STUDY OF NON CONVERGENCE ISSUES IN SEISMIC RESPONSE ANALYSIS OF BRIDGES

PEER Lifelines Research Program

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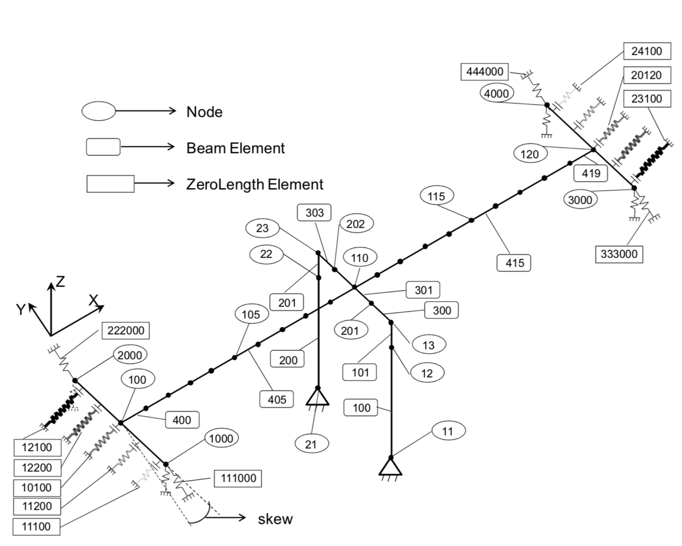
OBJECTIVES

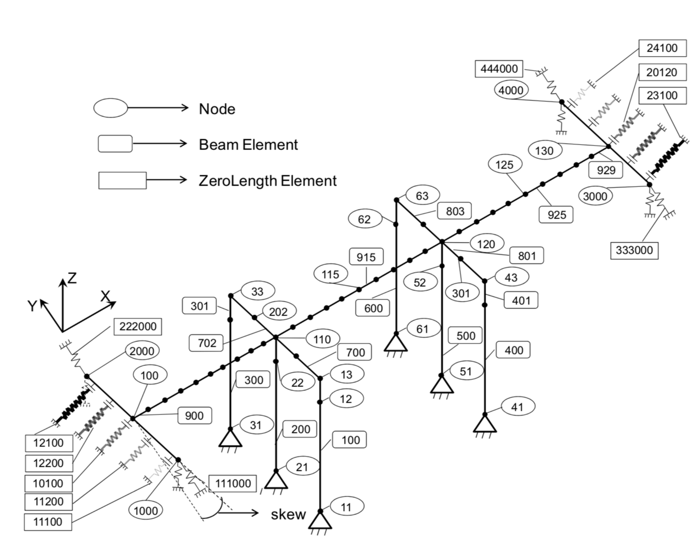
- Identify and classify problems **for non-convergent nonlinear dynamic analyses** (NDAs) of bridges under extreme seismic excitation.
- Identify robust material models, element models, and solution strategies in OpenSees.
- Develop **guidelines for robust NDAs of bridges** and consistent collapse risk assessment.

STUDY MODELS

- Typical highway bridges in California.



Source : Kaviani et al. - PEER Report 2014/01



Source : Kaviani et al. - PEER Report 2014/01

- Typical Material Models Investigated

Material Model	Application
Steel01	Behavior of the bearings and the steel rebar in the columns.
Steel02	Nonlinear behavior of steel rebar in columns.
Concrete01	Nonlinear behavior of concrete in columns.
Concrete02	Nonlinear behavior of concrete in columns.
Hysteretic	Behavior of bearings and soil responses.
ElasticPPGap	Support reaction at the abutments.
Impact Material	Gap between abutments and decks.

- Typical Element Models Investigated

Element Model	Application
Zero Length	Stiffness of soil and backwall in the abutment; stiffness of bearings; and stiffness of the foundations.
Forced-Based Beam-Column	Nonlinear behavior of columns and cap-beams.
Displacement Beam-Column	Nonlinear behavior of columns.
Elastic Beam-Column	Superstructures and known elastic regions of the column.
Beam with Hinges	Nonlinear behavior of columns where the plastic zone of the column is known.
Two Node Link	Transferring forces in the desired direction.

OBSERVATIONS

- **Time Integration Strategy**

An iterative time integration strategy like the **Implicit Newmark** appears to be more robust than an explicit strategy like Alpha OS. The latter may be helpful for overcoming convergence problems in a single step or a small number of steps.

- **Effect of Viscous Damping Model**

The choice of stiffness matrix in Rayleigh damping model seems to have negligible impact on the global response. At the element and material levels, the adoption of current stiffness or committed stiffness in Rayleigh damping doesn't influence the response. However, it is observed that the different combinations of initial, current and committed stiffness in Rayleigh damping do influence the convergence behavior.

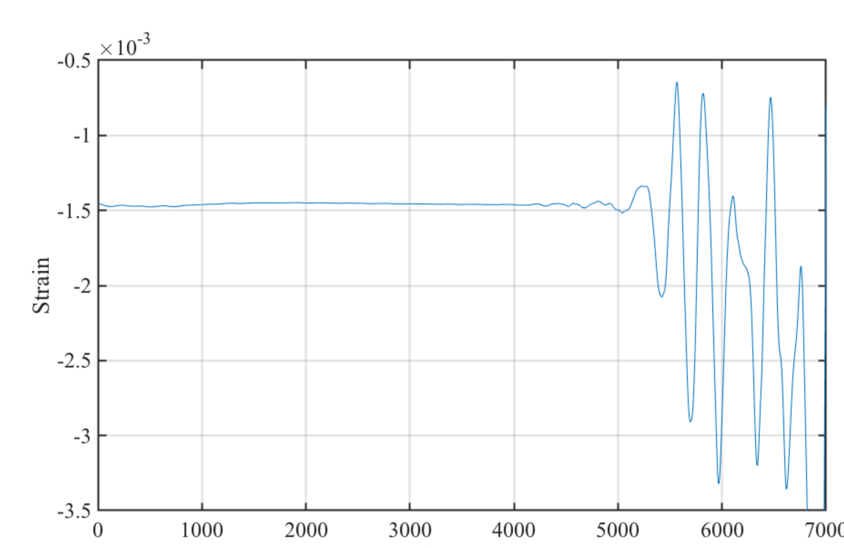


fig. 1 Fiber Response with10% Initial Stiffness and 90% Committed Stiffness

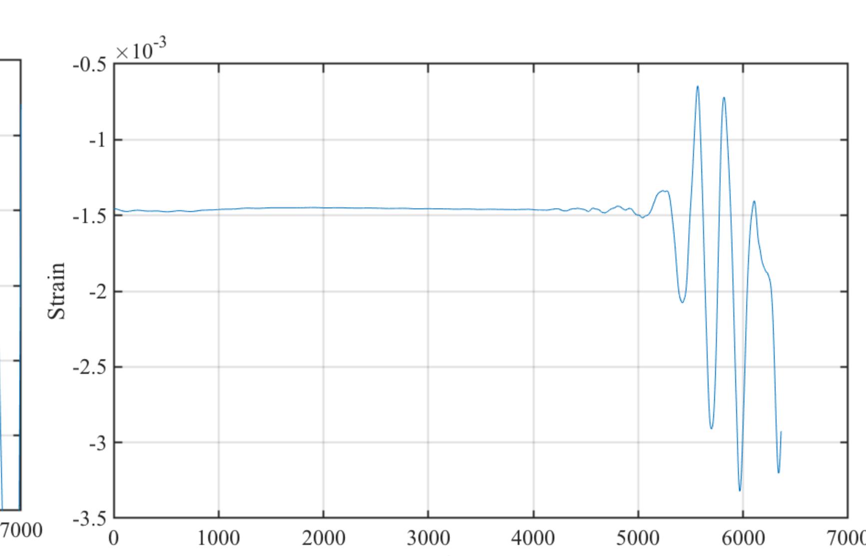


fig. 2 Fiber Response with 10% Initial Stiffness and 90% Current Stiffness

PRELIMINARY CONCLUSIONS

- Distributed inelasticity elements under softening response are sensitive to **the number of integration points** without a non-local smoothing strategy. In its absence it is recommended to limit the number of integration points to 3-4 for columns making sure that the integration weight of a single point is not smaller than a characteristic length (e.g. the dimension of the cross section).
- It is important to include **Line Search** before the iterations of the Newton solver, so as to control the size of the initial estimate.

WORK IN PROGRESS

- Investigate the effect of different viscous damping models on the response at the structural, element, and material levels.
- Investigate the interrelationship between element and structural iteration strategies for beam-column elements with force formulation.
- Investigate the effect of **zero-length elements** on convergence issues.

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