2011 ASCE SEI Structures Congress
April 16, 2011 - Las Vegas, Nevada

Computational Analyses of Quasi-Isolated Bridges with Fusing Bearing Components

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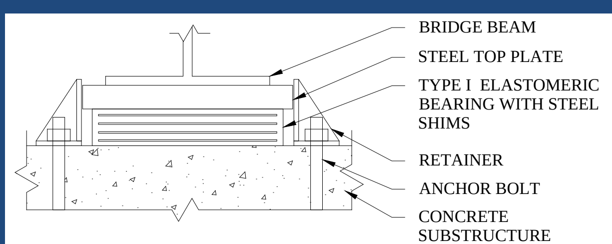
Introduction

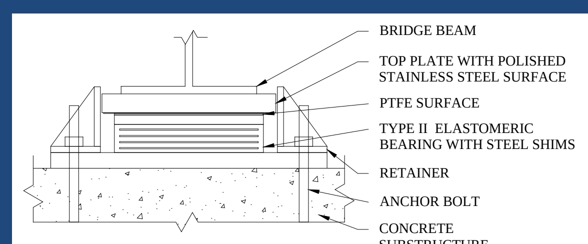
- IDOT Earthquake Resisting System (ERS):
  - Recently developed & adopted design approach tailored to typical Illinois bridge types (and in part addressing increased hazard levels in AASHTO)
  - Primary objective: Prevention of span loss
  - Three levels of design and performance:
    - » Level 1: Connections between super- and sub-structures designed to provide a nominal fuse capacity
    - » Level 2: Provide sufficient seat widths at substructures to allow for unrestrained superstructure motion
    - » Level 3: Plastic deformations in substructure and foundation elements (where permitted)

Quasi-Isolation for Bridges

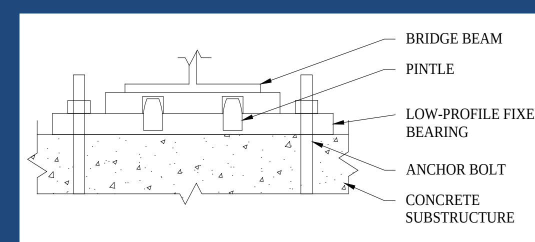
- Typical bridge bearing systems designed to act as fuses to limit the forces transmitted from the superstructure to the substructure
  - Type I bearings: bearings with an elastomer to concrete sliding surface
  - Type II bearings: elastomeric bearings with PTFE sliding surface
  - L-shaped retainers: designed to limit service load deflections
  - Low-profile bearings with steel pintles and anchorbolts



Elastomeric bearing on concrete



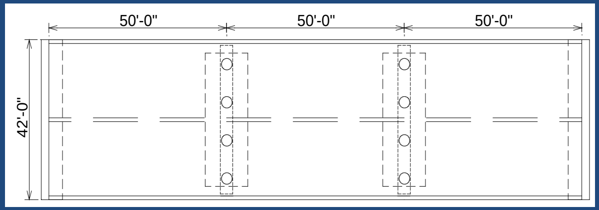
Elastomeric bearing with PTFE sliding surface



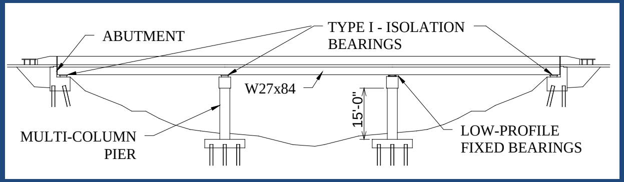
Low-profile fixed bearing

Bridge Prototype Model

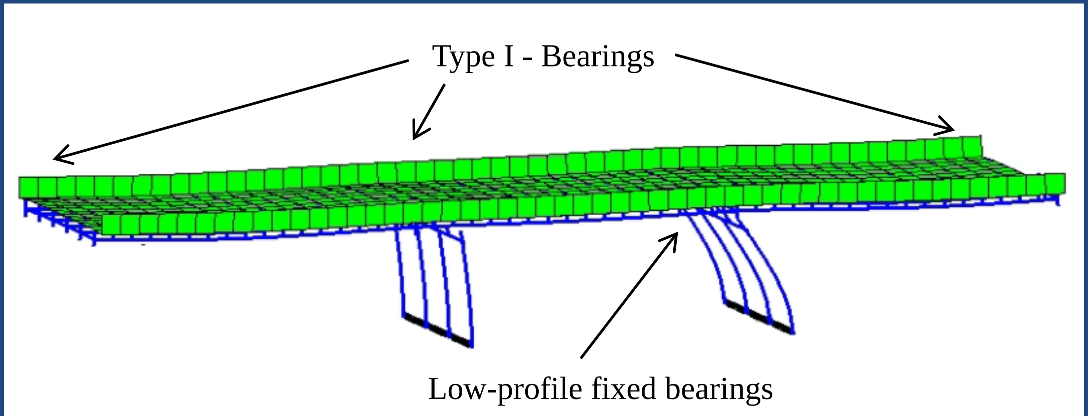
- Three 50’ spans with six W27x84 Gr. 50 composite girders and 8” concrete deck
- 15’ Tall multi-column intermediate substructures
- Concrete abutments with backwalls and 2” gap from deck
- Pile foundations for all substructures



Bridge Prototype Plan



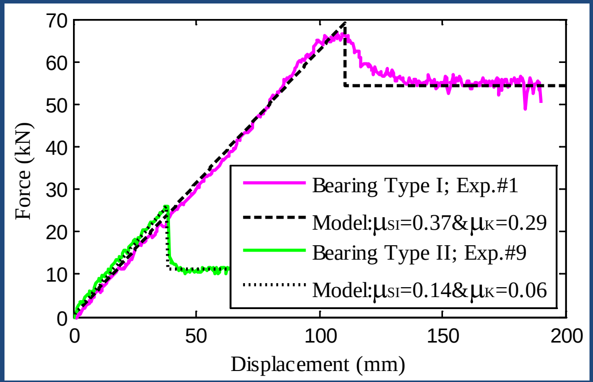
Bridge Prototype Elevation

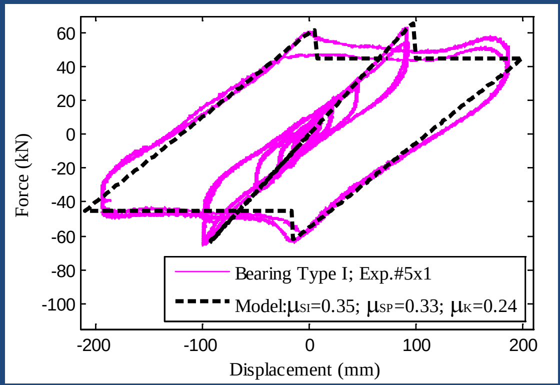


Mesh Representation of OpenSees Model

Modeling of Bearing Components

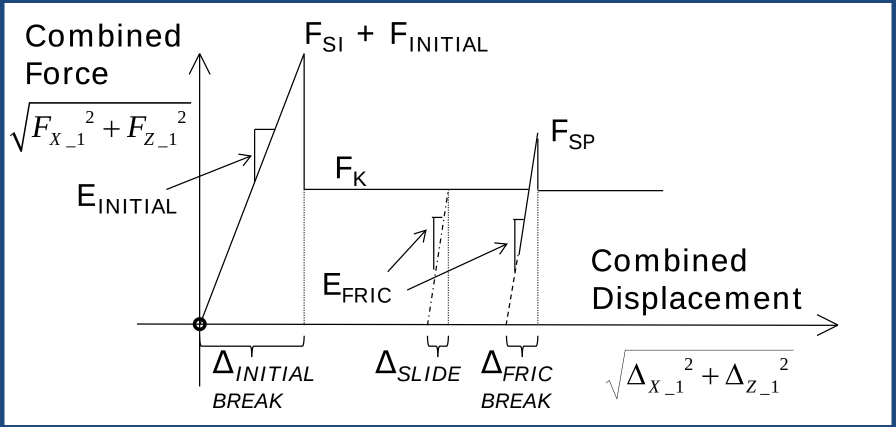
- Sliding elastomeric bearing models
  - Ongoing experimentation is studying behavior
  - Difference in static vs. kinetic coefficient of friction
  - Friction slip-stick behavior noted in cases

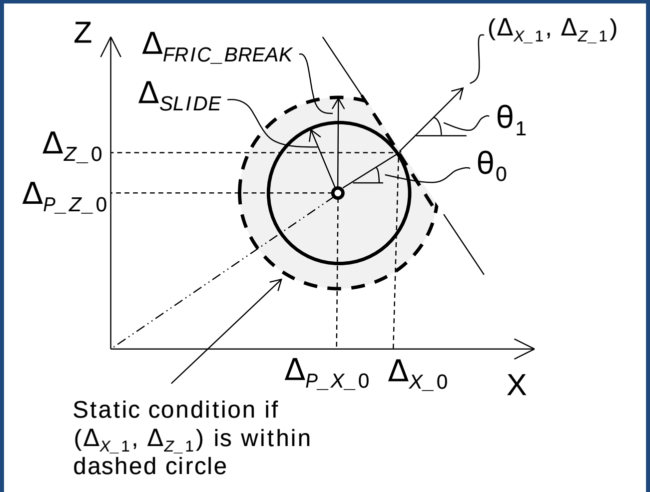




Bi-directional bearing elements

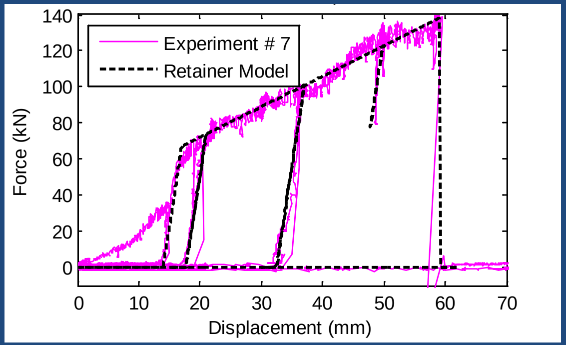
- Dependent on axial force
- Allows for initial capacity and different pre and post-slip static coefficients of friction
- Force-displacement behavior coupled in orthogonal shear directions
- Kinematic-hardening surface used to trace bearing movement

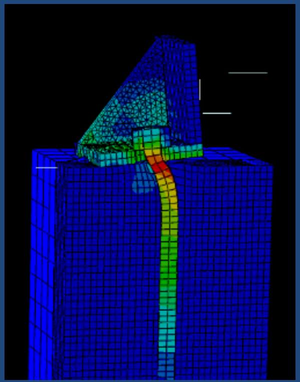


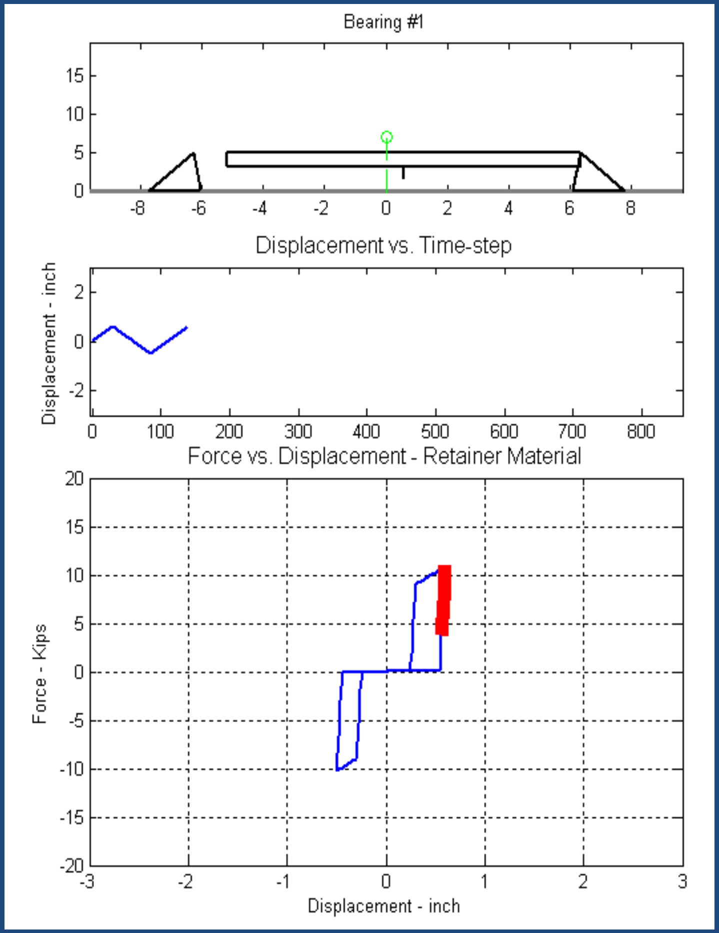


Modeling of Bearing Retainers

- Retainer simulation for System Analyses
  - Gap with elasto-plastic response until retainer fracture
  - Independent behavior of the (2) retainers
  - Calibrated based on experiments and Finite Element Modeling

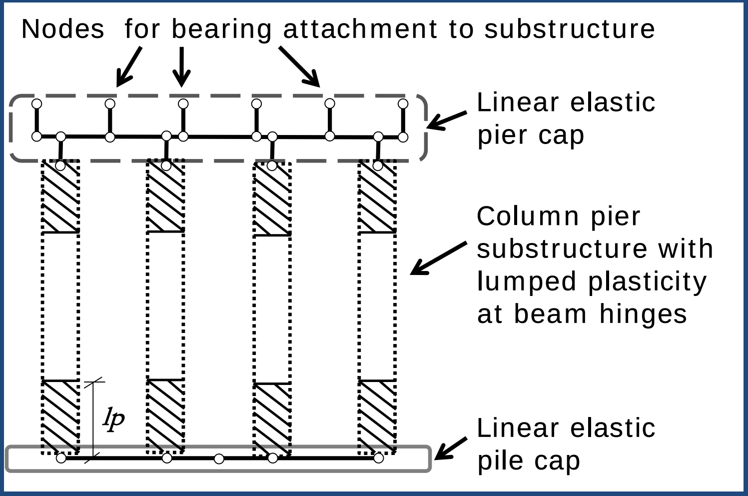


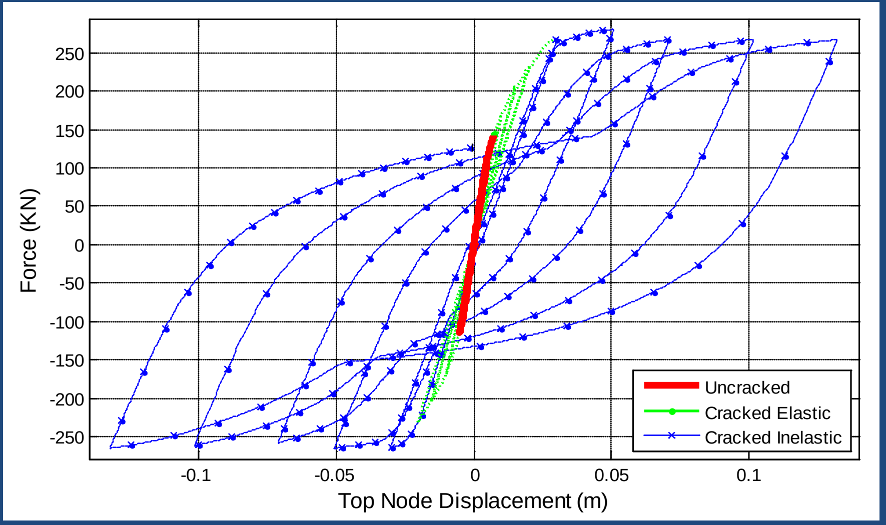




Intermediate Substructures

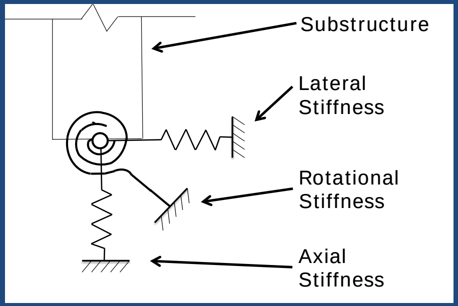
- Beam-column elements with lumped plasticity at nodes
- Fiber sections used to model nonlinear behavior at hinge locations of column

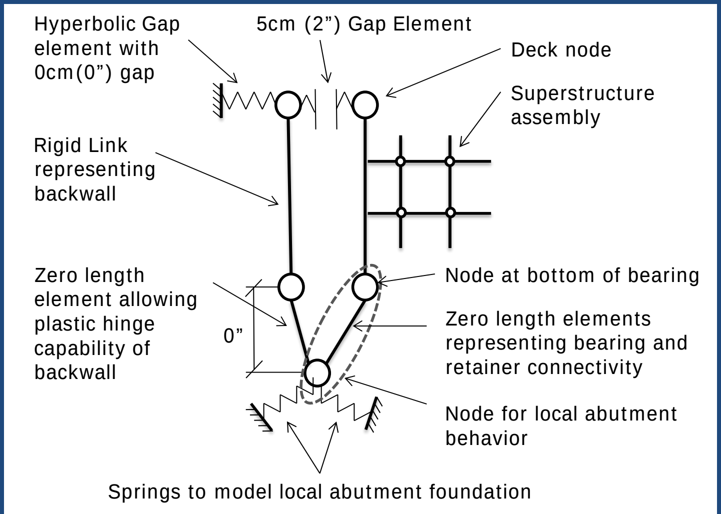


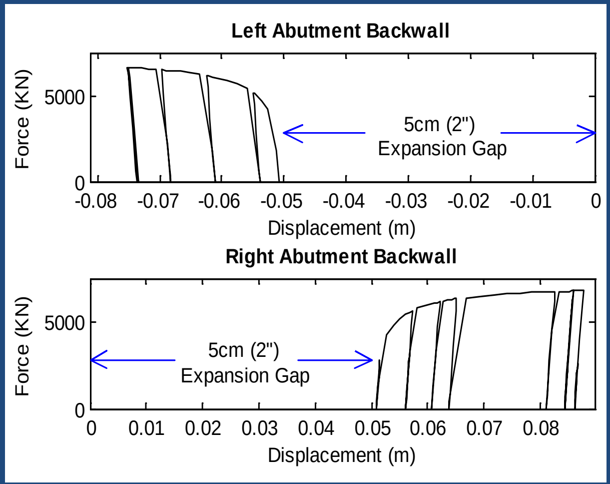


Foundations and Backwalls

- Pile group analysis performed to develop nonlinear force-displacement representation of foundations
- Hyperbolic gap material used to model backwall interaction





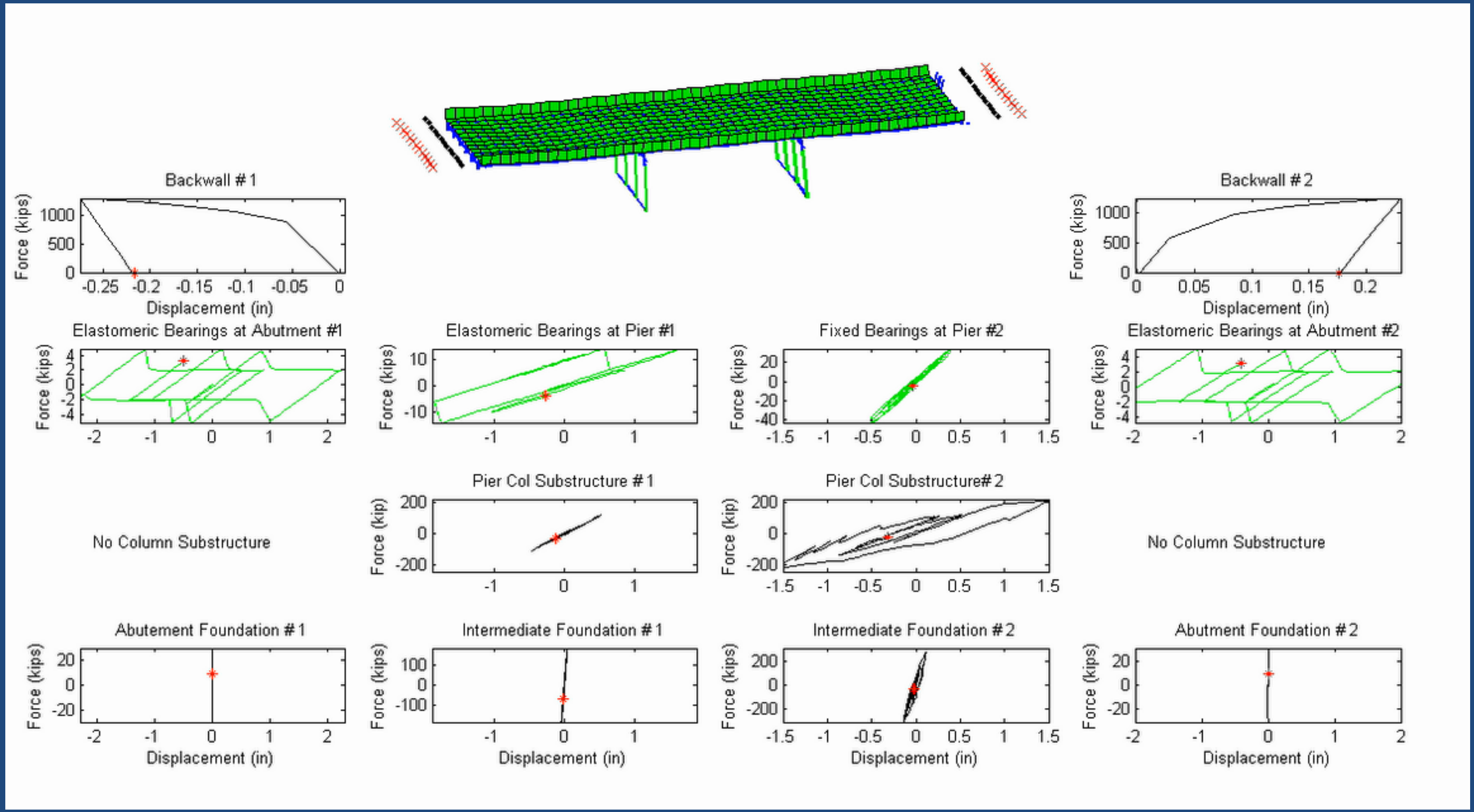


Limit State Identification Longitudinal

- Bearings
  - Elastomer deformation & nonlinear behavior
  - Yielding and fracture in anchor bolts & pintles of fixed bearings
  - Sliding of bearings on substructure
- Column and wall piers
  - Cracking of concrete
  - Yielding of reinforcement
  - Crushing of concrete
- Foundations
  - Plastic deformation of backwall & backfill
  - Plastic deformation of pile groups & pile caps

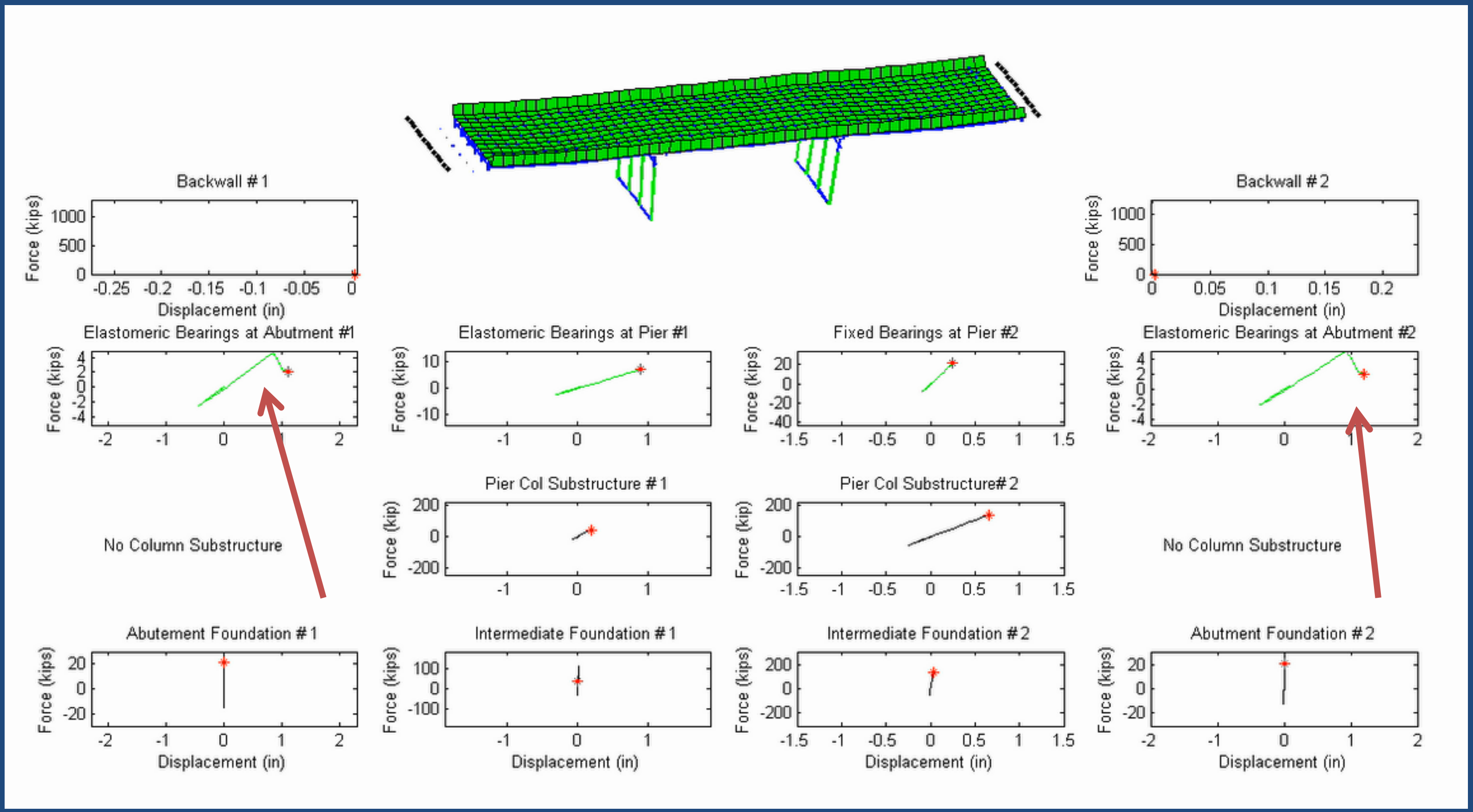
Longitudinal Analysis

- Limit state identification stiff foundation
- 2500 yr Paducah ground motion



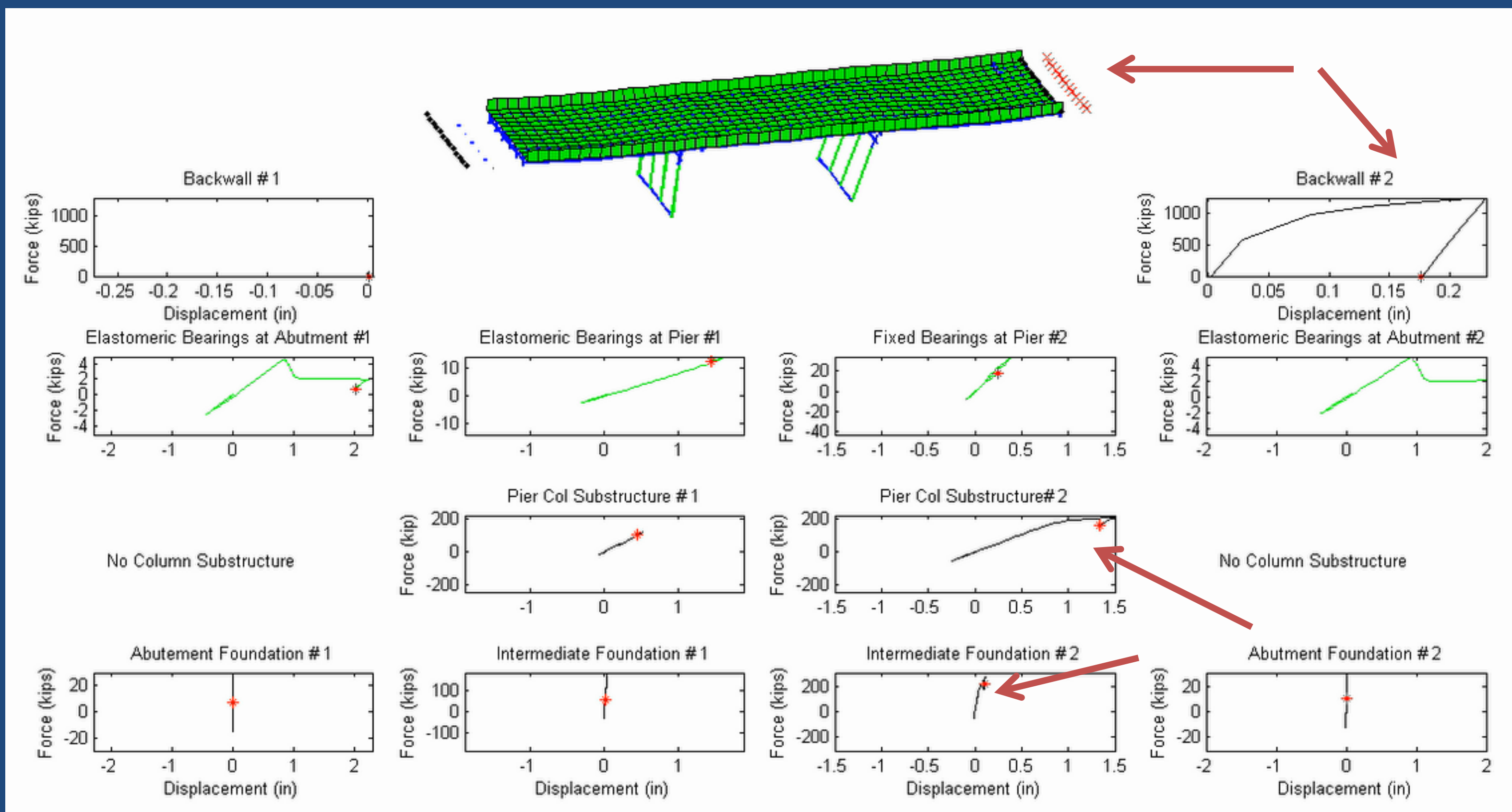
Longitudinal Analysis

- Slip of bearings at abutments



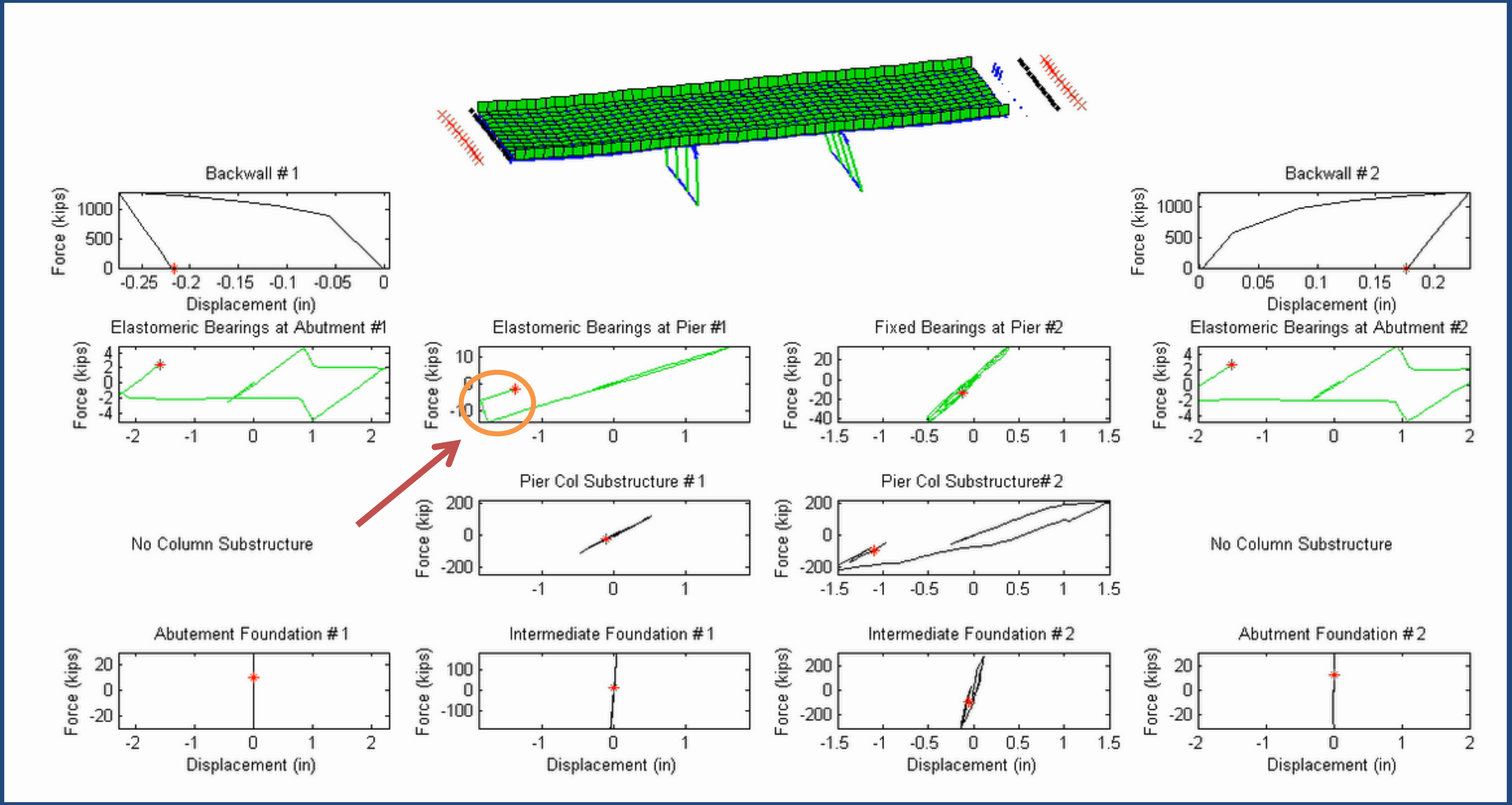
Longitudinal Analysis

- Yielding in substructure #2, backwall interaction, and plastic deformation in foundation



Longitudinal Analysis

- Slip of bearings at pier #1

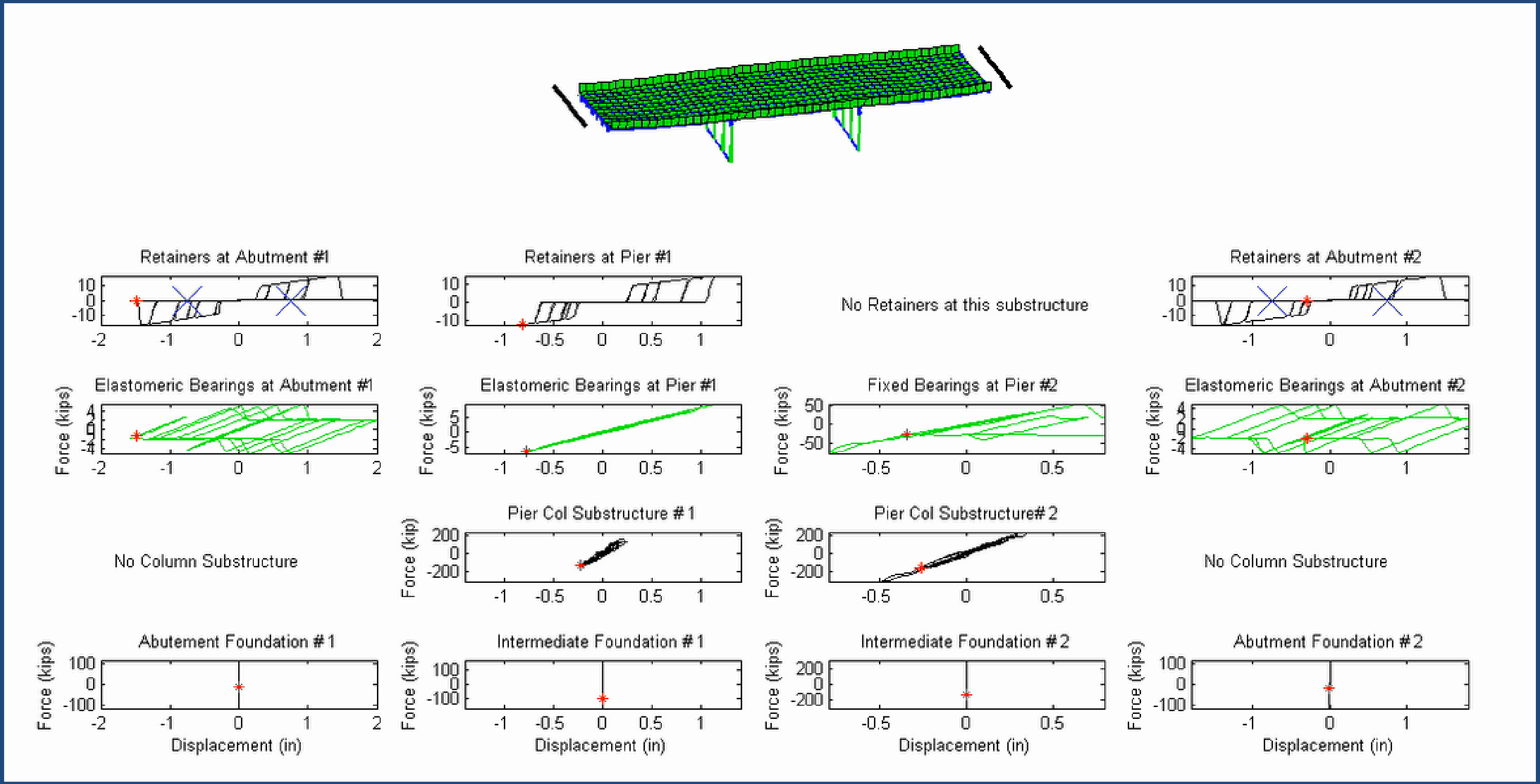


Limit State Identification Transverse

- Bearings
  - Elastomer deformation, retainer deformation with fracture & nonlinear bearing behavior
  - Yielding and fracture in anchor bolts & pintles of fixed bearings
  - Sliding of bearings on substructure
- Column and wall piers
  - Cracking and/or crushing of concrete
  - Yielding of reinforcement
- Foundations
  - Plastic deformation of pile groups & pile caps
  - Possible interaction with backwall & backfill

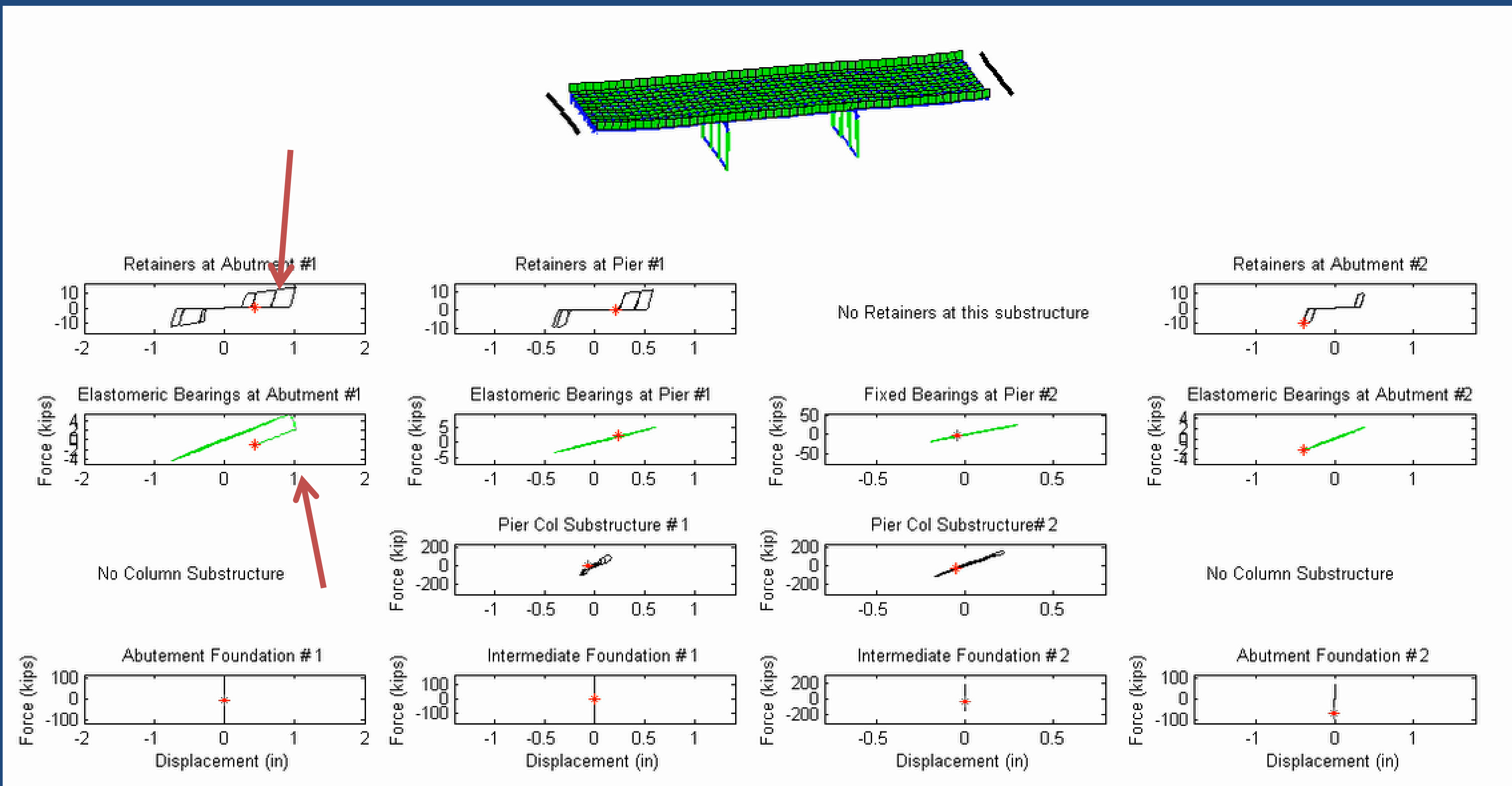
Transverse Analysis

- Limit state identification fixed foundation
- 2500 yr Paducah ground motion (only 8 Seconds)



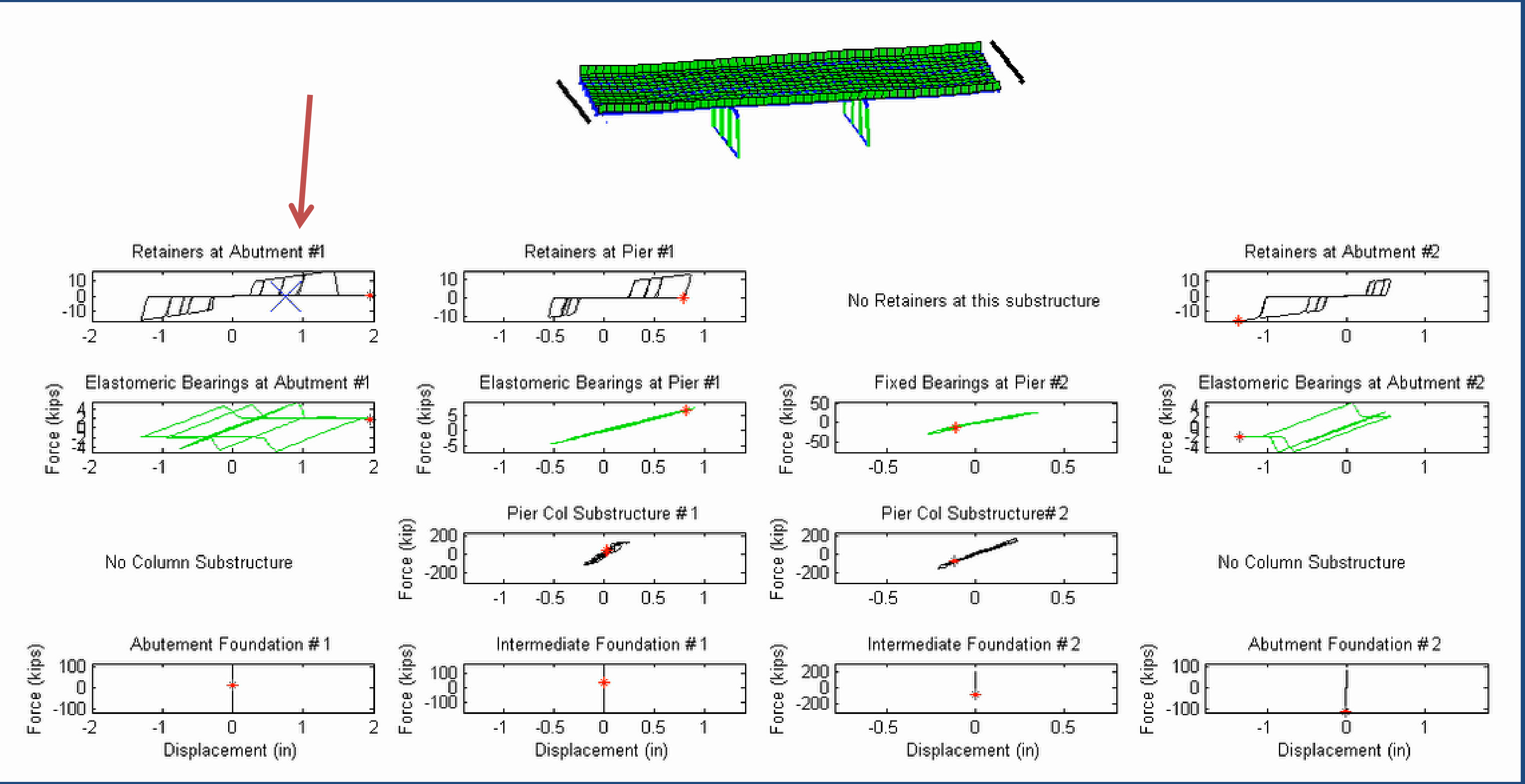
Transverse Analysis

- Plasticity in retainers and bearing slip at abutment # 1



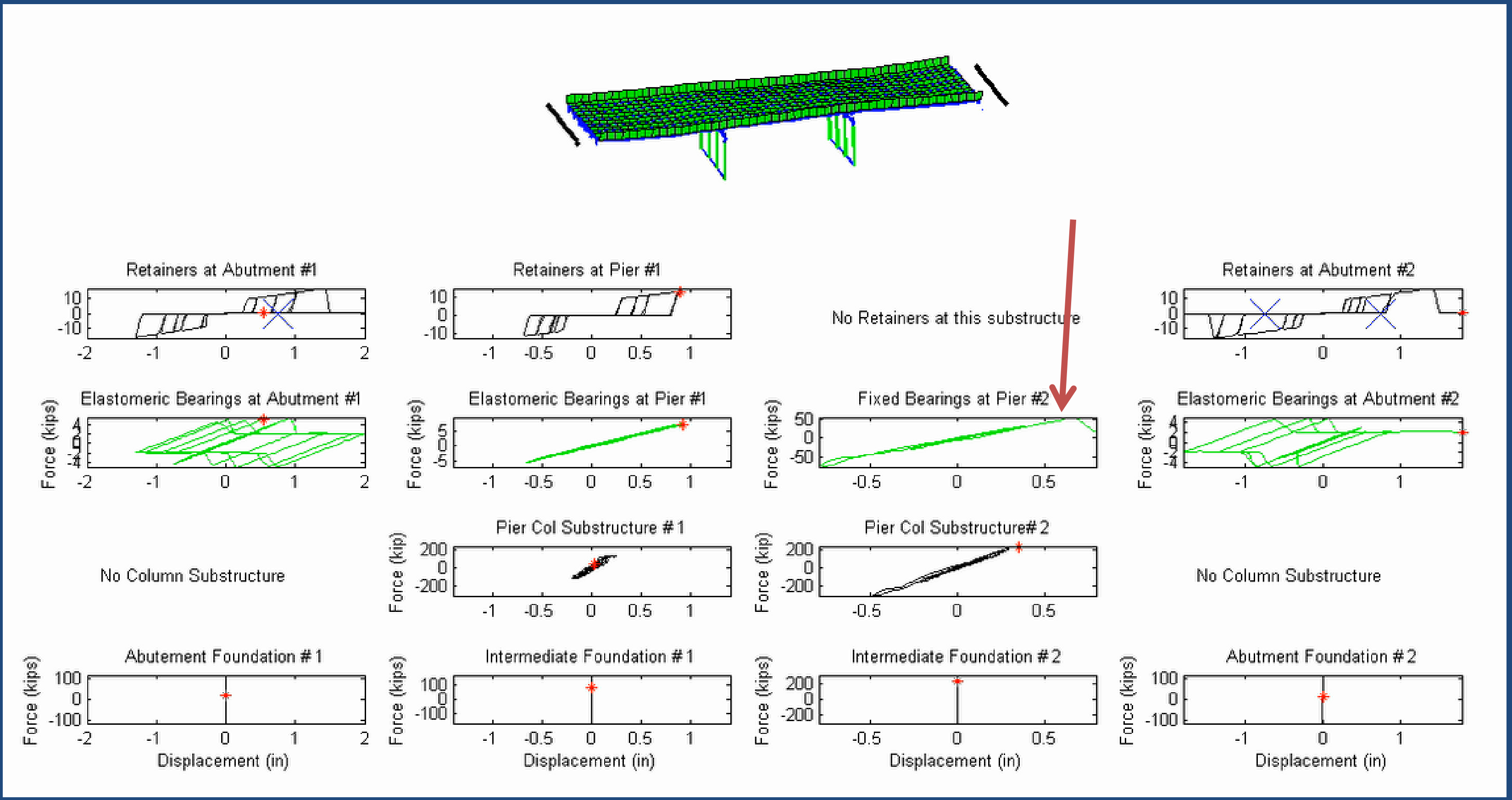
Transverse Analysis

- Fracture of retainer component



Transverse Analysis

- Fracture of fixed bearing



System Analyses Objectives

- Quantification of expected value and dispersion for:
  - Peak & residual bearing displacements
  - Peak force demands on fuse components
  - Peak force demands on sub-structures
  - Sequence of fuse & systems failure
- Parametric study to investigate influence of:
  - Superstructure length and type
  - Substructure height and type (column pier & wall)
  - Isolation bearings (Type I & Type II)
  - Foundation characteristics (stiff & soft soils)

Summary & Conclusions

- New element models represent key aspects of local bearing behaviors
- Global bridge model captures limit states for a realistic three dimensional analysis
- Flexibility of elastomeric bearings and sliding of bearings allows for quasi-isolated response
- Retainer elements and low-profile bearings need to be carefully detailed to limit forces on substructures
- Backwalls have a significant contribution in limiting longitudinal displacements