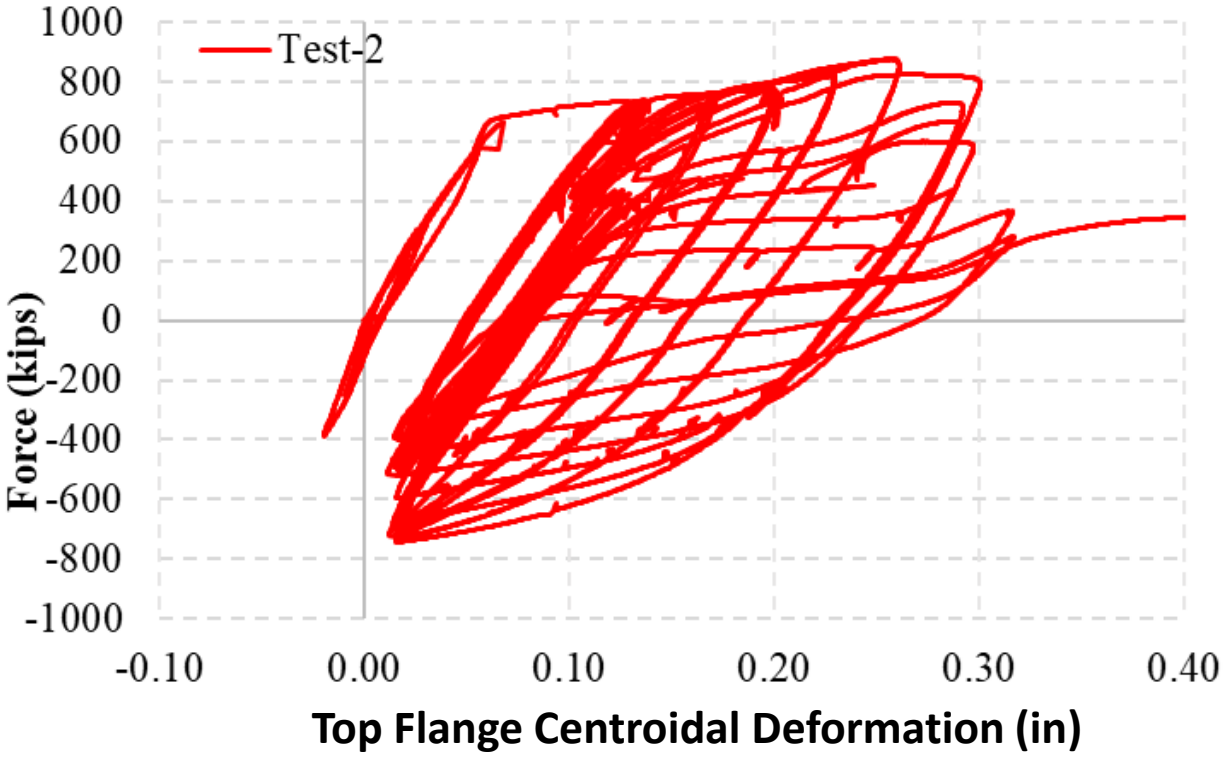
Collector Connection Behavior: TFW



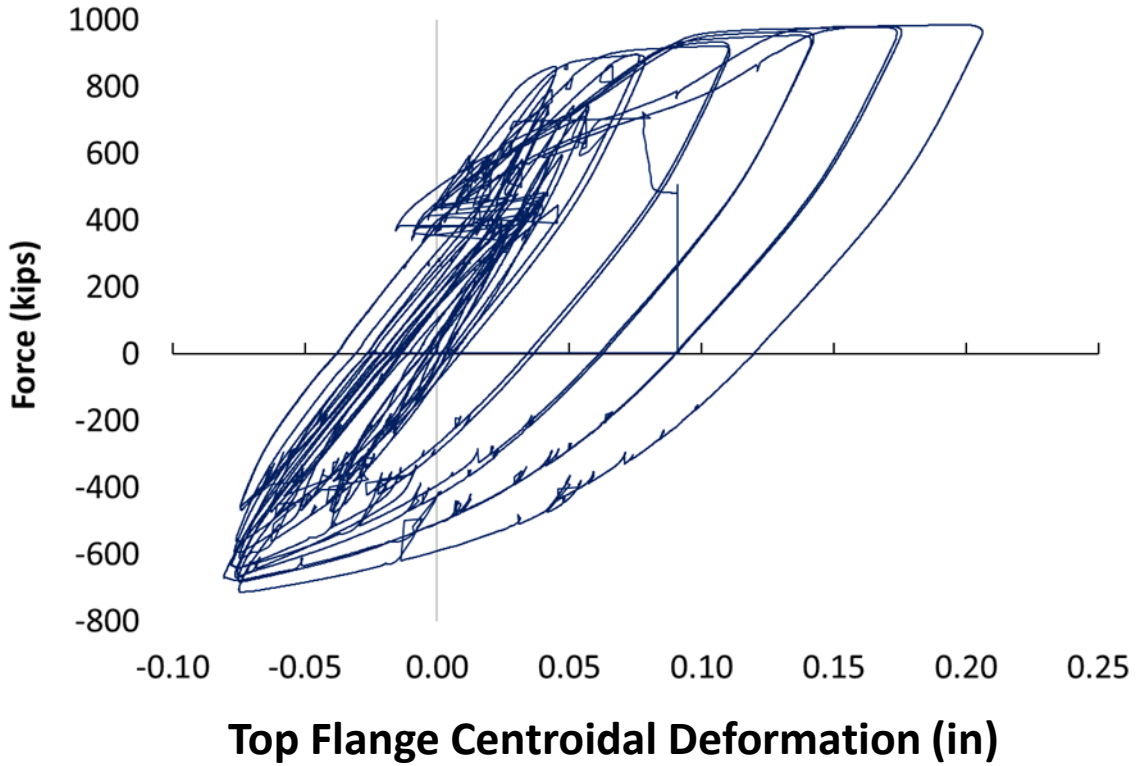


Key Results: TFW Connection Behavior

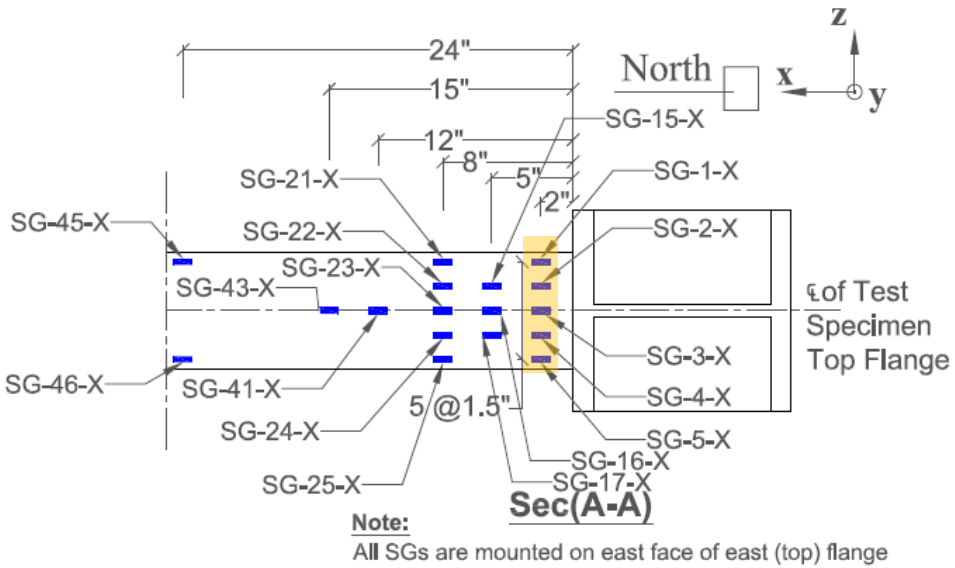
Test -2



Test -3

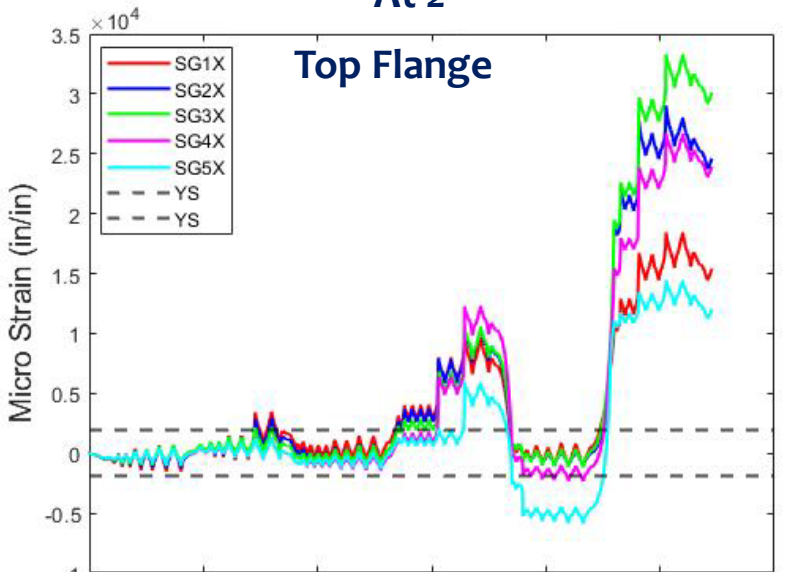


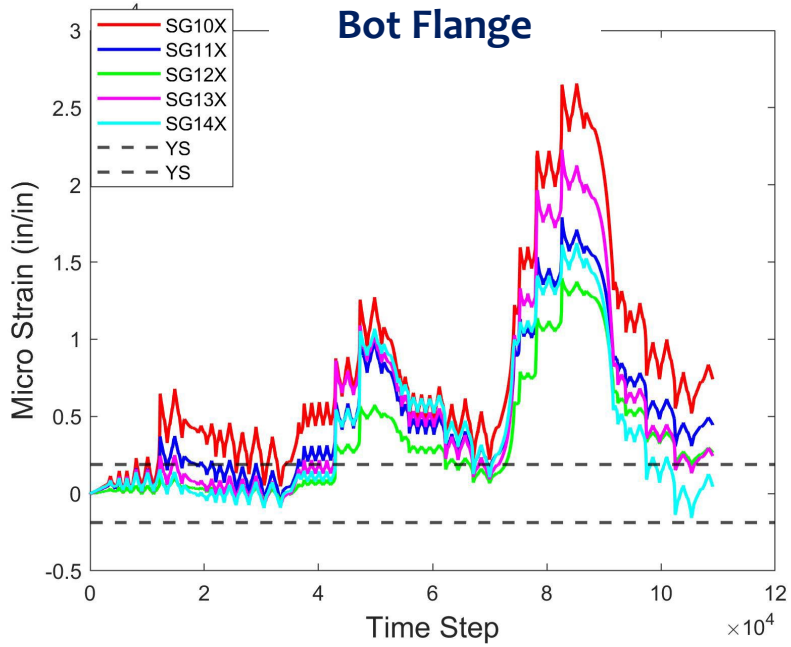
Key Results: Connection Region Strain



Instrumentation Plan on Top Flange (same layout on the bottom flange for AFW specimen)

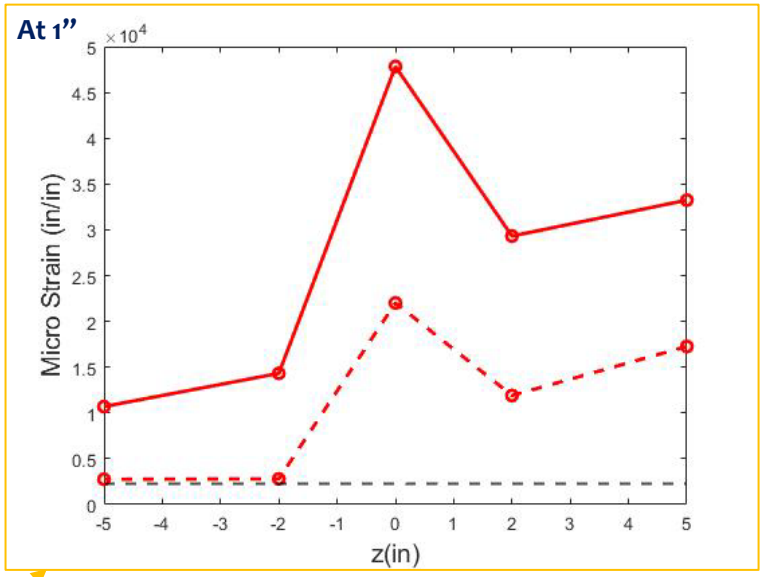
At 2”



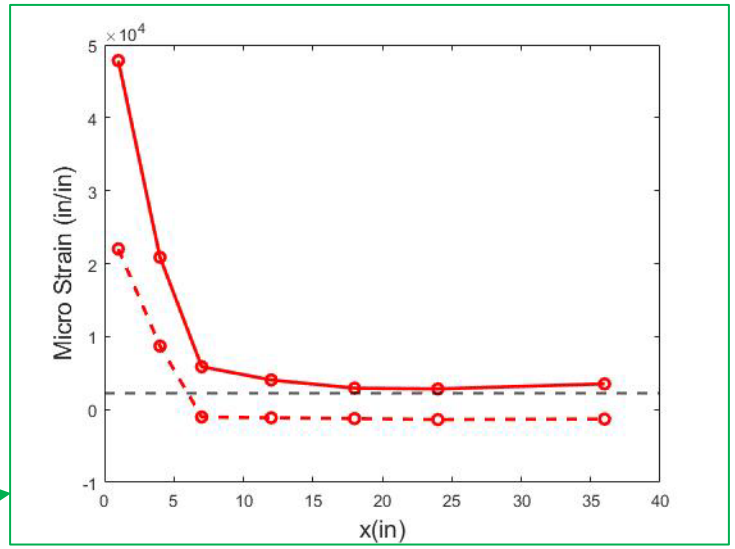


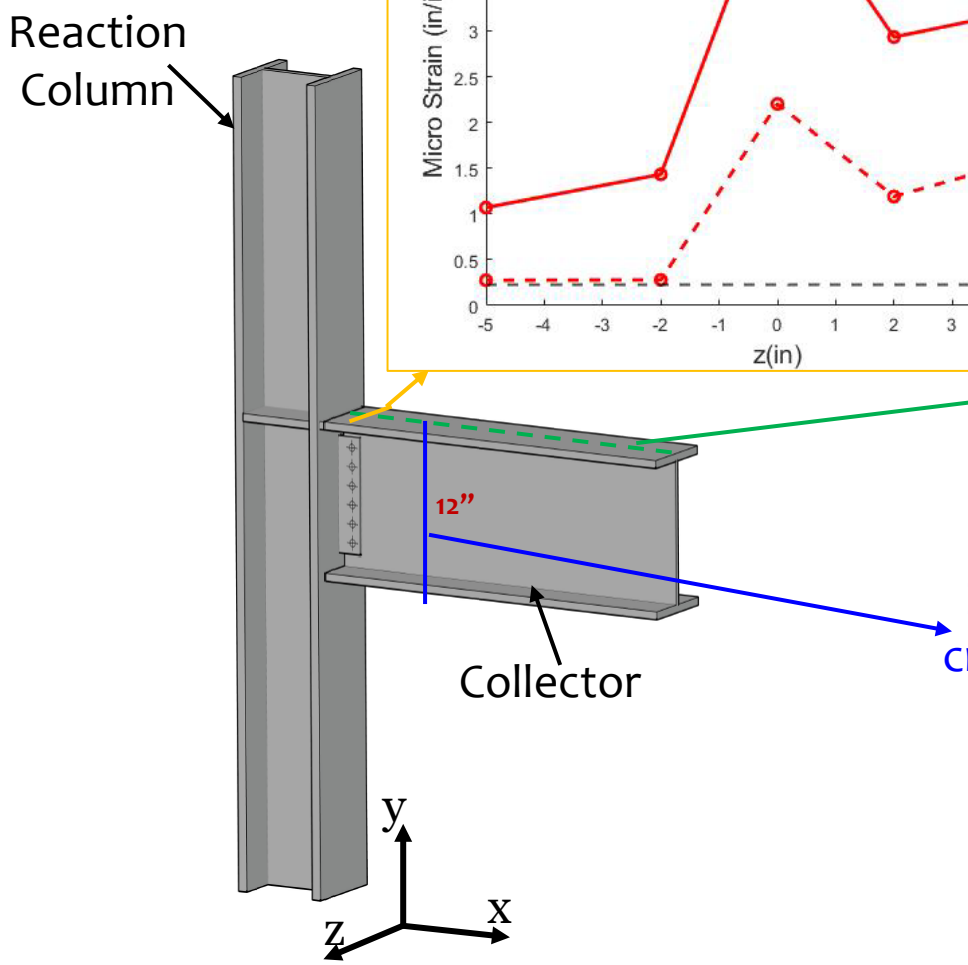
Key Results: Instantaneous Strain Profile

Profile across the transverse direction on TF

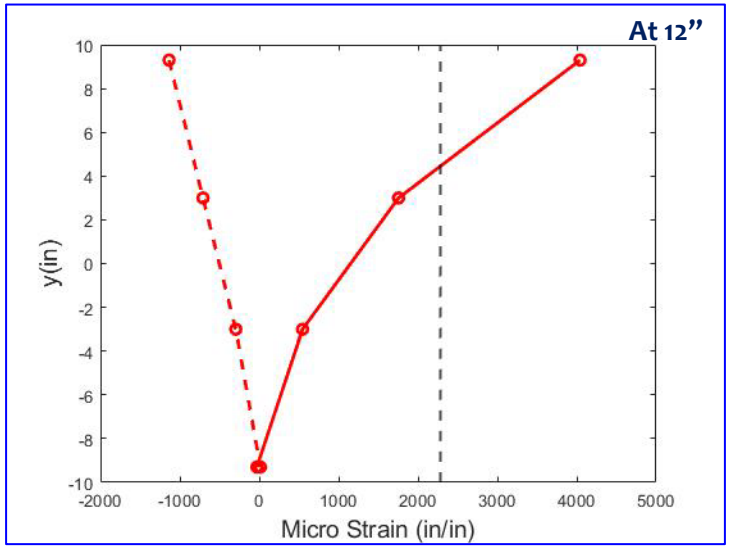


Strain profile on the longitudinal direction on the top flange





Profile across the cross section of the collector



Failure Mechanism: TFW (Test-2)

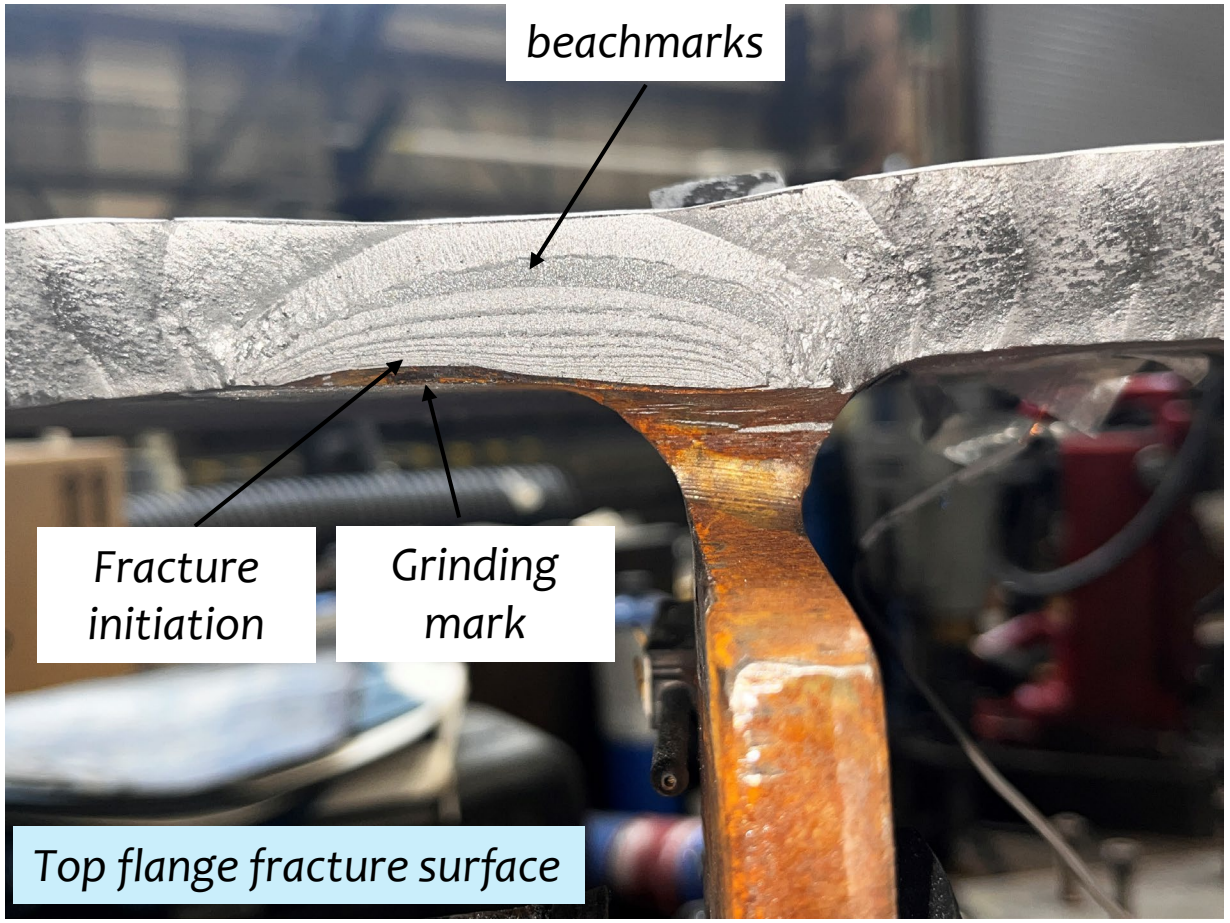
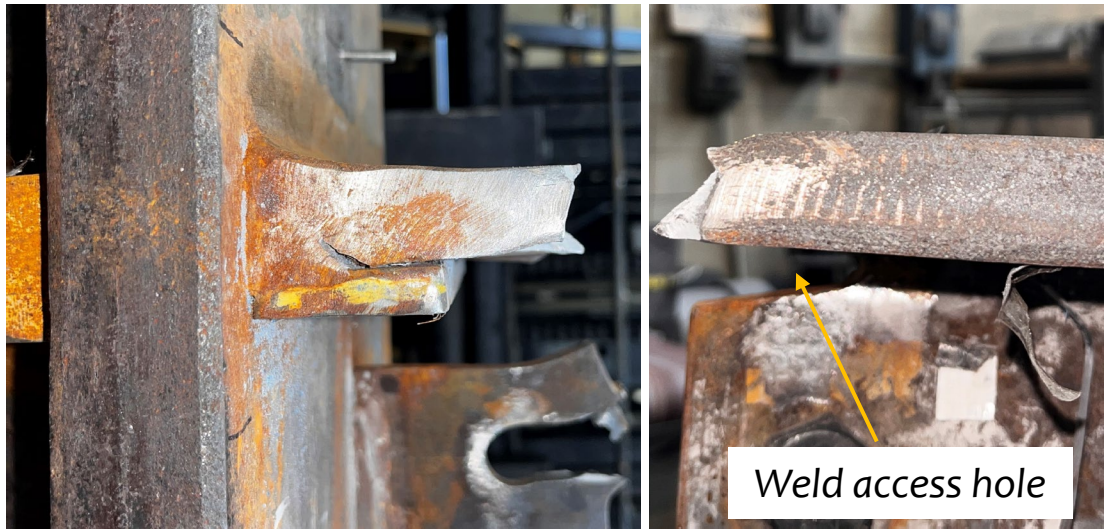


Fig: Test beam top flange



Observation:

- *Ductile failure started from the grinding mark*
- *Grinding marks are a common fabrication error that occurs from the grinding of edges during weld access hole preparation*
- *The crack initiated from the interior surface of the top flange at the location of a grinding mark and propagated through the thickness at the mid-region of the flange, as indicated by the beach marks. This suggests the crack grew under cyclic loading. Eventually, the crack extended across the entire flange, resulting in a complete fracture.*

Summary

- *Successfully applied various desired loading configurations to the collector connection*
- *Successfully completed testing of five large-scale collector connections.*
- *Currently working on four journal articles based on a large-scale experimental testing program.*