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Reimagining Risk and Resilience

Behavior of Seismic Collectors in Steel Building Structures

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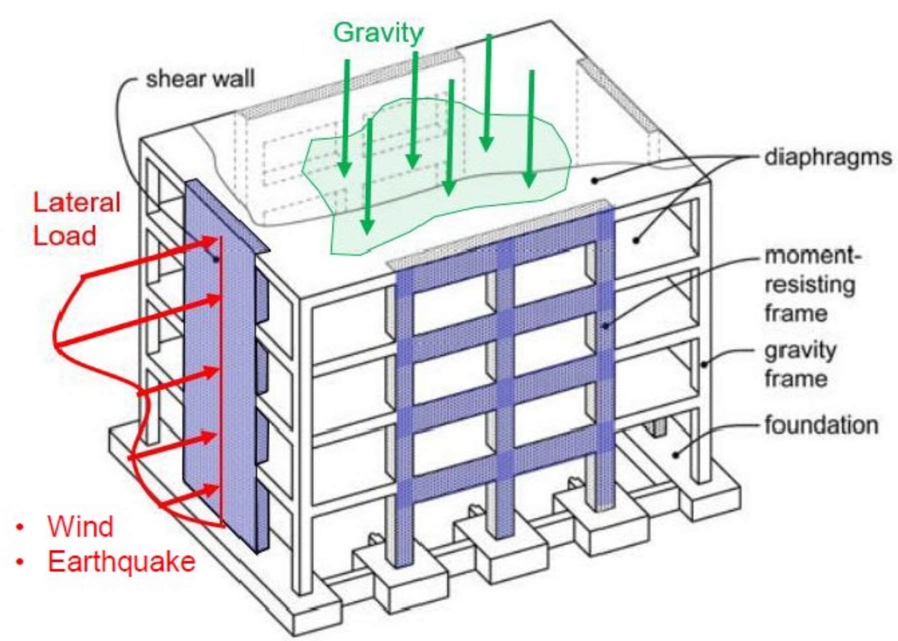
Wednesday, June 29

Outlines

- Introduction
- Test Program
- Analytical Study
- Modeling Approach
- Conclusion and Future Work

Lateral Load Resisting System



Systems	Types	Functions	Components
Gravity Load Resisting System (GLRS)	Vertical Elements	Support the gravity or vertical loads	Columns, etc.
	Horizontal Elements	Transfer gravity to vertical elements	Beams, Slabs, Deck
Lateral Force Resisting System (LFRS)	Vertical Elements	Transmit lateral forces from the upper levels to foundation	Columns, Bracing, Shear Walls.
	Horizontal Elements	Transfer lateral forces to vertical elements of the LFRS	Diaphragms, Collectors.

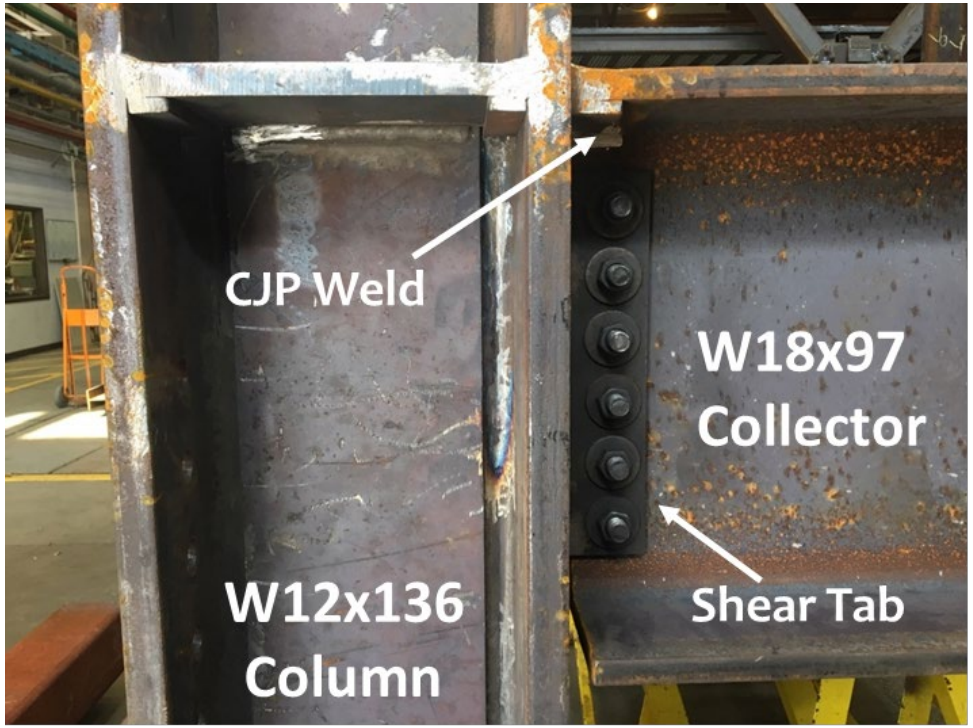
Seismic Collectors

- ***Critical elements that bring inertial forces to the primary vertical-plane elements of the Seismic Force-Resisting System.***

- ***Alternately carry tension and compression, while under the presence of effects from gravity load and frame lateral drift.***

- ***Collector failure is potentially catastrophic.***

- ***Current design code provisions rely on amplified collector design forces and simplifying design approximations.***



Research investigating

1. ***Nonlinear static and dynamic analysis of steel seismic collectors in steel composite floor systems and unfilled deck roof systems; and***
2. ***Large-scale testing of collector elements and collector connections.***

The research will provide new knowledge on

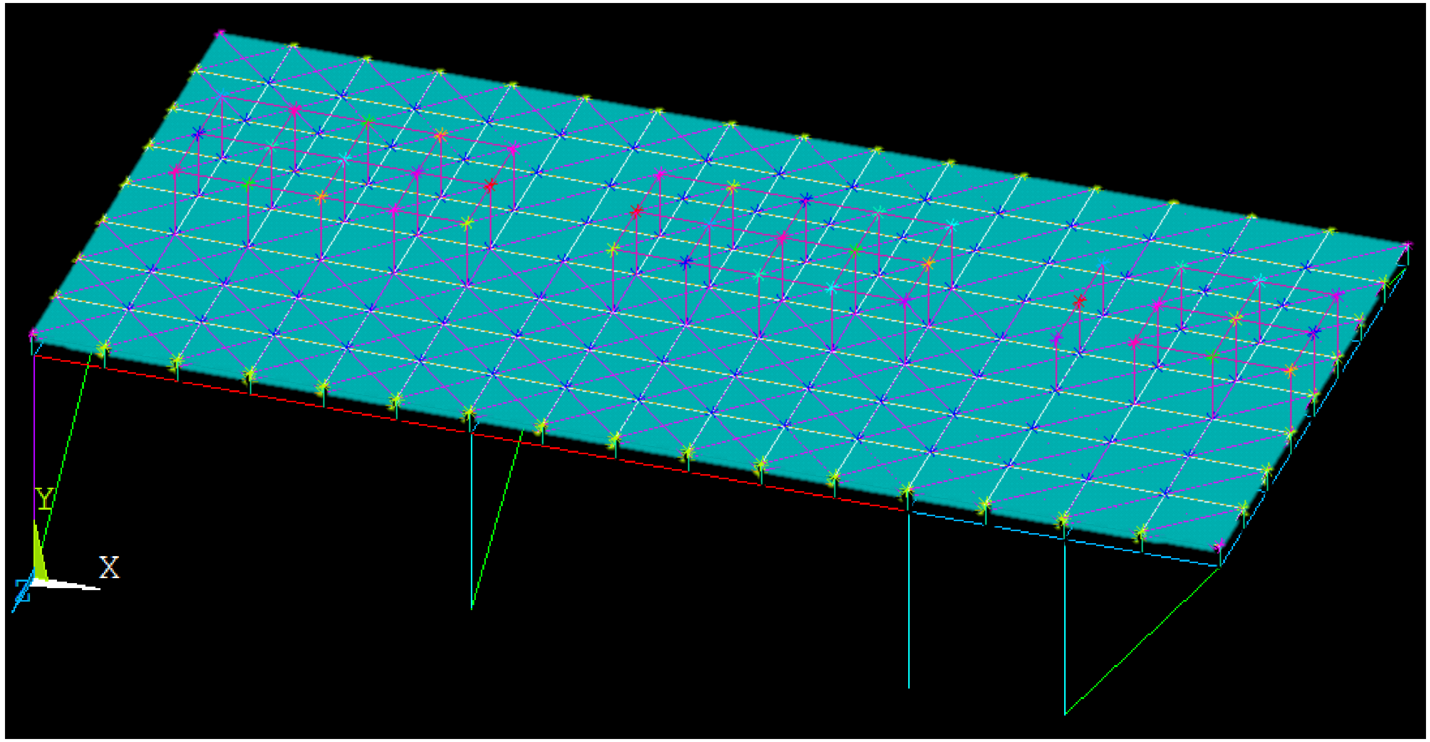
1. ***The collector seismic load path, including in the horizontal floor plane and the vertical force profile;***
2. ***Collector limit states, including collector connection failure and collector member stability modes;***
3. ***The role of the composite slab and deck in strut mechanisms and inherent bracing; and***
4. ***Collector properties (strength, stiffness and deformation capacity) in the presence of other actions (gravity load, frame lateral drift).***

Collector Load Path

Two-dimensional (2D) truss model in the (horizontal) plane of the floor in order to capture the strut action provided by the floor slab

The 2D horizontal truss model for the slab is connected to the underlying frame at the shear stud locations along the collector and gravity framing.

This model captures both concrete cracking due to inertial forces causing tension in the slab and the diagonal strut action due to inertial forces causing compression, including local crushing



Beam Truss Model

Beam Truss Model (BTM) (Lu and Panagioutou 2012)

Transverse and Horizontal Trusses

Pair of diagonal Trusses

Beta factor to account the reduction in Compressive strength due to normal tensile strain (Vecchio & Collins)

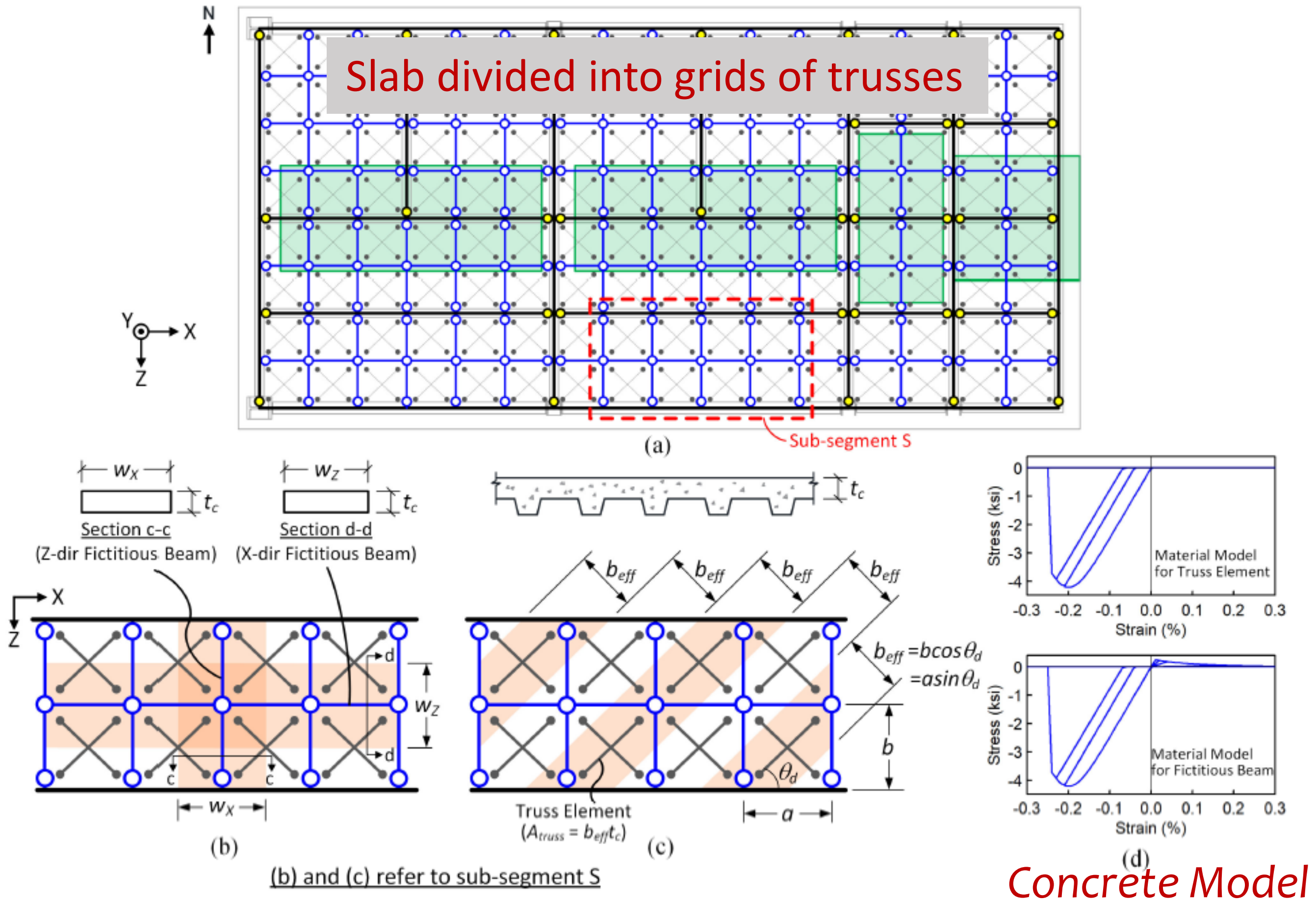
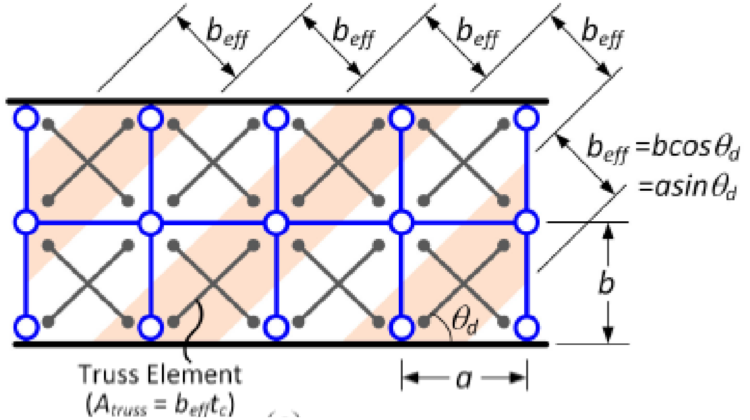


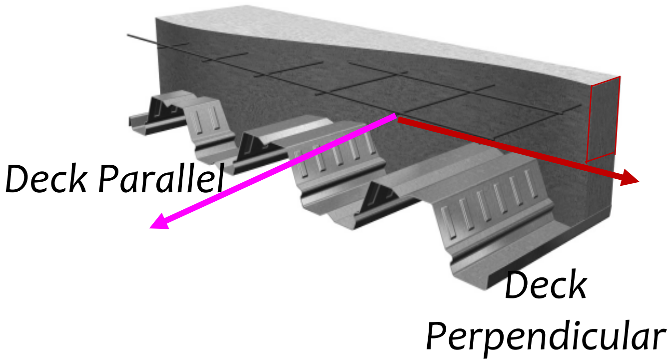
Figure 5.5 Schematic Description of Modeling of Concrete Slab Floor Diaphragm (Taking BT Model for Example)

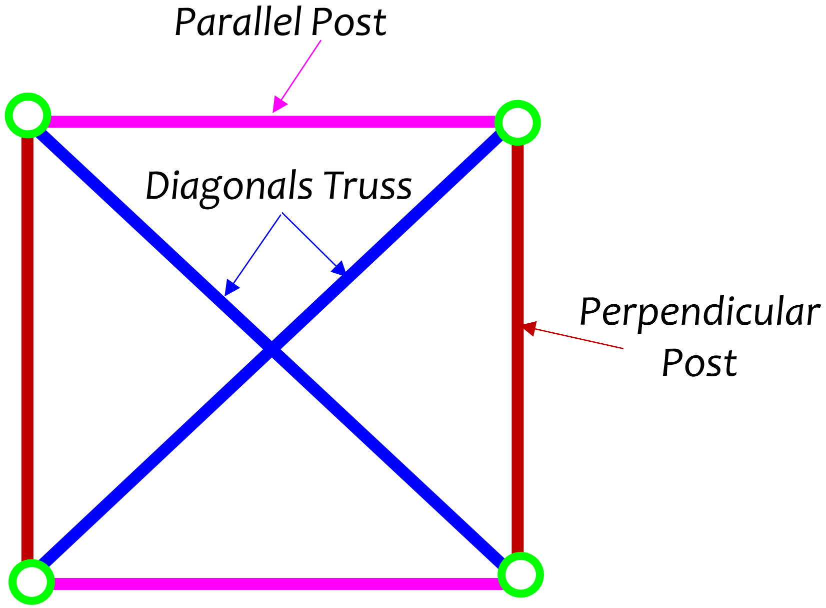
Chaohsien Li (2022)

Beam Truss Model

- ***Beam Truss Model (BTM) (Lu and Panagioutou 2012)***
- ***Transverse and Horizontal Trusses***
- ***Pair of diagonal Trusses***
- ***Beta factor to account the reduction in Compressive strength due to normal tensile strain (Vecchio & Collins)***
- ***Section Properties: Modified to match the axial and shear strength***
- ***Section properties of post are based on deck parallel and perpendicular section***







Validation of Truss Model

A steel plate was embedded in the top of the concrete blocks near the interior edge of the frame to facilitate the fastening of the steel deck sections to the south edge.

Blocks are anchored to the test floor by post tension 2in dia. high strength bolts

Flexible tee section were used to connect the edge beams with loading beam and south edge

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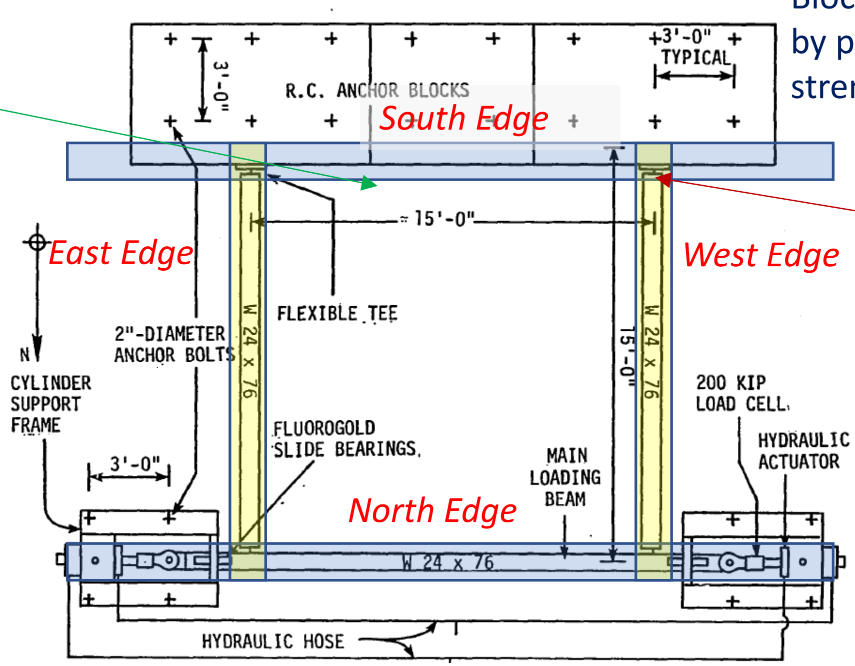


Two reversible hydraulic actuator, each has a capacity of 200 kips and both were driven with a closed loop servo-valve controlled system. The test frame was designed for a maximum load application of 400 kips.

Easterling & Porter 1994

Test No	Slab Thick (in)	Effective Thick (in)	Concrete Strength (ksi)	Deck Type	Deck Thick (in)	Edge Connectors (side)
10	2.2	3.756	3.3	5	0.062	60 Welds
9	2.58	4.0	5.412	4	0.058	60 Welds
13	2.53	4.04	6.187	4	0.058	60 Welds
19	2.75	4.25	2.681	9	0.062	60 Welds

Calibration of Truss Model

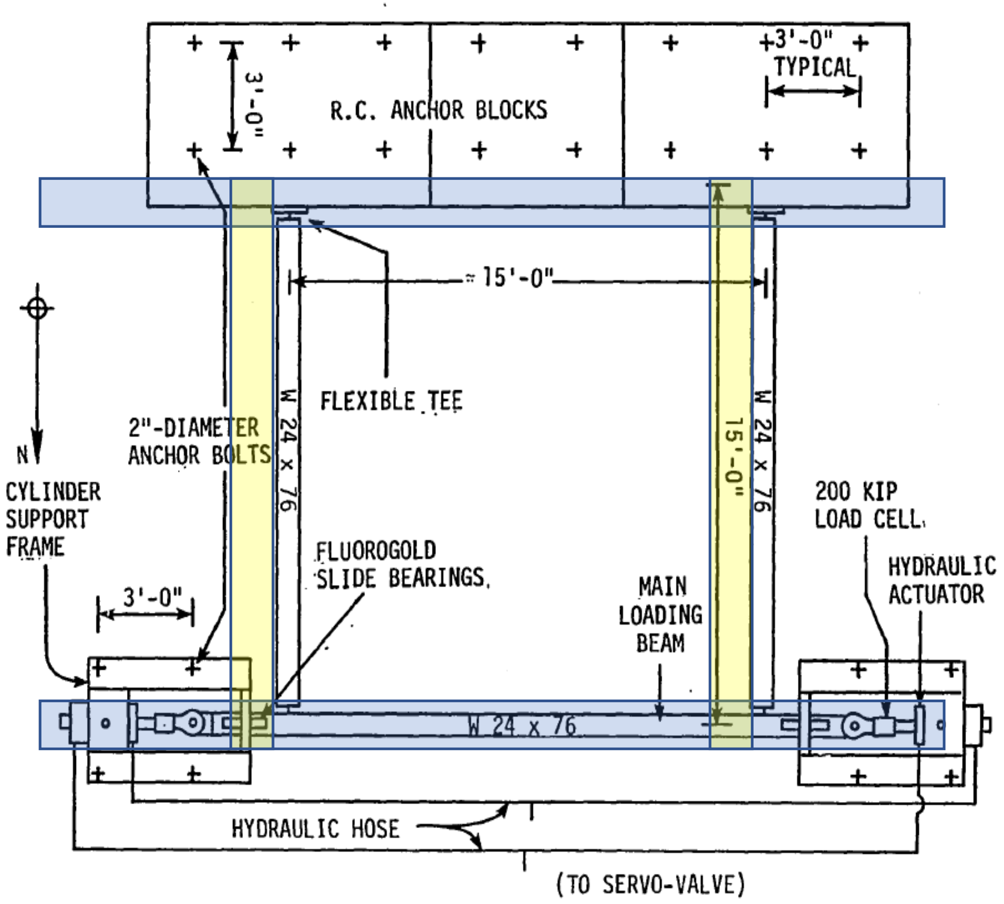
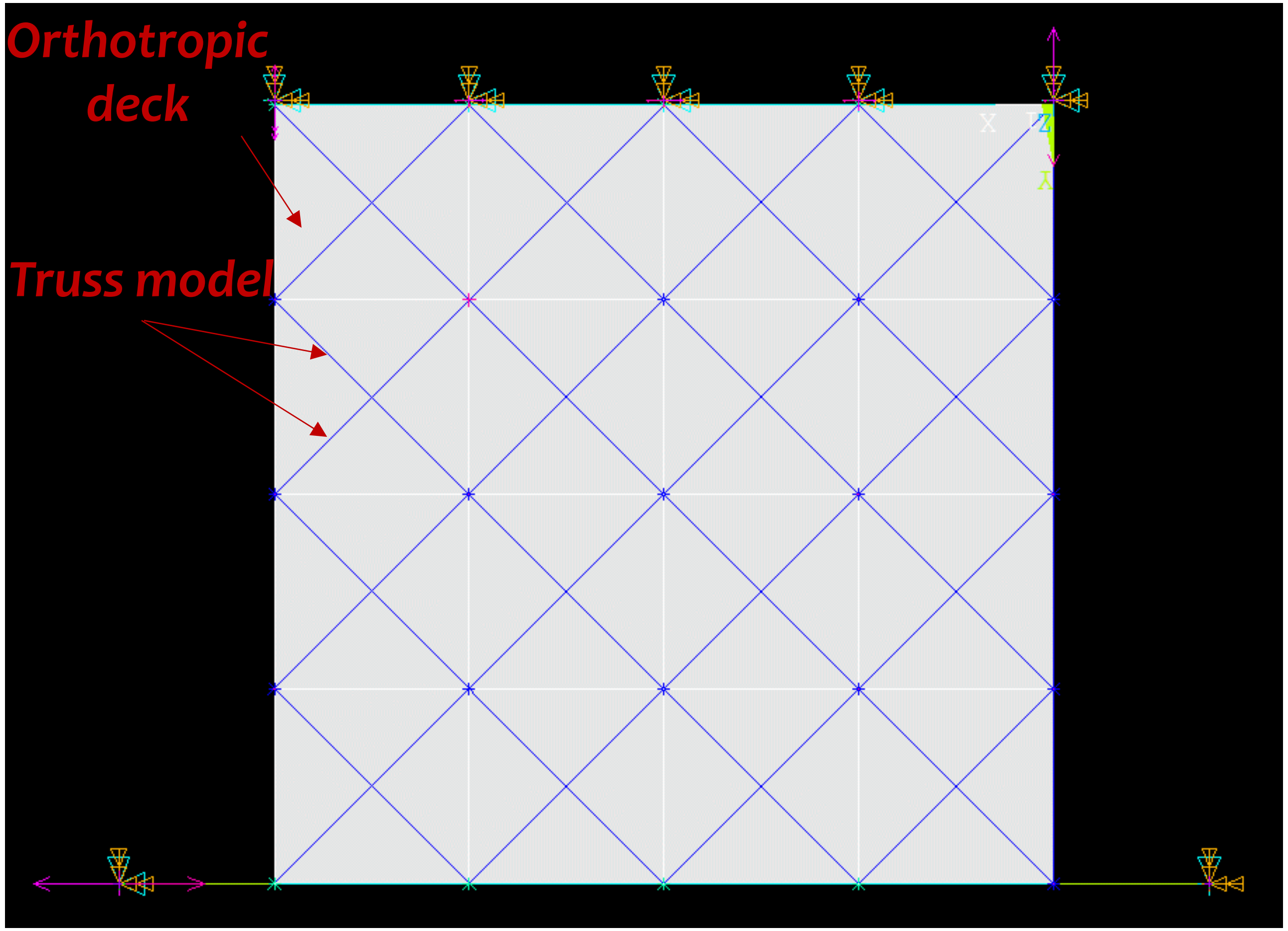


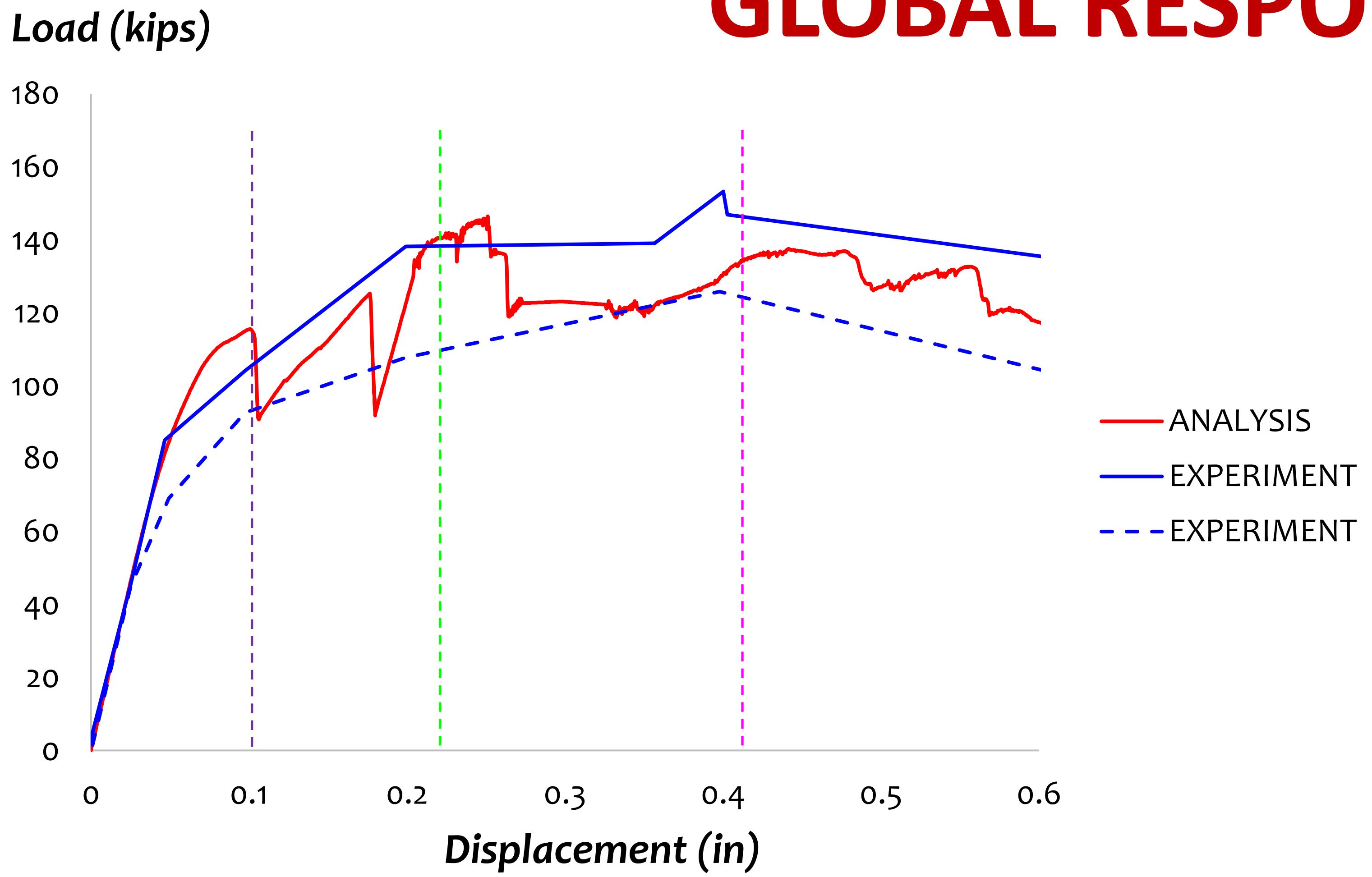
Figure 3. Diaphragm test frame schematic [11]

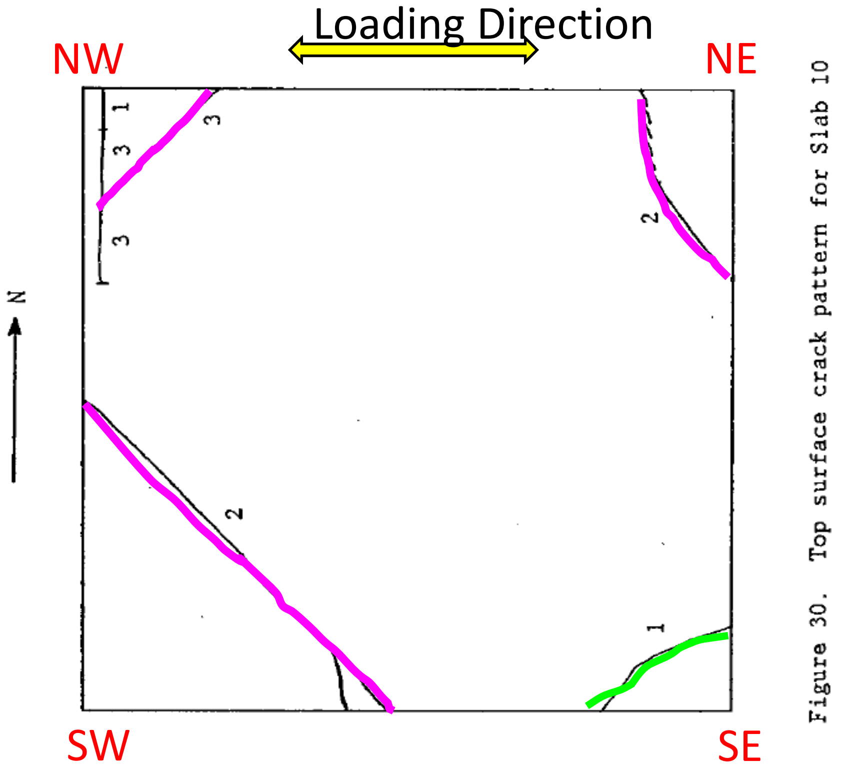
Test Setup



FE Model

GLOBAL RESPONSE

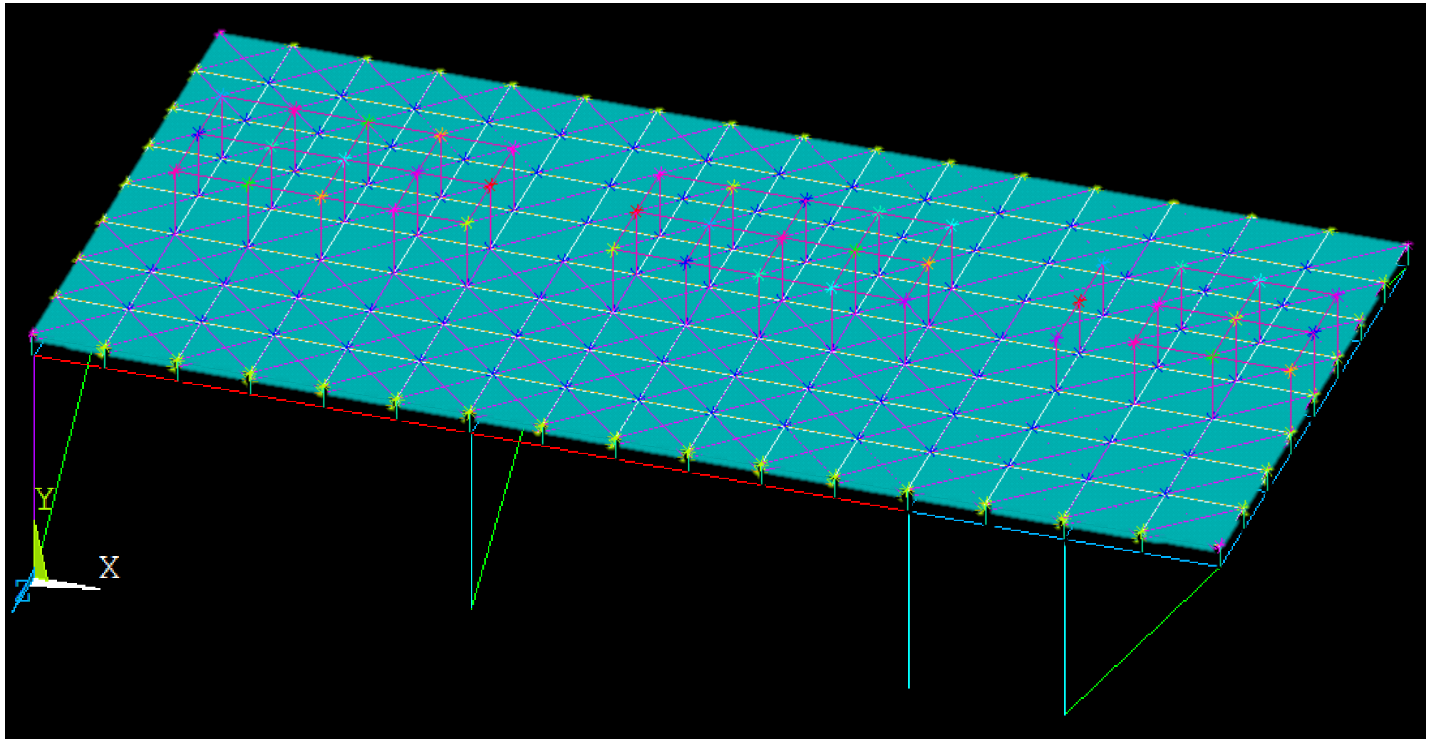




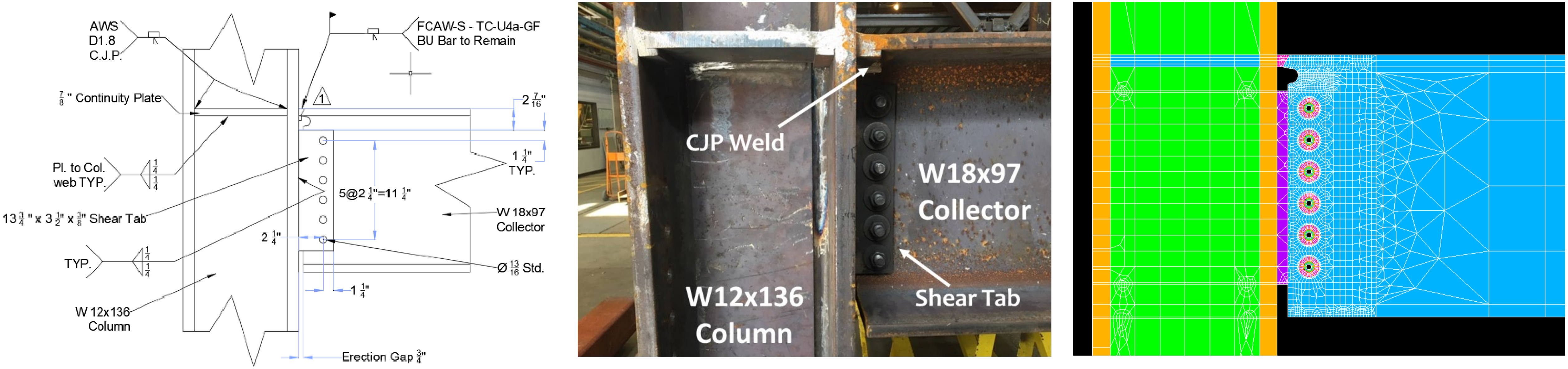
U_x = 0.1 in	*Diagonal cracks at the seams formed on the North and South faces of the slab*
U_x = 0.2 in west	*Diagonal cracks formed on SE and NW corners (crack 1)*
U_x = 0.4 in east, west	*Diagonal cracks formed on NE and SW corners (crack 2, crack 3)*

Collector Load Path

Verification of Truss Model with UCSD Shake Table Test



Collector Connection



TFW Collector Connection Testing: (a) Connection Detail; (b) Test Specimen; (c) FE Model.

- *Inertial force and transfer mechanism (via shear studs) occurs eccentrically to the centroid of the collector; and*
- *Some collector connections have an eccentric center of resistance.*

Collector Connection

Center of Force:

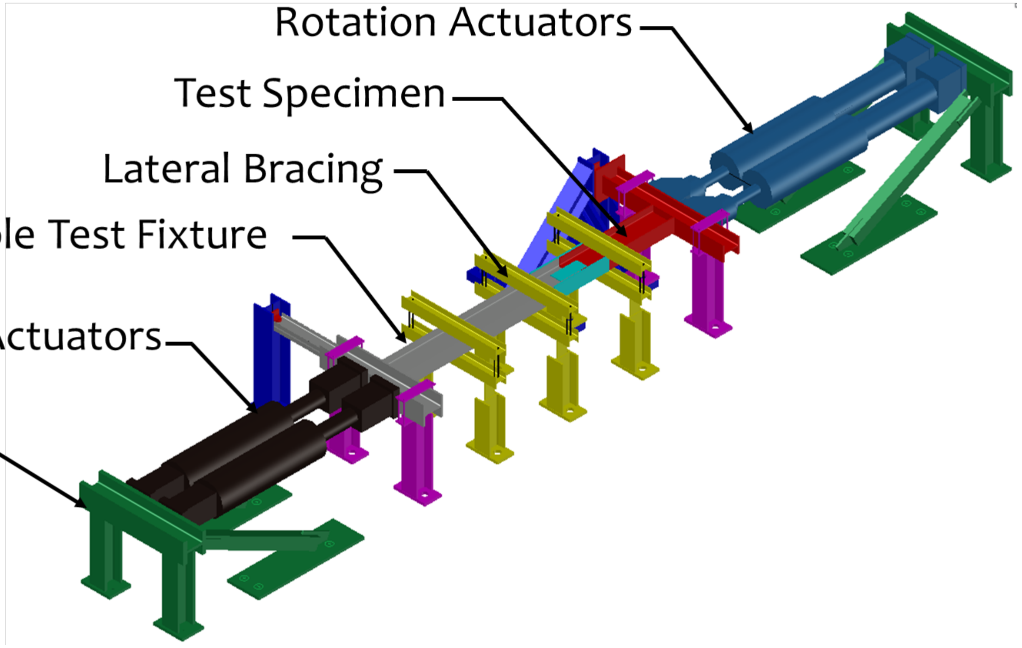
A pair of force-controlled actuators that can effectively simulate the center of applied collector force

Column Rotation:

A pair of displacement-controlled actuators that rotate the columns framing into the collectors to account for frame action

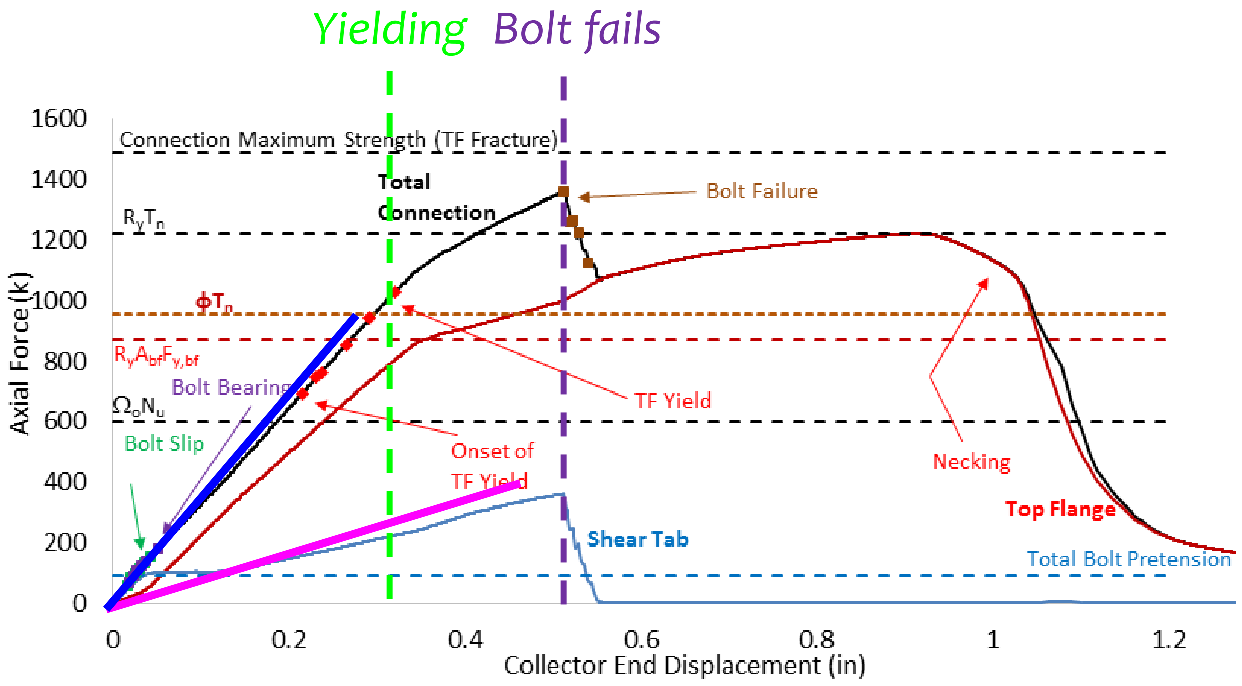
Floor/Roof System Bracing:

A short tributary width(~5') of the floor or roof system to simulate inherent floor/roof bracing

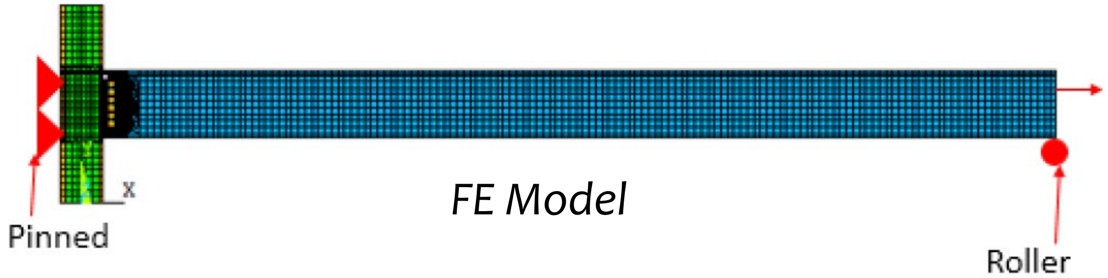


TFW Collector Connection Testing: Test Setup (Proposed)

Collector Connection



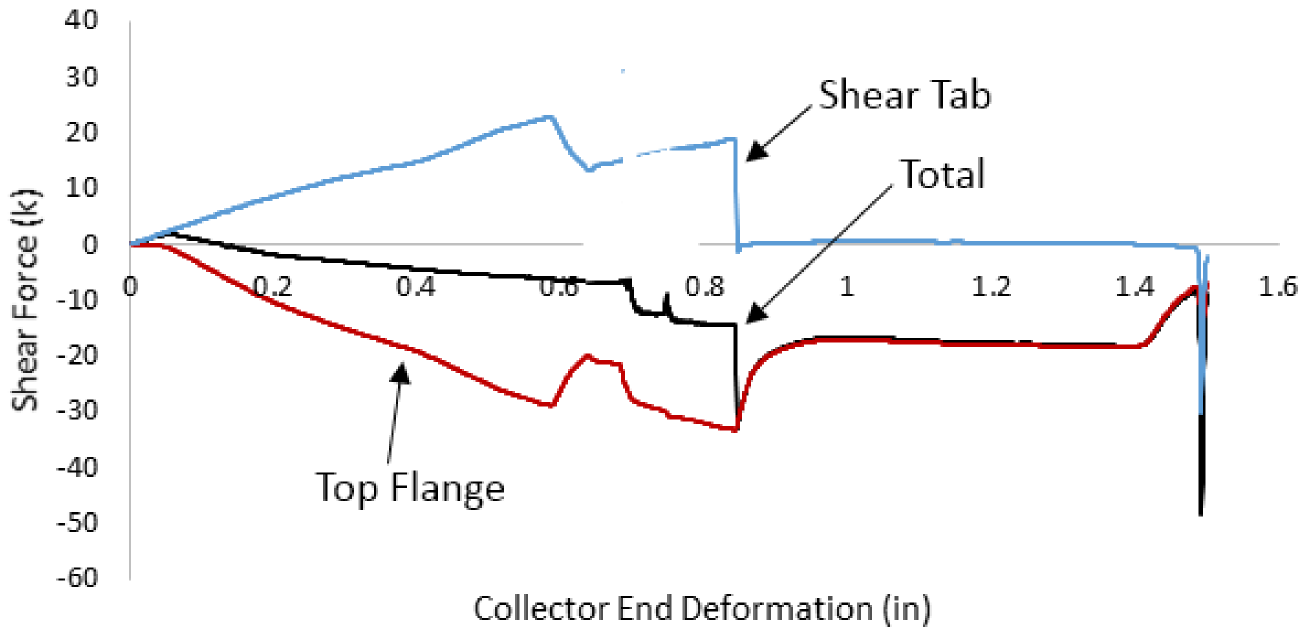
TFW Collector Connection Response: Pushover Analysis



FE Model

- ***The gravity shear tab connection provides a non-negligible contribution to the TFW connection stiffness and strength.***
- ***The shear tab, intended for gravity load transfer, participates in the collector force transfer.***
- ***Yielding of the flange connection does occur first, however the shear connection reaches a failure limit state first, due to combined tension and shear on the bolts.***

Collector Connection



TFW Collector Connection Response: Connection Force Distribution

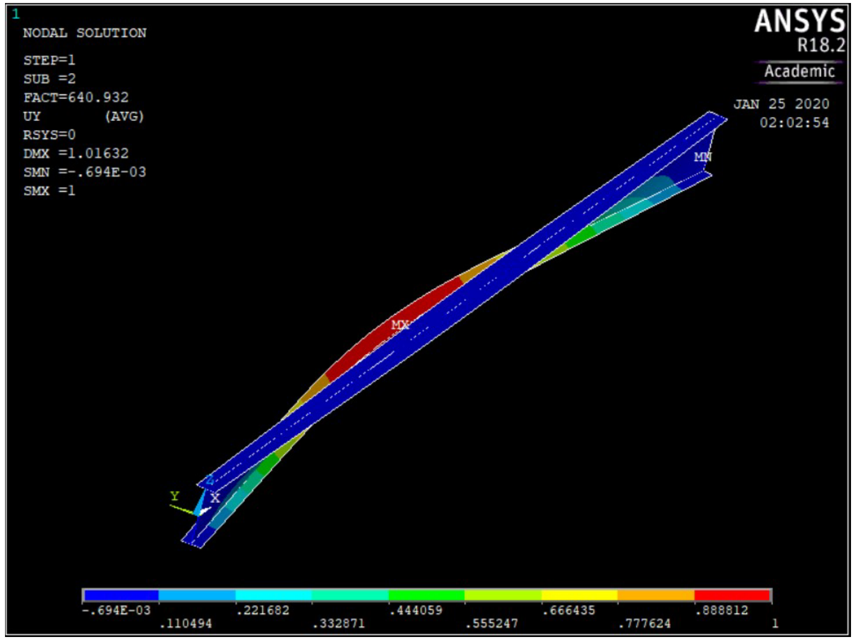
- ***The distribution of shear in the connection, here ignoring gravity load.***
- ***The shear tab and the top flange weld develop opposing shear forces, each significantly larger than the total shear induced by the connection eccentricity.***

Collector Stability

The analytical modeling of the collector member under compression load involves 3D nonlinear geometric and material modeling of the collector member.

Key aspects of the investigations of collector stability include:

- ***The determination of the inherent bracing of the floor system,***
- ***The participation of the slab in compression transfer, and***
- ***The effect of the connection boundary conditions, in particular during cyclic loading.***

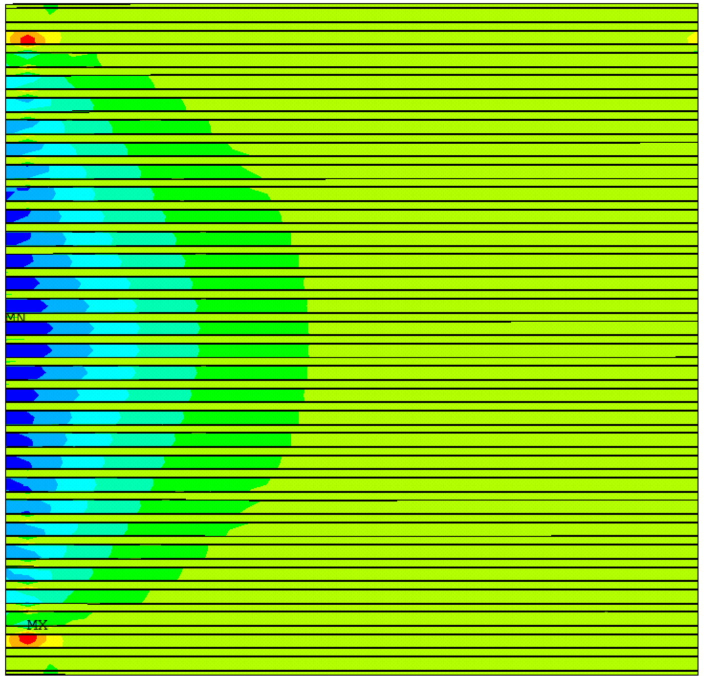


FE Model

Contour plot of transverse displacement for the isolated collector showing the collector is undergoing Constrained axis flexural torsional buckling (CAFTB)

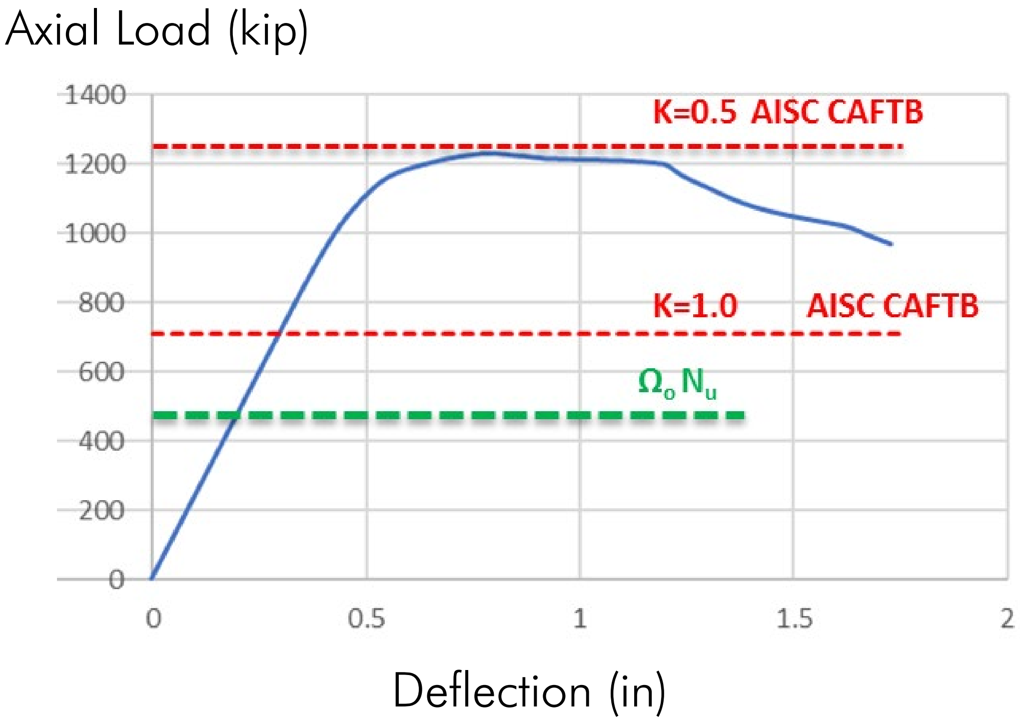
Collector Stability

Participation of deck/slab



- *A plan view of the bay showing the axial stress contour,*
- *Blue indicating high compression,*
- *Slab participating in force transfer as a collector member loses stiffness, even for deck oriented perpendicular to the collector;*

Collector load deflection plot



The design code prediction of collector compressive strength is well estimated in this case using the CAFTB limit state equation with an effective torsional length factor of 0.5.

Conclusions

1. The participation of the floor slab in strut action should be considered in the load transfer of the floor inertial forces to the collector system

2. The portion of the connection intended for gravity load transfer and the local slab should be considered in the collector force transfer across the collector connection

3. The controlling stability limit states for the collector depend on the floor or roof system parameters. Design expressions for collector compression strength provide good bounds to analytically-obtained response. The role of the collector connections in the cyclic response requires further investigation

4. The interaction of collector axial force and moment due to inter-story frame drift needs to be accounted in collector design

Questions

Shake Table @ UCSD

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