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

AISC + CHARLES PANKOW FOUNDATION (EXPERIMENTAL COMPONENT STUDIES)
- Untested details
- Unbonded dissipative elements to localize yielding
- Resilience

CA STRONG MOTION INSTRUMENTATION PROGRAM (VALIDATION AND BENCHMARKING)
- Moment Frame Buildings
- Range of foundation types

MODEL VALIDATION

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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### Model Validation

### Demands

### Component Models

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- Biaxial Bending

**UCL & UC DAVIS (RELIABILITY STUDY)**
- Exposed Base Reliability Analysis
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- Calibration of Resistance Factors added in Design Equations
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PEER Objectives

- Development and calibration of component (hinge) models for column base connections
- Nonlinear simulation of archetype frames with dissipative bases
- Application of simulation results for design development
- Inform component experiments and interpretation
- Development of design examples for moment frames with dissipative bases
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Component Hinge Models (for exposed and embedded type connections)

PHYSICS-BASED FUNCTIONAL FORM

CALIBRATION RULES
CSMIP Project on Base Flexibility

Richmond building results

<table>
<thead>
<tr>
<th>Base conditions</th>
<th>Error ((\epsilon))</th>
</tr>
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<tbody>
<tr>
<td>Fixed</td>
<td>Total average error: 0.85</td>
</tr>
<tr>
<td></td>
<td>NS average error: 0.83</td>
</tr>
<tr>
<td></td>
<td>EW average error: 0.82</td>
</tr>
<tr>
<td></td>
<td>Average error for the 1st story: 0.81</td>
</tr>
<tr>
<td>Pinned</td>
<td>Fixed: 0.45, NS: 0.48, EW: 0.47</td>
</tr>
<tr>
<td></td>
<td>Average error for the 1st story: 0.38</td>
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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
Key Results (Probabilities of Failure – P695)

- Weak base design feasible with $\Omega_0 = 3$
- These moments are up to 120% lower than 1.1RyM_p
- 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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Reliably Ductile Connection

Anchor Rods Specifically Detailed as Below-Ground Fuse

x4 Tests
Reliably Ductile Connection (Mason, Ali, Geoff - BIP)

Schematic Plan

Over-sized hole in baseplate

Shear Lug

Baseplate and threads remain elastic

Reduced Diameter Section

Rod isolated with tape

Polyethylene Tape -For Debonding-

Upset Threaded Rod
Ductile Behavior

Elastic Loading

Yield Mechanism in Anchors

(For clarity, shear key not shown)
Ductile Behavior

Elastic Unloading

Compression Yield Mechanism

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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

AISC/Pankow oversight committee

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Biaxial Bending (HILTI)

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)

Multiple Anchors in Tension -Not Only 2-
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 $\theta_{N.A} = \theta_{\text{Loading}}$

### Ratio vs Normalized Axial Force

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<thead>
<tr>
<th>Hilti/Model</th>
<th>0.00</th>
<th>0.50</th>
<th>1.00</th>
<th>1.50</th>
<th>2.00</th>
<th>2.50</th>
</tr>
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<tbody>
<tr>
<td>T4 Ratio</td>
<td></td>
<td></td>
<td></td>
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<tr>
<th>$P/(1.7.f_c.A_b)$</th>
<th>0.00</th>
<th>0.20</th>
<th>0.40</th>
<th>0.60</th>
<th>0.80</th>
<th>1.00</th>
<th>1.20</th>
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<tr>
<td>T1</td>
<td></td>
<td></td>
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<tr>
<td>T2</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>T3</td>
<td></td>
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<tr>
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Linear Distribution
Rectangular Dist.
Triangular Dist.
Single Force
Bearing Area
N.A
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T1
T2
T3
T4

N.A
Bearing Area

T4 Ratio
Reliability Study (UCL – UC Davis)

Design Considerations for Exposed Column Base Connections

AISC Design Guide One

- FOUR expected failure modes:
  - $\phi_{\text{concrete}} = 0.65$ 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:
  - $\phi_{\text{concrete}} = 1.0$ 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;

\[
AISC \text{ DG1: } \beta_{\text{plate}} = 1.9 \quad \beta_{\text{rods}} = 2.2
\]

\[
\phi_{\text{concrete}} = 0.65
\]

\[
\phi_{\text{concrete}} = 1.0
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