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Seismic Design Elements for the Gerald Desmond Cable-Stayed Bridge

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THE PORT OF LONG BEACH

ACKNOWLEDGEMENTS

- **Port of Long Beach/Caltrans**
  Joint Owners & Lead Development Agencies
- **Parsons-HNTB Joint Venture**
  Main Span – HNTB and Approaches – Parsons Lead

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Why Build a New Bridge?

- POLB & POLA – Largest Port Facility in U.S.
- Existing Bridge has very low sufficiency rating and is seismically substandard
- Insufficient Vertical Clearance Under Existing Bridge.
- POLB requires 200’ of Vertical Clearance to stay competitive with other ports.

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Project Overview

- **Main Span Set at 1000-ft**
- **Increase Vertical Clearance from 156-ft to 200-ft**
- **Includes almost 2 miles of Approach Structures**
- **166-ft Deck Width**
  Three Lanes of Traffic Each Way
  10-ft Outside and 12-ft Inside Shoulders

Criteria for New Bridge Section

- Must Be Economical
- Provide Signature Structure
- Good Seismic Resistance
- Minimize Impact to Port Operations
- Low Maintenance

Cable-Stayed Bridge Features

- **Shear Link Tower and End Bents:**
  - Hollow Concrete Towers and End Bents
  - Transverse shear links at Towers
  - Longitudinal shear links at End Bents
  - Tension Ties at Cables
  - Diaphragms at deck, below and above cables
- **Superstructure:**
  - Composite steel I-girder floor beams
  - Precast concrete deck panel with overlay
  - Hollow steel trapezoidal edge girder

Shear-Link Tower

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Shear-Link Tower

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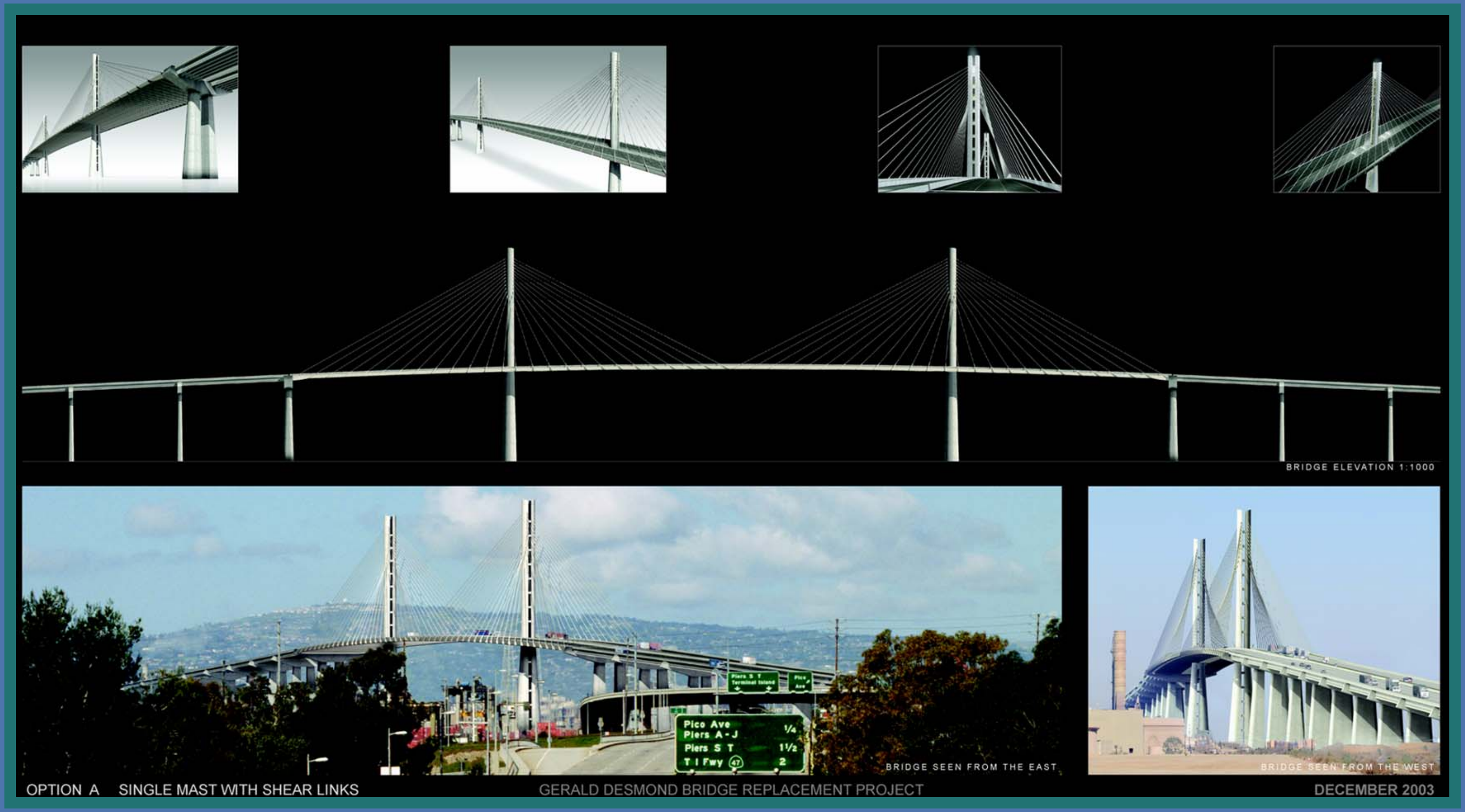
Shear Link Tower



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Tower Details

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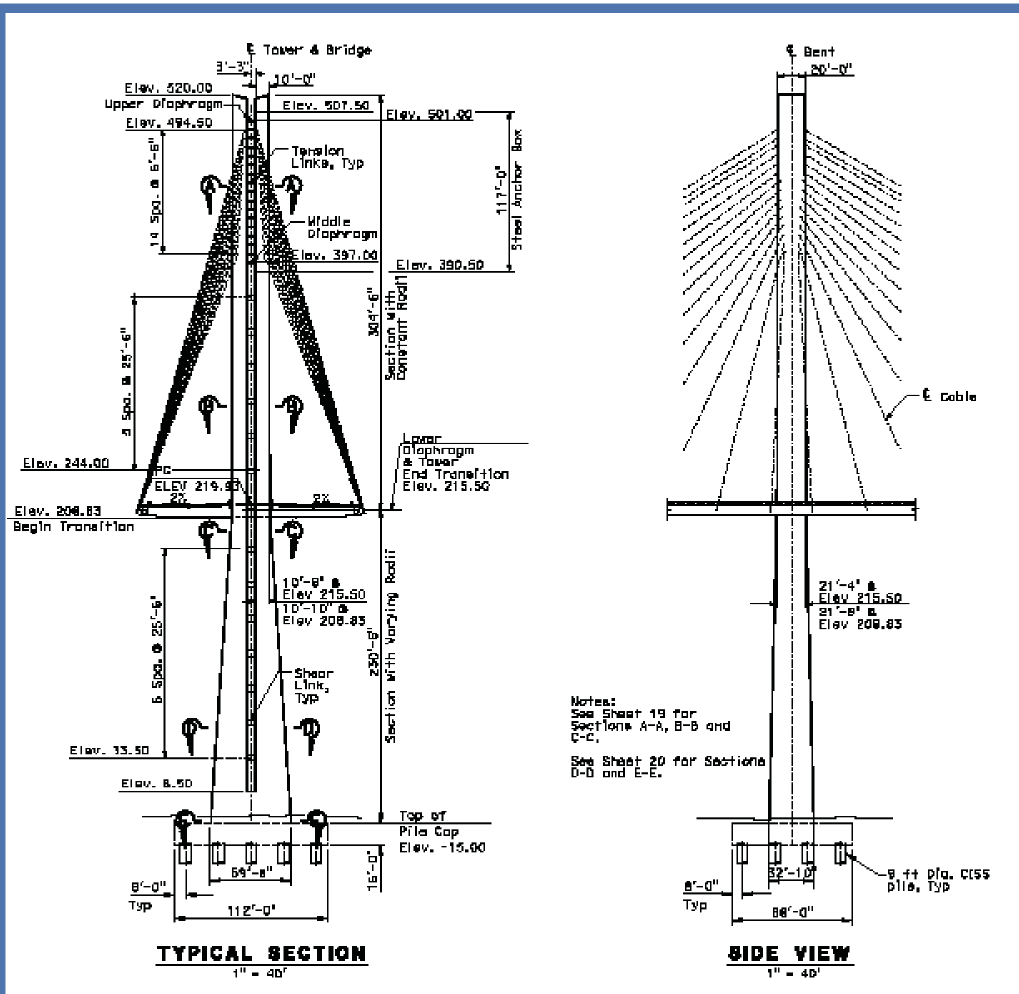

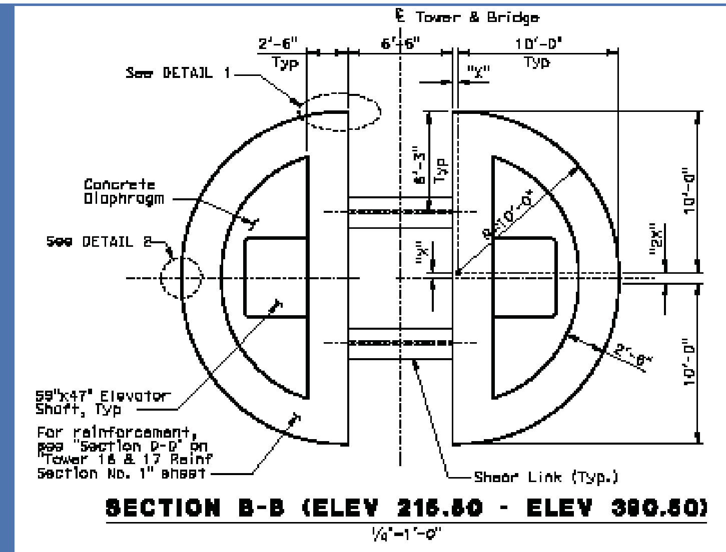

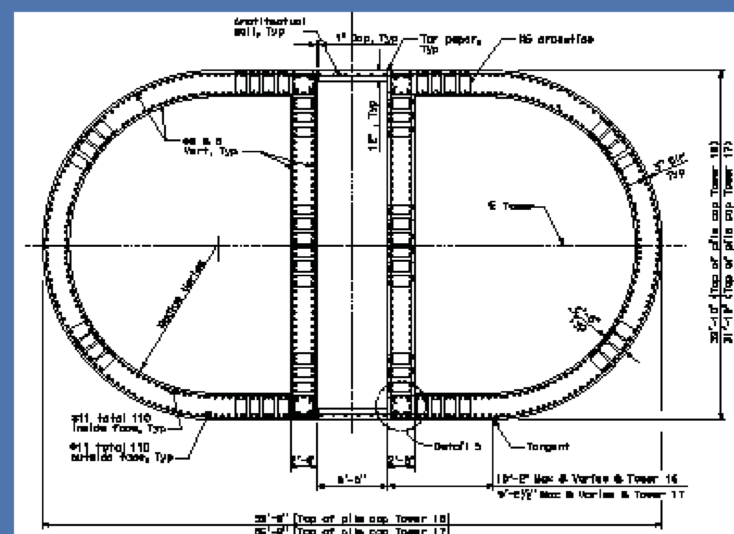

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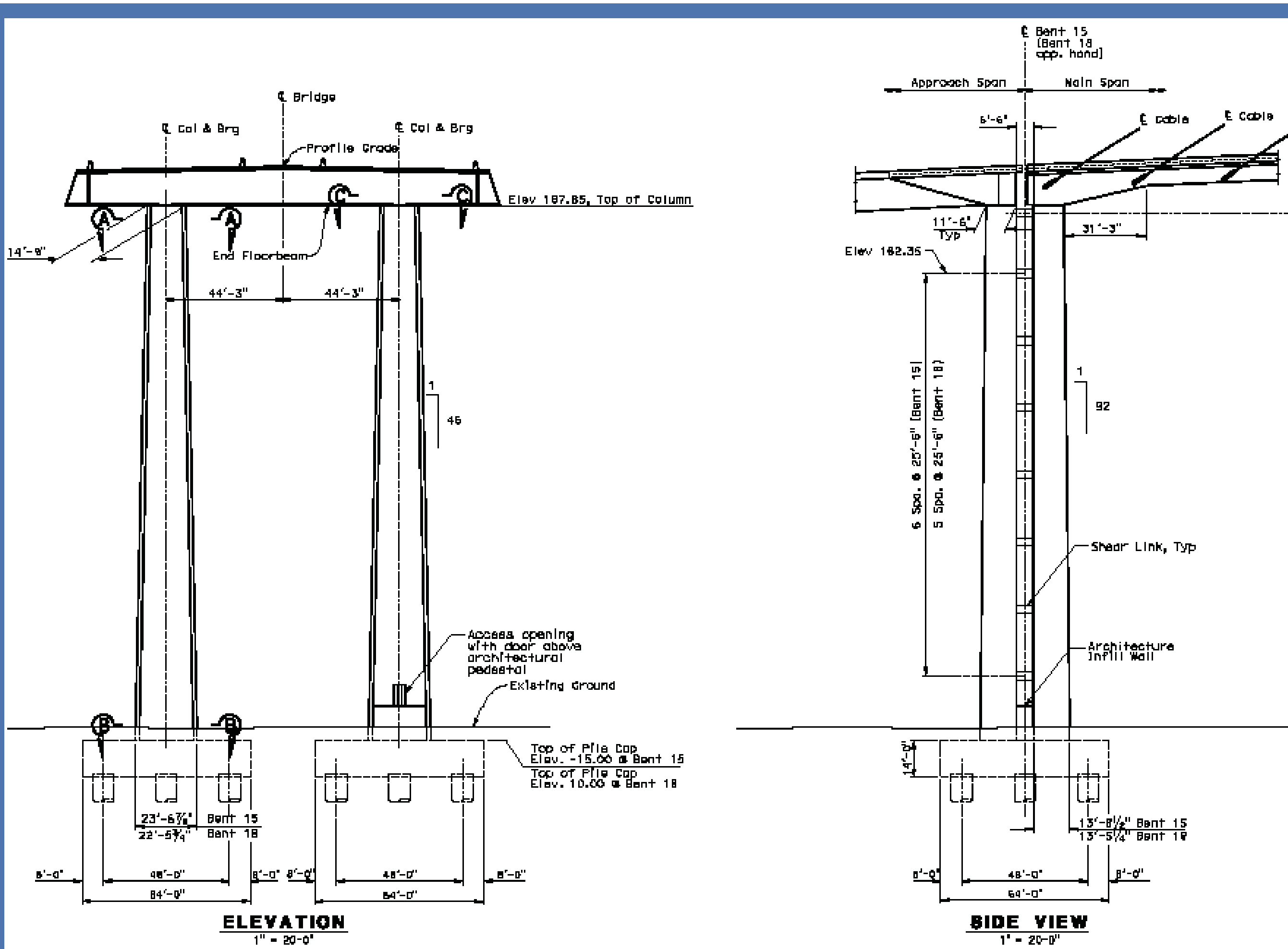
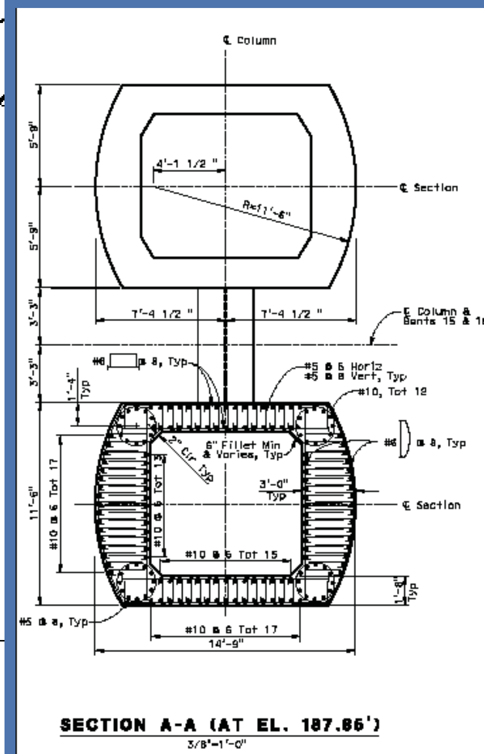
End Bent Details





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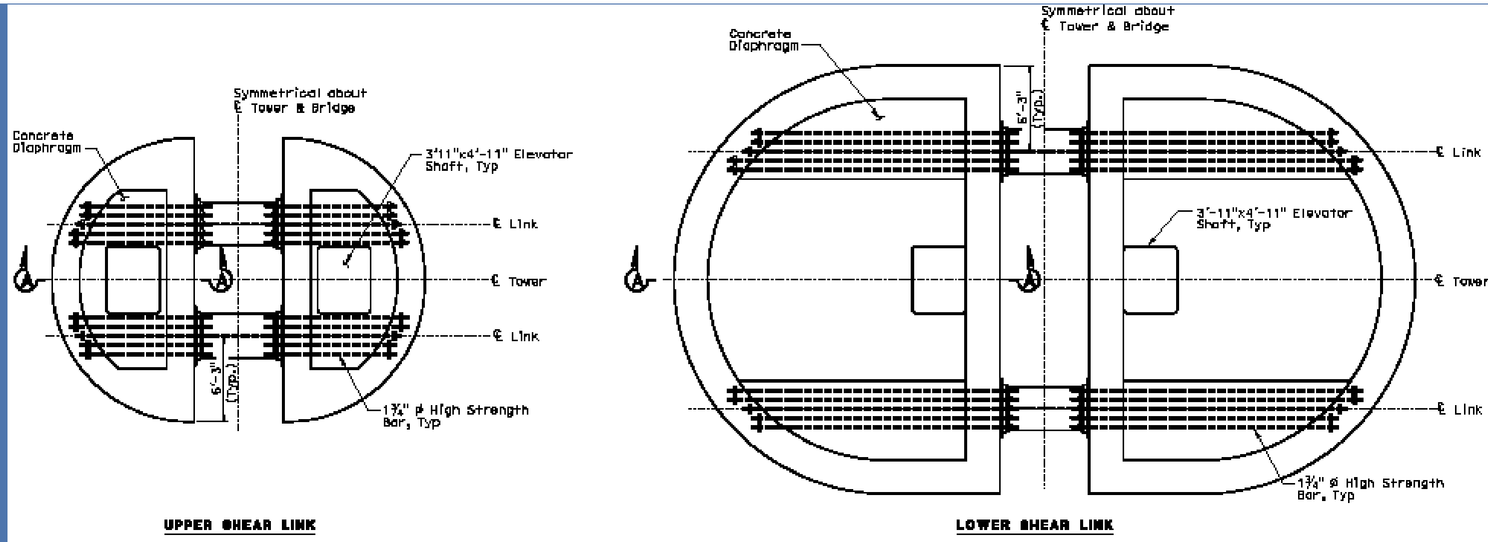
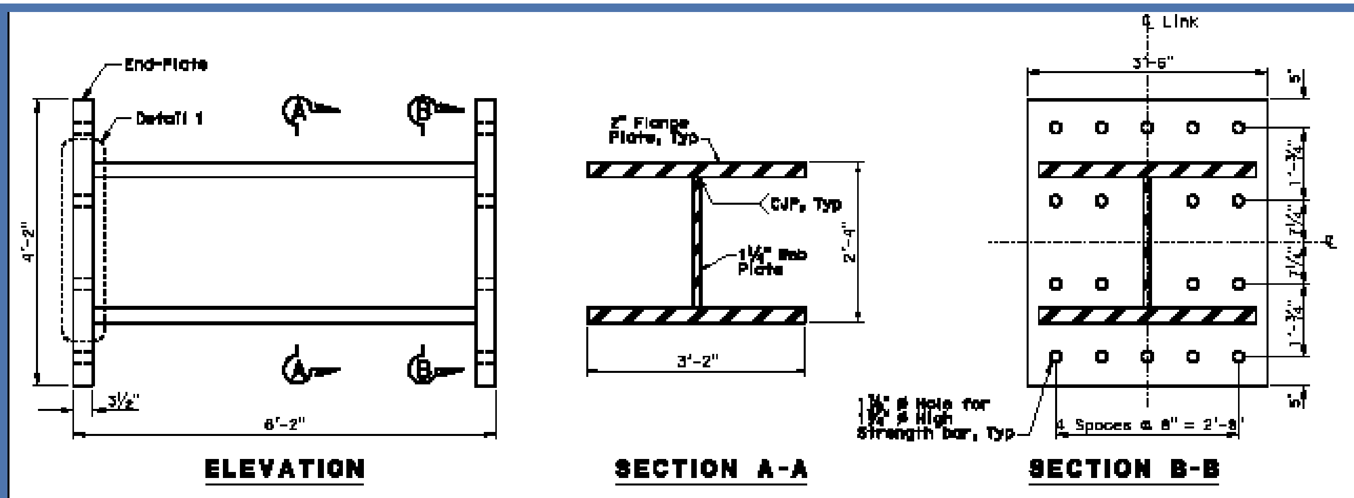
Shear Link Details

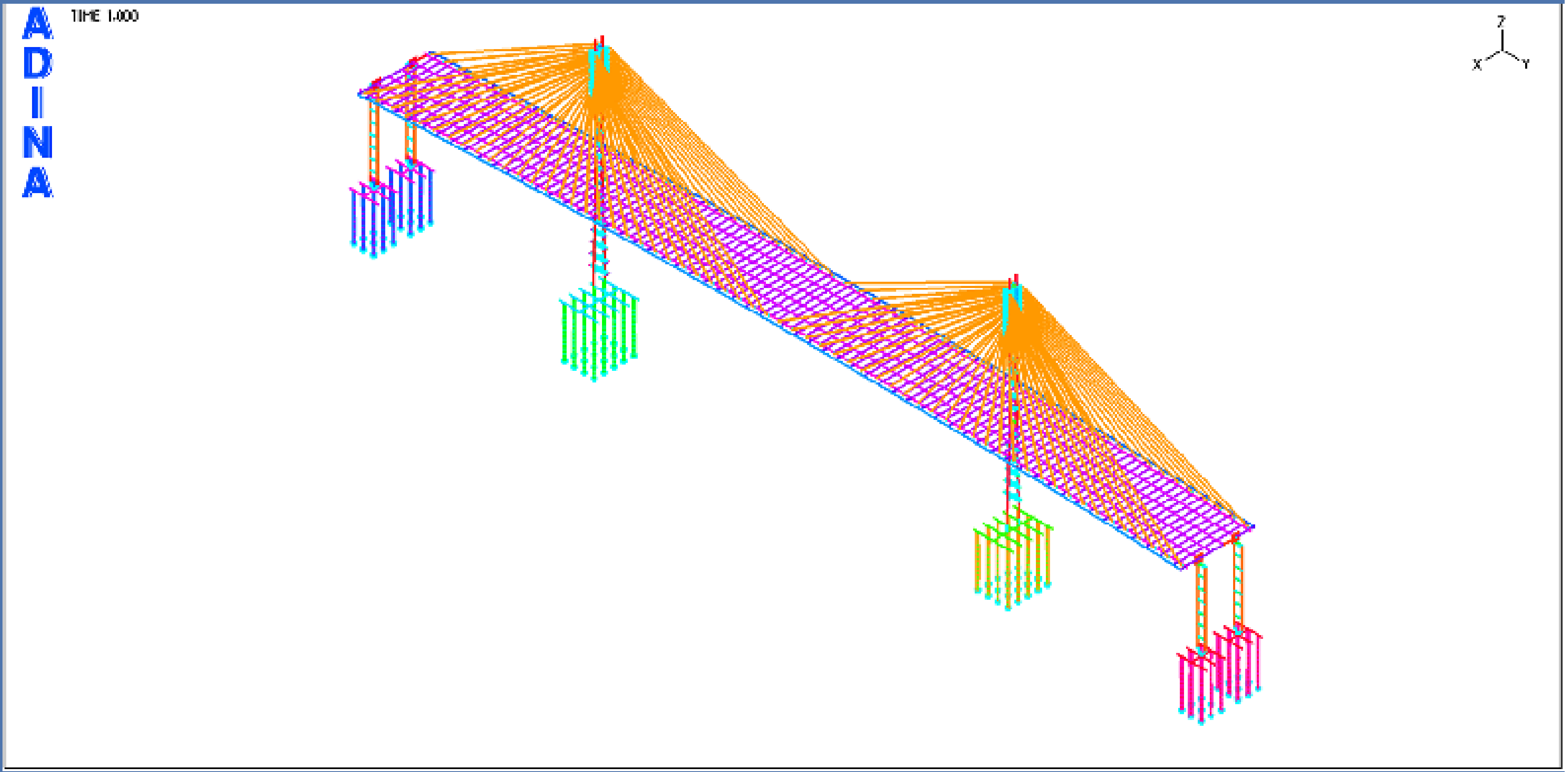




Seismic Design Criteria Summary

- Non-linear Time History Analysis
  - Functional Evaluation Earthquake (FEE)
  - Safety Evaluation Earthquake (SEE)
  - Three ground motions for SEE
  - One ground motion for FEE
  - Non-linear elements used in key locations
- Performance Based Criteria
  - Four levels of "Damage" defined
  - Significant Damage allowed in Shear Links and Expansion Joints

Seismic Model



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Seismic Model - Key Components

- **Foundations**
  - Pile elements modeled with M-C at top
  - Compression only non-linear soil springs
  - Soil springs allow soil gapping during inelastic response
  - Ground motions applied at base of each pile
  - All other ground nodes linked to base of pile
- **Substructure**
  - M-C elements used at base of tower and bents
  - Longitudinal shear links used at bents
  - Transverse shear links used at towers
  - Diaphragms used at deck level and below and above stay cables to limit twist between bent/tower legs

Seismic Model - Key Components

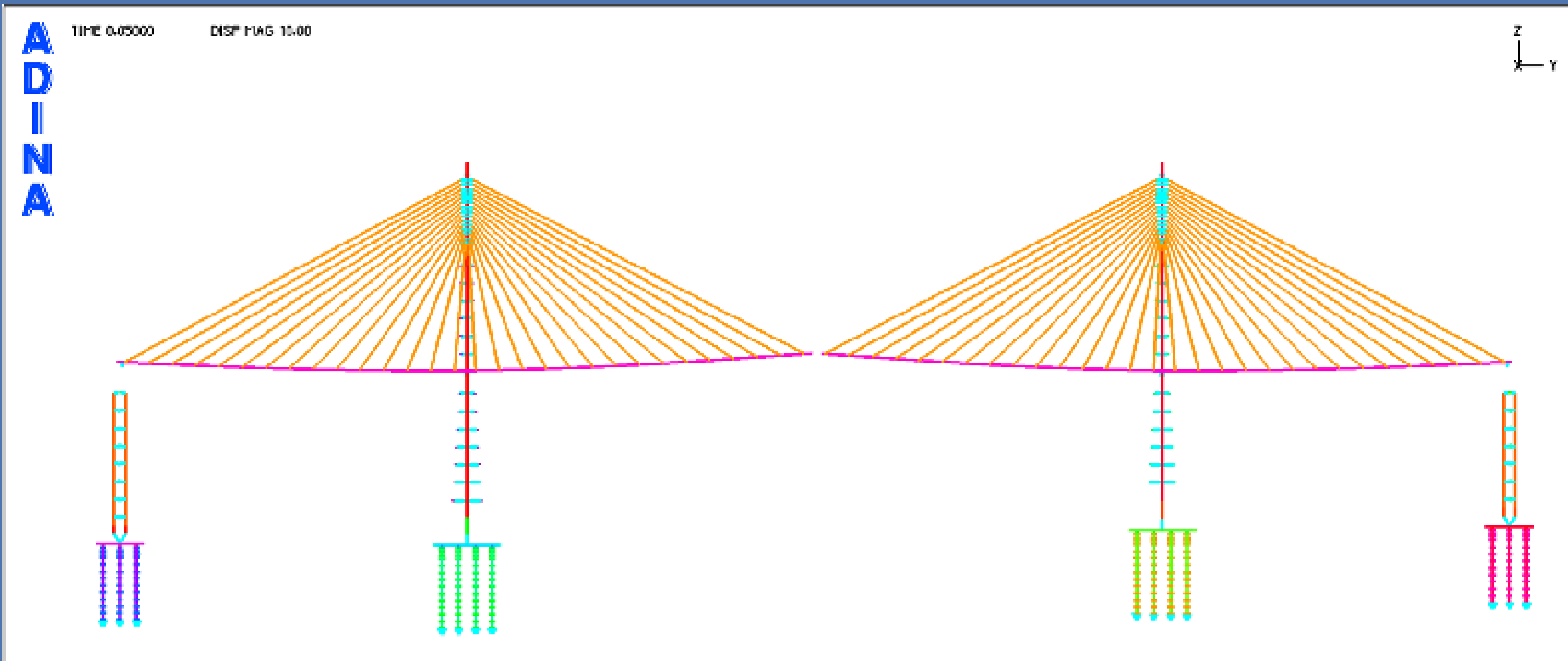
- Shear Links
  - Shear Link beams based on EBF concept
  - Modeled with truss elements to match shear vs. rotation of actual section
  - Beam elements added to model out of plane bending stiffness of shear link beams.
- Expansion Joints, Bumpers, Shear Keys
  - Compression only bumpers at deck tower leg disengages the deck in the longitudinal direction.
  - Bumpers engage the deck in the transverse direction.
  - Shear keys and rocker links truss elements used to pin the deck at the top of the end bents

Steps to Run the Model

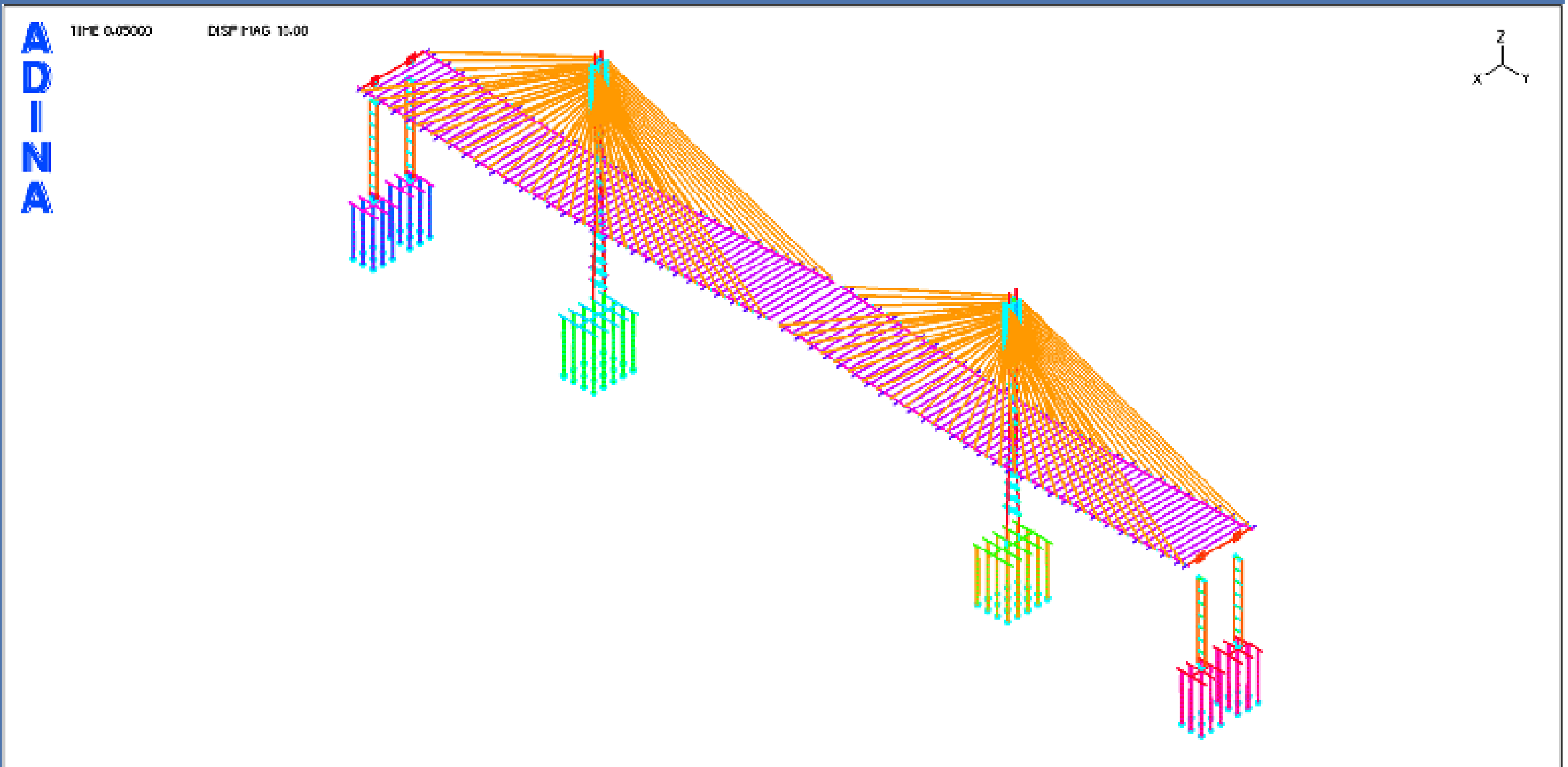
- **Dead Load**
  - Camber the superstructure and apply the trial 0 dead load using balanced cantilever construction sequence.
  - Connect superstructure at mid span and at end bents
  - Apply trial 1 dead load (barriers, utilities, etc.)
  - Connect bumpers at towers, shear keys and rocker links at end bents

- **Set Damping for Elastic Elements**
  - Perform Modal Participation Analysis
  - Use Rayleigh Damping equation and set anchor points such that 90% of the mass has a damping <4%.
  - Elastic element damping does not capture damping via moment curvature elements and foundation springs.

Dead Load Trial 0–Construction Staging-Elev.



Dead Load Trial 0–Construction Staging-ISO



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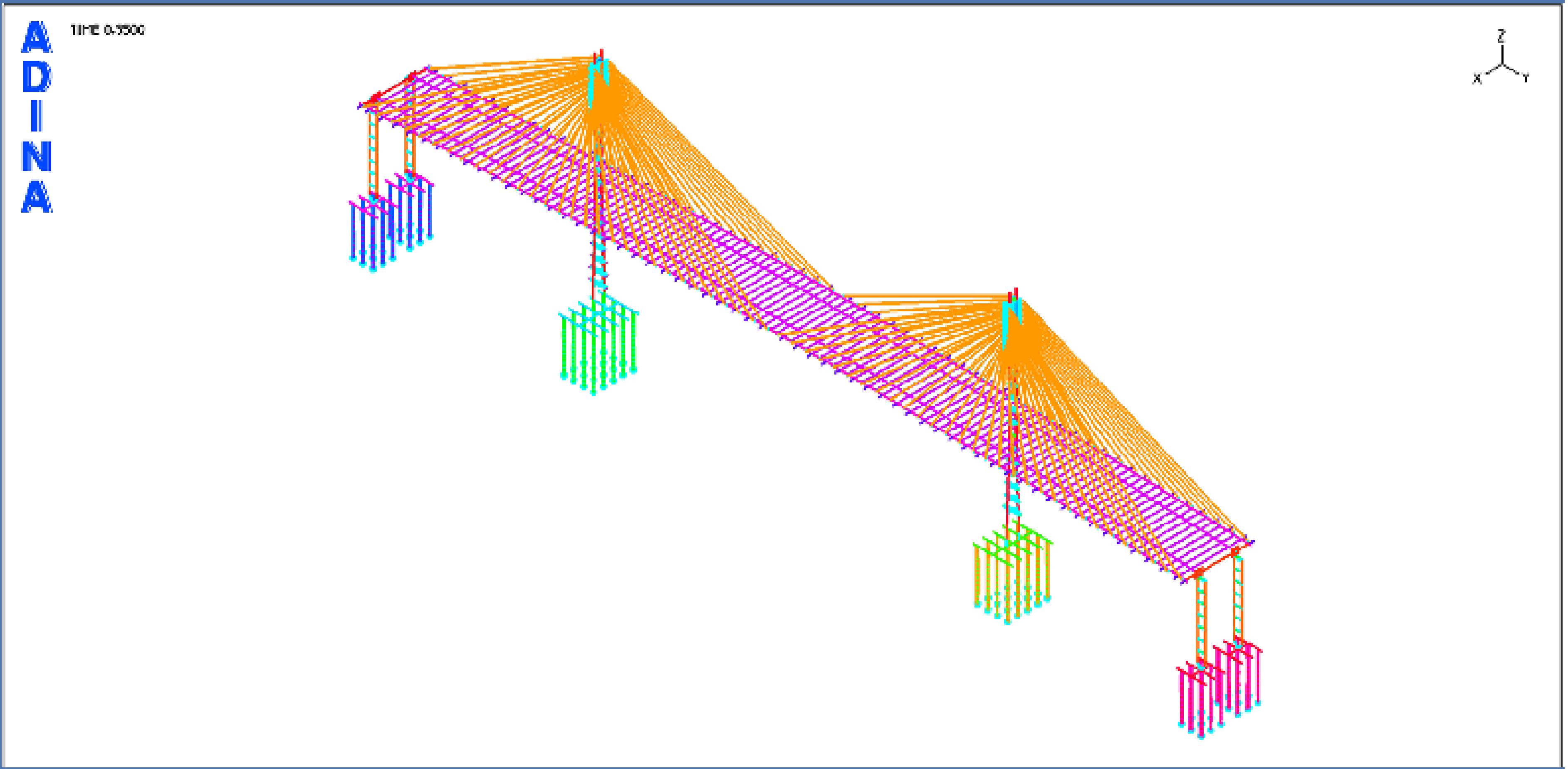
Dead Load-Connect Mid-Span and Bumpers



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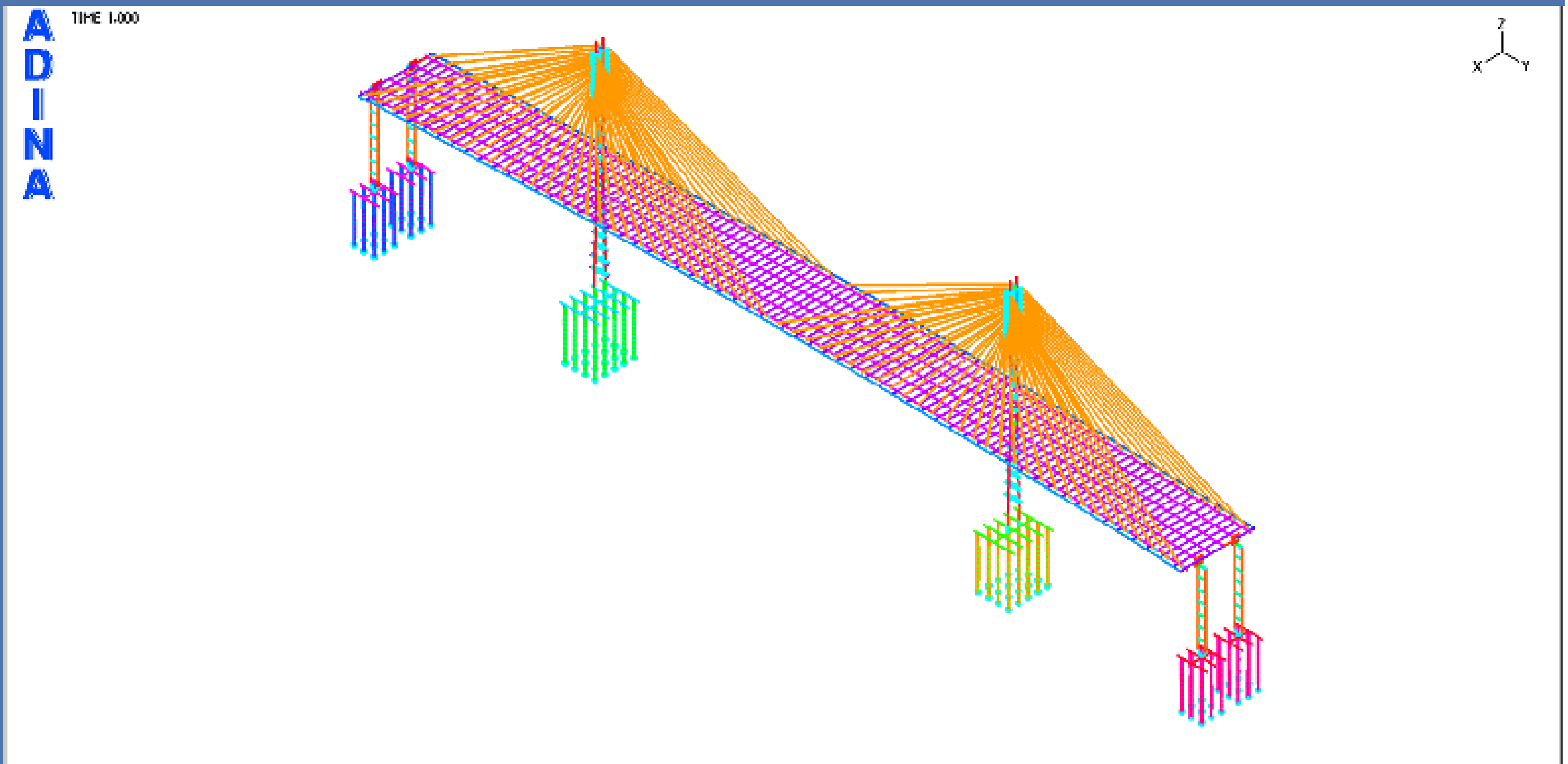
Apply Trial 1 DL, Bumpers and Shear Keys



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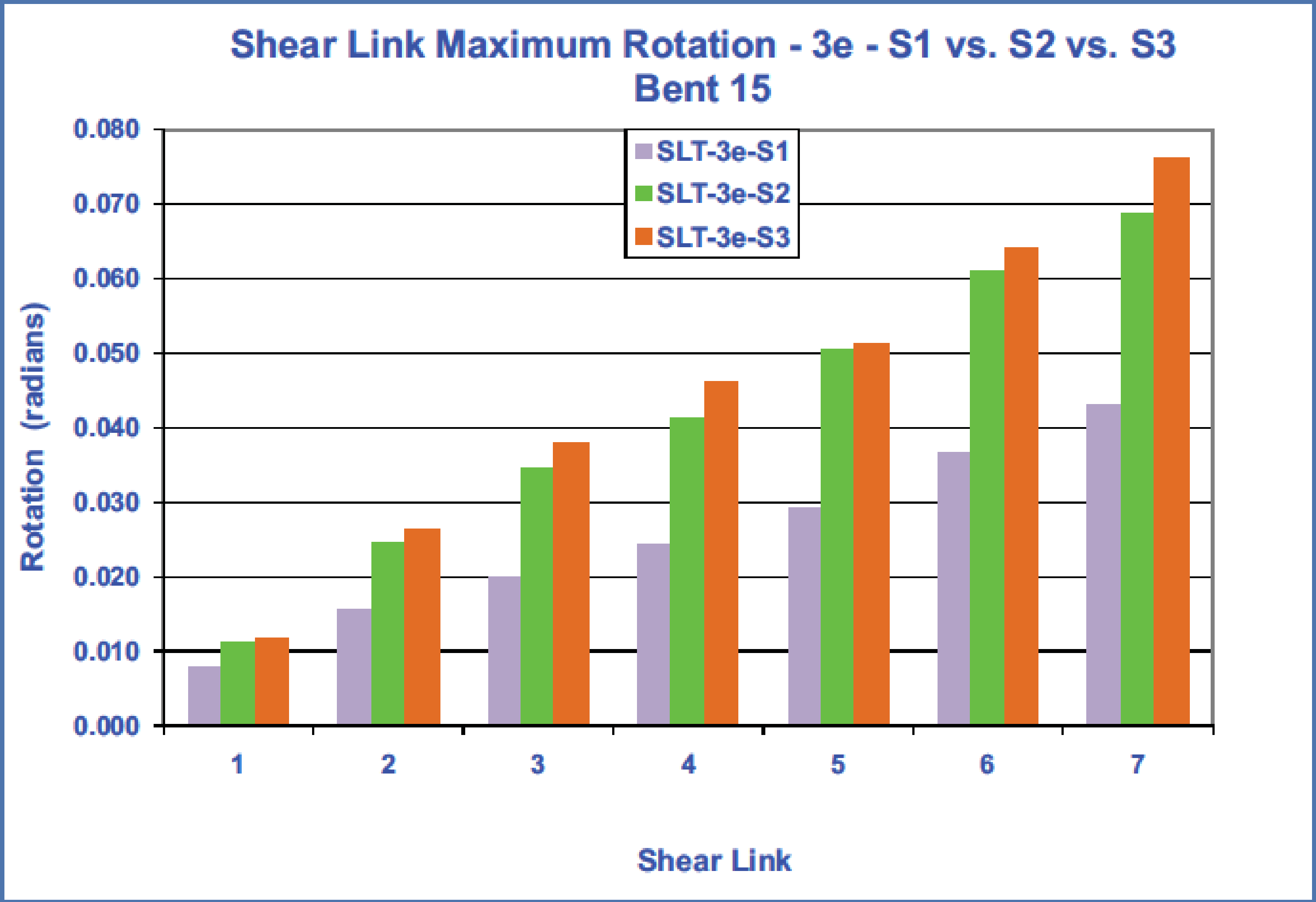
Steps to Run the Model

- Seismic Analysis
  - Run Ground Motions for SEE and FEE for Main Span model
  - Extract displacements, moment curvature, element forces, bumper nodal velocities
  - Process results and compare capacities

Seismic Analysis Results

- Tower and End Bents remain essentially elastic
- End Bent shear link rotation < 0.08 radians
- Tower shear link rotations < 0.05 radians
- CISS piles remain essentially elastic
- Deck Longitudinal Displacement < 4.0’
- End Bents Max Transv. Displ. < 2.5’
- Top of Tower Transv Displ. < 6.0’
- Top of Tower Longitudinal Displ. < 5.0’
- Residual Displacement < 0.5’

Shear Link Rotations – Bent 15



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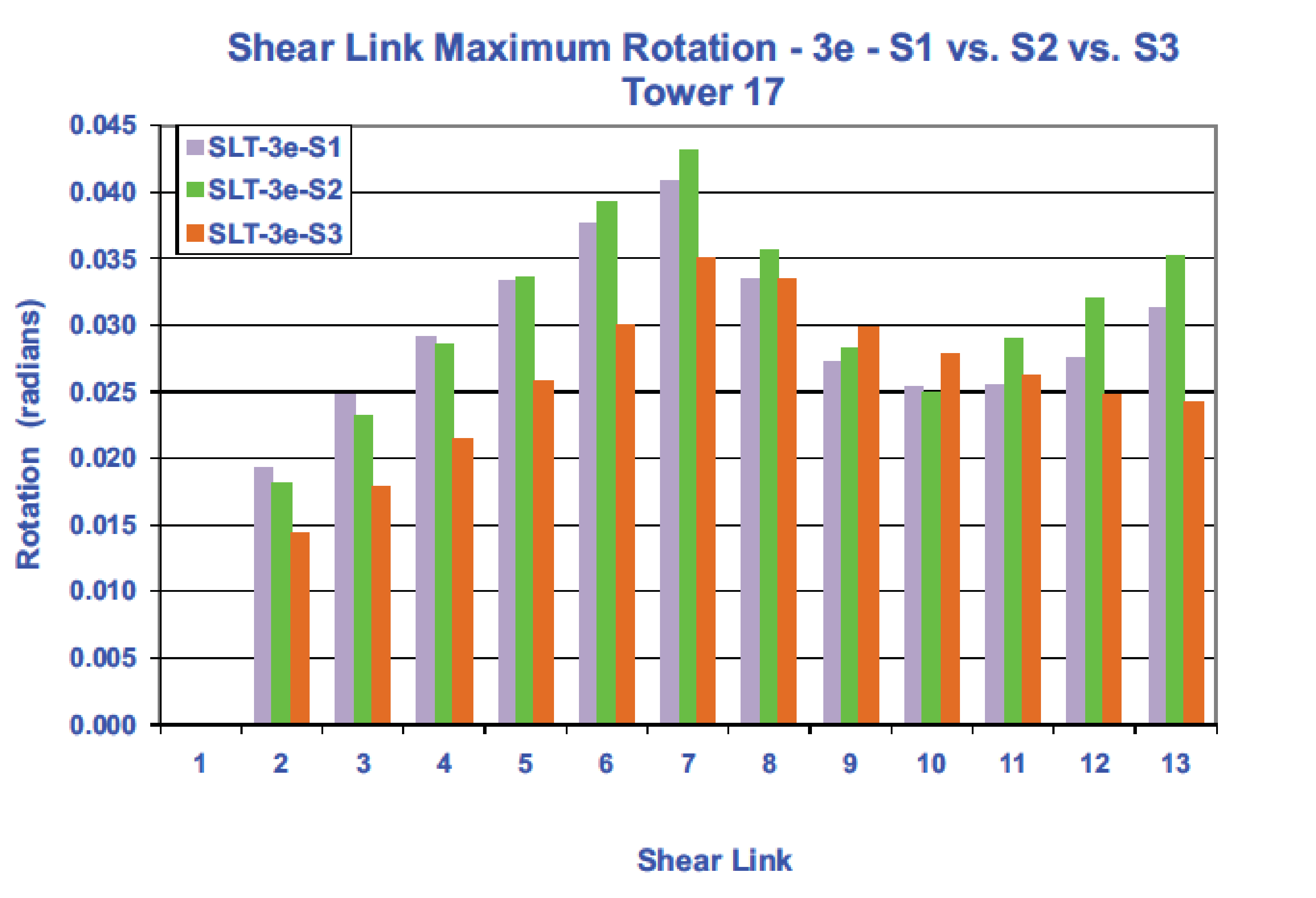
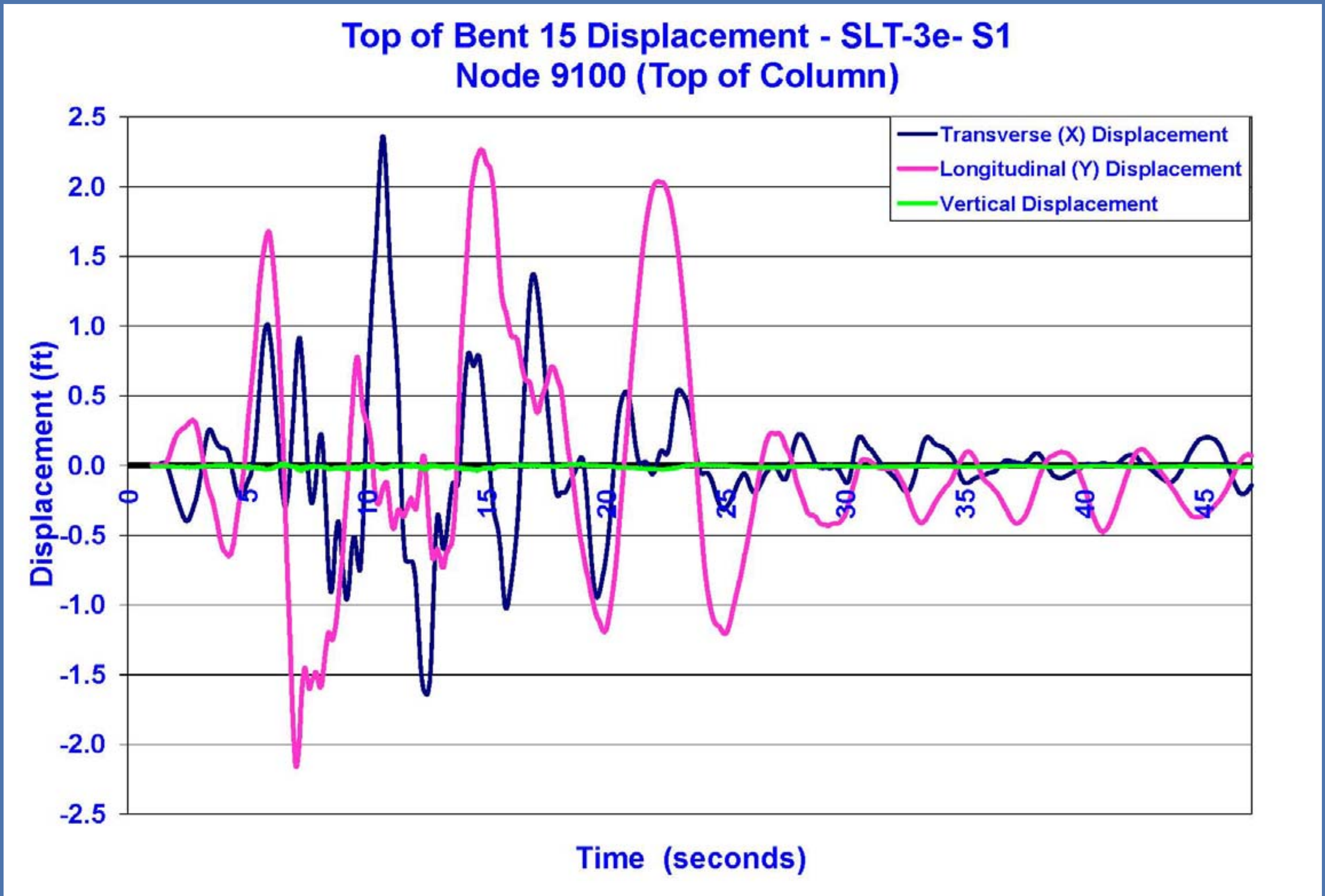
Shear Link Rotations – Tower 17



S1 Displacements – Bent 15



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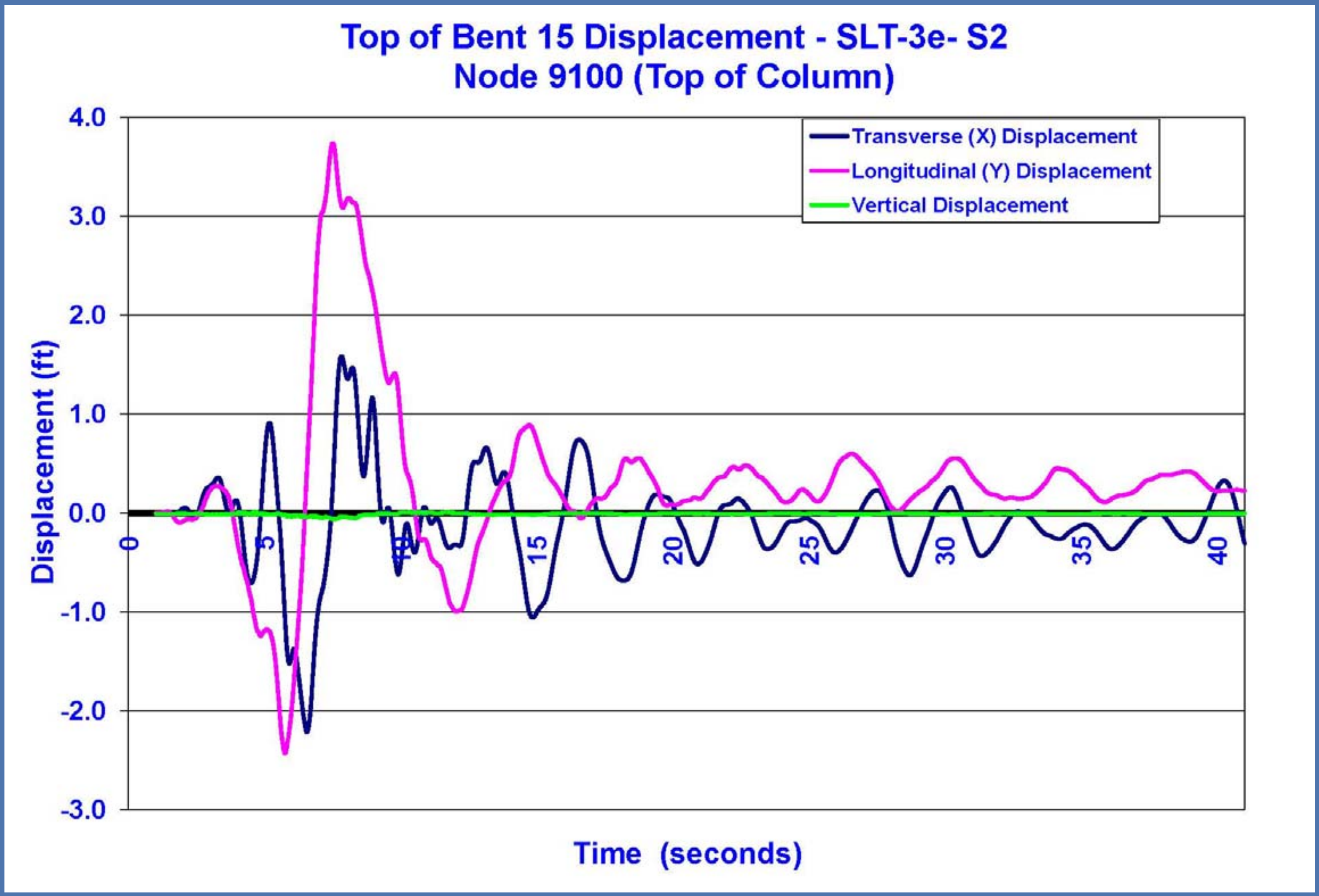
S2 Displacements – Bent 15



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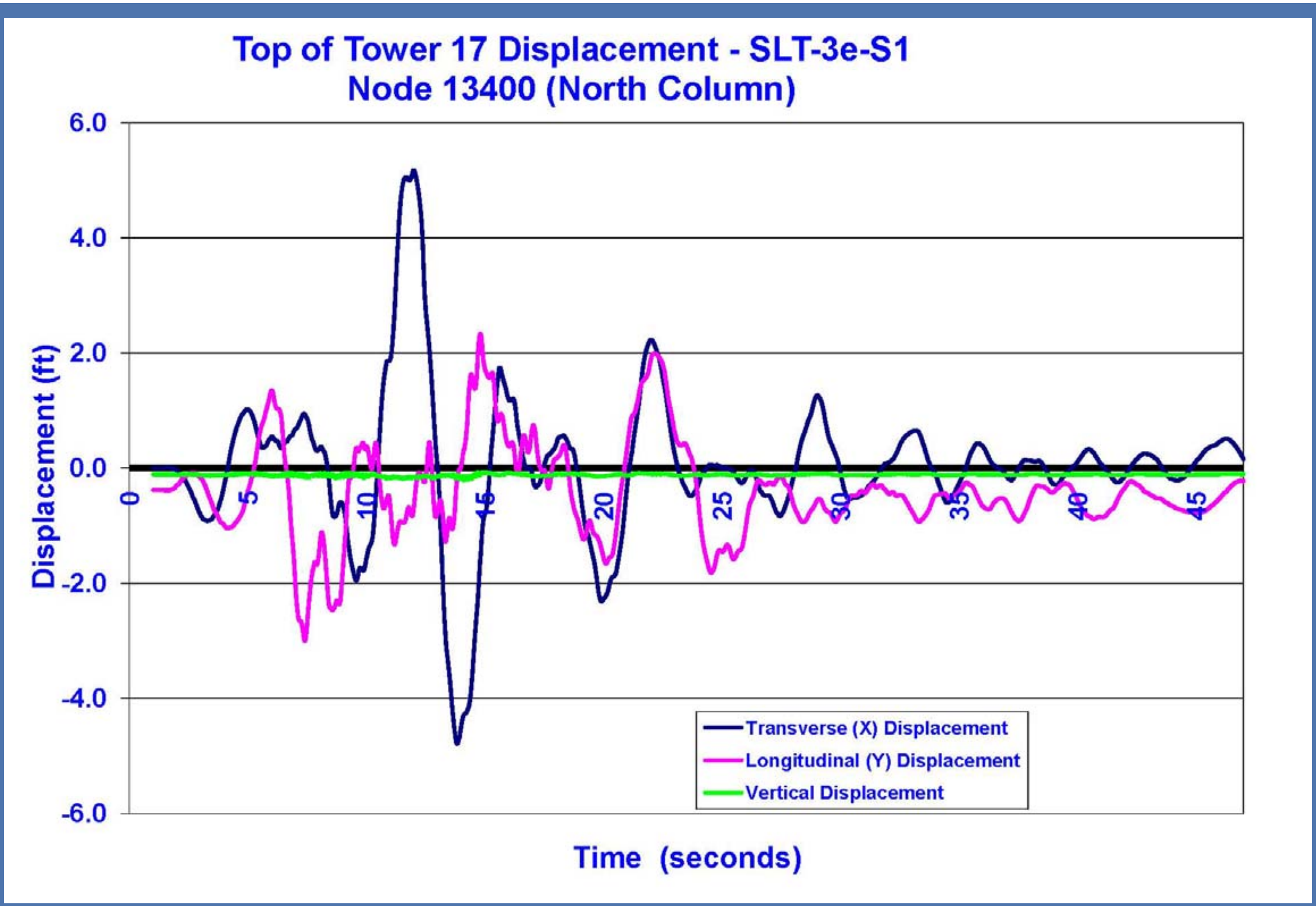
S1 Displacements – Tower 17



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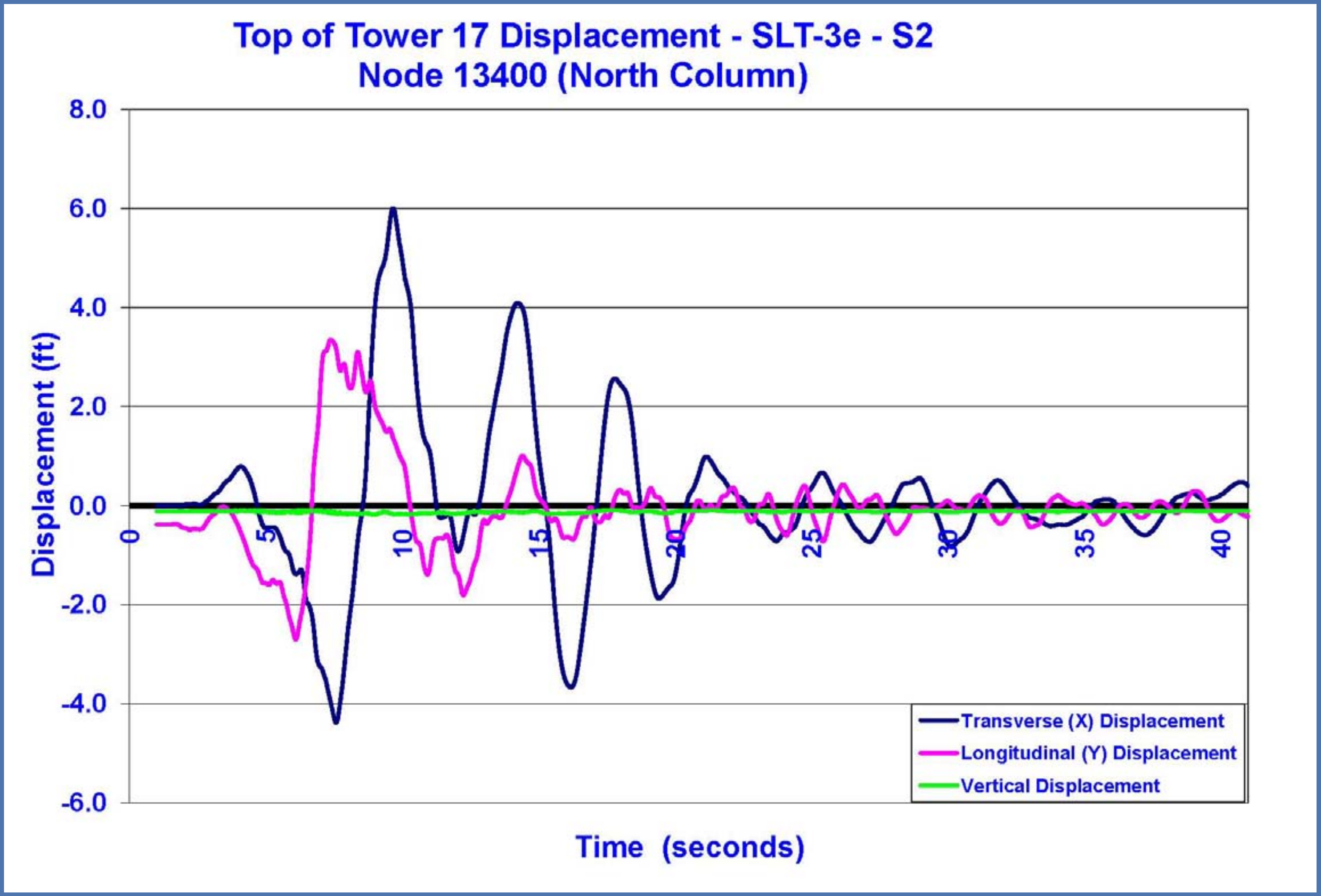
S2 Displacements – Tower 17



Lessons Learned

- Use of shear links protects other substructure and superstructure elements.
- Residual displacement is small. Analytically, removal of damaged shear links results in concrete towers and bents returning to plumb position.
- Approach structure does not significantly affect the response of the main bridge.
- Cable unloading will be studied further using non-linear elastic elements to capture stiffness reduction related to sag. Minimum cable force is approximately 10% of dead load cable force.