INVESTIGATION OF SEISMIC PERFORMANCE OF COLLECTORS IN STEEL BUILDING STRUCTURES

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Presentation Outline

1. Introduction
2. Background
3. Project Overview
4. Current Design Practice - Examples
5. Analytical Work
6. Experimental Work
1. Introduction

Advancing Knowledge on the Performance of Seismic Collectors in Steel Building Structures

- National Science Foundation (NSF) - Grant CMMI 1662816 (3 Year Project, started Aug 2017)

**Academic Collaborators**: University of Arizona, Lehigh University and UC San Diego

**Industry Collaborators**: AISC, Walter P. Moore, Degenkolb, OSHPD, AISI, SDI, Vulcraft

**International Collaborators**: University of Canterbury, SCNZ

**Outreach**: University of Arizona STEM Learning Center, Tucson Unified School District
2. Background: Seismic Load Path

Vertical-plane SFRS elements provide a laterally stiff load path to the foundation.

Seismic Collectors serve as the critical link between the diaphragm and the vertical elements.

Floor diaphragms transfer inertial forces laterally from the floor slab and attached elements.

Typically floor framing serve as collectors.

Load Path from the seismic mass (most of which originates from the floor slab) to the foundation.
2. Background: Modern Building Layouts

Hospital Building, Oakland, CA

- Braced Frames
- Seismic Collector Length = 125’ over 5 bays
- Seismic Collector Length = 50’ over 2 bays
2. Background: Collector Design

Collectors transfer primarily axial forces and must be designed for both tension and compression with System Overstrength Factor ($\Omega_o$).

- **Compression** design focuses on the stability of the collector member *(non-composite member)*.
- **Tension** design focuses on the strength of the collector connection.

![Diagram showing Flexural Buckling, Torsional Buckling, and Constrained Axis FTB](image)
2. Background: Problem Statement & Objective

Collectors are critical elements and have complicated behavior because they reside in floor system.

There is a need to better understand the collector element characteristics and the collector load path to ensure safe and economical design.

Objectives: The project objectives are to advance the knowledge on the seismic behavior and performance of steel collectors.
3. Project Overview

<table>
<thead>
<tr>
<th>Research Thrusts</th>
<th>Collector Connection</th>
<th>Collector Element</th>
<th>Collector System</th>
<th>Seismic System</th>
</tr>
</thead>
<tbody>
<tr>
<td>DESIGN</td>
<td><img src="image1" alt="Collector Connection Design" /></td>
<td><img src="image2" alt="Collector Element" /></td>
<td><img src="image3" alt="Collector System" /></td>
<td><img src="image4" alt="Seismic System" /></td>
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<tr>
<td>ARIZONA</td>
<td><img src="image5" alt="Arizona Design" /></td>
<td><img src="image6" alt="Arizona Collector Element" /></td>
<td><img src="image7" alt="Arizona Collector System" /></td>
<td><img src="image8" alt="Arizona Seismic System" /></td>
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<tr>
<td>LEHIGH</td>
<td><img src="image9" alt="Lehigh Design" /></td>
<td><img src="image10" alt="Lehigh Collector Element" /></td>
<td><img src="image11" alt="Lehigh Collector System" /></td>
<td><img src="image12" alt="Lehigh Seismic System" /></td>
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<td>UCSD</td>
<td><img src="image13" alt="UCSD Design" /></td>
<td><img src="image14" alt="UCSD Collector Element" /></td>
<td><img src="image15" alt="UCSD Collector System" /></td>
<td><img src="image16" alt="UCSD Seismic System" /></td>
</tr>
</tbody>
</table>

- Added Mass
- Collector Line
- X-shaped Cables
- ASCE 7-16
- MCE
- DBE

Gravity System: W16x36 (29), W24x66 (26)

Seismic Collectors: W24x162 (54)

Hospital, Oakland, CA

Collector Connections

- Shear Tab with multiple bolt rows (MST)
  - Medical Center, Downey, CA

- Top Flange Welded (TFW)
  - Airport, SFO, CA

- Both Flanges Welded (AFW)
  - Hospital, Oakland, CA

Hospital, Mountain View, CA
5. Analytical Work: Overview

- **Floor System**
  Collector Axial Force Profile and Load Path in the horizontal plane of diaphragm

- **Collector Connection**
  Collector Connection backbone response and Load Path in the vertical plane of collector

- **Collector Member**
  Collector Member stability limit states and evaluation of inherent bracing

2D Model – Plane Stress Model
- Collector – W24x162
- Connection – TFW
- Shear Tab – 18” x 4” x ¾”
- Bolts – 6 – 1” Dia, A325, Full P.T.
- WUF-W Detail
5. Analytical Work: Moment Rotation

Moment Rotation Behavior of TFW collector Connection

Plastic Strain at 2% rotation

Deformed Shape
5. Analytical Work: Frame Drift

Rotation column and then place the collector under tension

Effect of Frame Drift on Collector Connection Response

- Initial Rotation: 1%
- Total Connection
- Bolt Failure
- 24% reduction in ductility
- 18% reduction in strength
- No initial Rotation
- Shear Tab
- Top Flange
5. Analytical Work: Load Path

Horizontal Plane of Diaphragm

Vertical Plane of Collector

Center of Force: between top flange & top of shear tab

5 bay collector line with TFW connections

Collector Axial Force Profile as collector system takes on damage
6. Experimental Work at Lehigh

1. Examine Steel Seismic Collector Connections:
   - **Tension** Response
     - Effect of Cyclic Loading
     - reversal into compression
     - Effect of Frame Rotation
   - Connection Characteristics
   - Limit State Sequence
     - Typical Practice vs. Alternative Design Approaches

2. Examine Steel Seismic Collector Members:
   - **Compression** Response
     - Inherent Bracing of floor system
     - Slab Participation
   - Stability Limit States

Collector Connection Test

Collector Member Test

Gravity Load

Inertial Force Direction

Collector Axial Force

TEST 2(C)

Key Features

- **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.
### Collector Connection Tests

<table>
<thead>
<tr>
<th>Test #</th>
<th>Connection</th>
<th>Scale</th>
<th>Tab Design</th>
<th>Weld Access</th>
<th>Loading</th>
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<td>T/C/ROT</td>
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### Collector Member Tests

<table>
<thead>
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<th>Test #</th>
<th>Connection</th>
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<th>Slab</th>
<th>Deck Orientation</th>
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<td>No</td>
<td>Parallel</td>
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<td>14 - 16</td>
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<td>As needed based on research findings and Industry Advisory Group input</td>
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</table>
6. Lehigh Testing: Connection Details

Collector Connections

¾ Scale: TFW

D.C.W. as per WPS
Weld Access Hole
AWS D1.1
Bolts
¾" A325X Full P.T.
Bolt Holes
Standard Holes
Continuity Plate
7/8" Thick
Backing bar
Remain
Column
W 12x136
Shear Tab
Full Depth
13.75x4x3/8
Erection Gap
0.75

2/3 Scale: AFW

D.C.W. as per WPS
Weld Access Hole
AWS D1.1
Bolts
5/8" A325X Full P.T.
Bolt Holes
Standard Holes
Continuity Plate
7/8" Thick
Backing bar
Remain
Column
W 12x136
Shear Tab
Full Depth
11.75x4x3/8
Erection Gap
2/3
6. Proposed Experimental Work at UCSD

1-2 Test Structures

Specimen 1: Composite Floor
- 0.4 scale specimen
- Reconfigurable SFRS
- Ability to examine multiple connection
- Objective is to characterize load path and evolution of cyclic damage

Specimen 2: Unfilled Roof Deck with Joist System
- In discussions with AISI, SDI for a potential companion project
## Project Timeline

<table>
<thead>
<tr>
<th>Steel Diaphragm Collector Research Project</th>
<th>Pre-Grant</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
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<tr>
<td><strong>Research Task / Event</strong></td>
<td>1-10</td>
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<td>21-30</td>
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<td>B - Construction</td>
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<td>D - Data Interpretation</td>
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<td>Collector Models</td>
<td>A - Build Initial Models</td>
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<td>B - Test Prediction</td>
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<td>C - Calibrate Models</td>
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<td>D - Parameter Studies</td>
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<td>Design Recommendations Reporting</td>
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</table>

**Panels of Research**
- Existing: Grey
- New: Grey with blue
- Existing & New: Grey with blue arrows
Thank You