# Overview

- **Research Results to Date:**
  **Improving and understanding the seismic performance of pile-to-wharf connections**
  - Marginal wharfs with vertical precast piles
  - Fragility functions for piles and connections
- **Immediate Research Effort:**
  **Seismic performance of marginal wharf systems**
  - Models of piles, current and improved connections
  - Nonlinear modeling of system including soil
- **Long-term Research: Improved seismic performance of all port structures with batter piles.**

# Pile-to-Wharf Connection Tests

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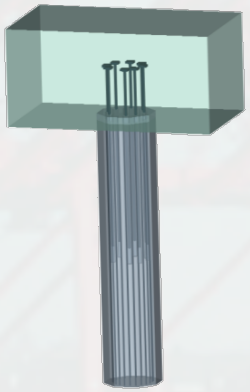
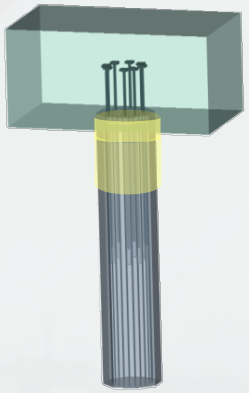
# Current Connection Designs



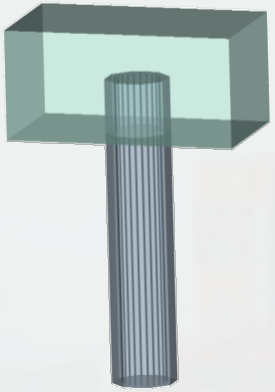
## Embedded Dowel Connection

- Very commonly used
- Can include inward and outward bent dowels, T-headed dowels, or bond bars



## Extended Pile Connection

- Used when pile is over driven
- Extension is RC



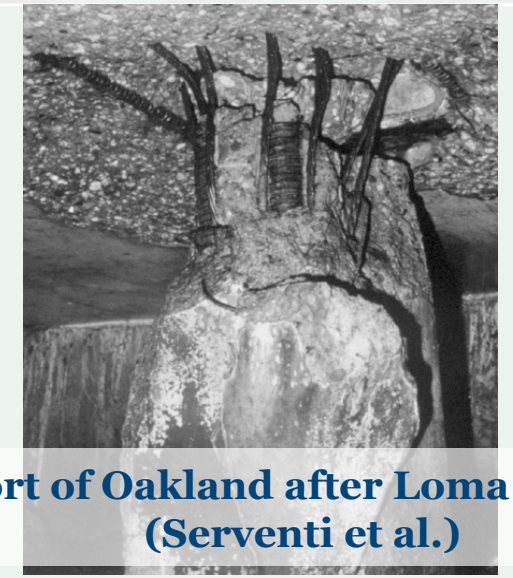
## Embedded Pile Connection

- Generally provides high fixity of pile

## Extended Strand Connection

- Older connection
- Difficult to construct

# Damage Observed After Earthquakes

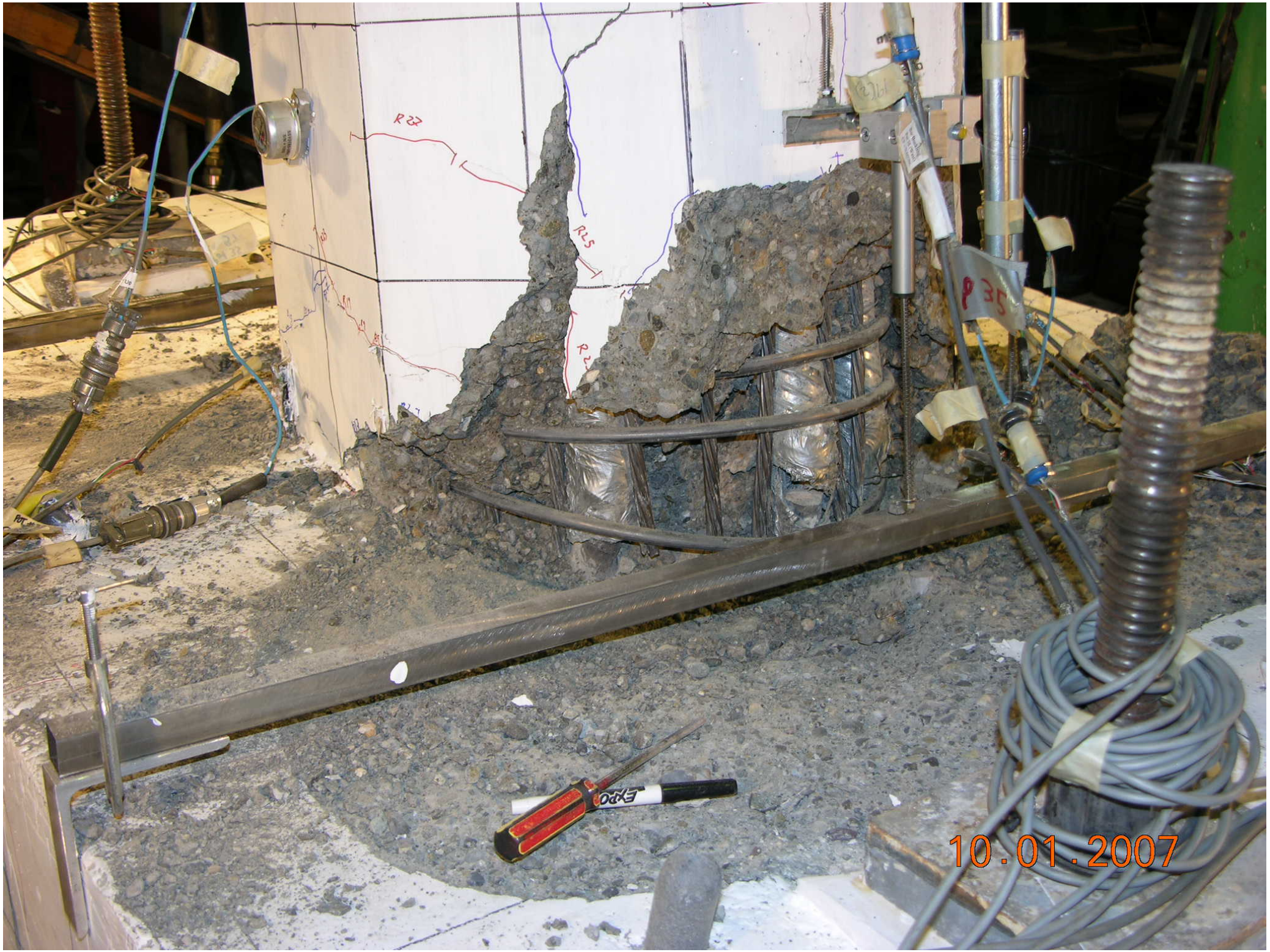


Port of Oakland after Loma Prieta (Serventi et al.)

Precast Pile with damage concentrated in the connection (extended strand connection?)

Approach Jetty after the Great Sumatra Earthquake (Rai et al. 2006)

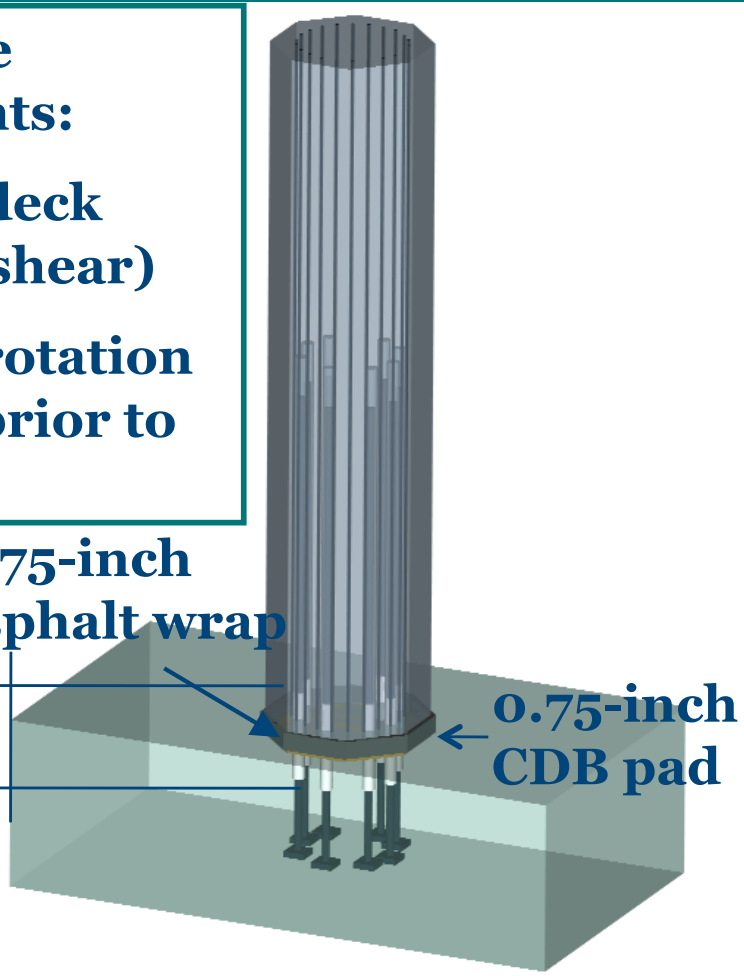
Inadequately confined RC pile with damage concentrated in the pile.

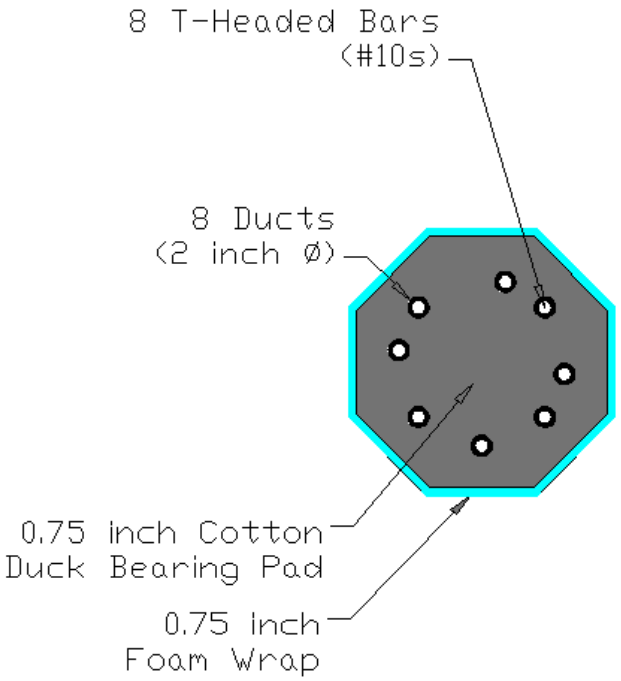

10.01.2007

# CR: Controlled-Rocking

**Performance Improvements:**

1. **Reduced deck damage (shear)**
2. **Increase rotation capacity prior to spalling**

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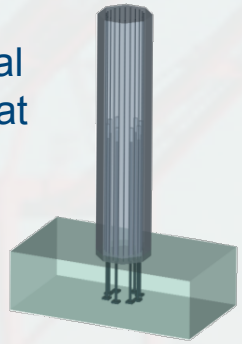
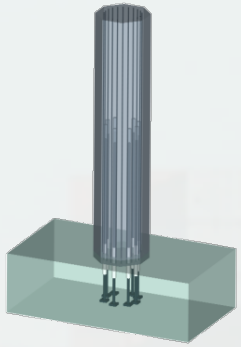
# PEER Test Specimens

450 kip Axial Load Repeat Test



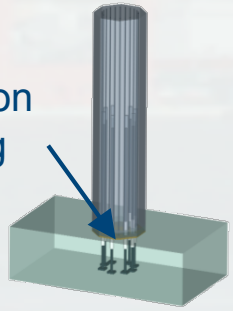
**Specimen 13: CR Connection II**

900 kip Axial Load



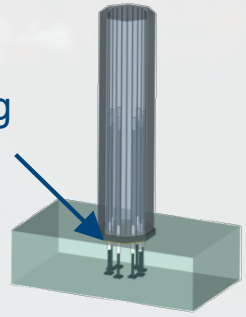
**Specimen 14 : CR Connection III**

0.75 inch Annular Cotton Duck Bearing Pad



**Specimen 15: Annular CR Connection – Cotton Duck**

0.5 inch Annular Fiberlast Bearing Pad

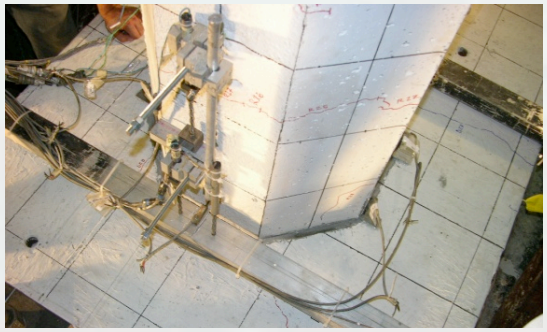


**Specimen 16: Annular CR Connection – Rubber Pad**

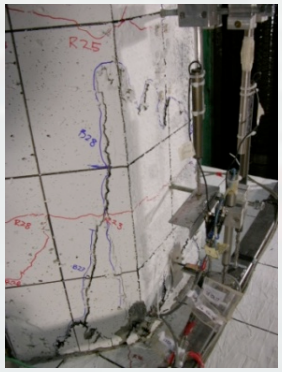
# Damage Comparison at 2.5% Rotation

**Specimen 9: Current Design**

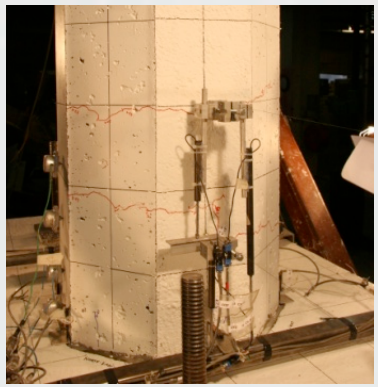
**Specimen 13: CR Connection**



**Specimen 14 : CR Higher Axial Load**



**Specimen 15: Annular: CDBP**

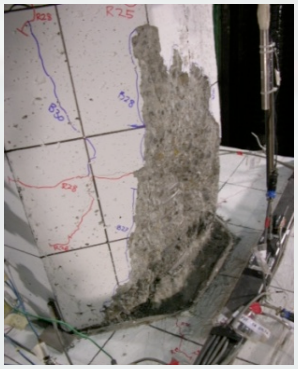


# Damage Comparison at 5.5% Rotation

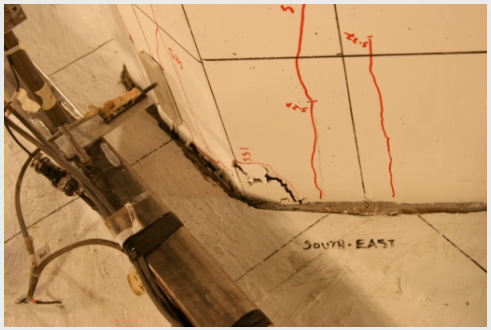
**Specimen 9: Current Design**

**Specimen 13: CR Connection**

**Specimen 14 : CR Higher Axial Load**



**Specimen 15: Annular: CDBP**



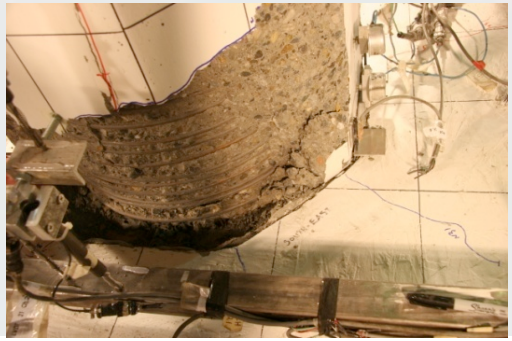
# Damage Comparison at 8.5% Rotation

**Specimen 9: Current Design**

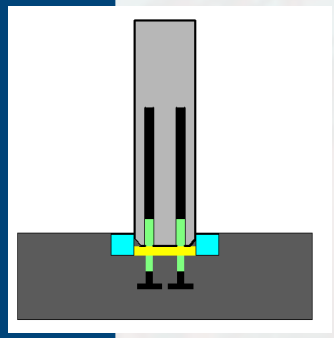
**Specimen 13: CR Connection**

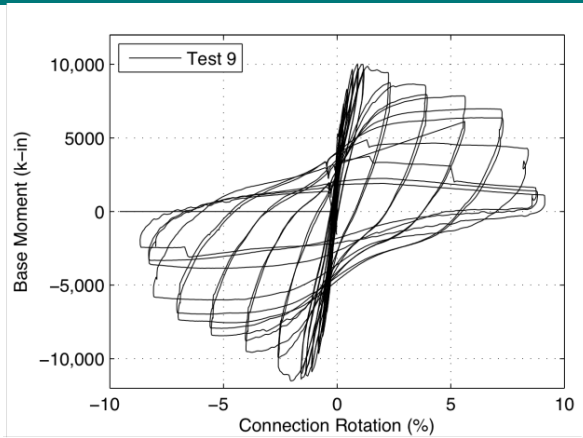
**Specimen 14 : CR Higher Axial Load**

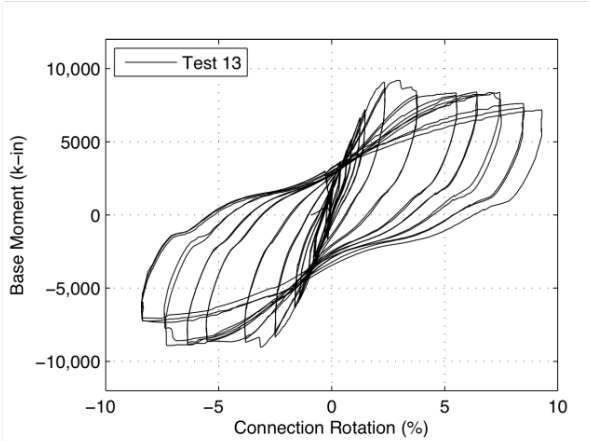
**Specimen 15: Annular: CDBP**

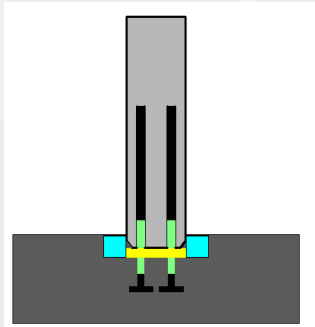


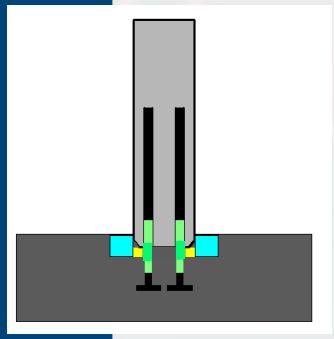
# Hysteretic Behavior-Moment/Rotation

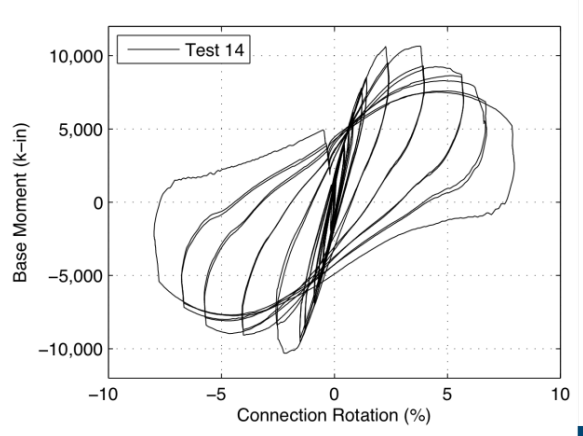


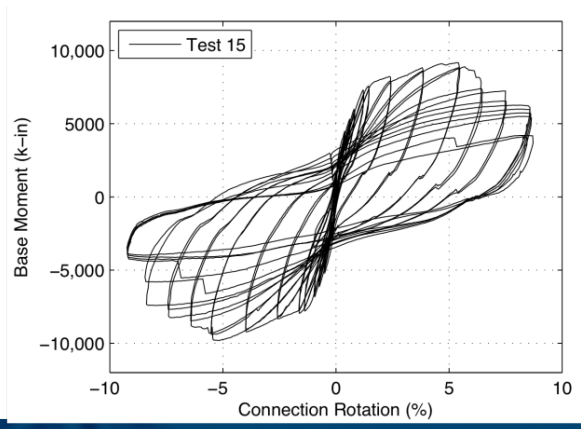


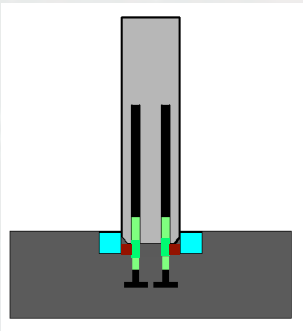





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# Current Focus: Performance Assessment

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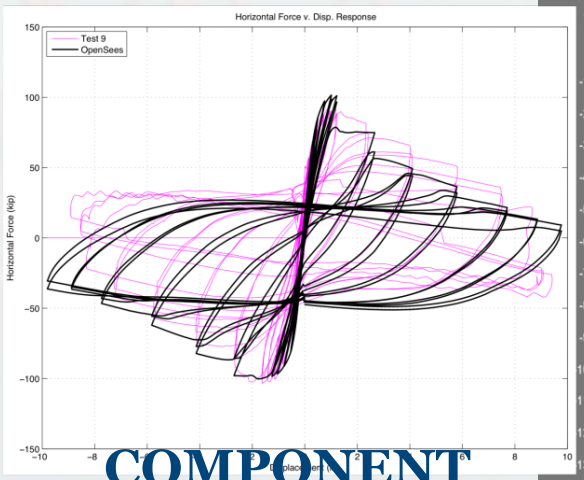
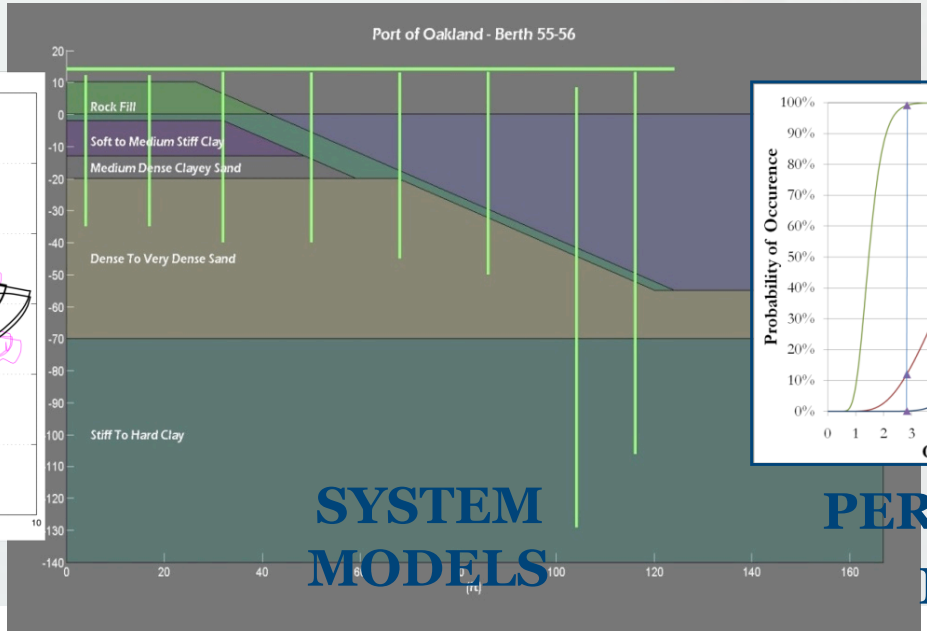
# Objectives

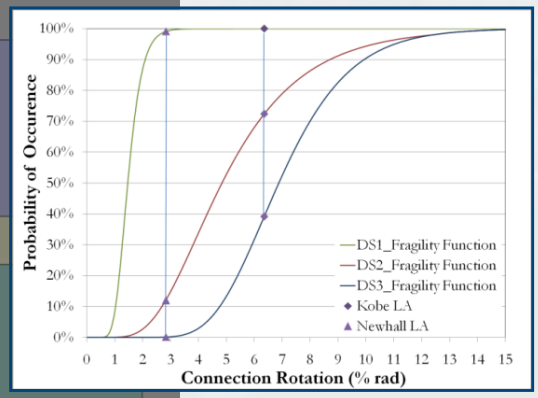
Quantify performance of marginal wharf with current connection and improved connections




COMPONENT MODELS




SYSTEM MODELS




PERFORMANCE MODELS

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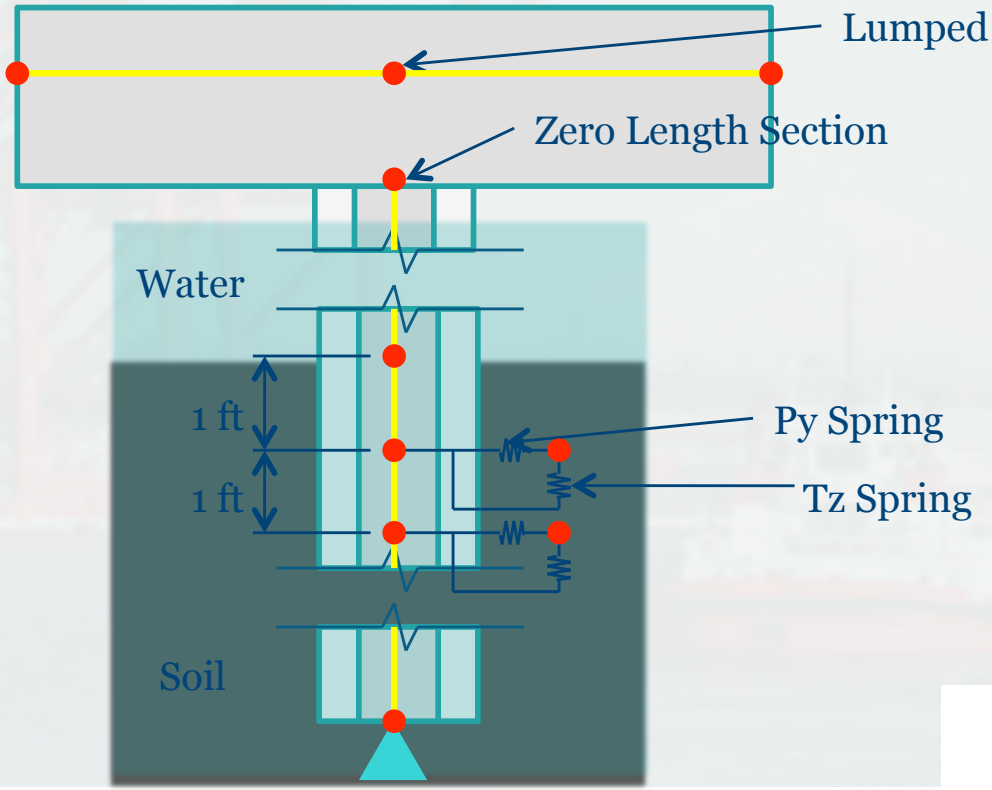
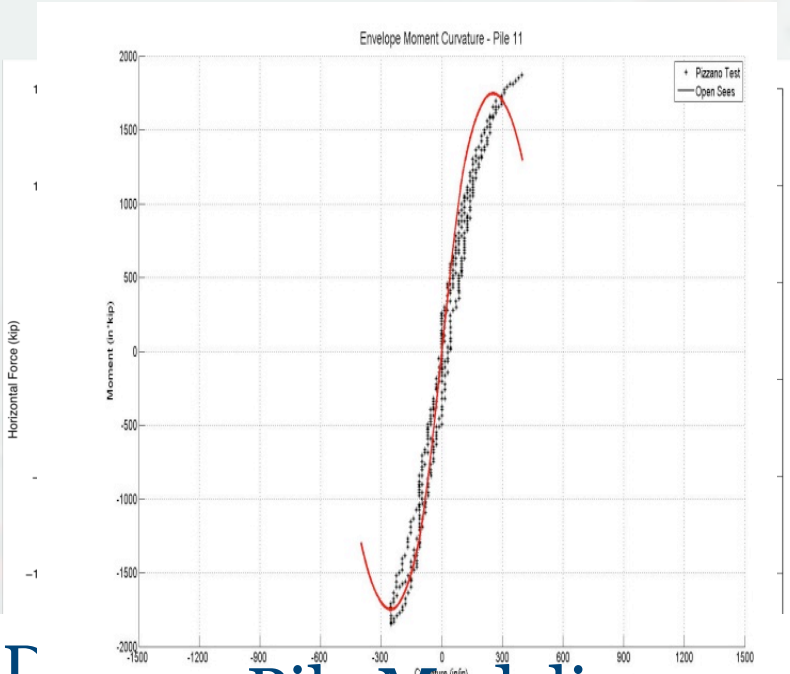
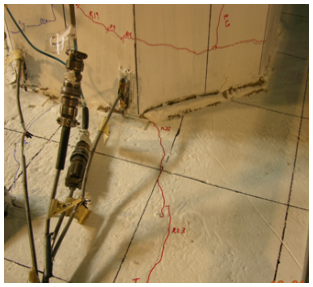
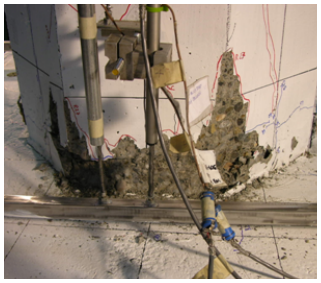
# Models



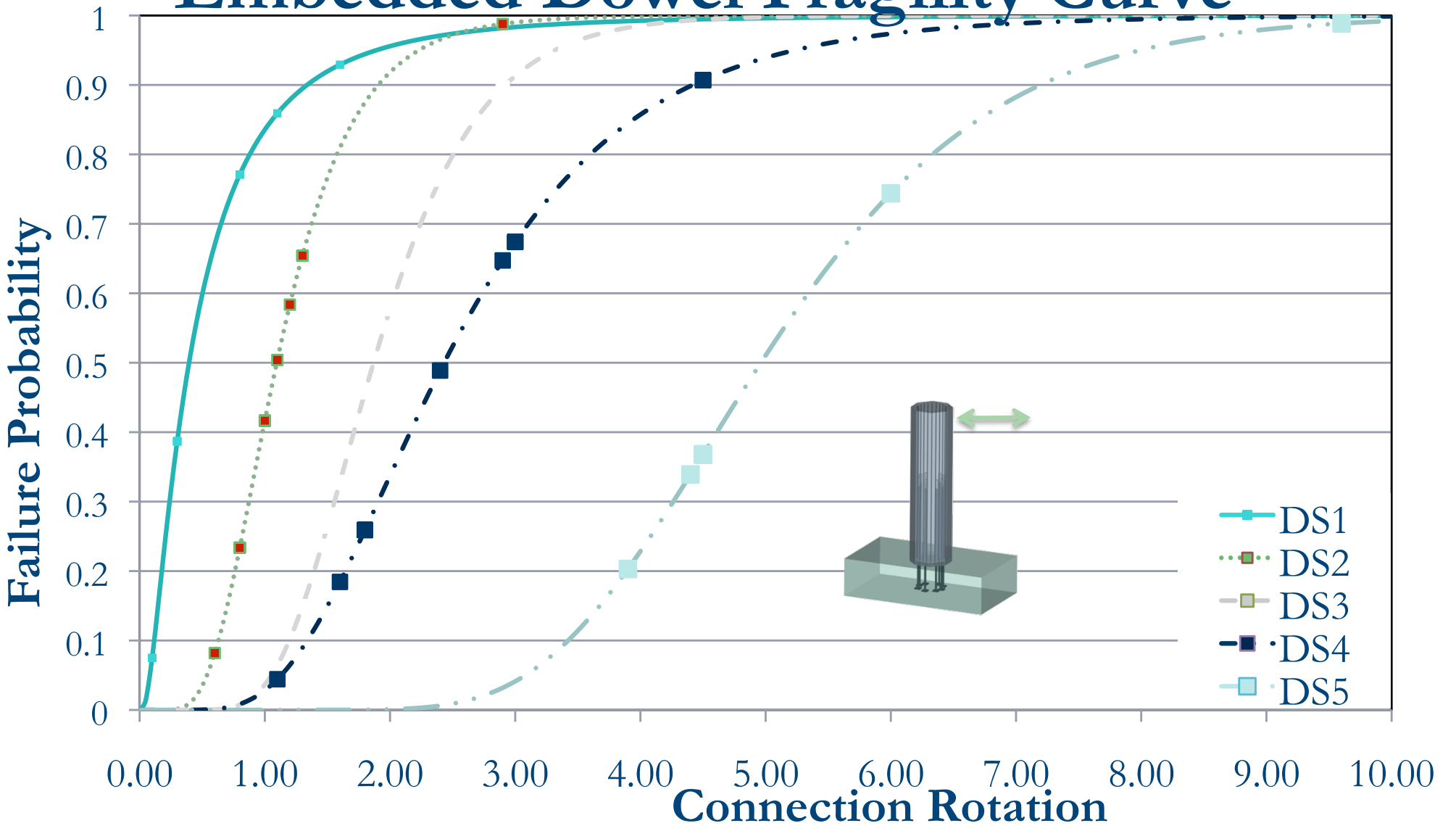

D Pile Modeling

# Damage States

| | DS1 | DS2 | DS3 | DS4 | DS5 |
|---|---|---|---|---|---|
| |  |  |  |  |  |
| **Damage States** | Pile Cracking | Major Cracks in the deck | Moderate pile spalling, no displacement | Deck Spalling, exposed bent rebar | Badly damaged pile head |
| **Repair** | Epoxy inject cracks. | Clean andepoxy inject cracks | Remove spalled concrete. Apply shotcrete. | Chip out spalled concrete. Paint rebar . Epoxy-inject cracks. Apply shotcrete &coat repair. | Replace with new pile adjacent to broken pile. |

# Fragility Curves

## Embedded Dowel Fragility Curve



# Proposed Research (Y2)

- **Recent Accomplishments:**
  - Verified modeling of pile
  - Developed and verifying CR connection model
  - Developed model of marginal wharf in Oakland
- **Proposed Research Tasks:**
  - Performance models for CR connection
  - Soil modeling and ground motion input (w/ P. Arduino)
  - Nonlinear dynamic response history analyses to determine performance of current and improved ports.
  - Resources required: 1 year and $60,000.

# Future Experimental and Analytical Study

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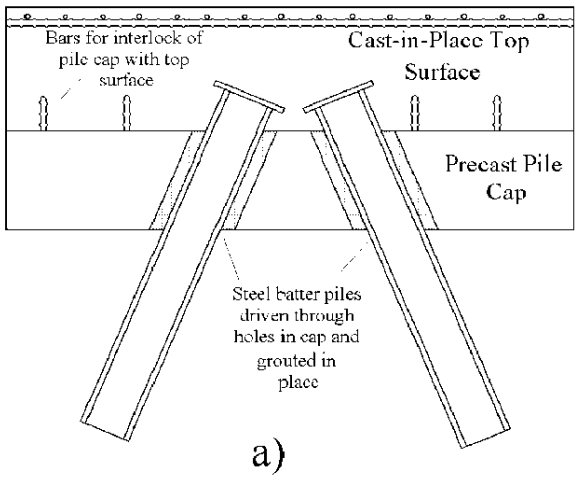
# Future Work: Batter Piles

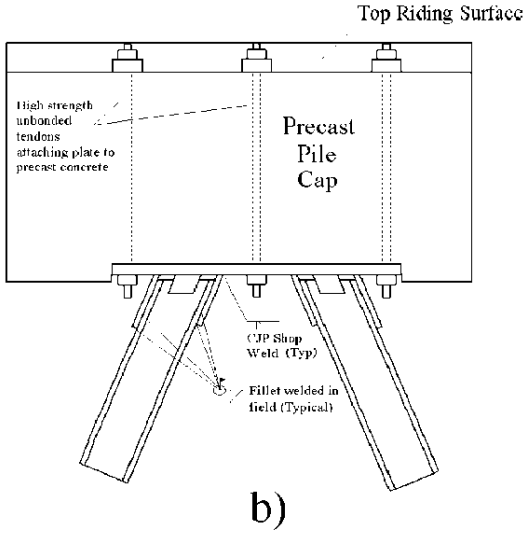
- **Improving the performance of Marginal Wharfs**
  - Improved connection will reduce connection damage
  - Assess vulnerability of piles below the soil line
  - Stiffer structural systems to reduce damage: batter piles
- **Extending results to structural systems of Alternative Port Terminals**
  - Intermediate Hubs
  - Piers
  - Liquefied Natural Gas (LNG) ports

# Proposed Batter Pile Connections

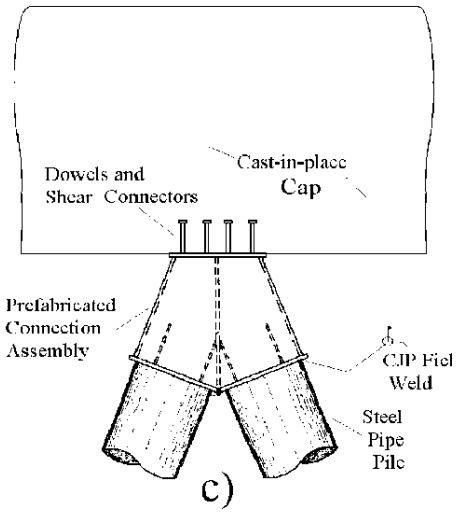
## Embedded Section Connection




## Through-Rod Connection




## Shear-Dowel Connection



# Future Work: Improving Performance with Batter Piles

- Analytical study of system performance
- Experimental investigation of connection performance
- Analytical and performance models of connection
- Quantifying improvements in system performance

# THANK YOU!

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