Dissipative base connections for moment frame structures in airports and other transportation systems

Amit Kanvinde, UC Davis
Ahmad Hassan, UC Davis

17 January 2020

Project Team and Collaborators

UC Davis
- Amit Kanvinde, PI
- Ahmad Hassan, PhD Student
- Tomasz Falborski, former postdoc now faculty at Gdansk University, Poland
- Vince Pericoli, former postdoc now Engineer at Sandia Labs

PEER BIP Partner, Forell Elsesser
- Mason Walters
- Ali Roufegarinejad
- Geoff Bomba

UC Irvine (collaborator)
- Farzin Zareian
- Pablo Torres Rodas, now faculty at Univ San Francisco de Quito, Ecuador

Brigham Young University (adviser)
- Paul Richards

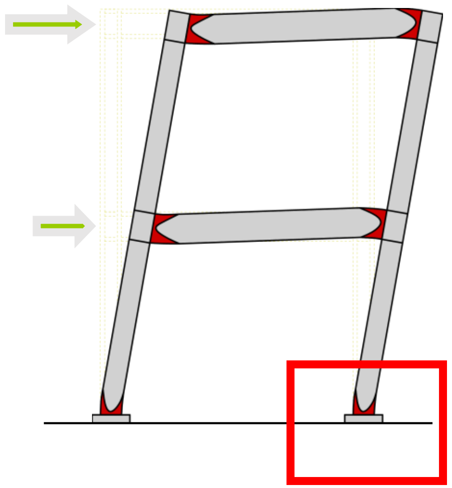
University College London (UCL) (collaborator)
- Carmine Galasso
- Biao Song, PhD Student

Acknowledgments

- PEER
- American Institute of Steel Construction
- Charles Pankow Foundation
- California Strong Motion Instrumentation Program, CA Department of Conservation

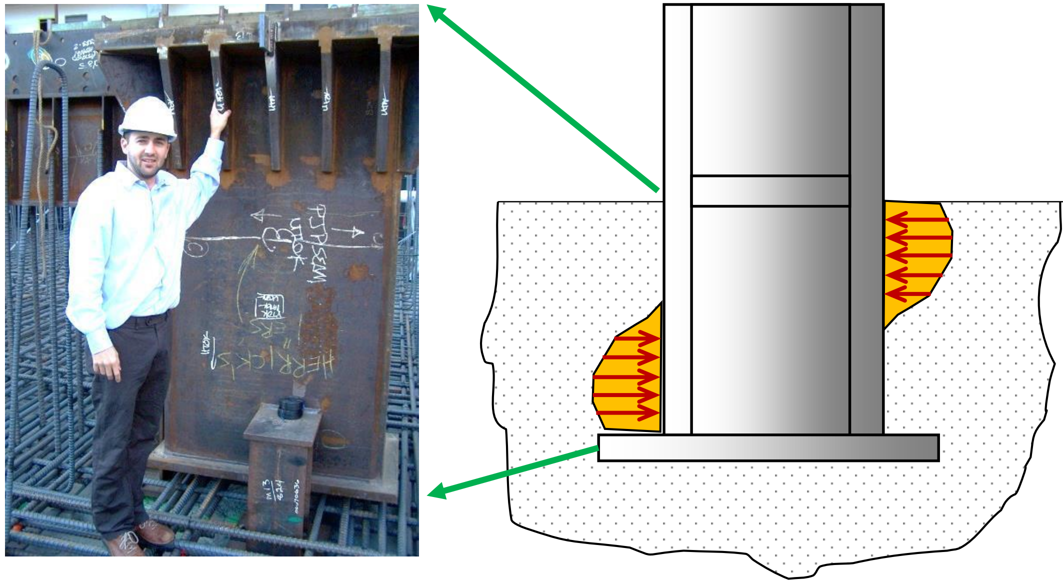
Overview

- Steel Moment Resisting Frames and buildings are critical to airport (and other transportation) infrastructure
- Research on column base connections in SMRFs has lagged research on other connections
- Implications for connection as well as frame design



Specific Issues

- Designing bases to be stronger than columns is impractical and expensive
- No information on systems with weak bases
- No experimental data on several common base connection details
- Design does not usually account for interactions between base connection and frame



Overall Research Plan

PEER (SIMULATION BASED SYSTEM STUDIES)

- Component models for strength/stiffness/hysteresis
- Demonstrate frame performance with dissipative/flexible bases
- Methodology to design frame-base system with such bases
- Motivate research on ductile and repairable bases

DEMANDS

AISC + CHARLES PANKOW FOUNDATION (EXPERIMENTAL COMPONENT STUDIES)

- Untested details
- Unbonded dissipative elements to localize yielding
- Resilience

COMPONENT MODELS

MODEL VALIDATION

CA STRONG MOTION INSTRUMENTATION PROGRAM (VALIDATION AND BENCHMARKING)

- Moment Frame Buildings
- Range of foundation types

OUTCOMES

- Design methodology for Frames with Weak Bases
- Rigorous Consideration of base-frame interactions
- Details that make this possible + data on untested details

- Code changes (e.g., AISC 341)
- Design Guide One update, Design Manual Updates

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HILTI (FEM SIMULATIONS)

- Biaxial Bending

UCL & UC DAVIS (RELIABILITY STUDY)

- Exposed Base Reliability Analysis

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- Nonlinear simulation of archetype frames with dissipative bases
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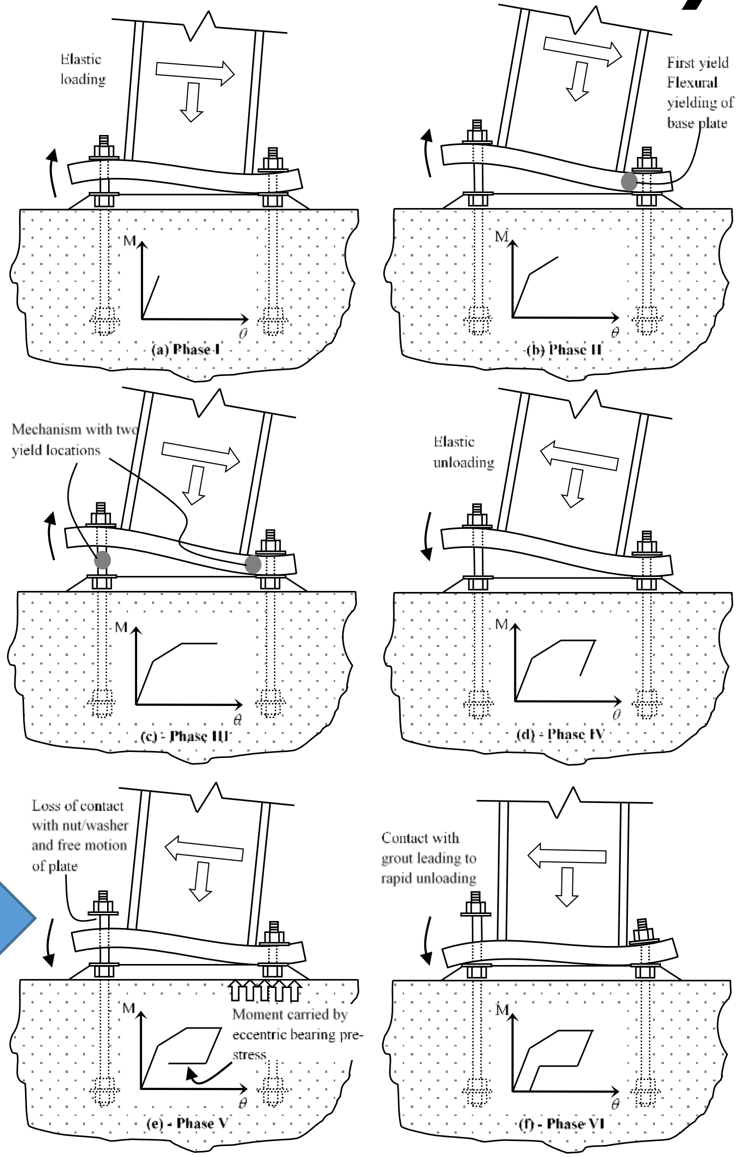
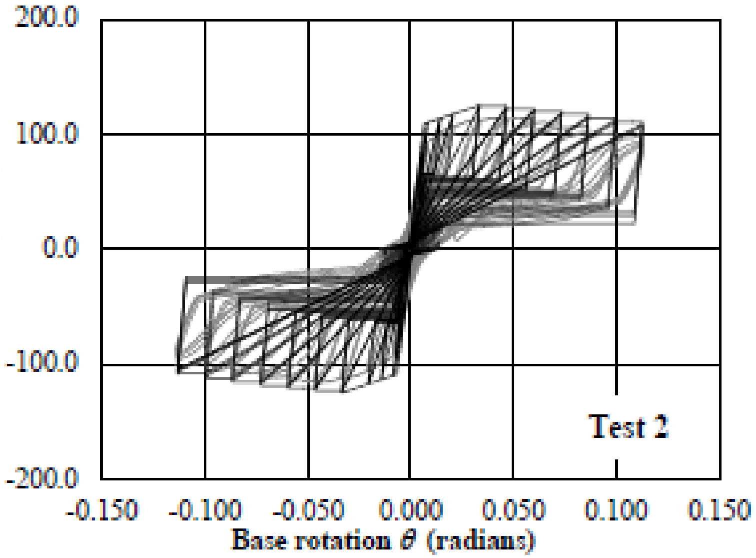
Component Hinge Models (for exposed and embedded type connections)

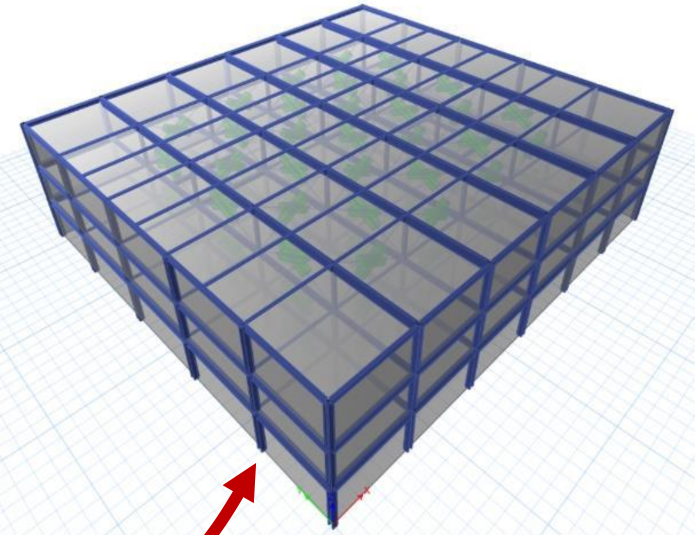


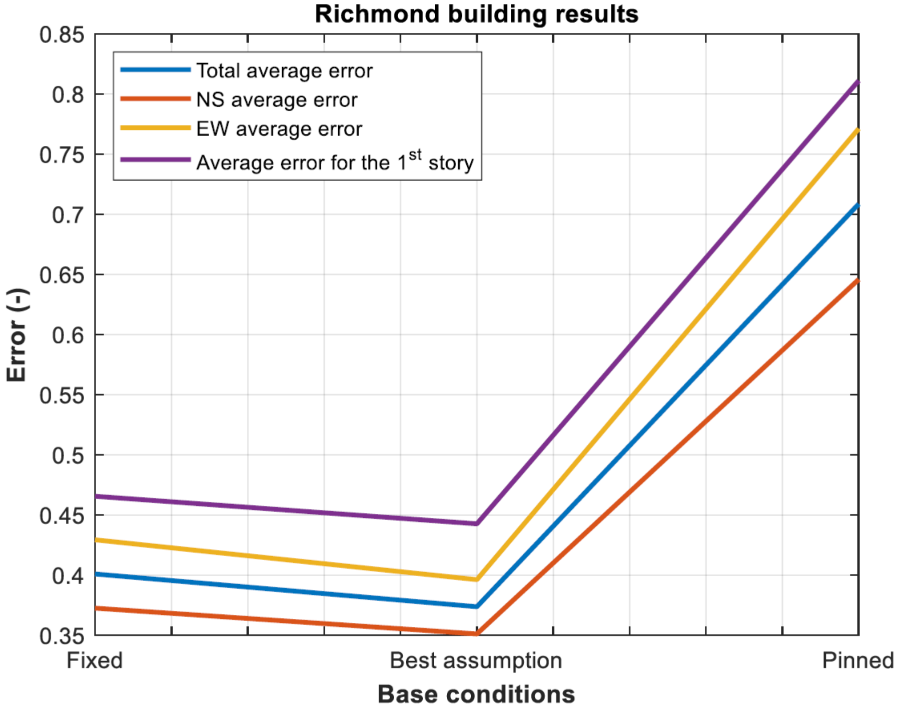
CALIBRATION RULES

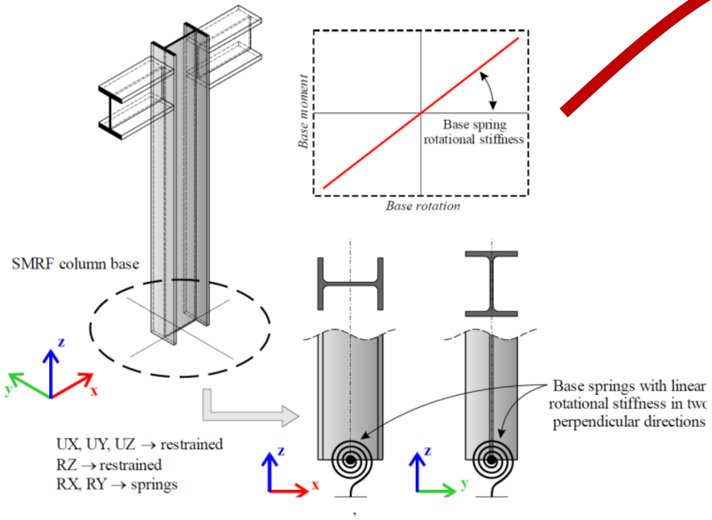
PHYSICS-BASED FUNCTIONAL FORM



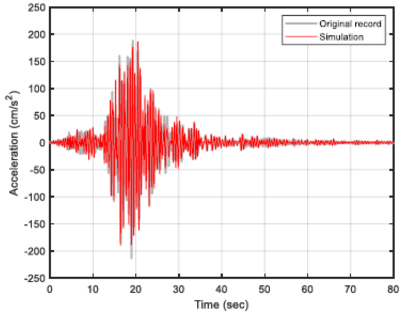
CSMIP Project on Base Flexibility





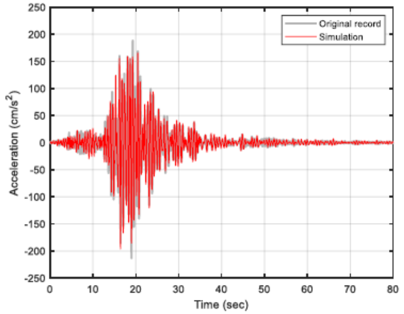


Fixed



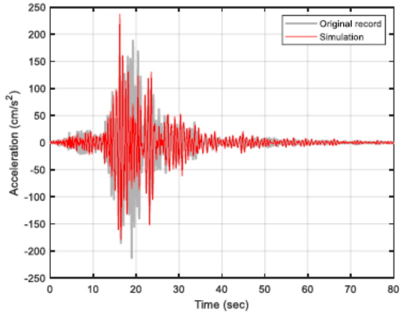
Error = 0.449

With base springs



Error = 0.3519

Pinned



Error = 73.81

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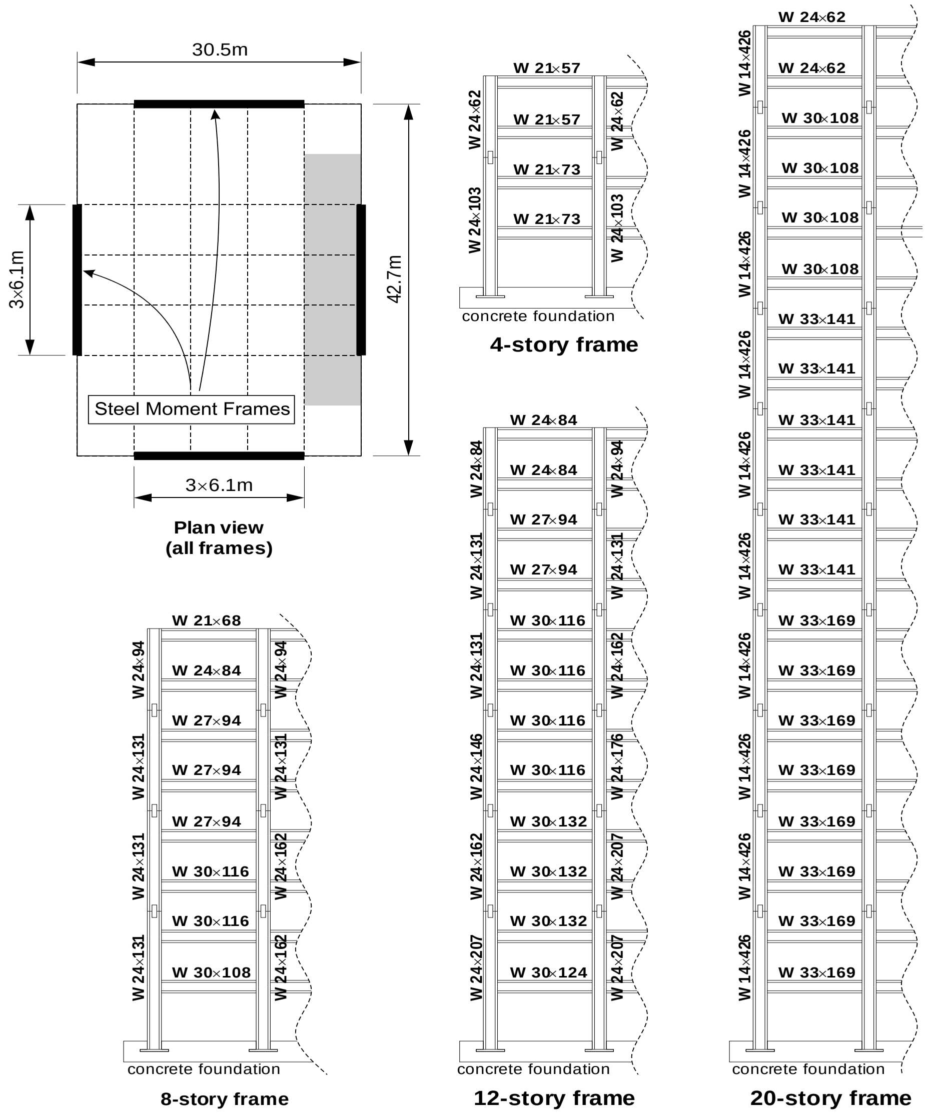
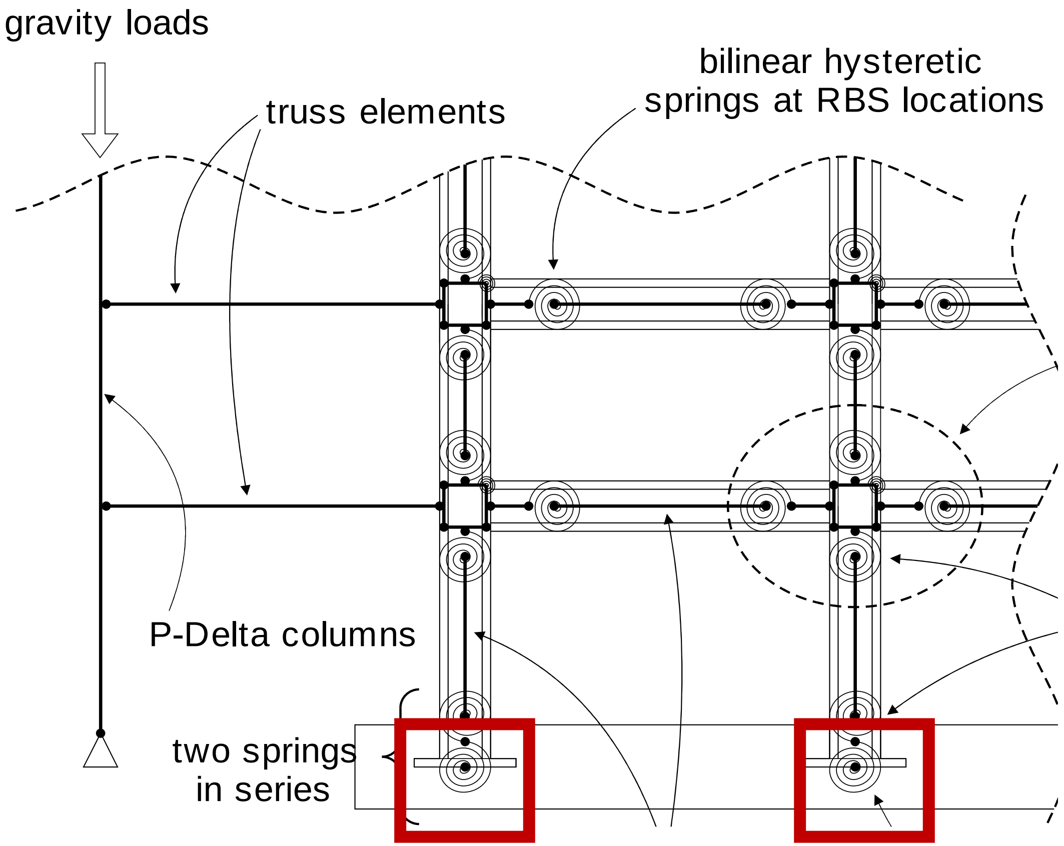
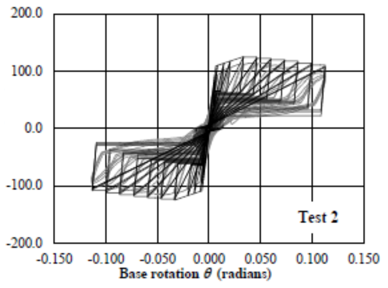
FEMA P695 Parametric Study using base connection models

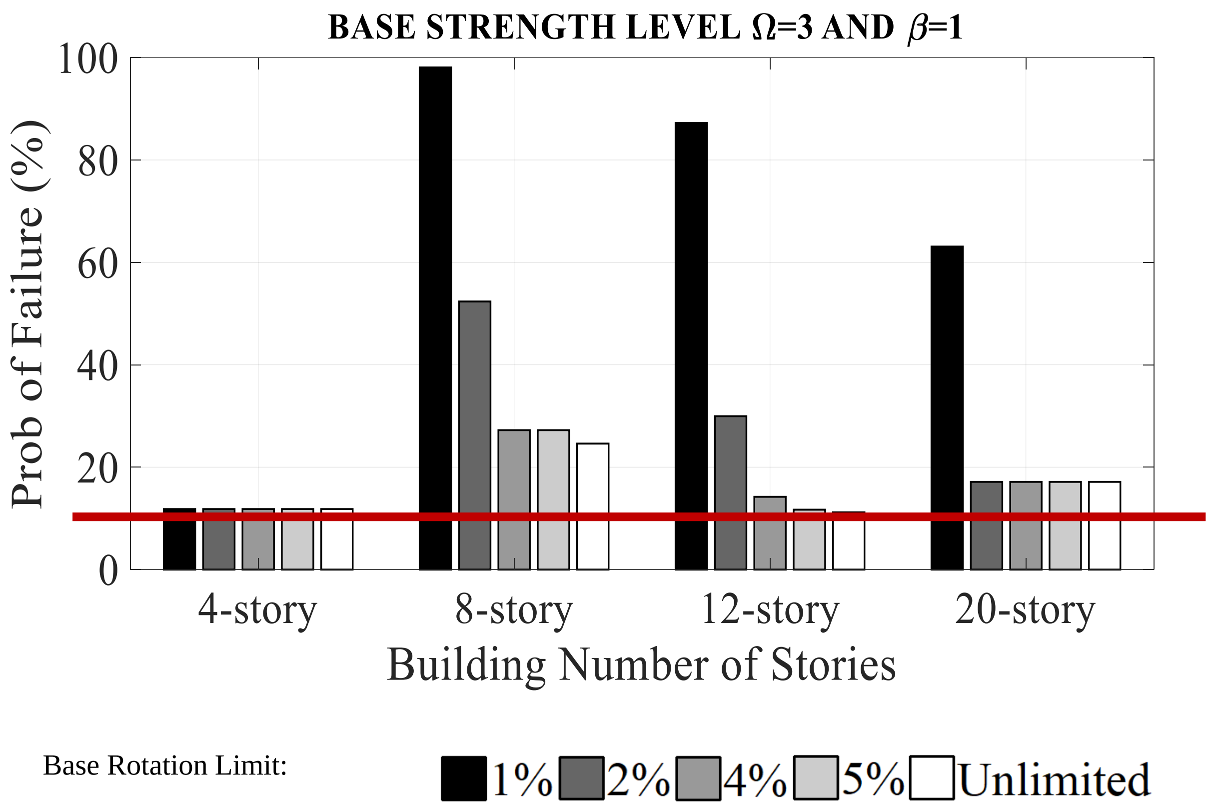




BASE CONNECTIONS MODELED BASED ON NEWLY DEVELOPED APPROACHES



Key Results (Probabilities of Failure – P695)



Falborski et al., (2019 – in press) "The effect of base connection strength and ductility on the seismic performance of steel moment resisting frames," Journal of Structural Engineering, American Society of Civil Engineers.

- Weak base design feasible with Ω_0=3
- These moments are up to 120% lower than 1.1RyMp
- For 8-20 story buildings, rotation capacity of 0.05 needed (target for new details)
- Fairly realistic to achieve based on past data

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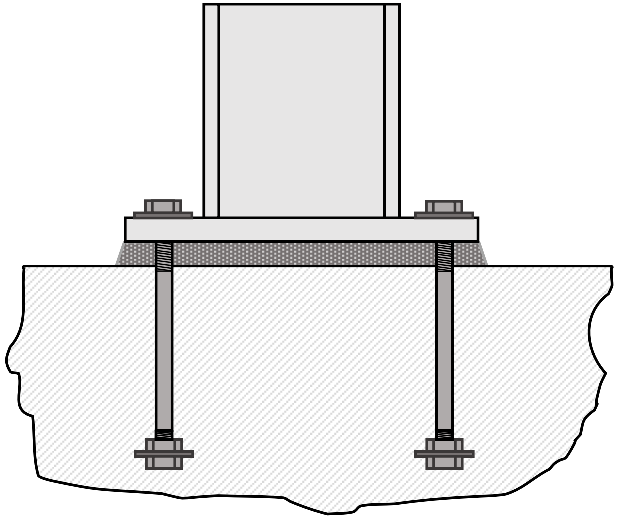
Experimental Study (AISC/Pankow)

Phase I:

➢ Base connections with Reliably Ductile Details as well as Shallowly Embedded Details

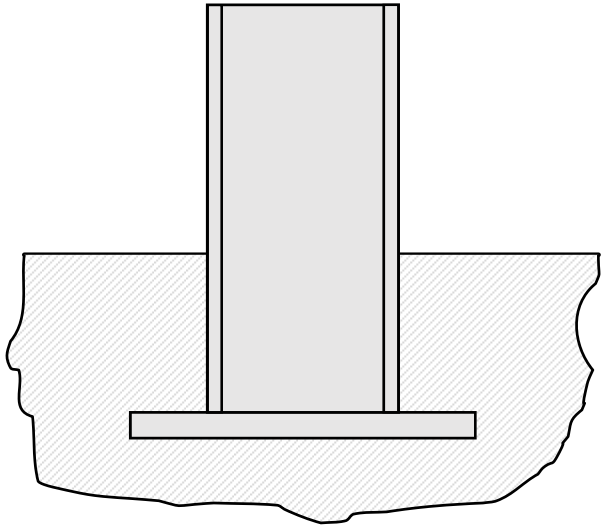
- 7 tests
- Fall 2019 – Winter 2020
- Testing launches within next weeks



Phase II:

➢ Untested details for Deeply Embedded Connections

- 7 tests
- Fall 2020



Design Guides and Wrapup

➢ Fall 2021

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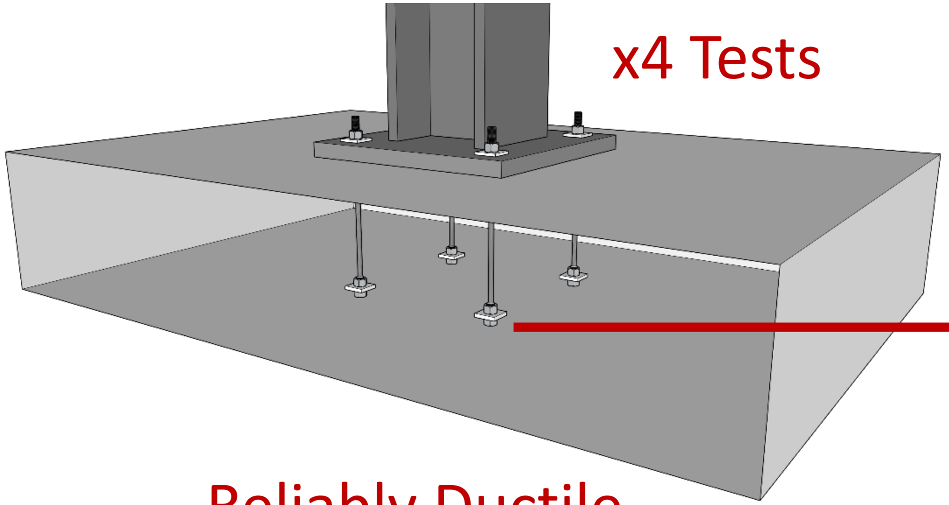
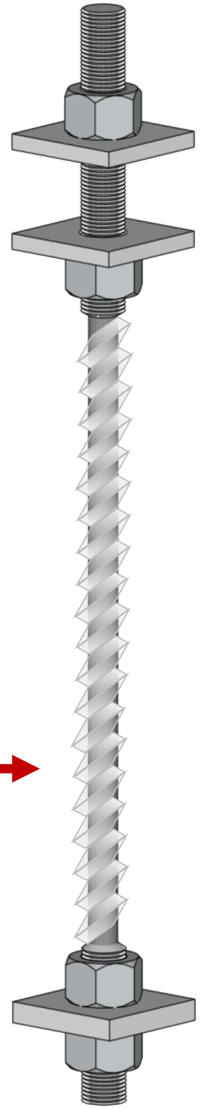


x4 Tests

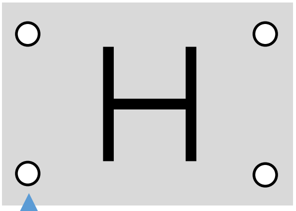
Reliably Ductile Connection

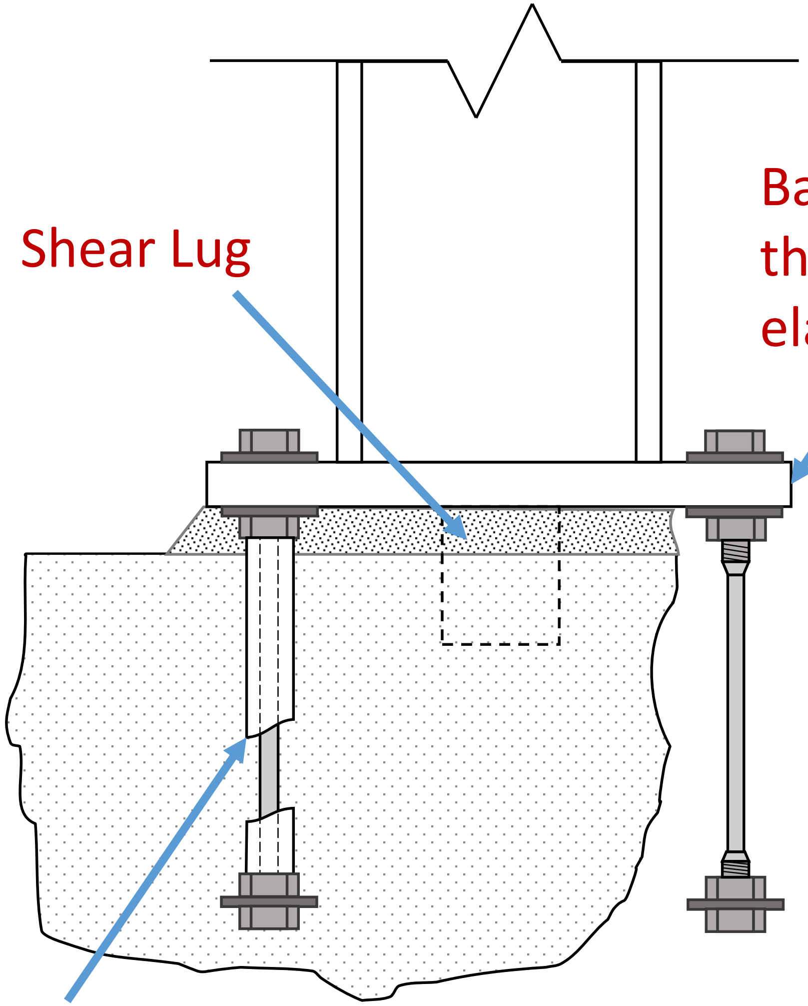
Anchor Rods Specifically Detailed as Below-Ground Fuse

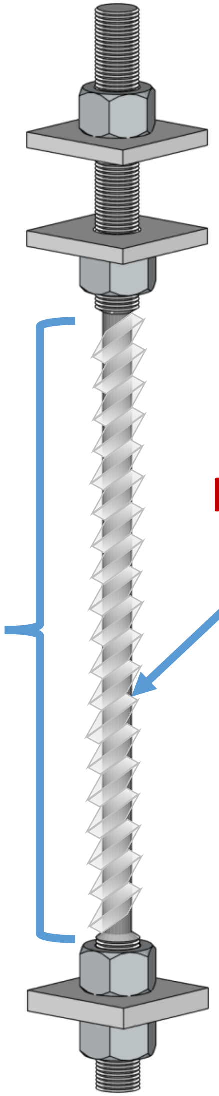


Reliably Ductile Connection (Mason, Ali, Geoff - BIP)

Schematic Plan

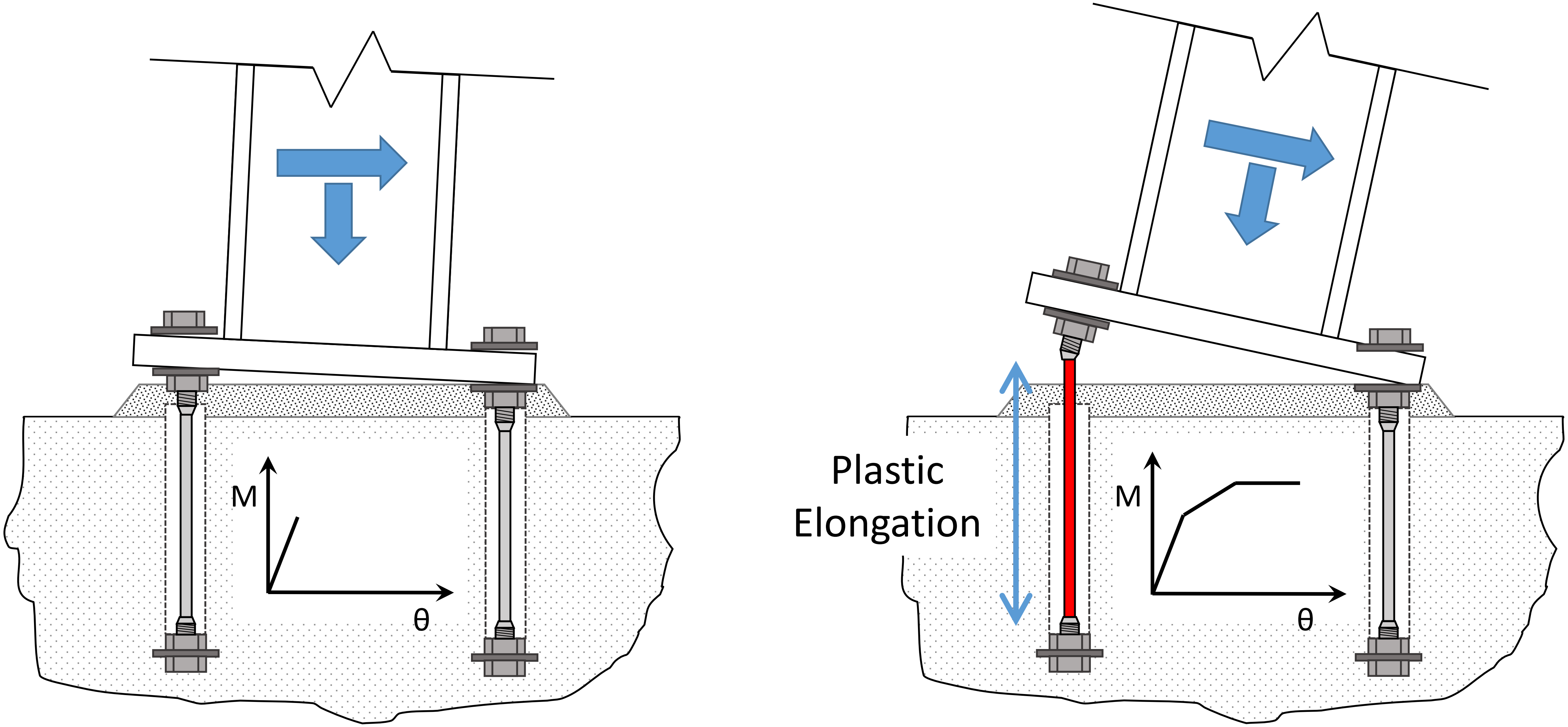






Upset Threaded Rod

Ductile Behavior

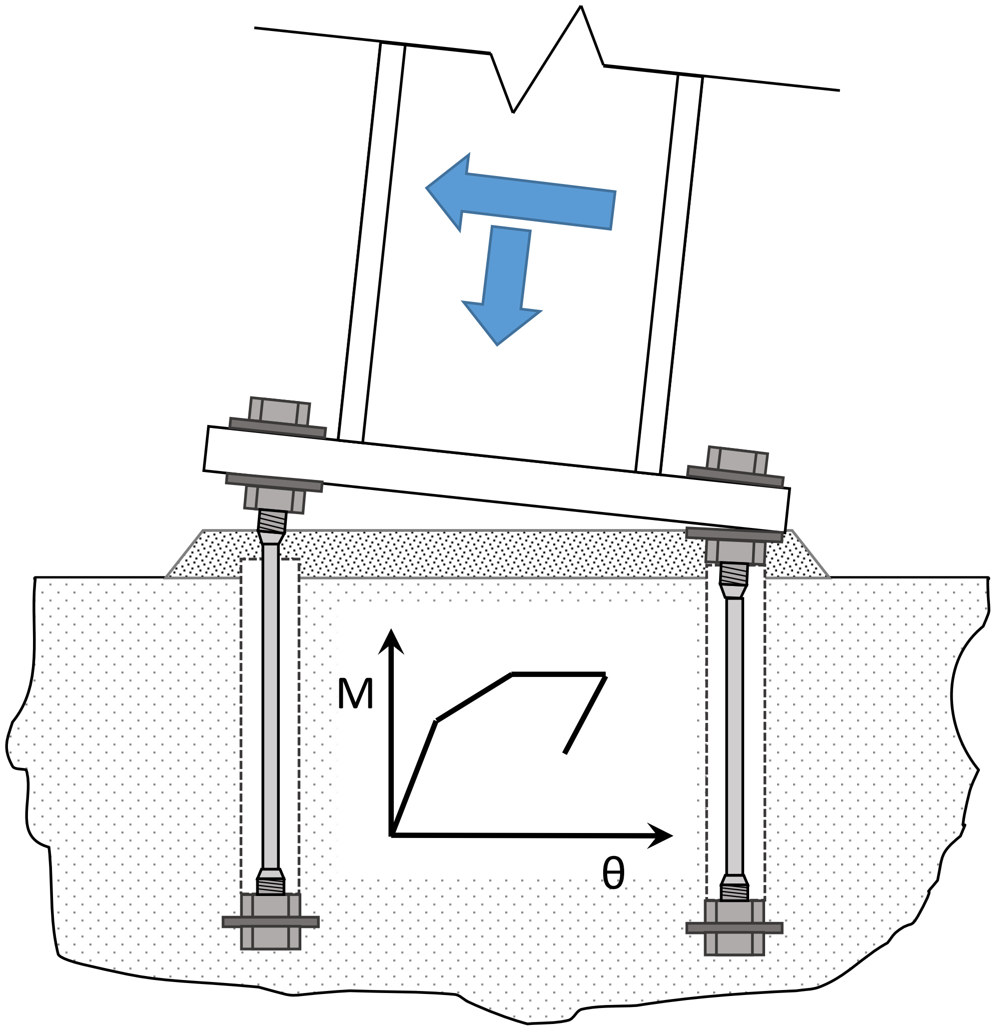


Elastic Loading

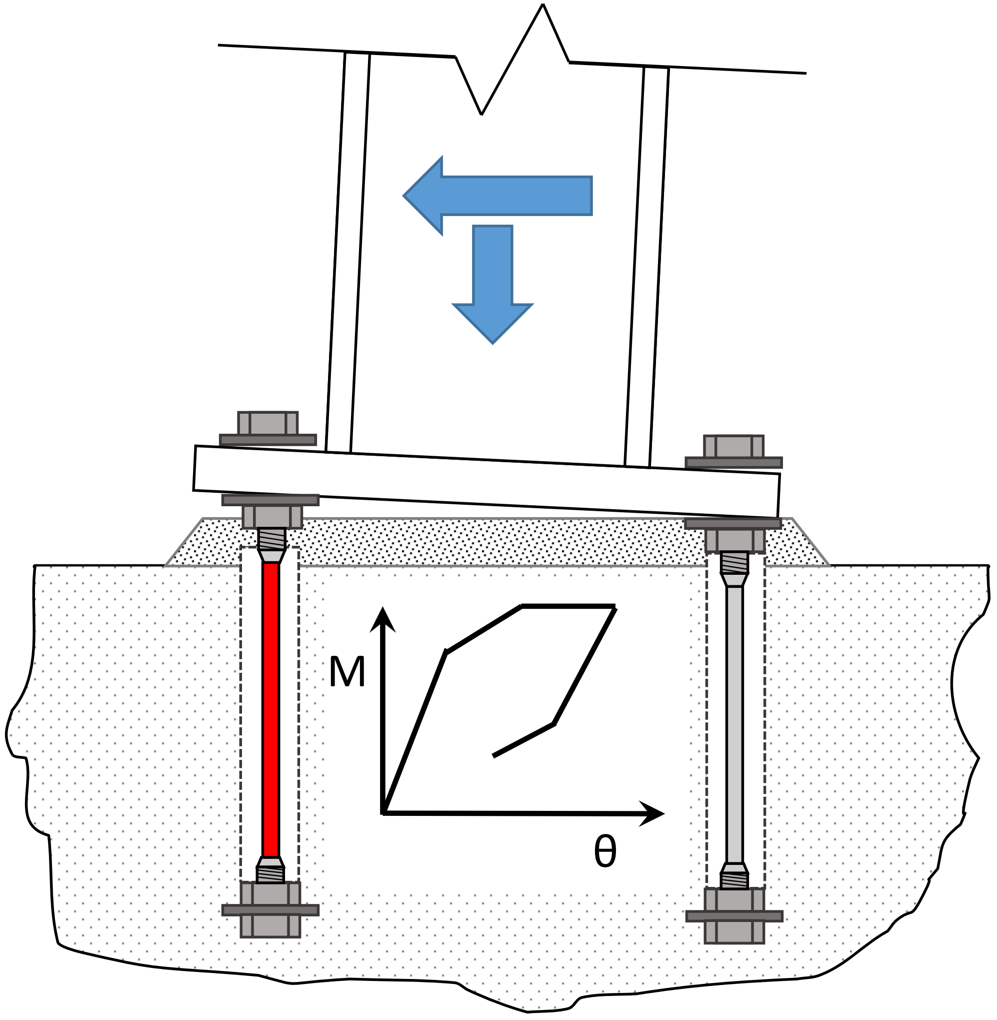
Yield Mechanism in Anchors

(For clarity, shear key not shown)

Ductile Behavior



Elastic Unloading



Compression Yield Mechanism

(For clarity, shear key not shown)

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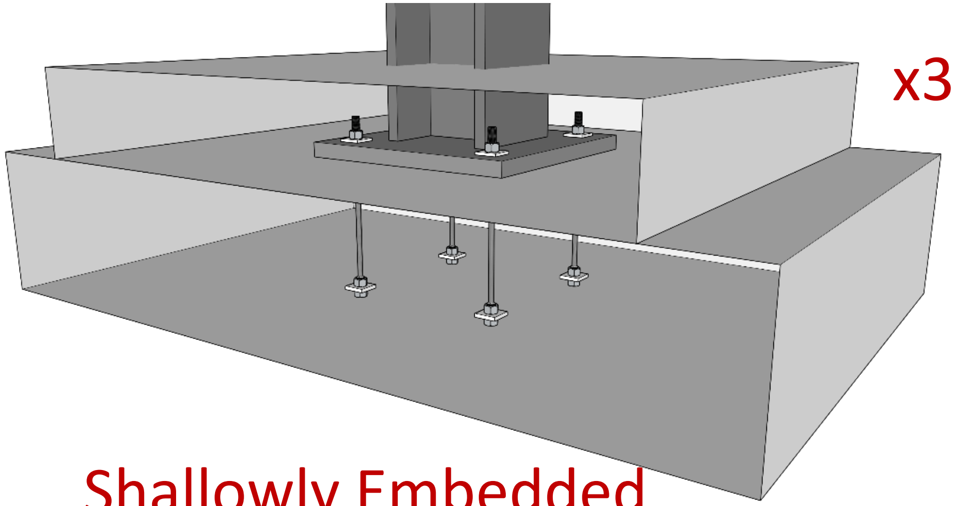

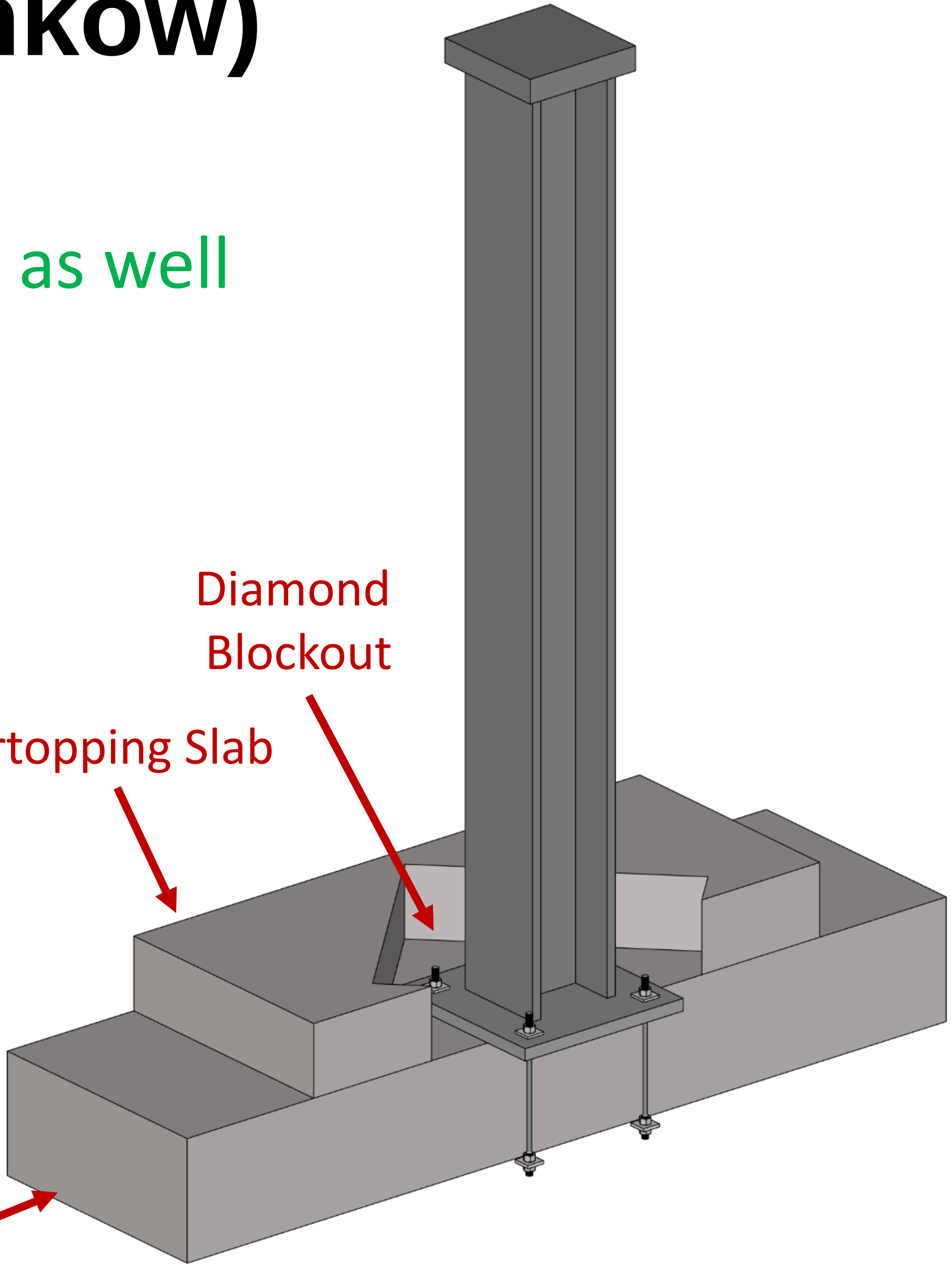

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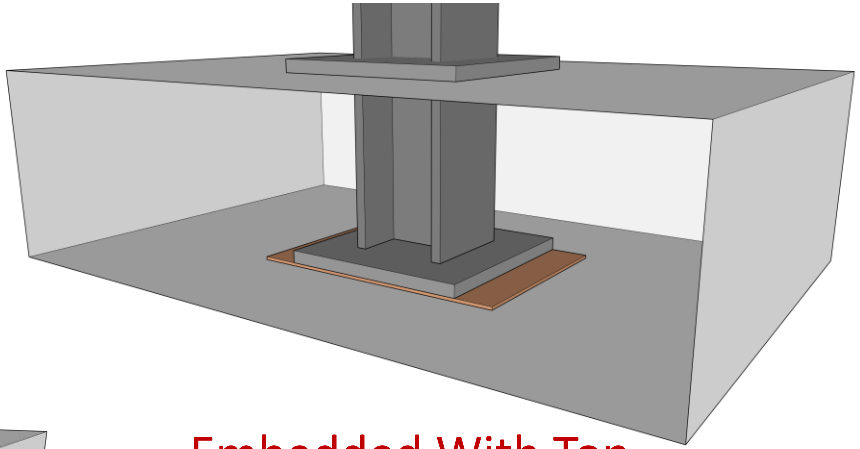
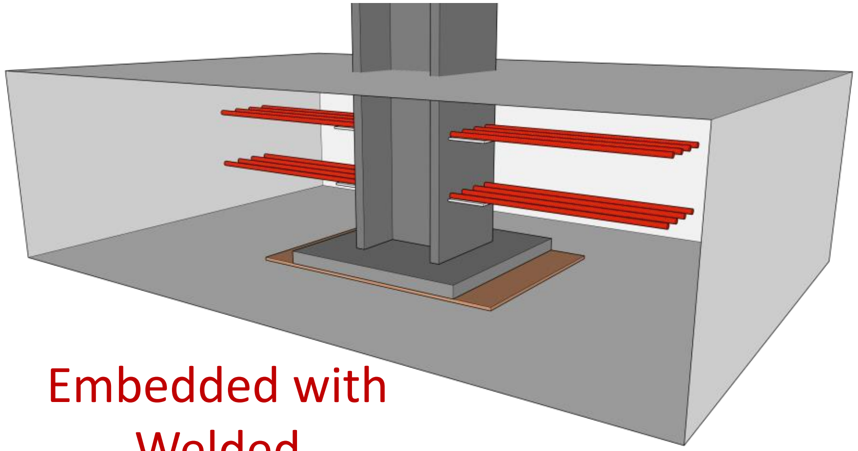
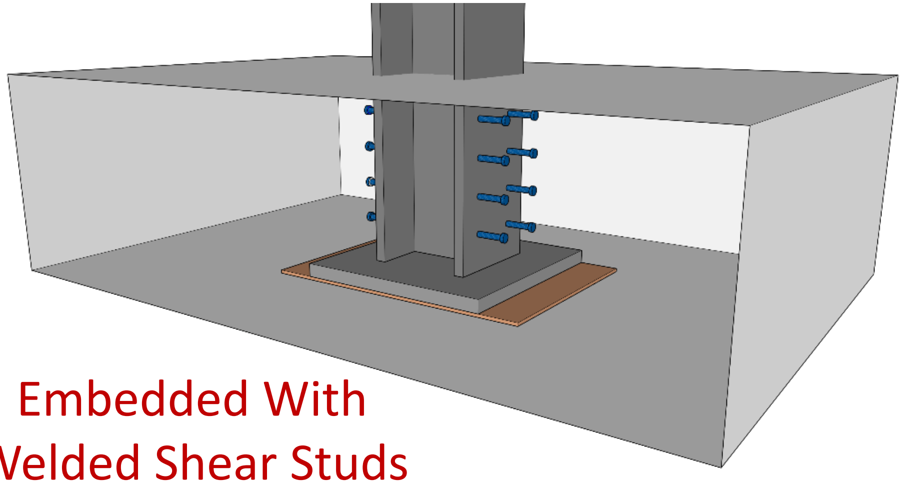


Embedded With Top Plate



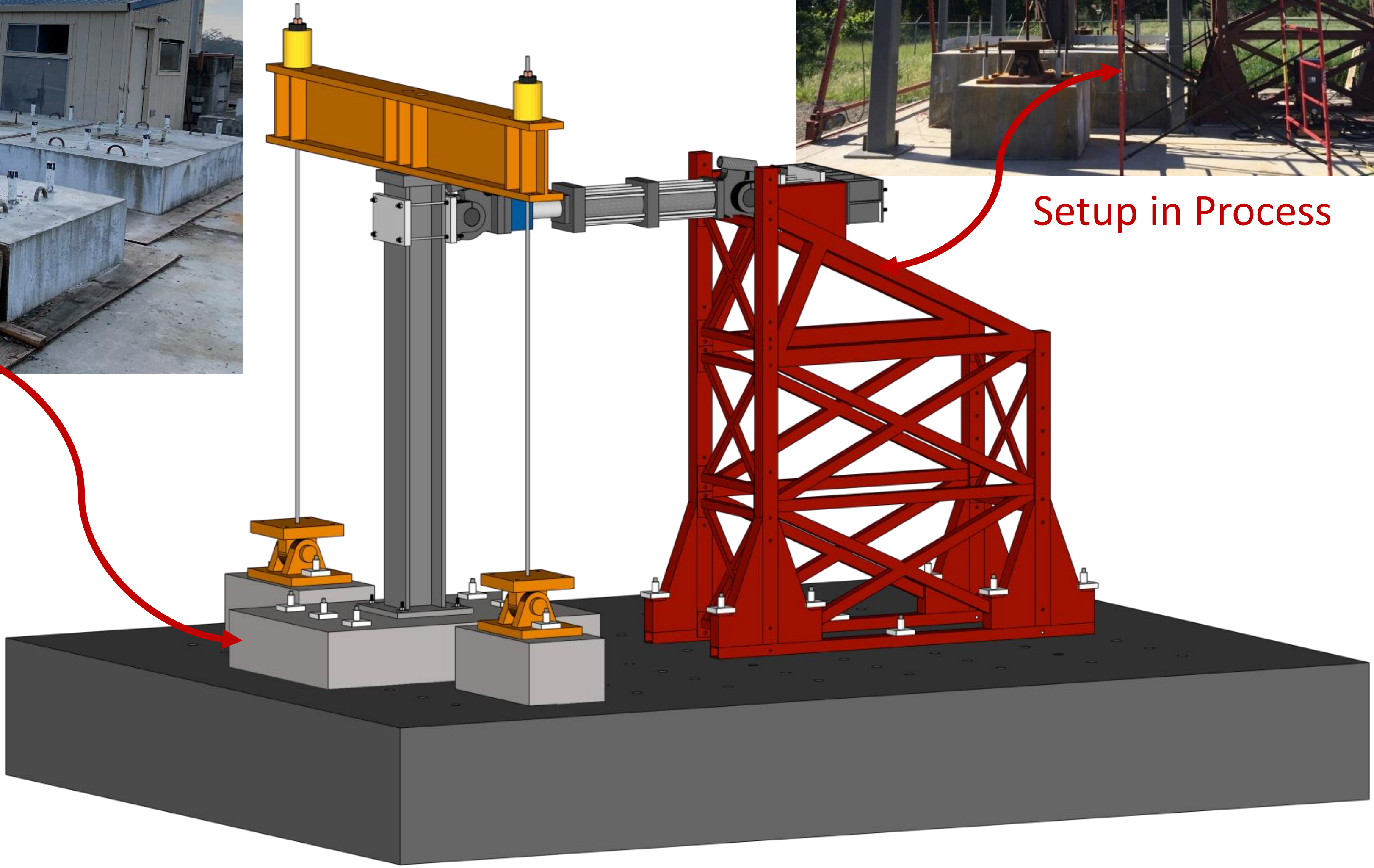
Embedded with Welded Reinforcement



Embedded With Welded Shear Studs

Setup and Status

x7 Specimens Cast & Cured



Setup in Process

Final Phase – Design Guide/Code Development:
- Design Guide One (~2021)
- Seismic Design Manual
- AISC 341

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Name		Affiliation	Title
1	Tom Sabol (Chair)	Engelkirk	Principal
2	Rick Drake	Fluor Corporation	Senior Fellow Structural Engineering
3	Joe Zona	Simpson Gumpertz & Heger	Senior Principal
4	Subhash Goel	University of Michigan	Emeritus Professor
5	Chia Ming Uang	UC San Diego	Professor
6	Tim Fraser	Steel Structures Detailing	VP Operations and Engineering
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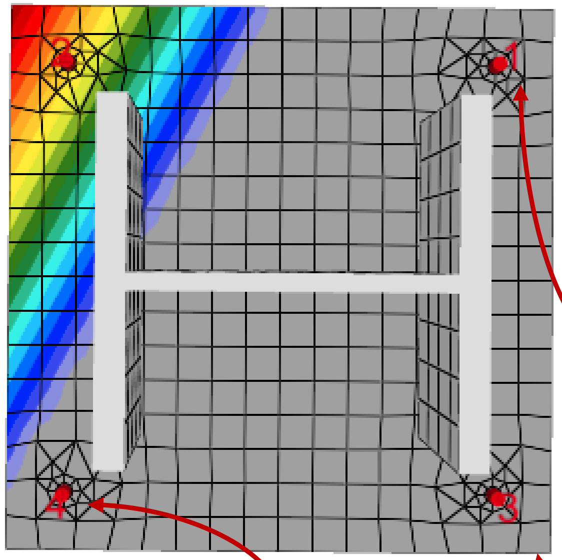
Biaxial Bending (HILTI)



Multiple
Anchors in
Tension
-Not Only 2-

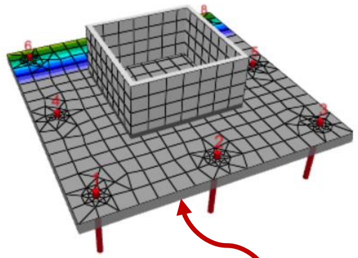
Problem:

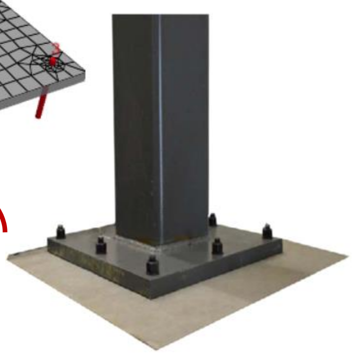
- Interaction between 2 directions (Bidirectional Effects of Seismic & Wind Loads)
- Compromises strength of connection
- Bearing Stresses & Anchor Force Distribution
- Not addressed by current guidelines (AISC Design Guide 1)

Biaxial Bending (HILTI)

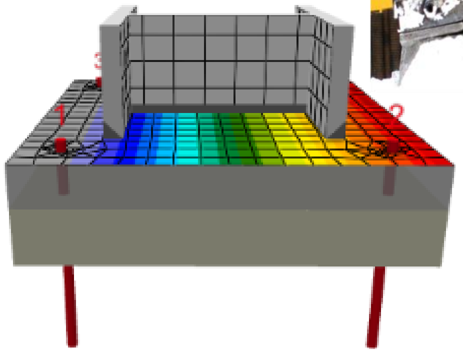
Software Validation

- Validated against 2 series of existing experimental data with various configurations (Uniaxial)
- Accurate Predictions for Anchor Forces





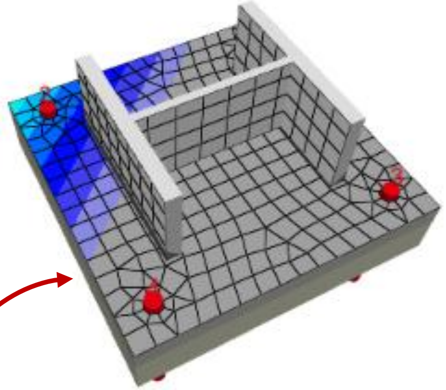
Kanvinde et al. (2014)

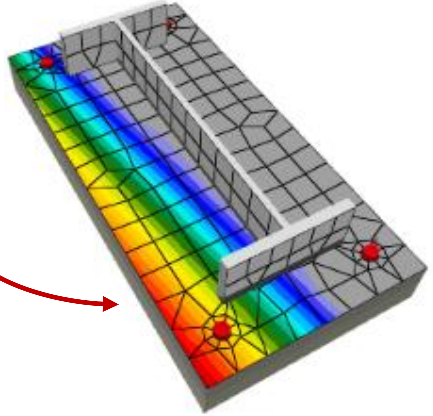


Gomez et al. (2010)

Biaxial Insights

- Bearing Stresses
- Distribution of Axial Forces





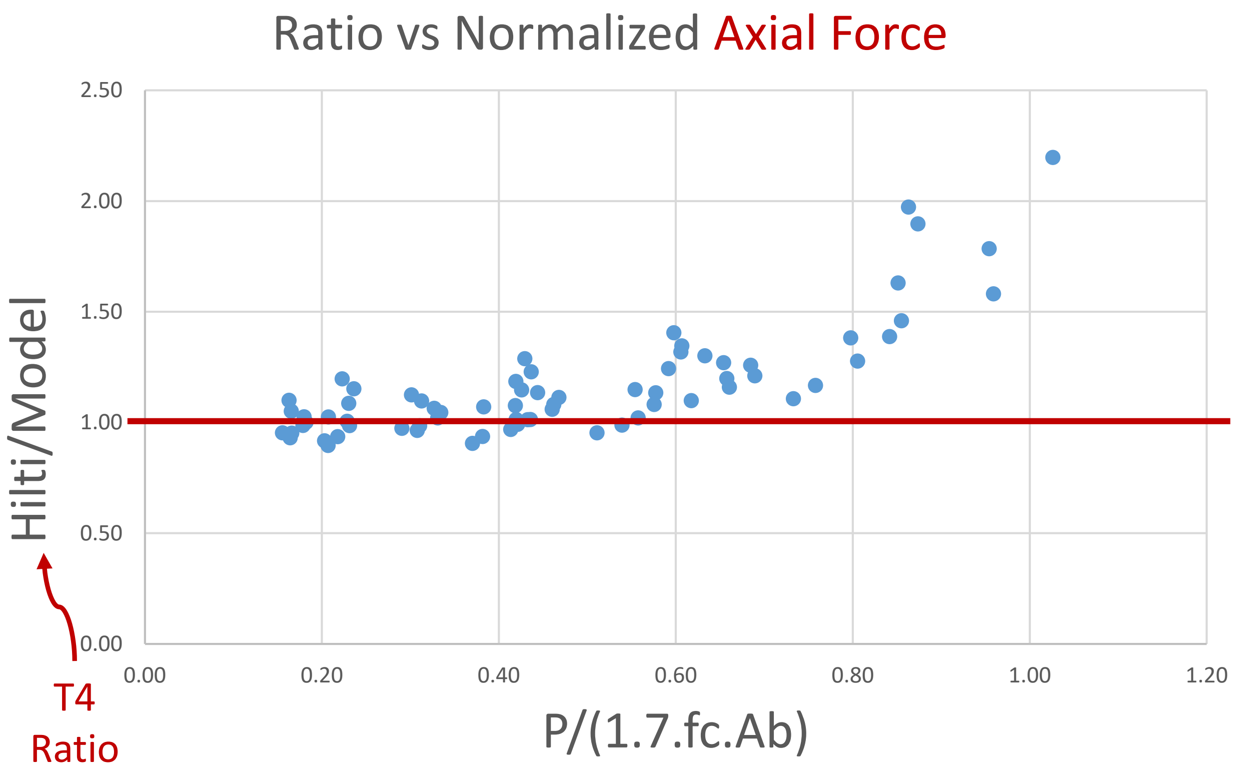
Fairly Representative through Varying

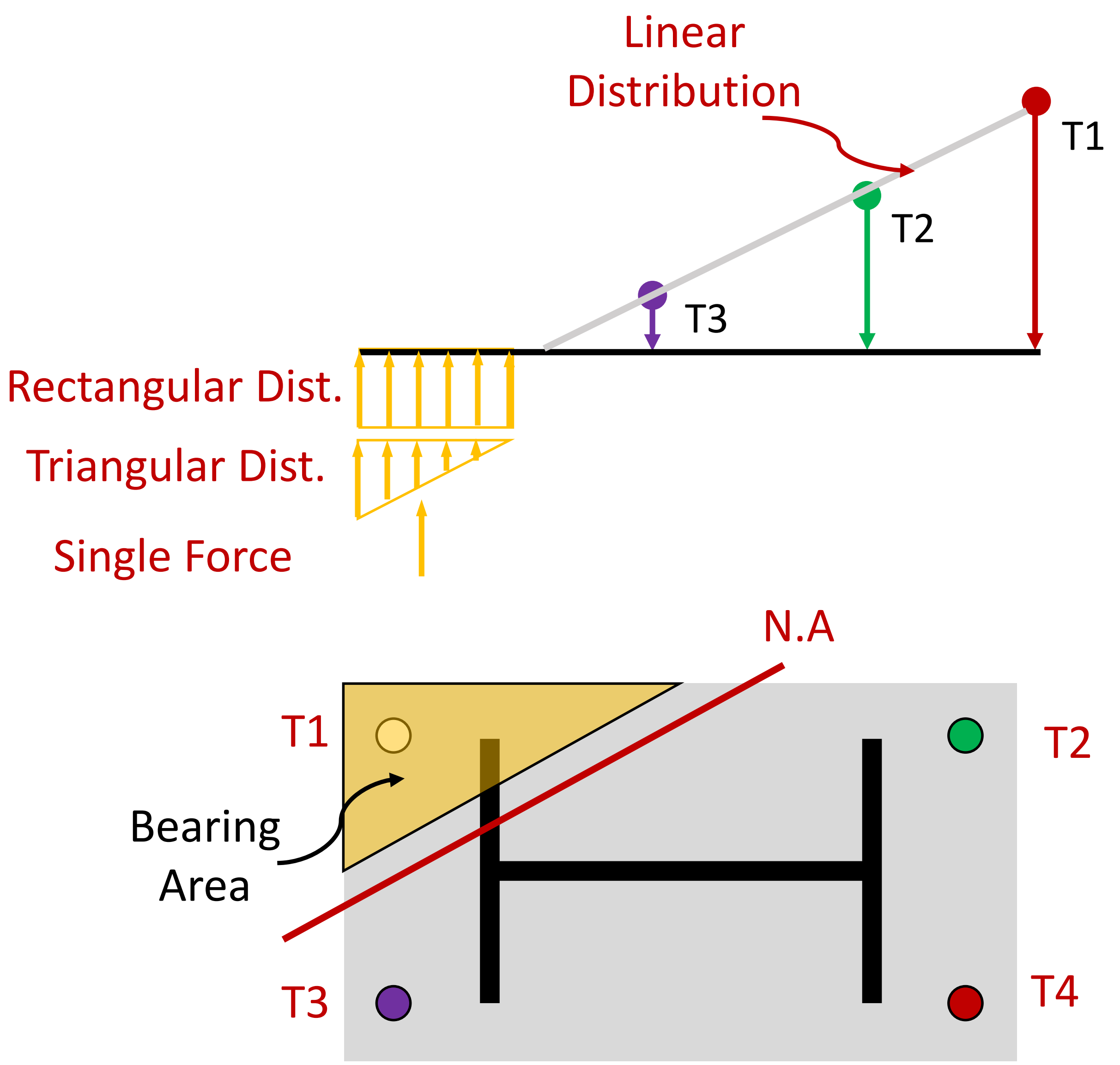
- Geometry
- Moment Angles
- Level of Axial Load
- Connection Strength

Biaxial Bending (HILTI)

Model Formulation

- Probing Bearing Stress distribution for error reduction (including DG1 assumption)
- Assume Linear Distribution of forces in anchors
- Assume Neutral Axis Orientation $\theta_{N.A} = \theta_{Loading}$





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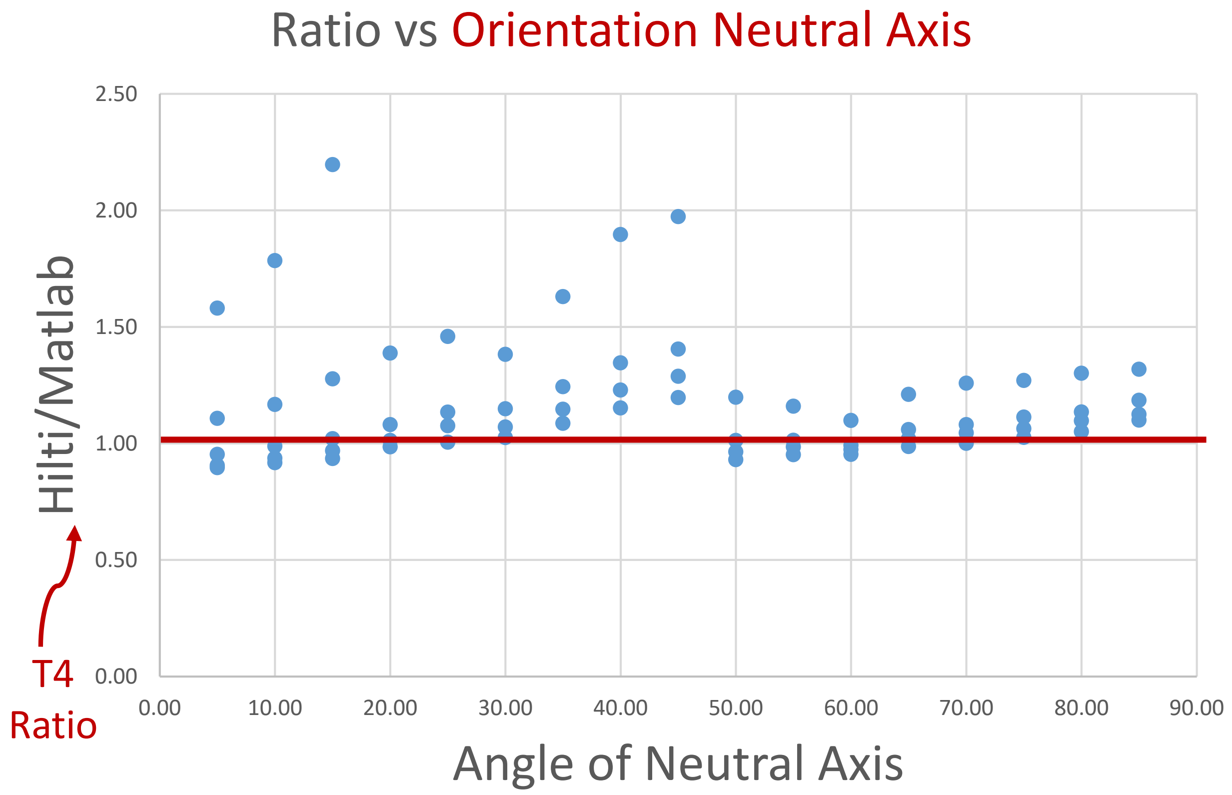
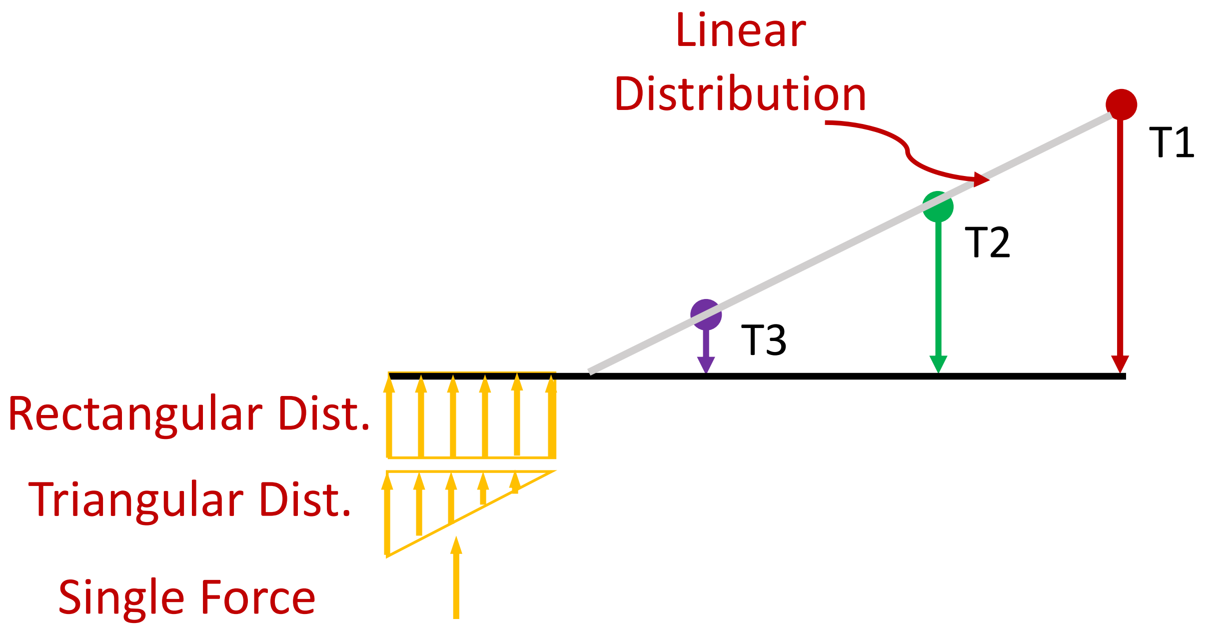
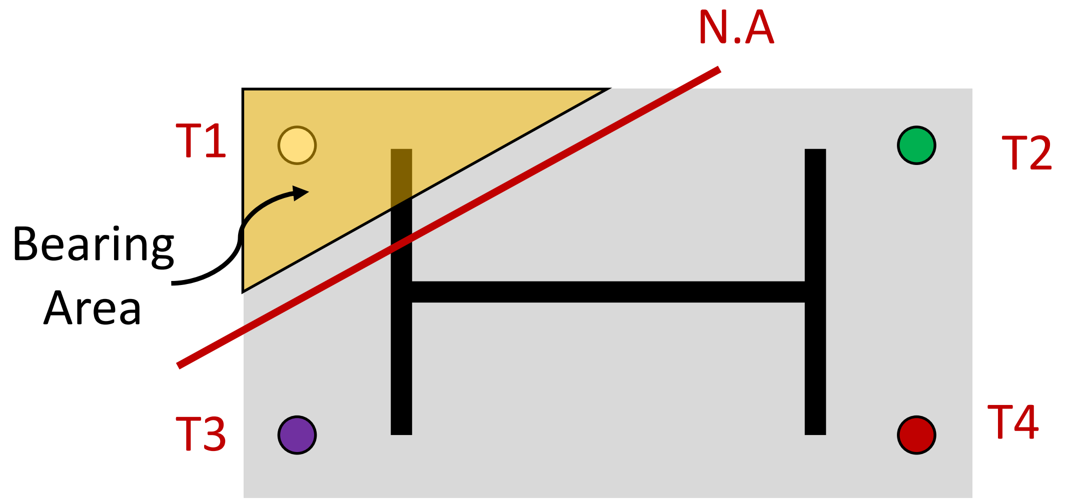




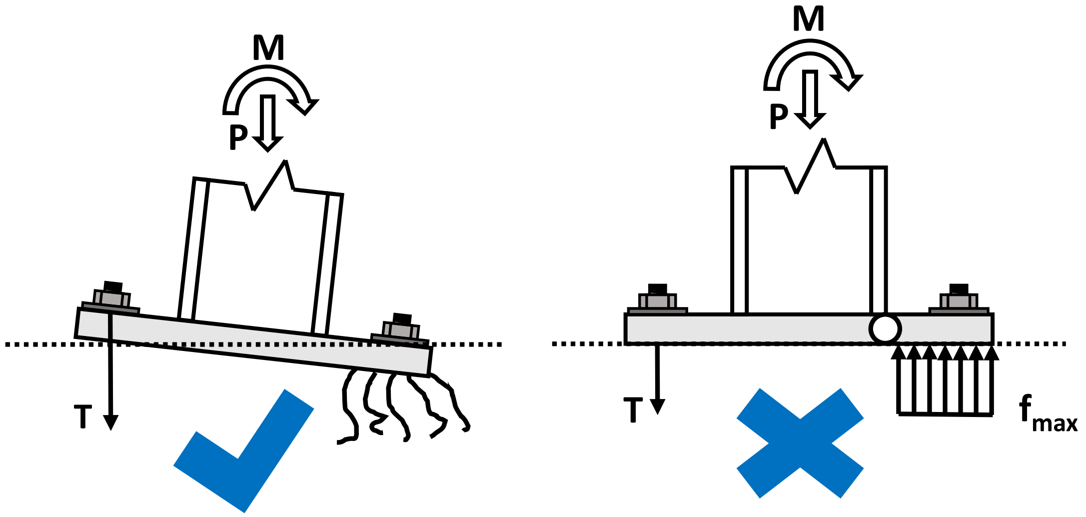


Reliability Study (UCL – UC Davis)

Design Considerations for Exposed Column Base Connections

AISC Design Guide One

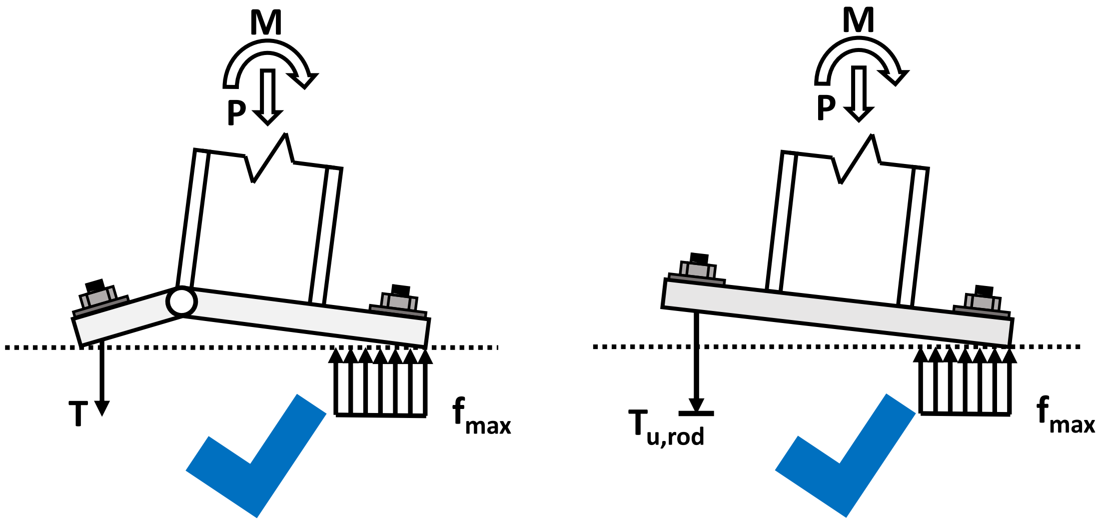
- FOUR expected failure modes:



- $\phi_{concrete}$ = 0.65 is used to determine the imposed loads;
- $\phi_{\text{plate in bending}}$ = 0.9 and $\phi_{\text{rod in tension}}$ = 0.75

Proposed Approach

- THREE **Mechanics Based** failure modes:



- $\phi_{concrete}$ = 1.0 is considered to determine the imposed loads;
- $\phi_{\text{plate in bending}}$ and $\phi_{\text{rod in tension}}$: to be determined from **Reliability Analysis**

Reliability Analysis

- **59 representative design cases (P-M pairs):**
  - 4 x 4-story frames (both exterior & interior bases);
  - 2 x design locations (LA & SAC);
  - 3 x design load types (earthquake, wind & gravity);
  - 2 x cases from AISC DG1;
  - 1 x case from SEAOC design manual.
- **Sources of uncertainty:**
  - Sectional geometries;
  - Material properties;
  - Applied loads;
  - Mechanical models.
- **Limit-state functions:**
  - Concrete bearing failure;
  - Base plate flexural yielding (compression or tension side);
  - Anchor rods axial yielding.
- **Monte-Carlo simulation:**
  - Reliability index (β) as a function of ϕ;