Nonlinear Seismic Study

Status Report

By:

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Purpose and Objectives

- Purpose: Use of Nonlinear Analysis in Design of Ordinary Bridges
- Objective:
  - More Refined and Reliable Seismic Design
  - Take Advantage of Modern Tools
  - Provide Guidelines for consistent and reliable application in design

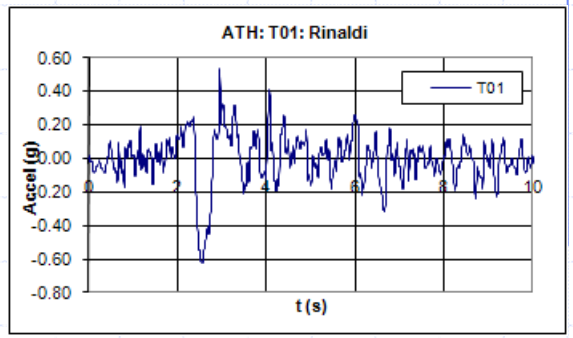
Background

- Long Time Ago (Pre-1971):
  - Pseudo-static Analysis: 2%g to 10%g
- 1971: Dynamic Analysis:
  - Response Spectrum Analysis (Multi-modal with R-factors)
- 1989: Importance of Ductility:
  - Displacement-Based Design: Push-over
- Future: Modeling Nonlinear Behavior
  - Nonlinear Time History analysis

Challenges

- Understanding Nonlinear Behavior
  - Analytical Research and Lab Tests
- Software Tools
  - Accuracy, Speed, Convergence
- Modeling Techniques
  - Plastic Hinge, Span Hinge, Abutment Backfill
- Loads
  - Acceleration Records – Actual and Synthetic

Scope of Study

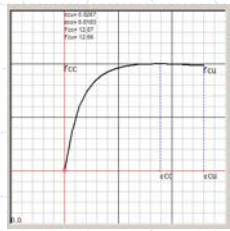


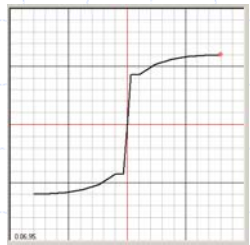
- Single Column Analysis
  - Near Field Effects
  - Identify key issues in modeling
  - Expected Results
- Ordinary Bridge Case Study
  - Identify modeling issues/concerns
  - Compare Results with RSA and Pushover

Caltrans

Single Column Analysis

- Issues Encountered and Addressed
  - Modeling: Material Models
    - Concrete
    - Reinforcing Steel



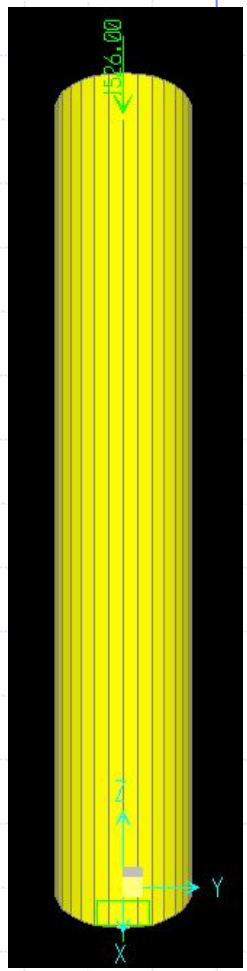


  - Near Field Velocity Pulse Effects
  - Residual Displacement Prediction

Caltrans

Single Column Analysis - Modeling

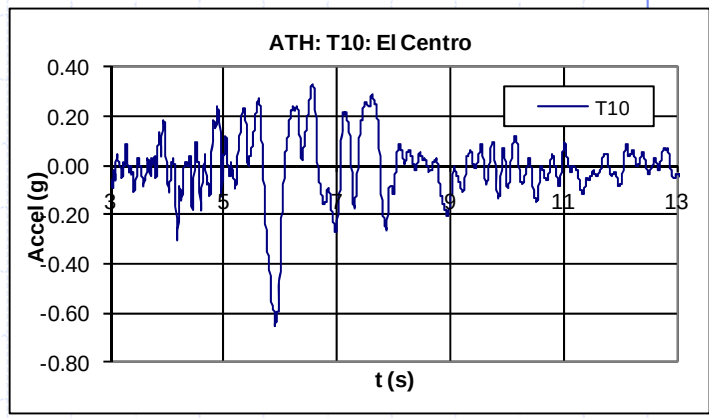
- Fixed at the base, Free at top with concentrated mass at top (1526 kips)
- L=34', diameter = 6'
- 1% steel modeled as #14 bars in circular hoop
- Fiber hinge (concentrated hinge) at base
- Monotonic Push, Cyclic Push, Time History
- Software: OpenSees and SAP2000

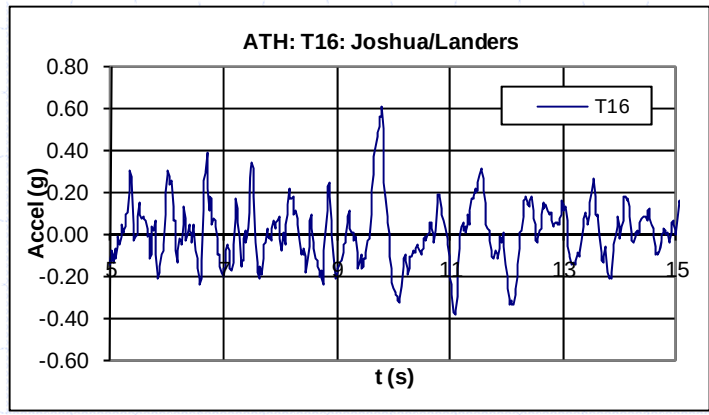


Caltrans

Single Column Analysis - Modeling

- EQ Records
  - Twenty Acceleration Records
  - 10 near-field records with forward directivity (velocity pulse)
    - Includes Rinaldi, 2xChichi, Kobe, Tabas, ...
  - 10 near-field records with backward directivity (no pulse)
    - Includes Loma Prieta, Landers, Northridge, ...



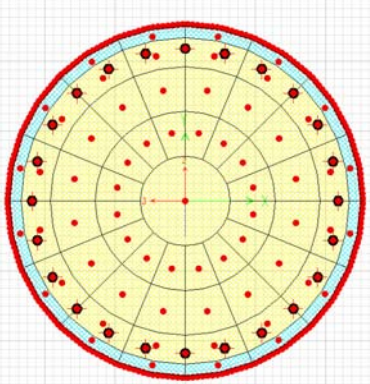


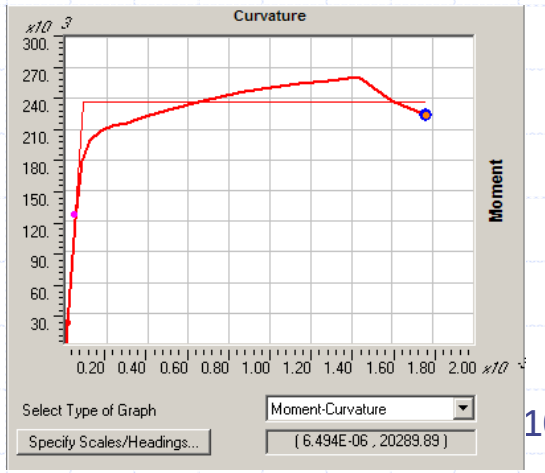
Single Column Analysis - Modeling

- Modeling Considerations - Materials
  - Concrete Model
    - Mander confined for core
    - Mander unconfined for cover
    - No tension for concrete
  - Steel Model – Limit for modeling failure
    - Bilinear – Hardening is indefinite - NG
    - Hysteretic – Hardening is approximate - better
    - Reinforcing Steel – slower, but more accurate

Single Column Analysis - Modeling

- Modeling Considerations – Fiber Hinge
  - Adjusts to axial force levels automatically
  - Need enough refinement for accuracy
    - 16 wedges x 4 rings = minimum
    - 32 wedges x 8 rings = sufficient accuracy
  - Located at middle of plastic hinge length
  - OpenSees is Faster than SAP2000
  - SAP2000 is easier to use





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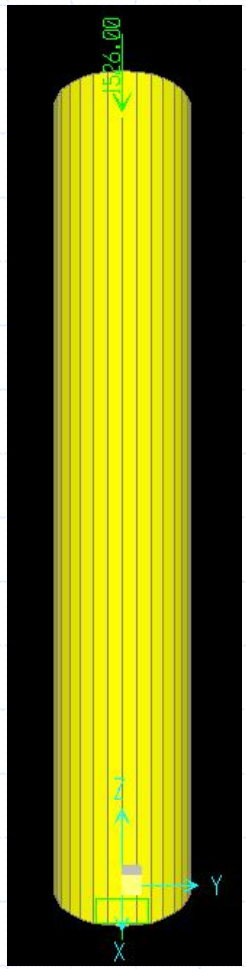
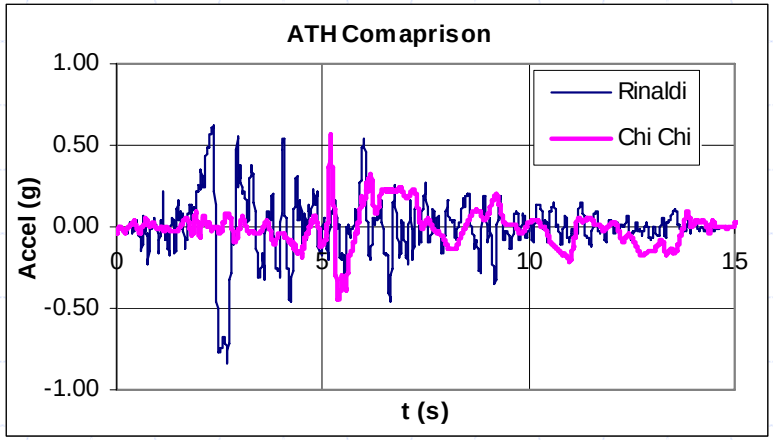
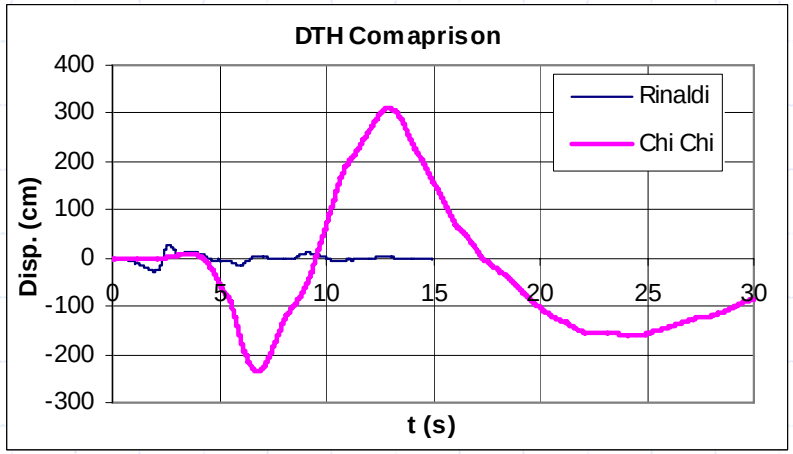
Single Column Analysis – Near Field

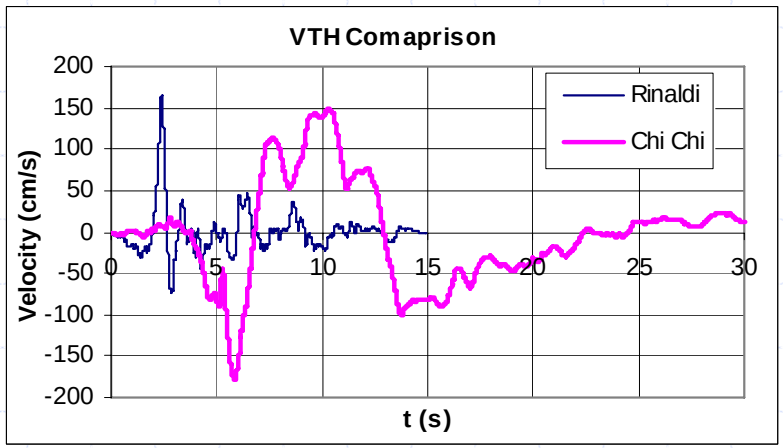
- 6ft dia., 34 ft long, 1% steel
  - T=1.4 sec (Col. 6)
- 6ft dia., 34 ft long, 2% steel
  - T=1.2 sec (Col. 6A)
- 6ft dia., 41 ft long, 2% steel
  - T=1.6 sec (Col. 8)



Near Field Records: Rinaldi &Chichi

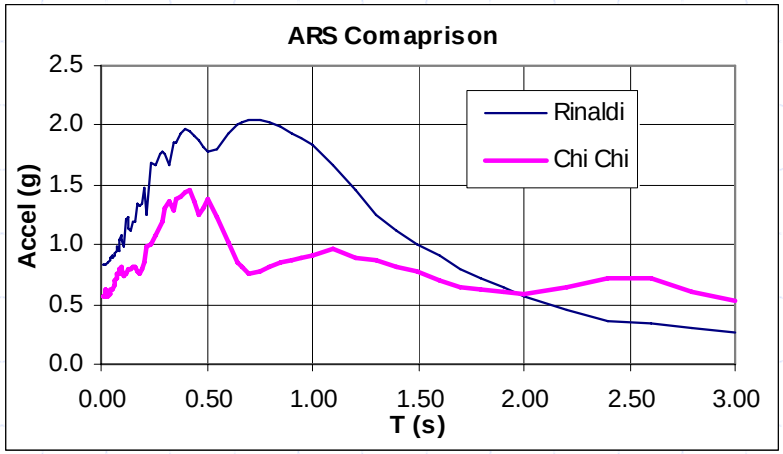


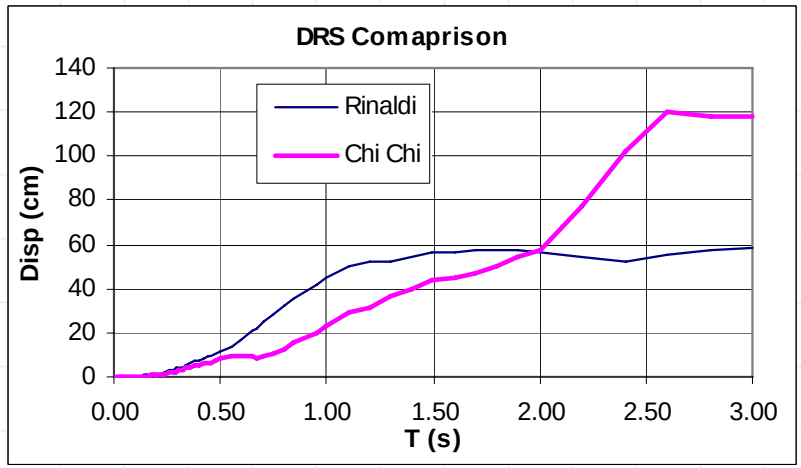


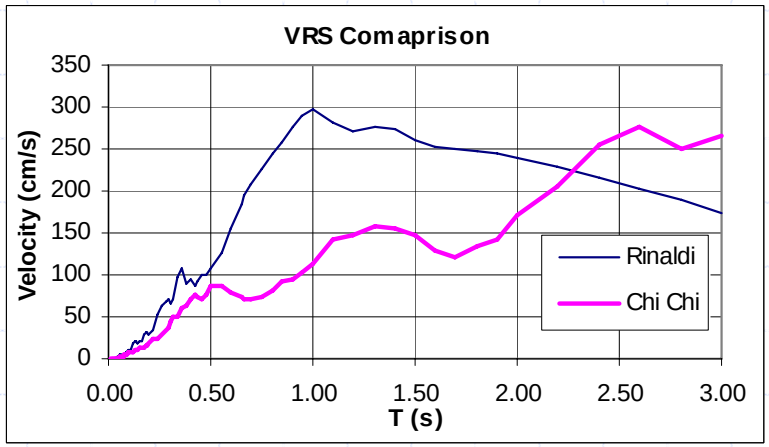


- Rinaldi:
  - Dist=7.1 km
  - PGA=0.84g, PGV=166cm/s
- Chichi:
  - Distance: 0.8km
  - PGA=0.57g, PGV=177 cm/s

Near Field Records: Rinaldi &Chichi

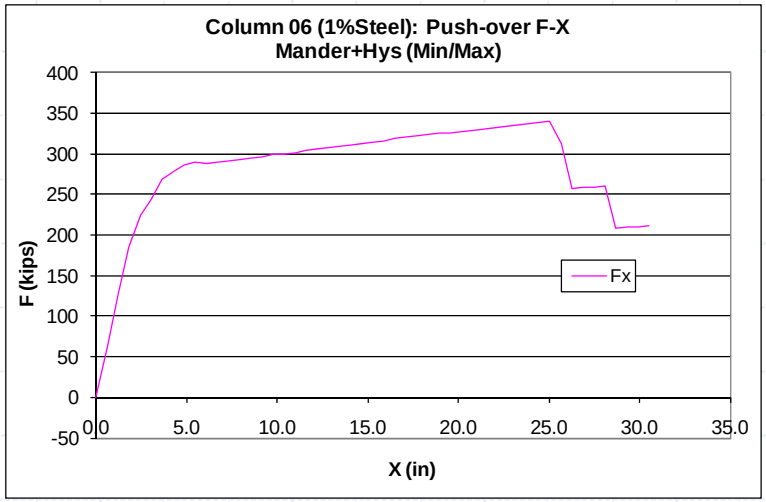


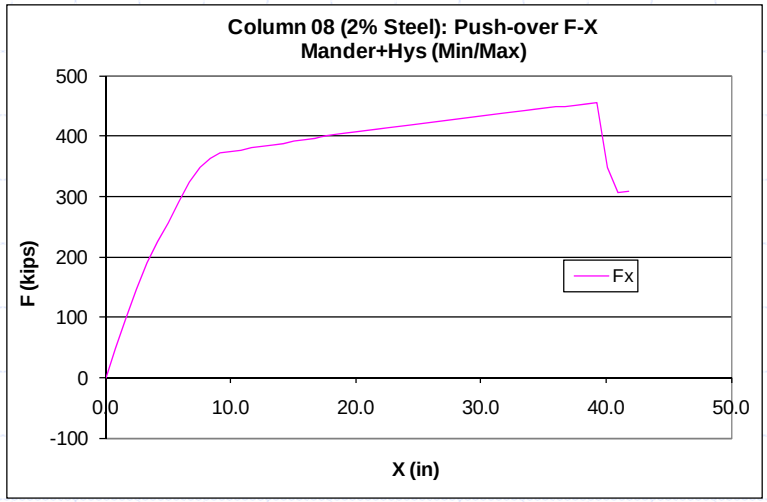


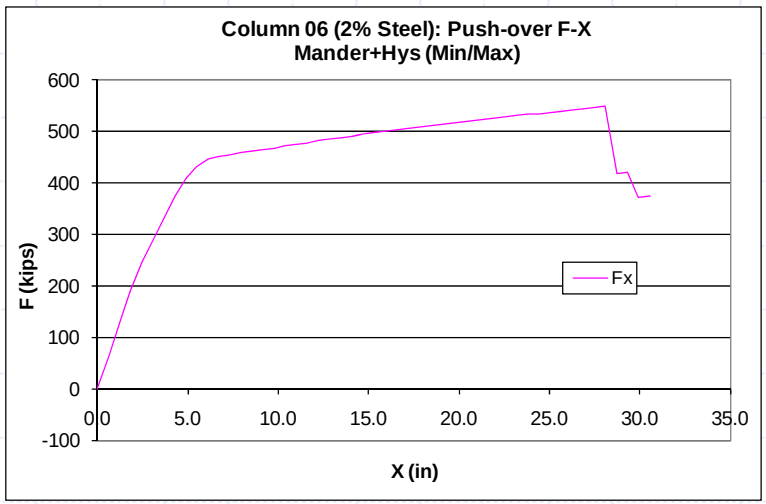


- Note: Chichi disp. Keeps increasing beyond the 3 sec period

Single Column – Push-over







Col.	Cap.	Max Disp. Capacity
6	340 k	24”
6A	550k	27”
8	450k	39”

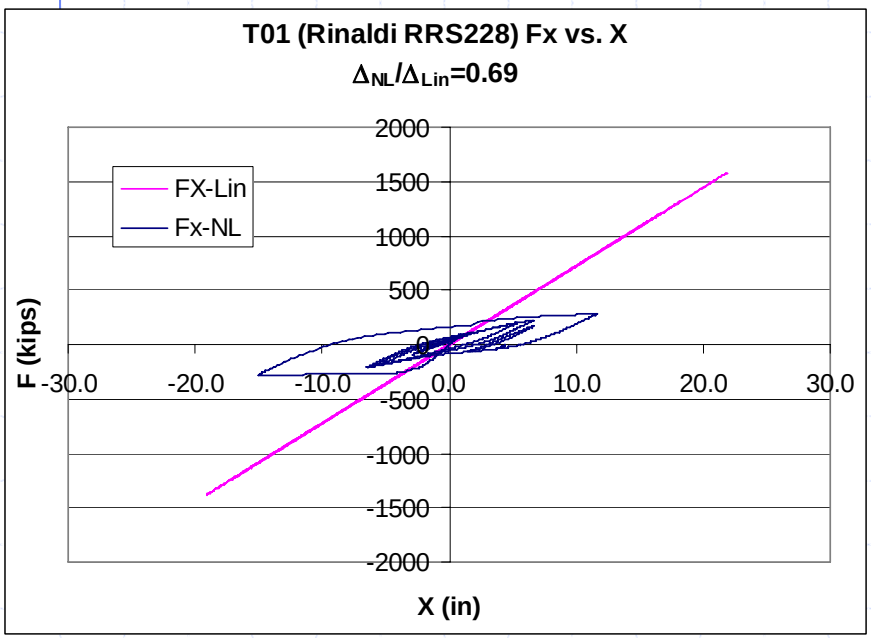
Single Column Analysis

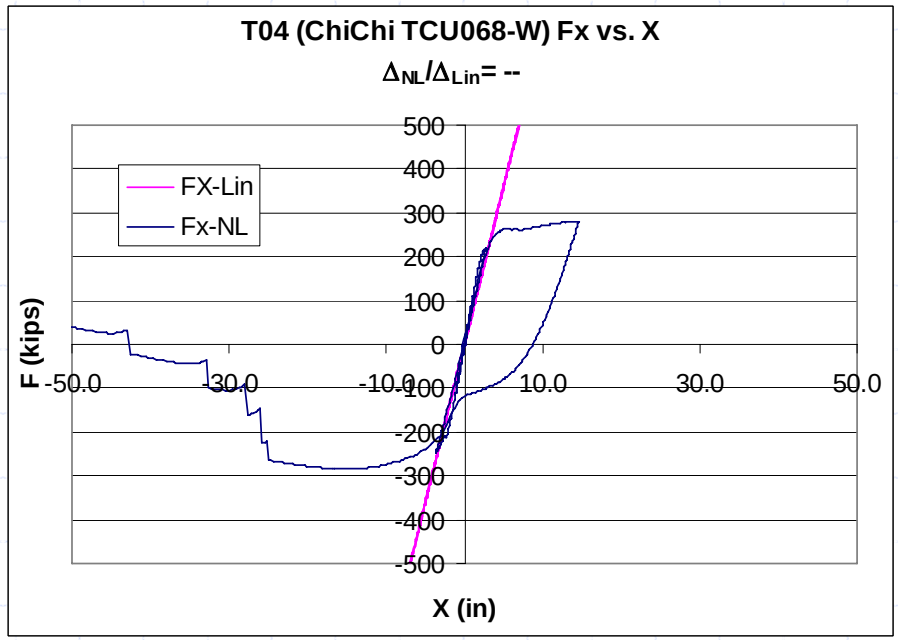
Record	Col	Cμ (NL/Lin)	Max Disp. Demand
Rianldi	6	0.69	15.9”
	6A	1.00	20.5”
	8	0.74	17.9”
Chichi	6	Failed	Failed
	6A	2.25	27.9”
	8	2.53	49.3”

- Note:
  - Col. 6 has P-delta and hardening steel
  - Col. 6A and 8 have hysteretic steel

Force-Displacement Graphs

- Base F vs. Top disp. – Col. 6
  - Rinaldi and Chichi68





Velocity Pulse Effect

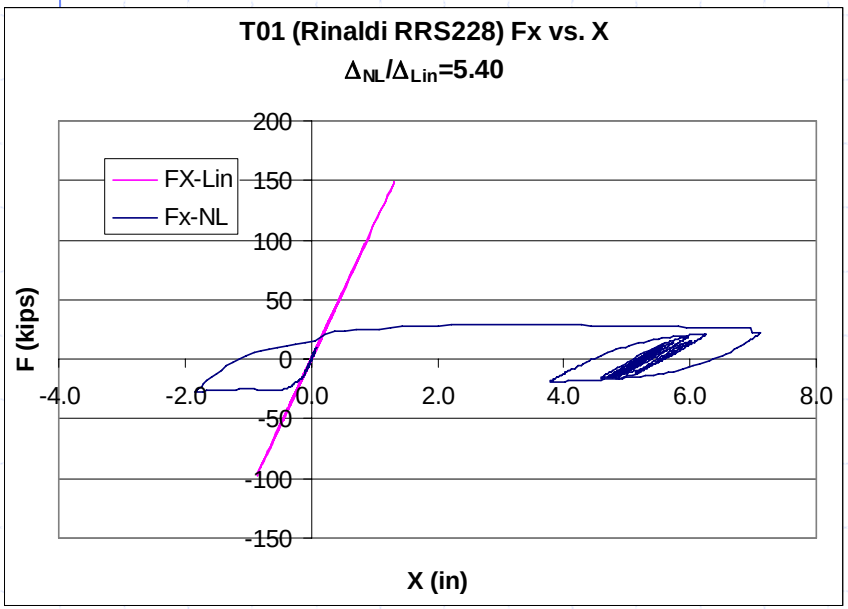
- Analyzed cases:
  - Velocity amplitude: 100, 200, 300 cm/s
  - Velocity period: 2, 4, 6 sec
  - Rebar in column: 1%, 2%, 3%
- Conclusion:
  - Velocity pulse period is important
  - Initial acceleration must be large enough to cause nonlinear effect
- Chichi period=~10sec, Rinaldi period=~1 sec

Residual Displacement (RD)

- RD is small in all analyses
  - Modeling shortcoming?
  - Material limitation?
  - Analysis Engine/Integration method?
  - Reality?
- Study actual Tests

Residual Displacement (RD)

Opensees



SAP2000

- UNR Tests – Had measured RD
- Analyzed in Opensees and SAP2000

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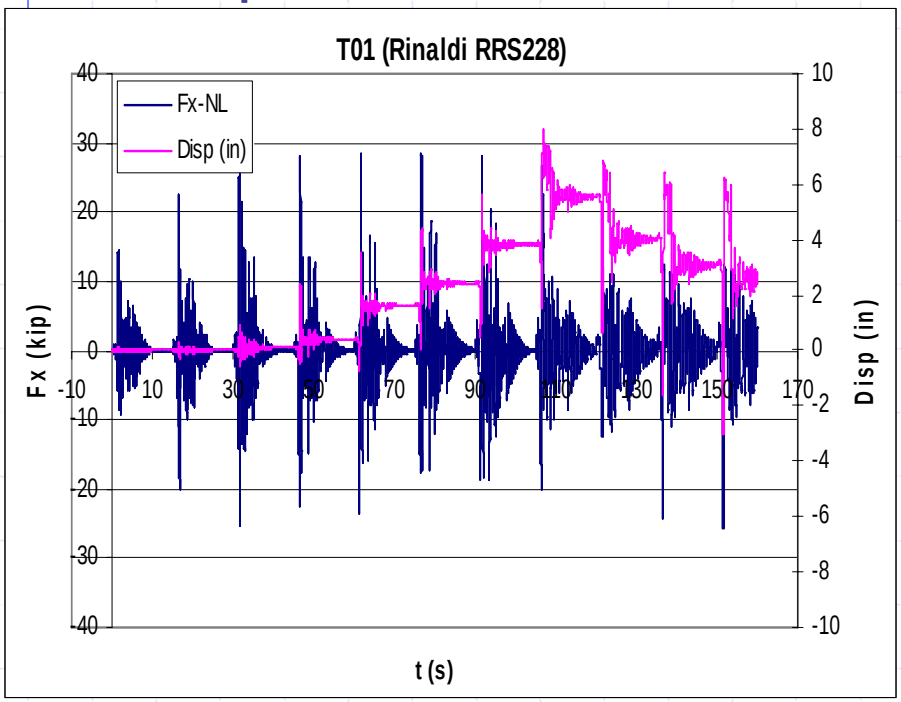
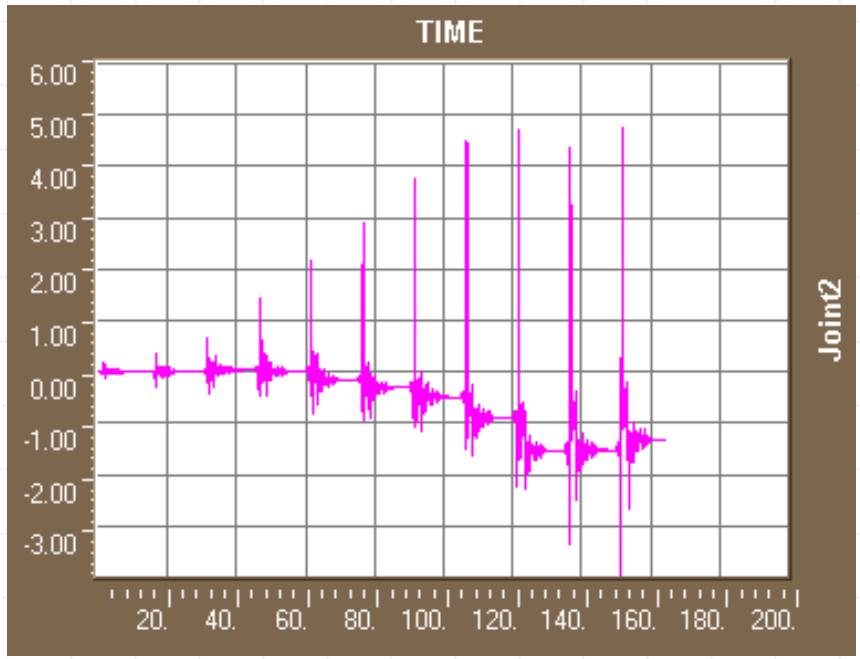
Residual Displacement (RD)

- Test Results duplicated RD -> Analysis OK

Opensees



SAP2000



Conclusion: Nonlinear Analysis is Reliable ...

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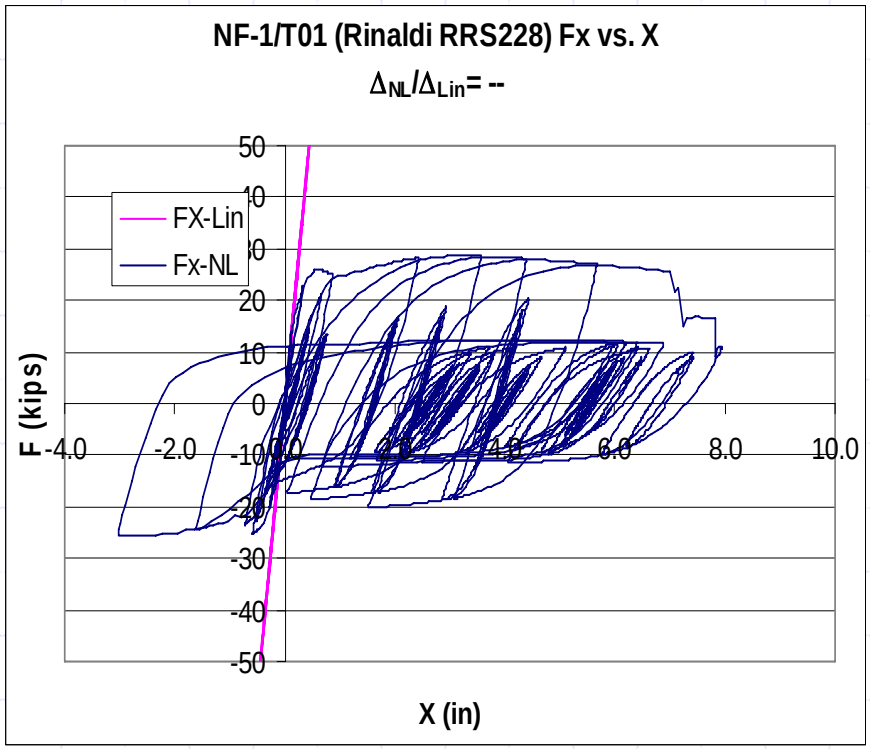
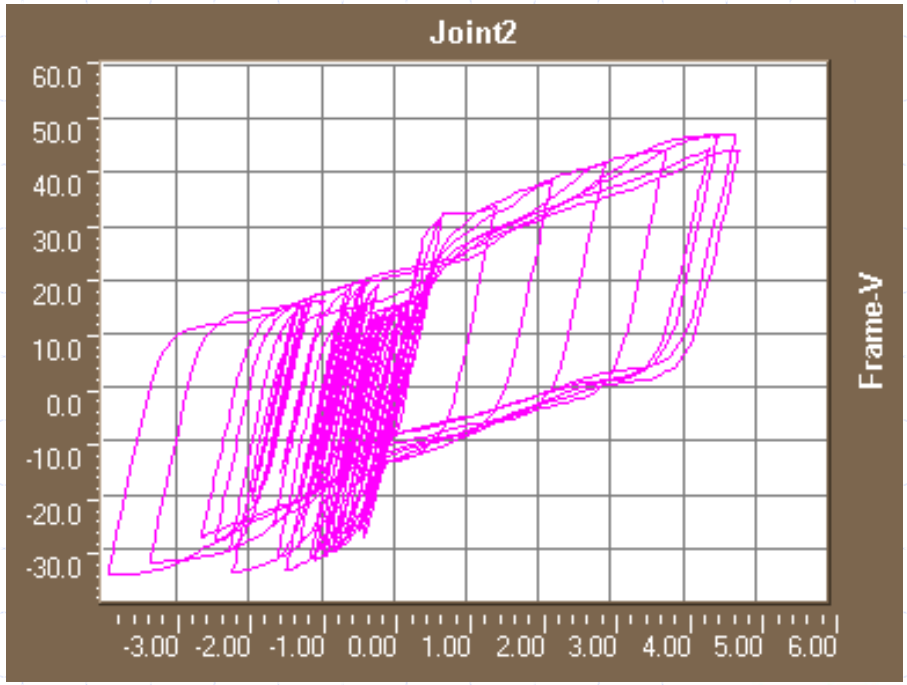
Residual Displacement (RD)

- Bilinear steel model is too strong (NG?)

Opensees



SAP2000



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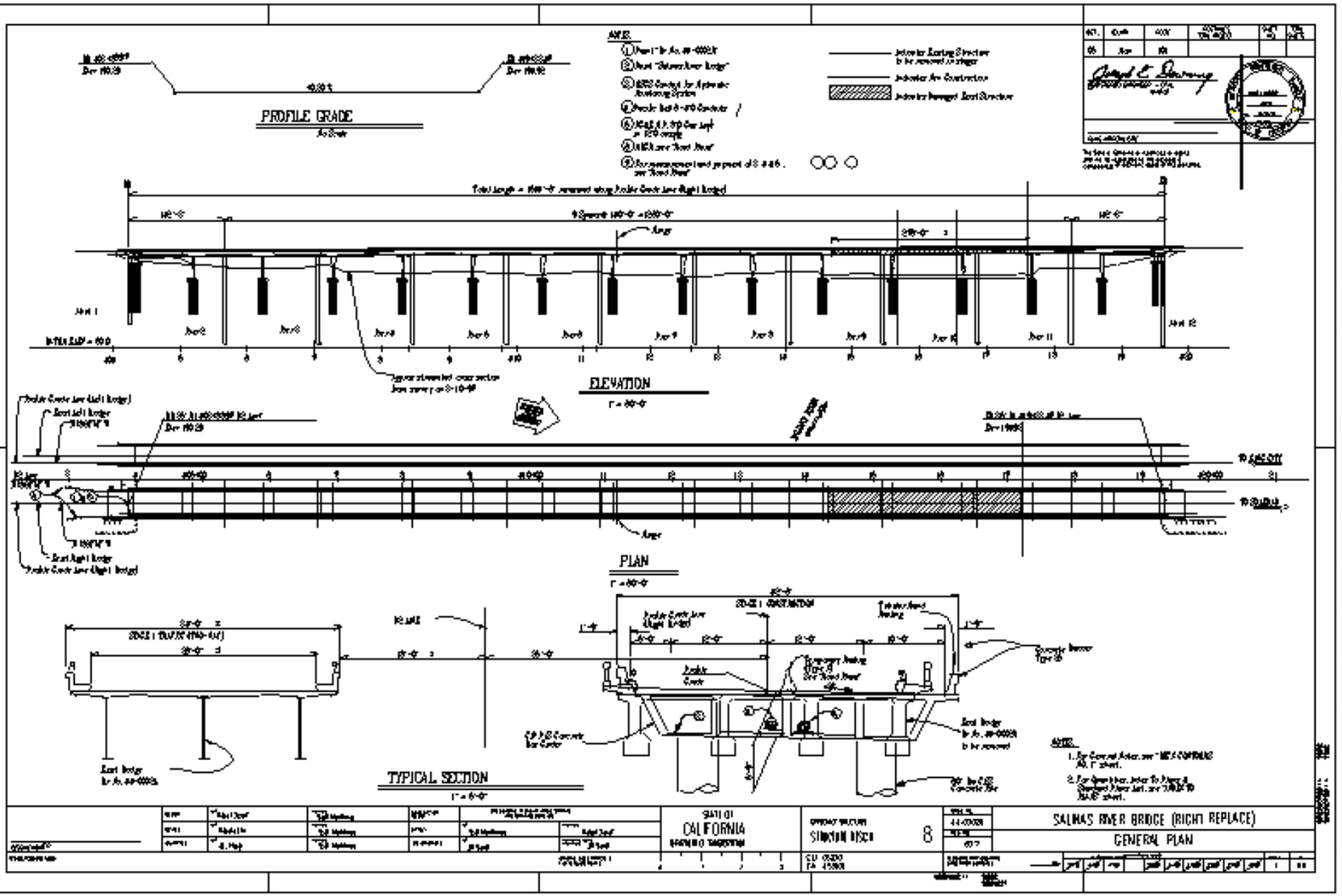
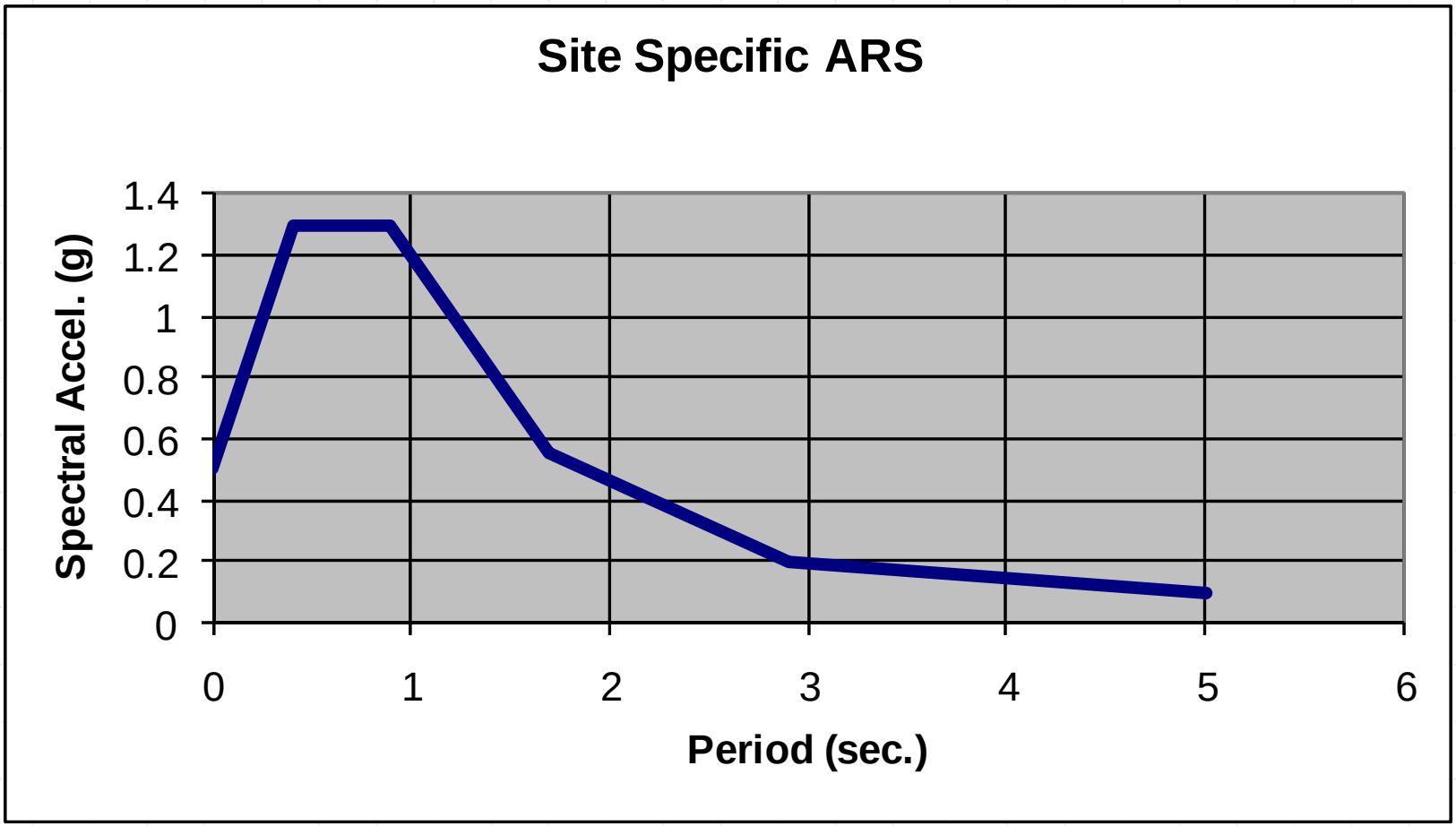
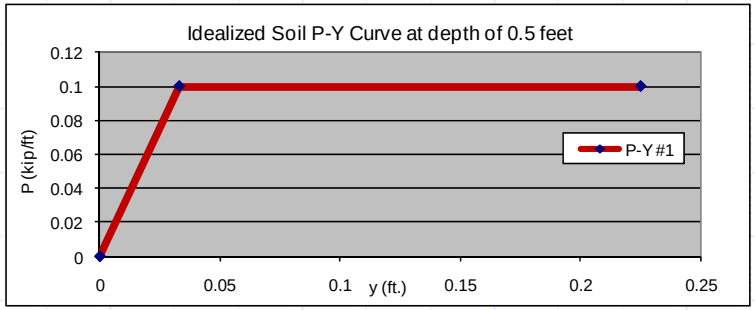
Example: Salinas River Bridge

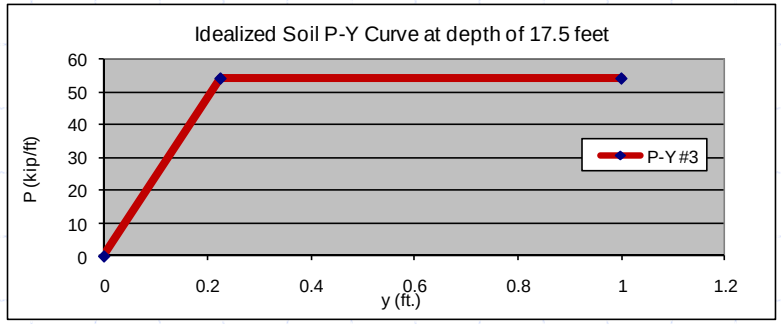

PROFILE GRADE
ELEVATION
PLAN
TYPICAL SECTION
CALIFORNIA
SALINAS RIVER BRIDGE (RIGHT REPLACE)
GENERAL PLAN

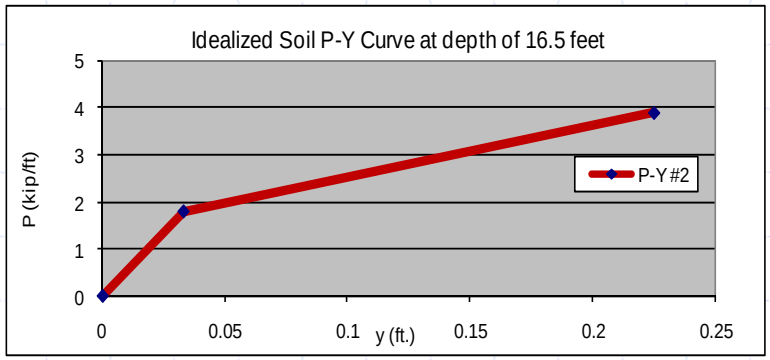
Salinas River Bridge: Site Specific ARS

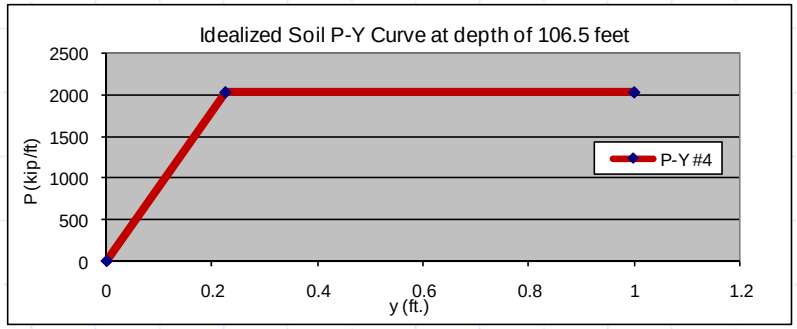


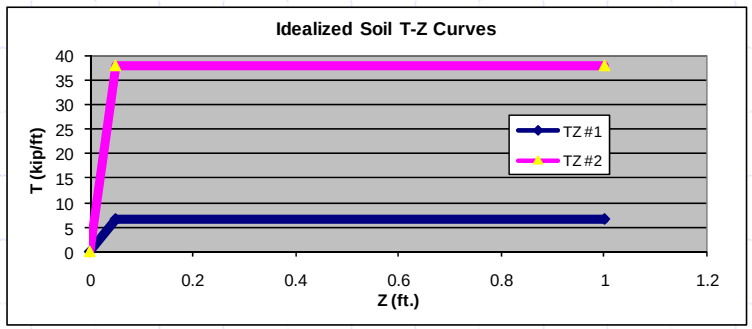
Salinas River Bridge: P-y Curves

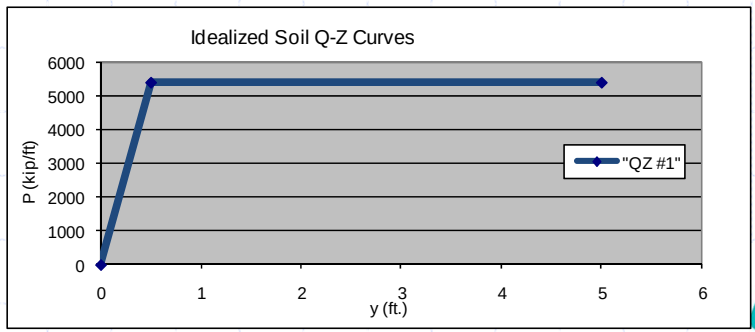




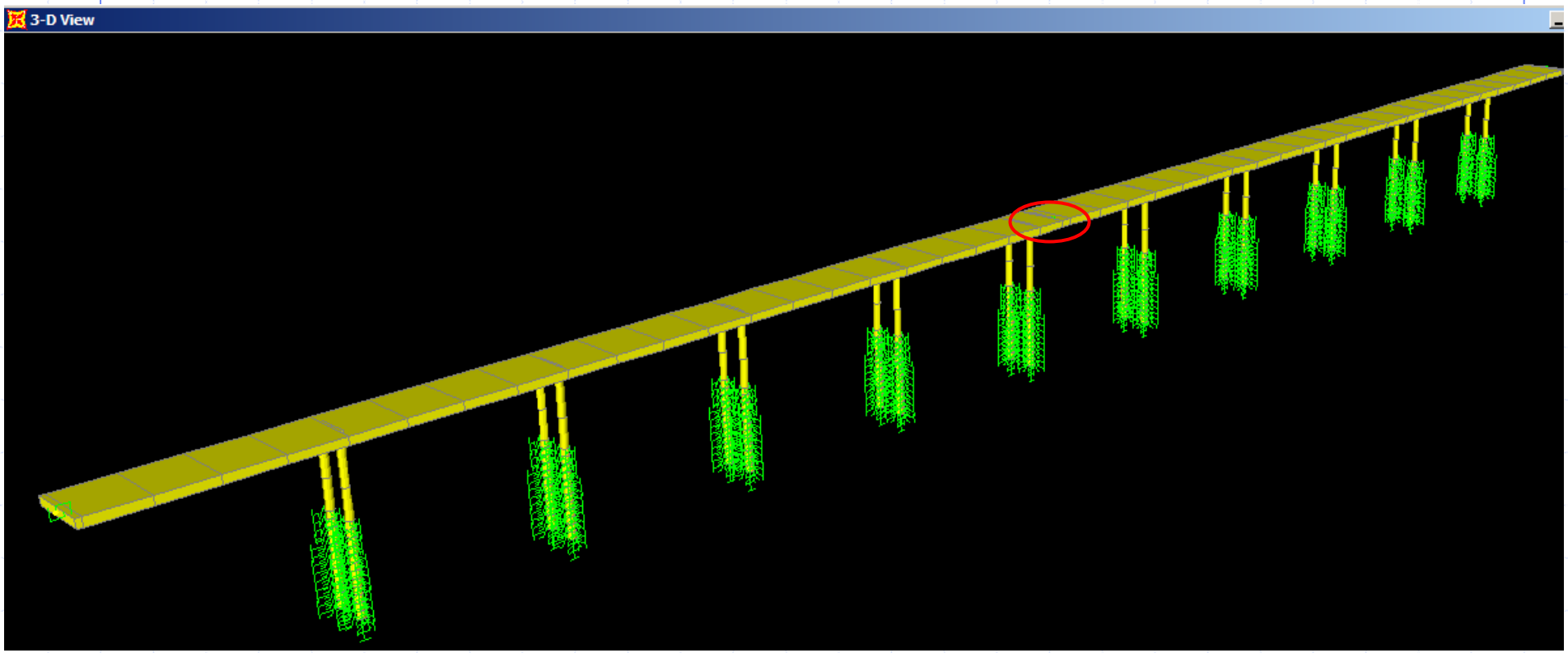








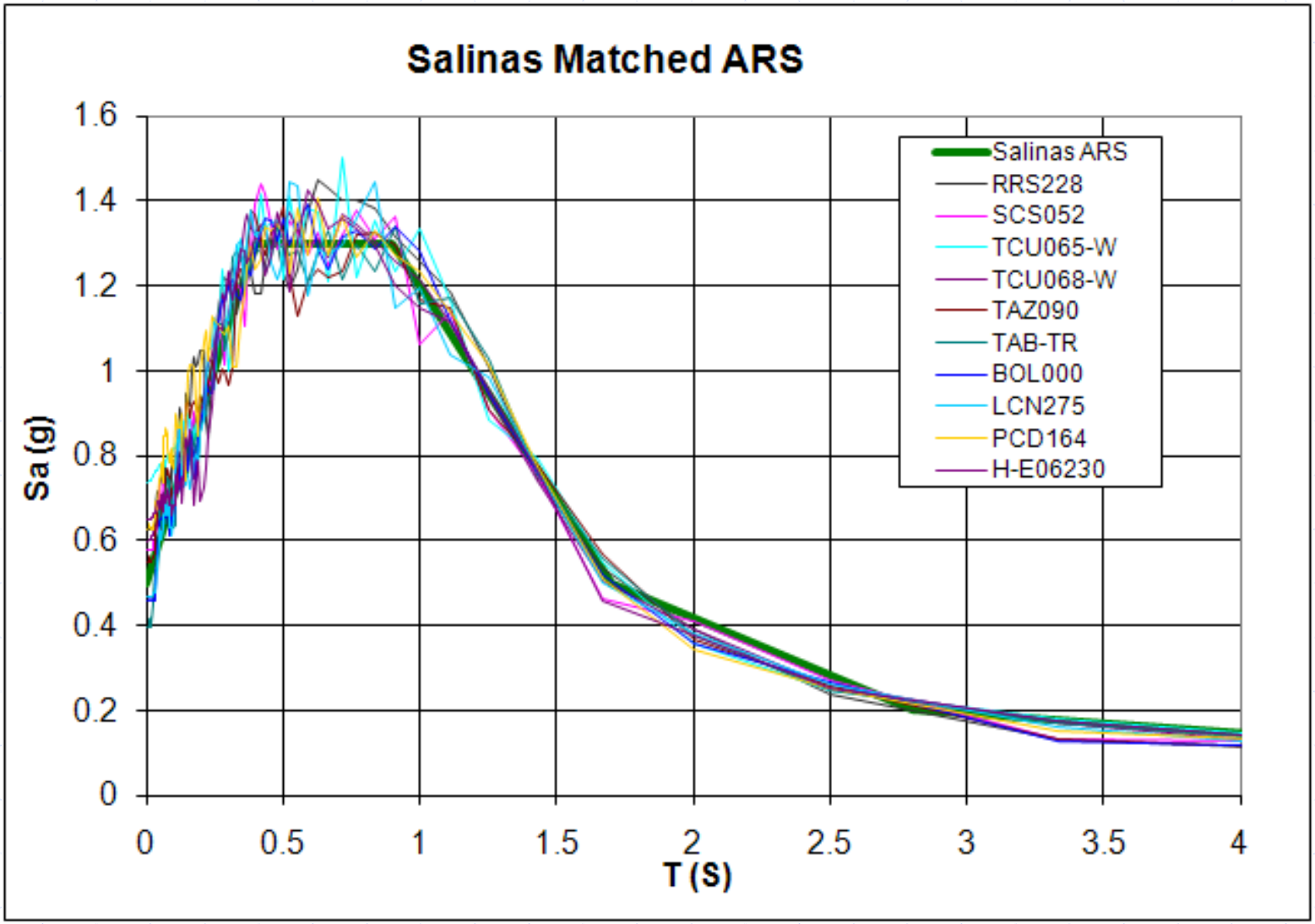
Salinas River Bridge: Model



Salinas: Analysis Options

- Demand:
  - Simplified Single Mode
  - Response Spectrum Analysis
  - Nonlinear Time history
- Capacity:
  - Reduced Elastic Limit: Z-Factor
  - Static Push-over

Salinas River Bridge: Site Specific ARS



Salinas: Analysis Options

- Demand vs. Capacity:

	Single Mode	RSA	Nonlinear THA Avg / S-dev
Longitudinal	16.23” (36.8”)	15.7” R= 2.8 (18217/6080)	15.58”/2.76”
Transverse	18.6” (41.7”)	19.2” R= 2.9 (17739/6080)	14.63”/1.28”

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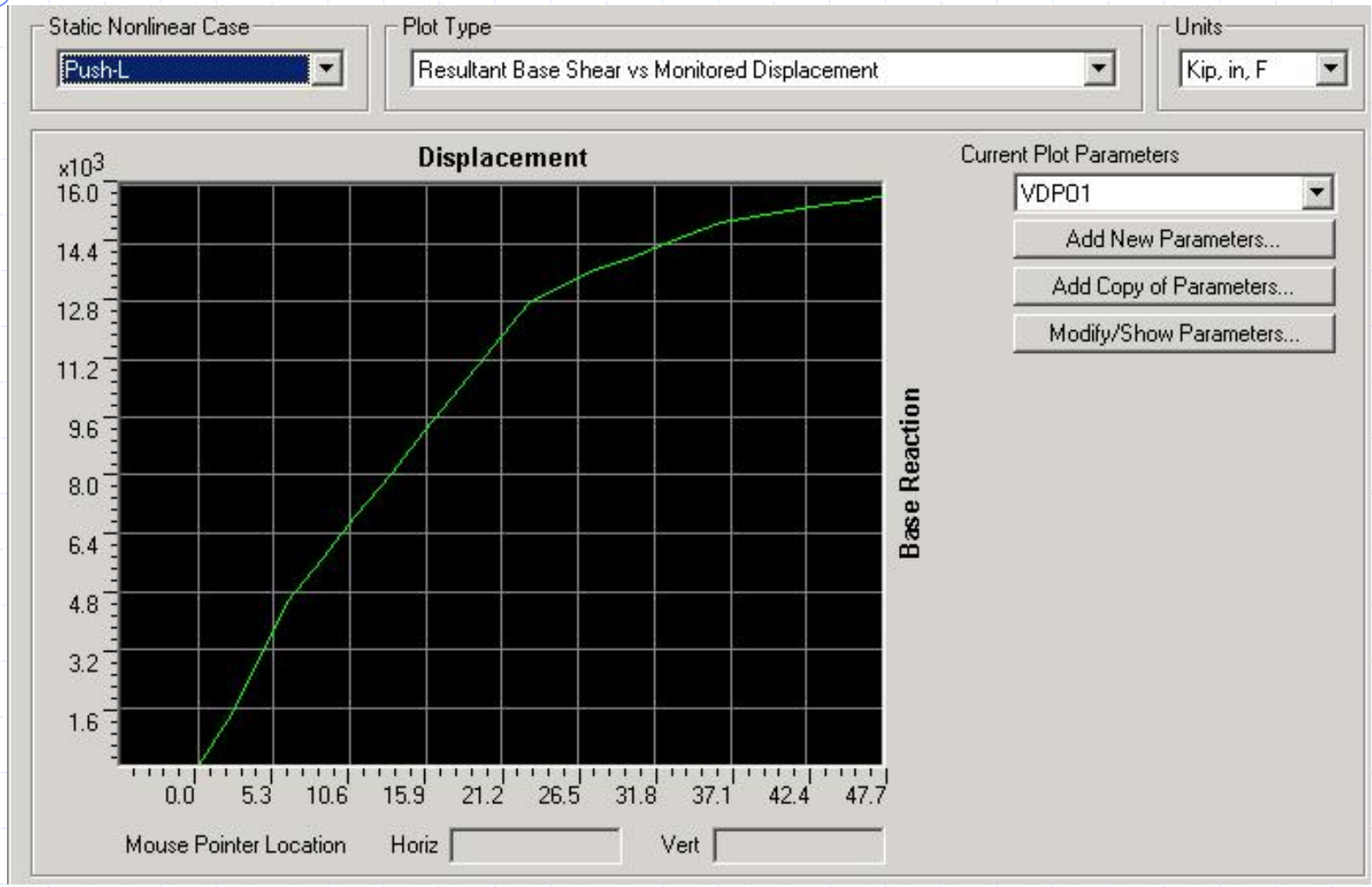
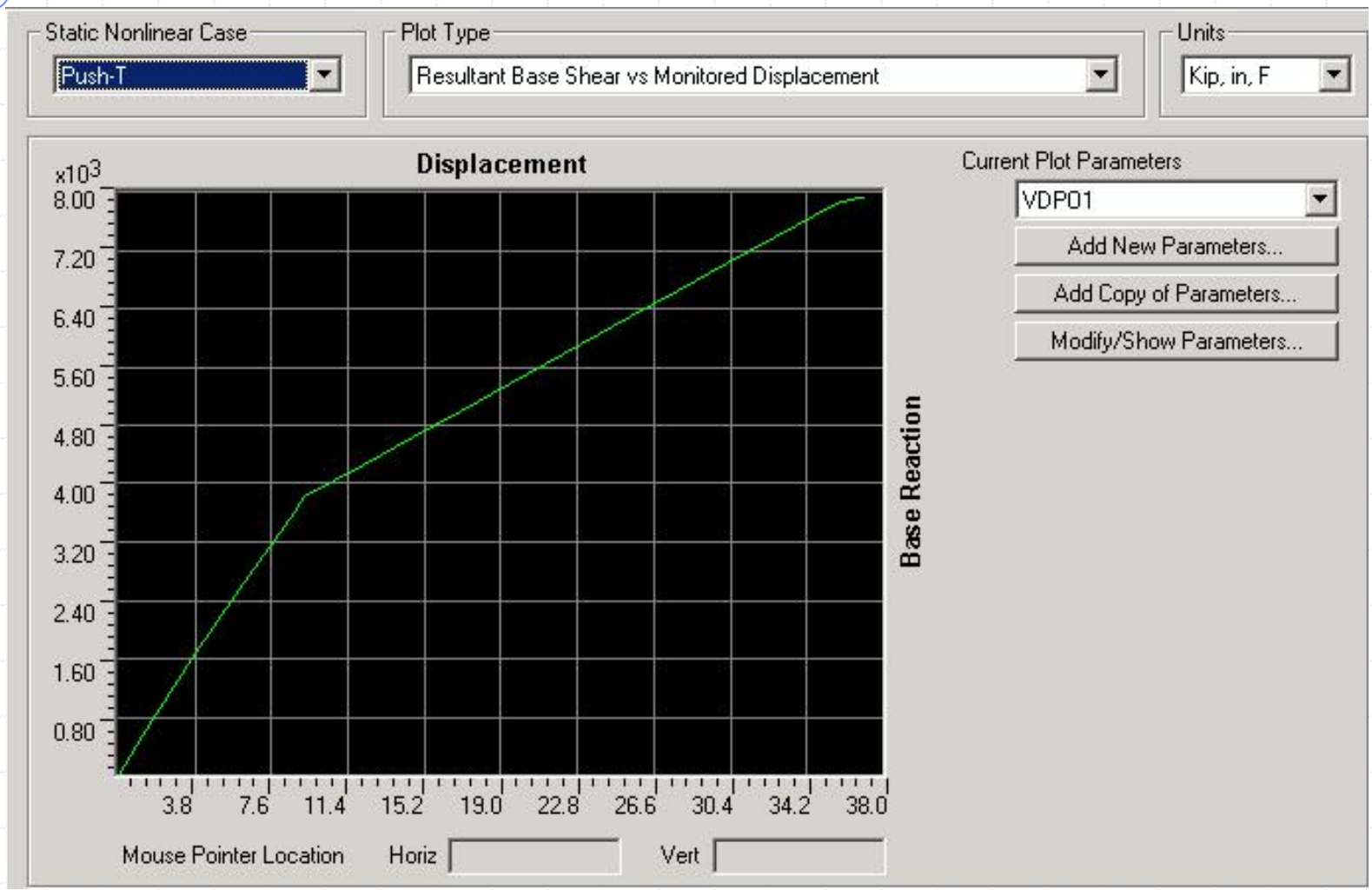
Salinas: Push-over-Longitudinal



Salinas: Push-over-Transverse



Salinas: THA Displacements

- EQ Records with Velocity Pulse

EQ Record	Longitudinal (in)	Transverse (in)
Rinaldi ‘94	17.80	15.24
Sylmar ‘94	11.39	15.61
ChiChi65 ‘99	**18.82**	12.4
ChiChi68 ‘99	15.38	12.76
Kobe ‘95	13.25	13.73
Tabas ‘78	16.96	16.11
Bolu ‘99	15.28	13.11
Landers ‘92	14.71	**16.24**
San Fern. ‘71	17.14	13.94
El Centro ‘79	15.84	16.04

Caltrans

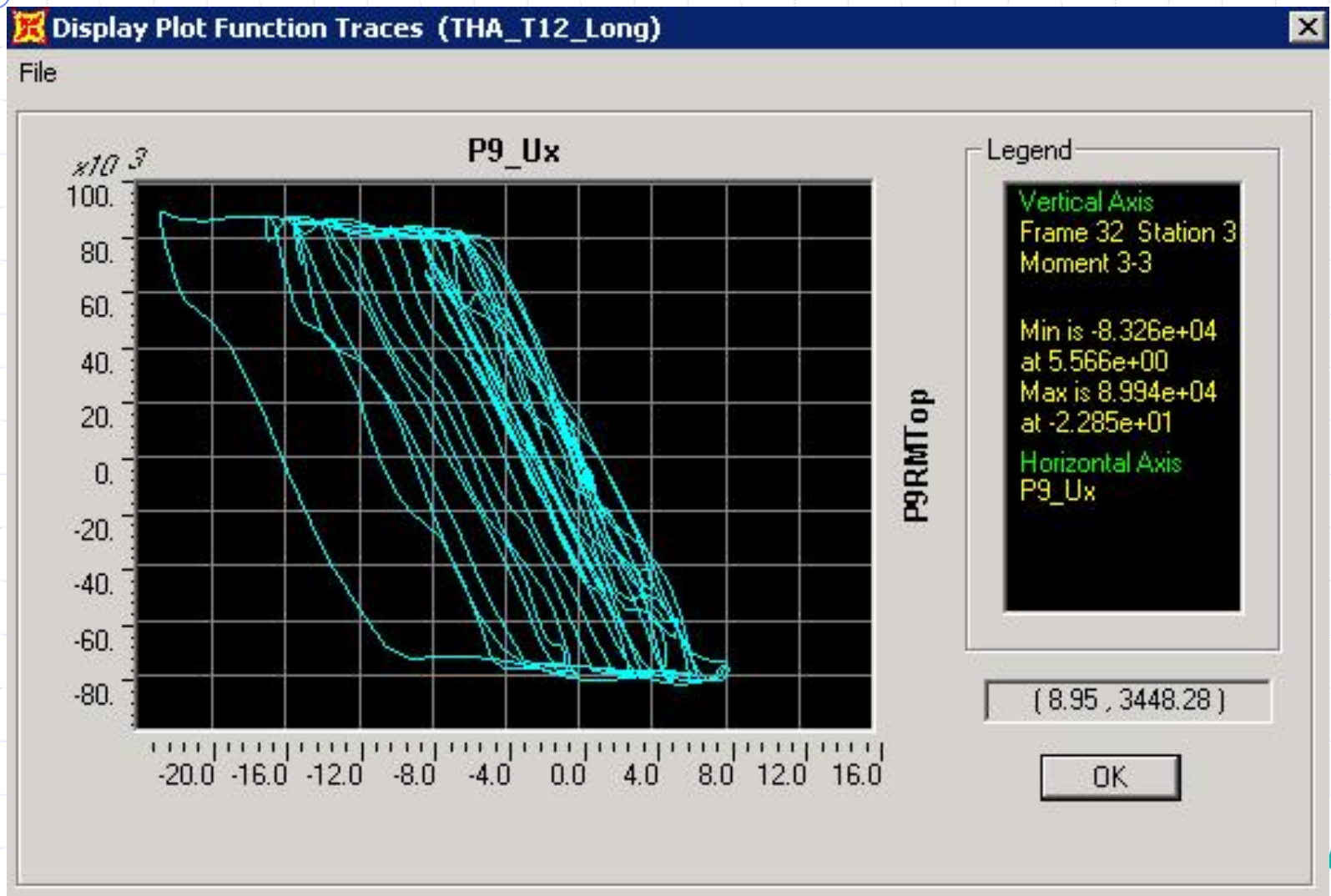
Salinas: THA Displacements

- EQ Records w/o Velocity Pulse

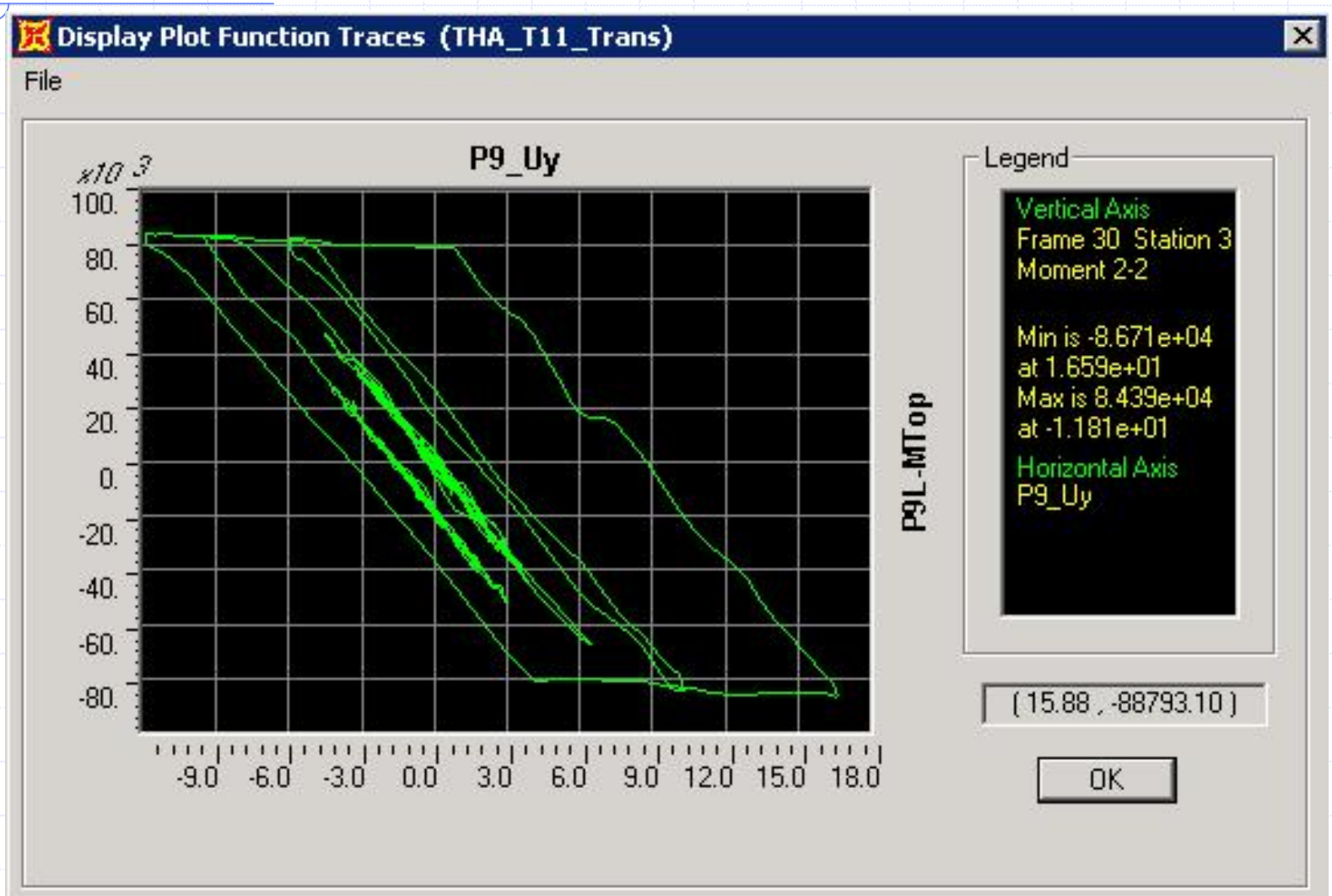
EQ Record	Longitudinal (in)	Transverse (in)
Agarias ‘79	12.46	**16.62**
Bonds ‘79	**22.85**	14.15
Castaic ‘94	12.49	14.23
Superst. ‘87	13.02	15.8
LomaPrieta ‘89	15.3	15.32
Joshua Tree ‘92	13.48	15.05
Morongo ‘92	15.86	14.24
Kagogawa ‘95	14.68	15.34
Nishi Nishi ‘95	15.17	12.92
Coyote Lake ‘79	19.66	13.75

Caltrans

Salinas: M vs. X At Bent 9, EQ#12



Salinas: M vs. Y At Bent 9, EQ#11



Remaining Issues

- Input record selection/generation to be streamlined
- Modeling guidelines to be standardized
- Material models and convergence issued to be identified
- Tools to be streamlined
  - Opensees is hard to use in production
  - SAP2000 can be slow for production

Conclusions/Status

- Nonlinear analysis tools are available
- General modeling guidelines are available
- Column Hinge Model
  - Based on Moment Curvature
  - Fiber-hinge
- EQ Records:
  - Records can be adjusted to ARS
  - Near-field effects can be analyzed