


Tilt Errors on Recorded Accelerations from Instrumented Structures

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Overview

- SDOF equation of motion and dynamic instability
  - Classical Eq. of motion formulation for SDOF oscillator
  - Re-formulation for coupled horizontal and vertical accelerations
  - Re-formulation for coupled horizontal, vertical, angular accelerations and tilt
- Engineering implications of multi-component coupling
  - Multi-component response spectra
  - Soil-structure interaction
- Tilt due to response of structure
  - Bridge Example
- Summary of major findings

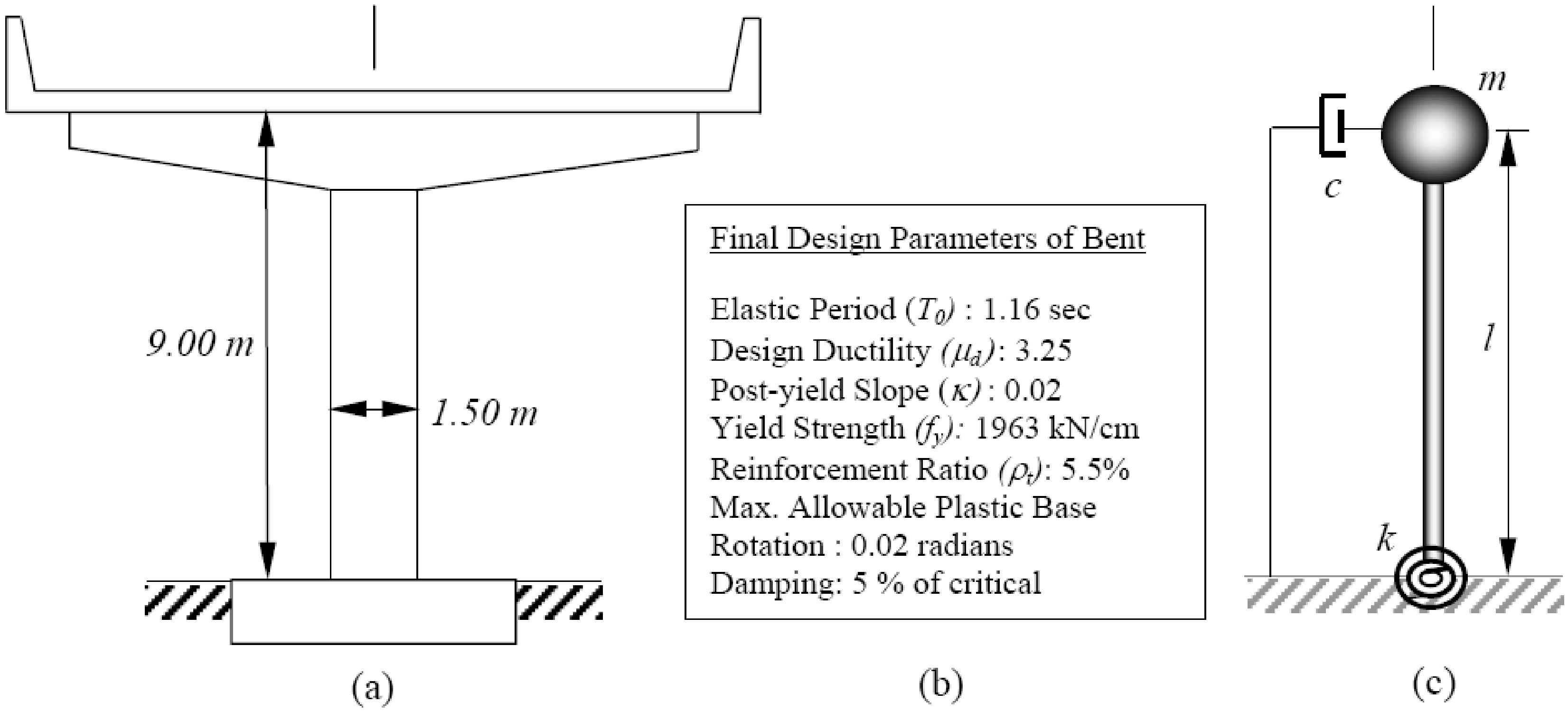
Highlights !!!

- Even for small oscillations, pendulum is sensitive to the translational acceleration, angular acceleration, cross-axis motion and tilt.

- A method of tilt estimate, based on a difference in tilt sensitivity of vertical and horizontal pendulum, allows estimating relatively large amplitudes of tilting

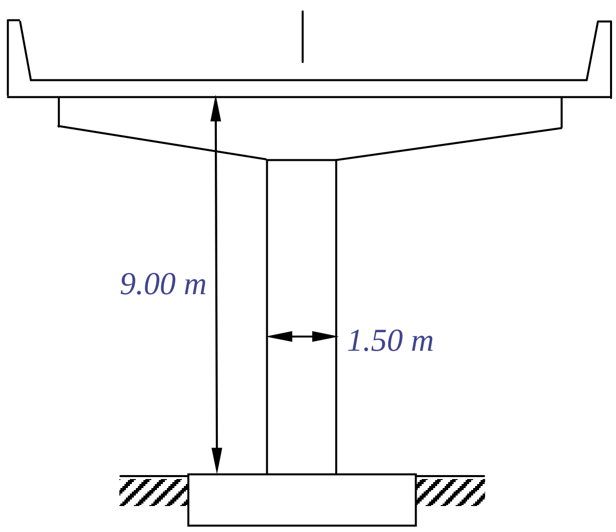
- Results of tilt estimates, using existing strong-motion records, demonstrate the importance of independent measurements of rotations during earthquake shaking.

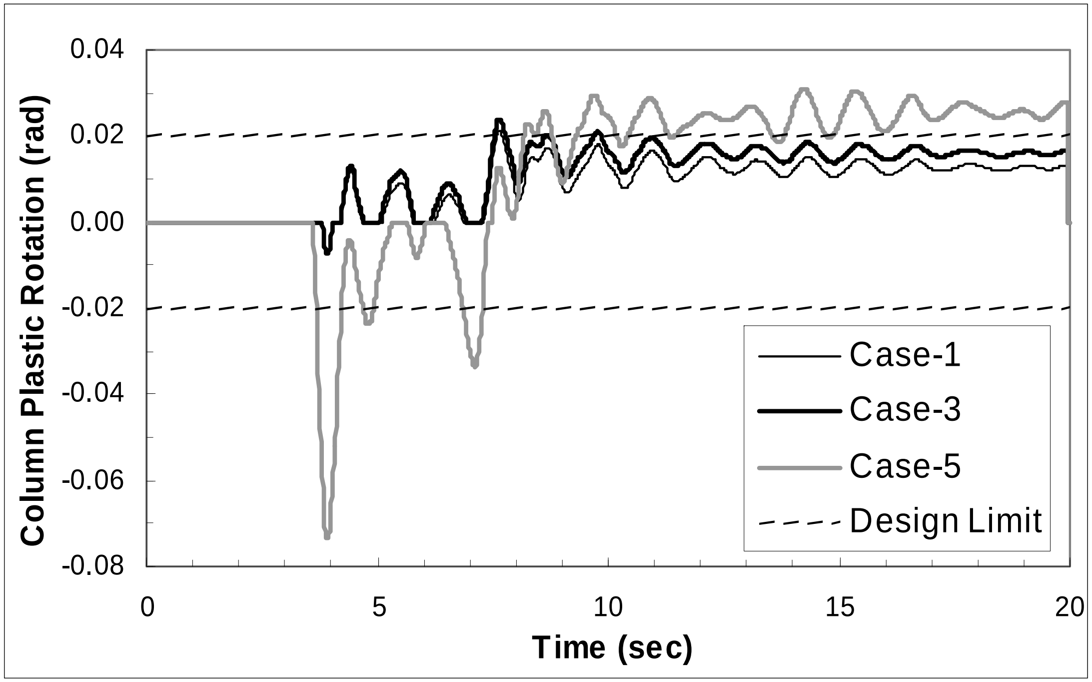
Case study: Single Column Bridge Bent



(a) Single column of a bridge bent; (b) Design parameters; (c) Idealized SDOF system.

Column Plastic Rotation Demand





Case-1 satisfies the design criteria by producing peak plastic rotation not exceeding but close to 0.02 radians. This design limit is exceeded in Case-3 by amount of 20 percent, whereas Case-5 exerts large influence on drift demand by pushing the system to almost 8 percent plastic rotation.

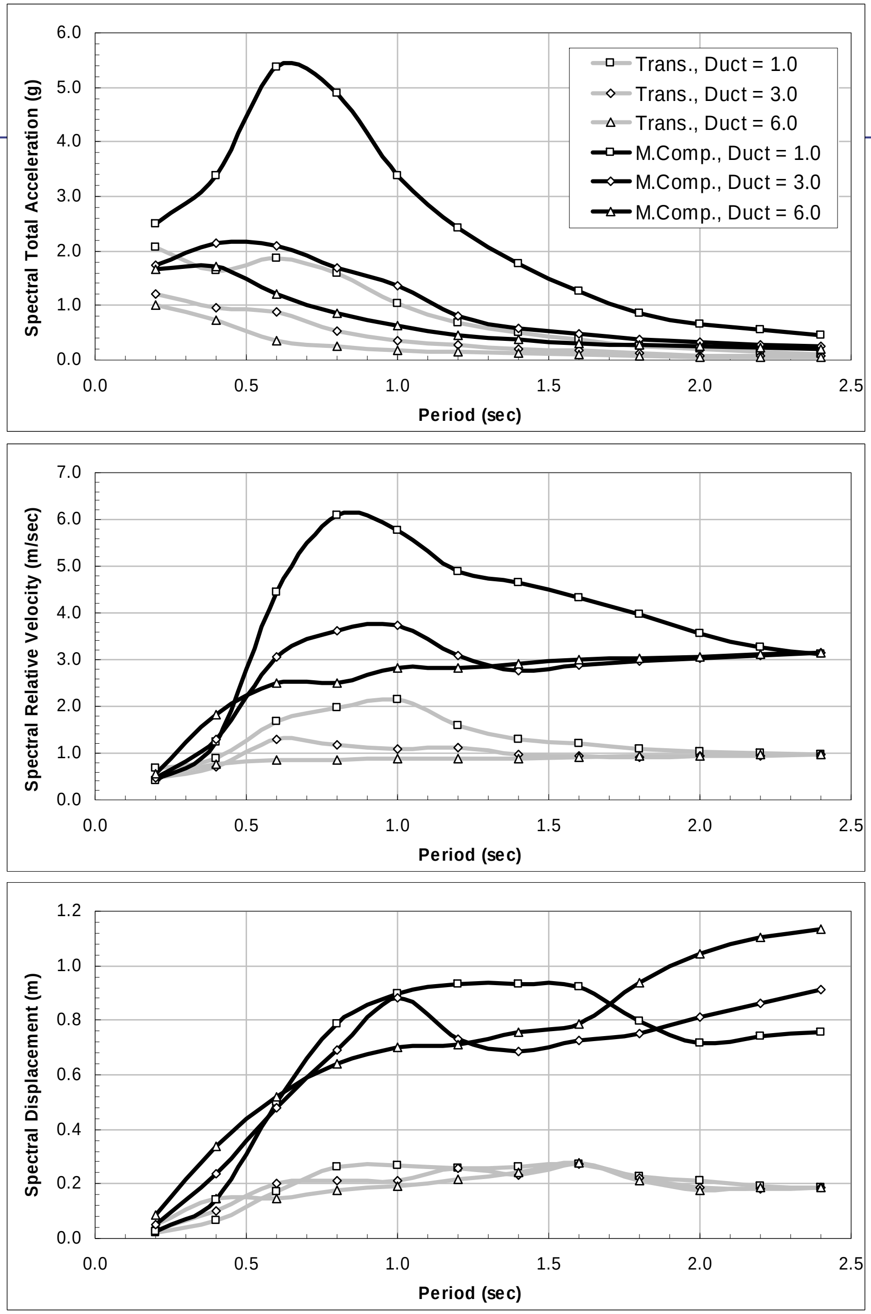
Column plastic rotation demands imposed by translational motion (Case-1), coupled translational and vertical (Case-3) and coupled translational, vertical and tilt (Case-5)

(*Note: Dashed lines indicate permissible plastic rotation constraint by the design*).

Multi-Component Ground Motion Response Spectra

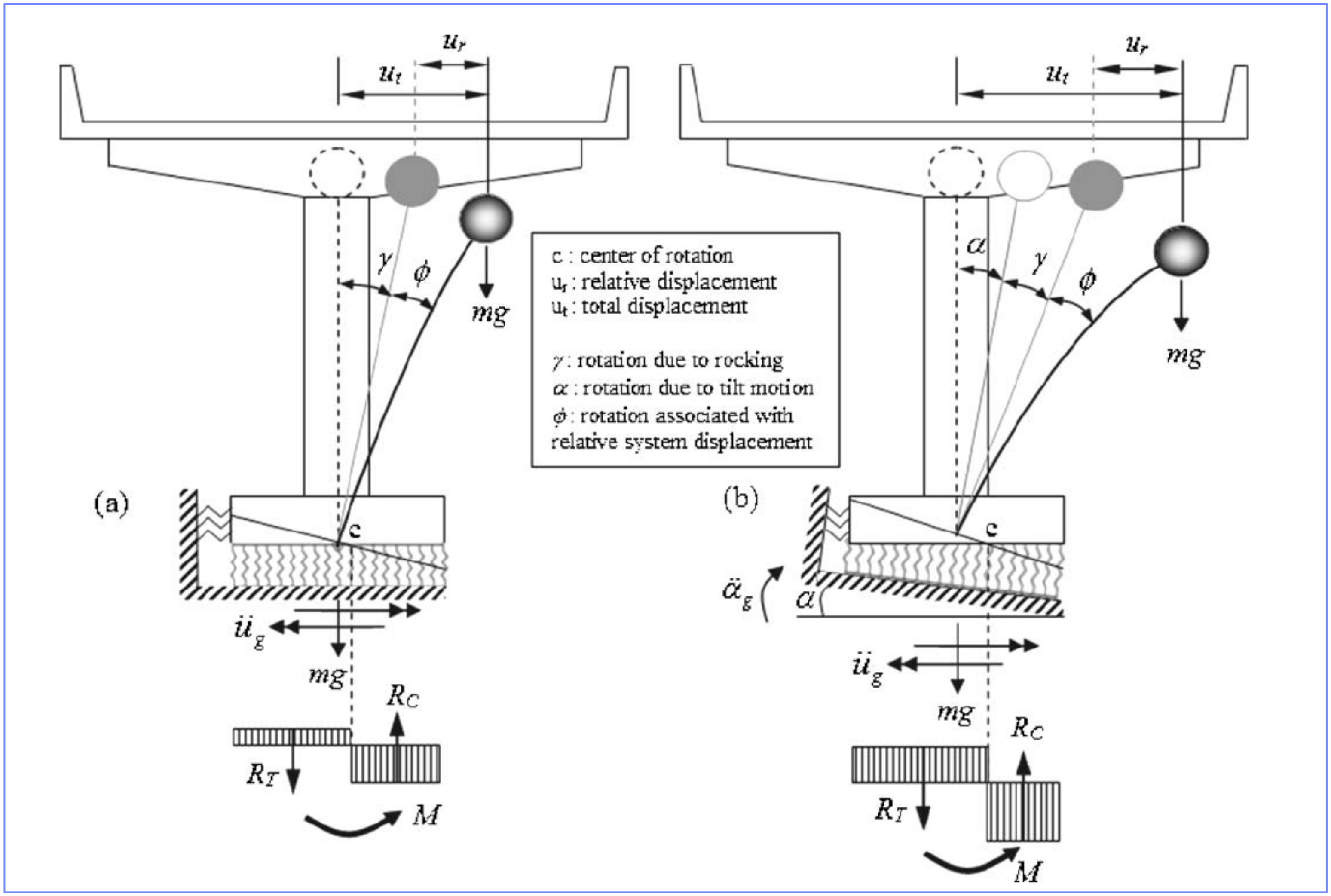
Constant-ductility inelastic response spectra for acceleration, velocity and displacement

(Trans: Translational motion only w/o P-Δ; M.Comp.: Multi-component excitations with P-Δ).



Proposed spectrum reflects kinematic characteristics of the ground motion that are not identifiable by the conventional spectrum itself.

Soil-Structure Interaction



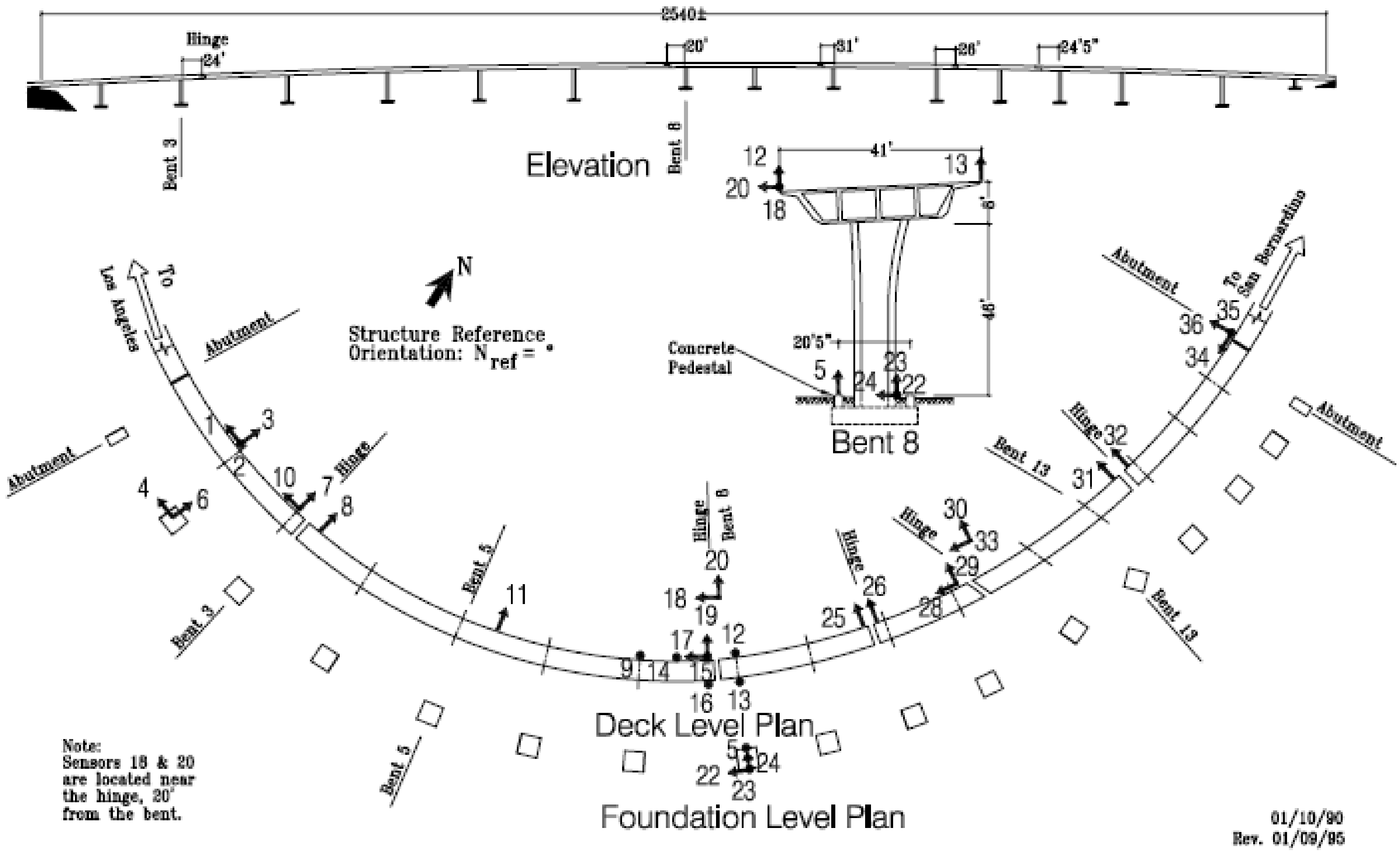
San Bernardino – I10/215 Interchange Bridge

Bridge experienced strong shaking during the M 7.3 Landers earthquake of June 28, 1992
Fault distance 81 km; PGA = 0.18 g
Max structure acceleration = 0.82 g

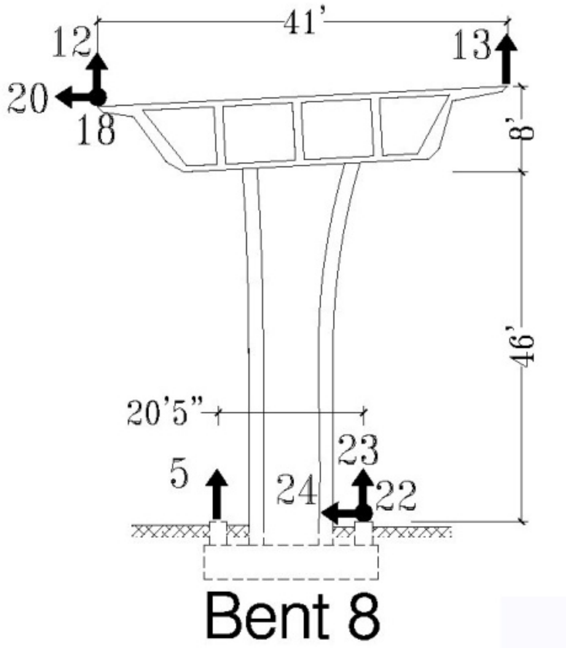
Bridge instrumentation

San Bernardino – I10/215 Interchange Bridge
Station 23631

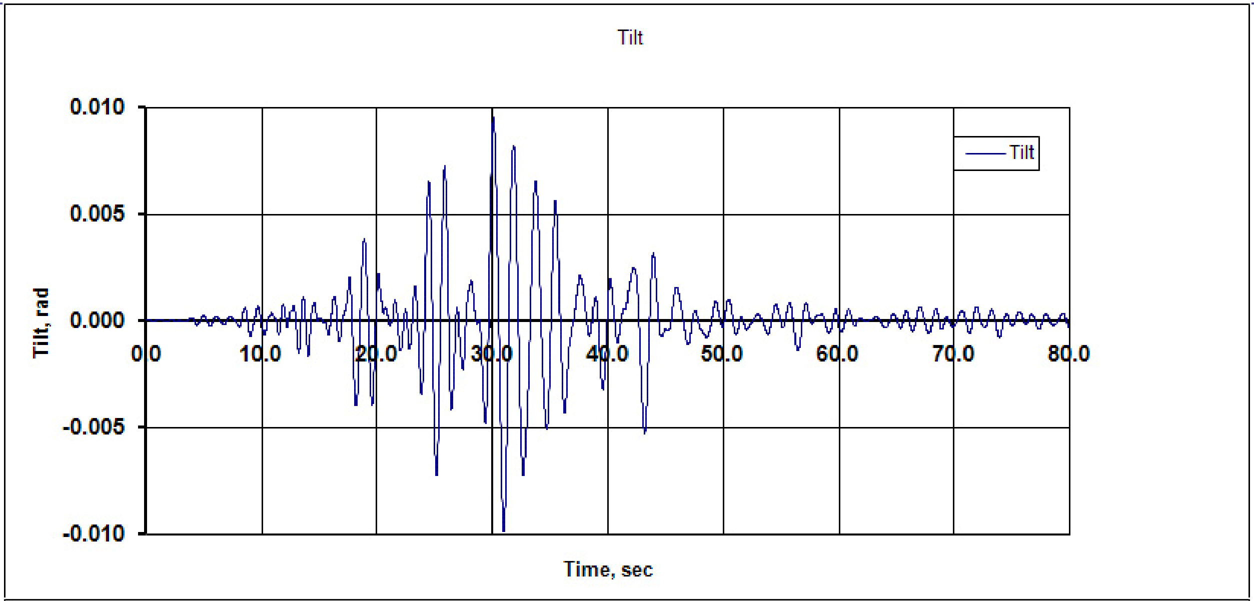
34 accelerometers on the bridge
3 accelerometers at a free-field

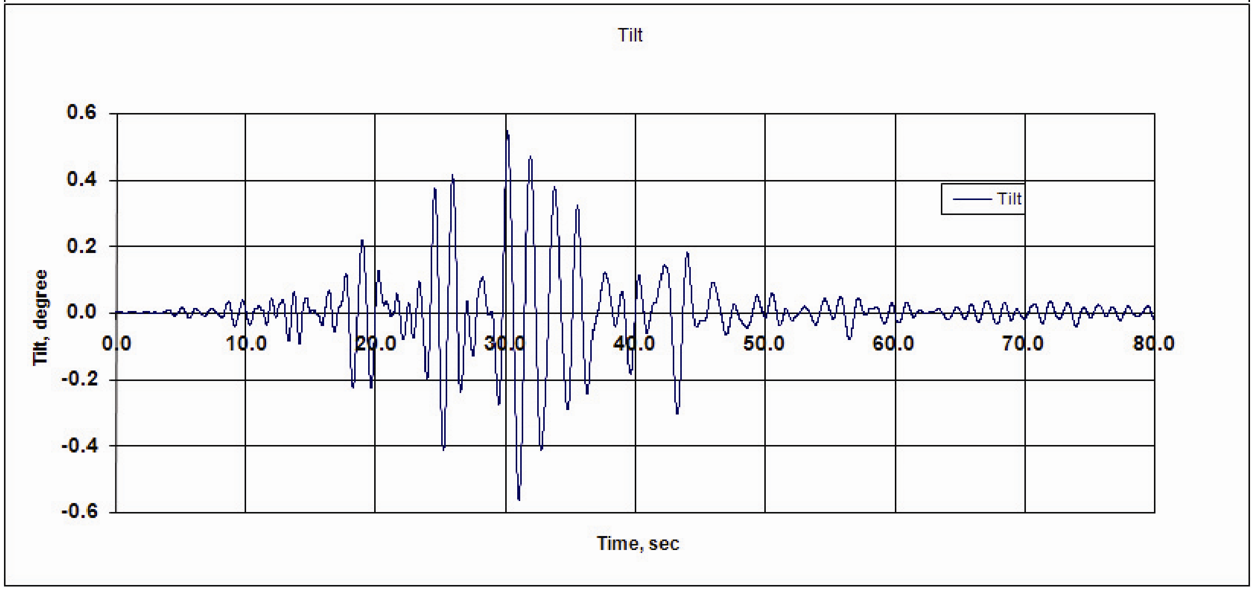


Tilt at Bent during M7.3 Landers Earthquake

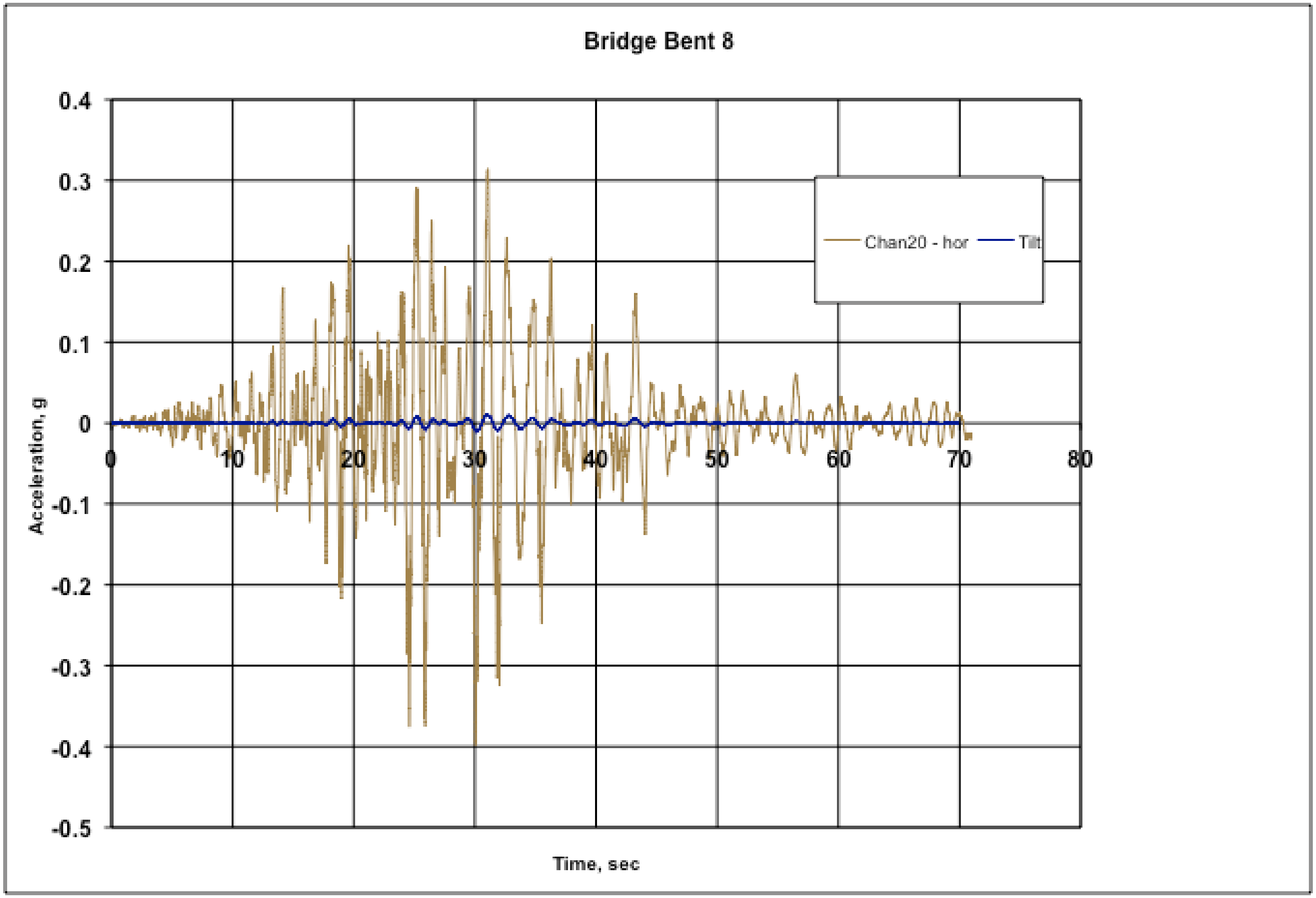


Tilt extracted from the difference in recordings of vertical sensors reached max of 0.56 deg.

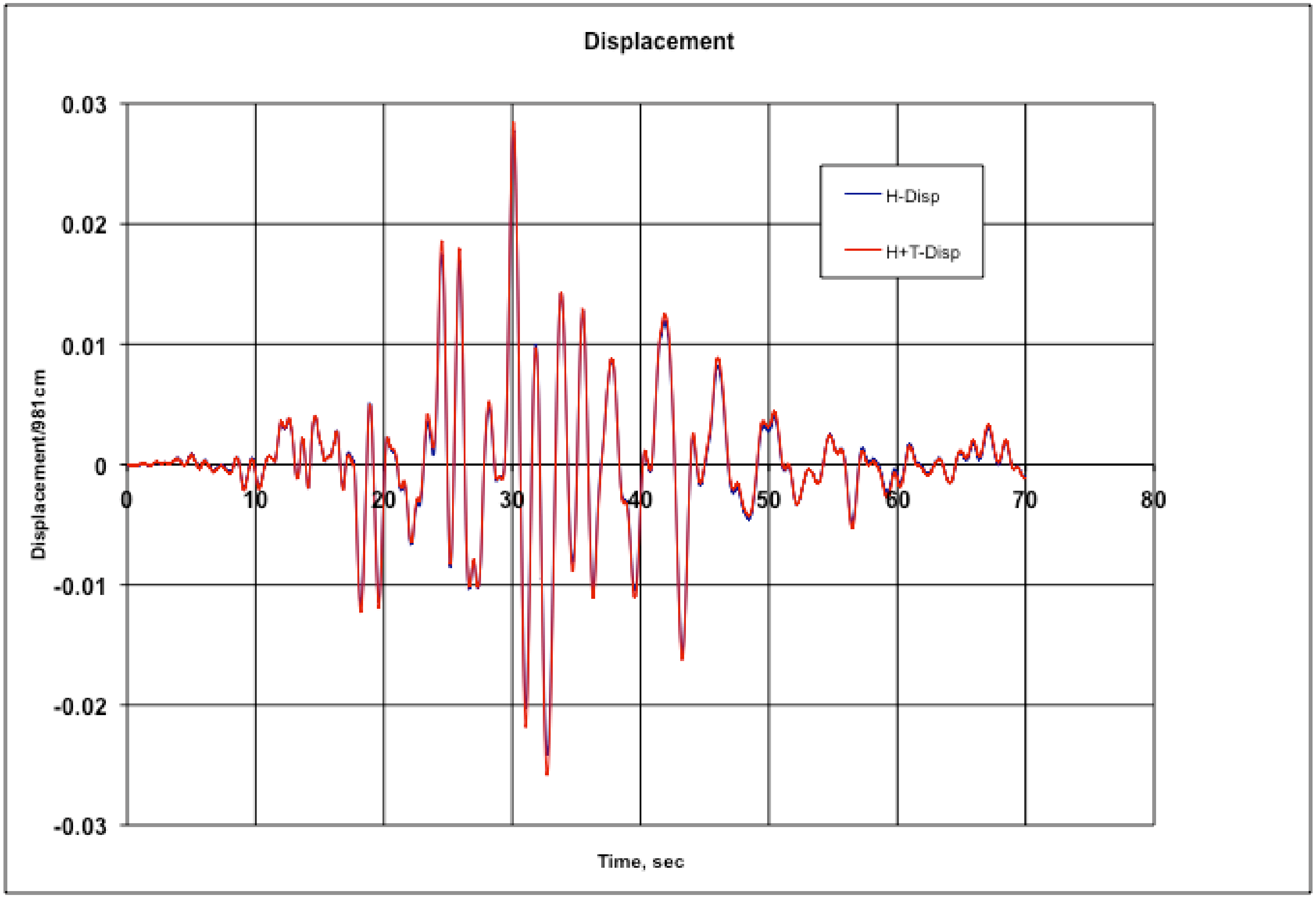




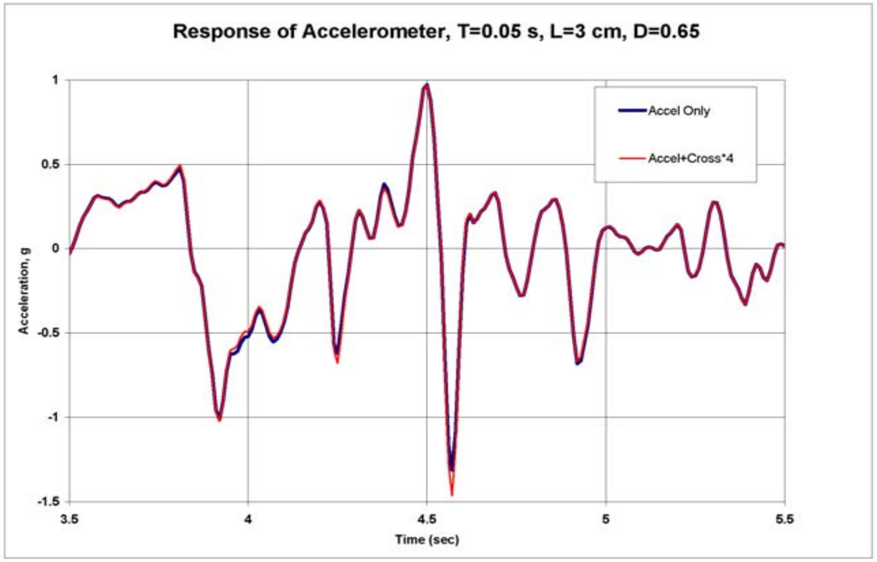
Comparison of Translational and Angular Acceleration at the Deck Level

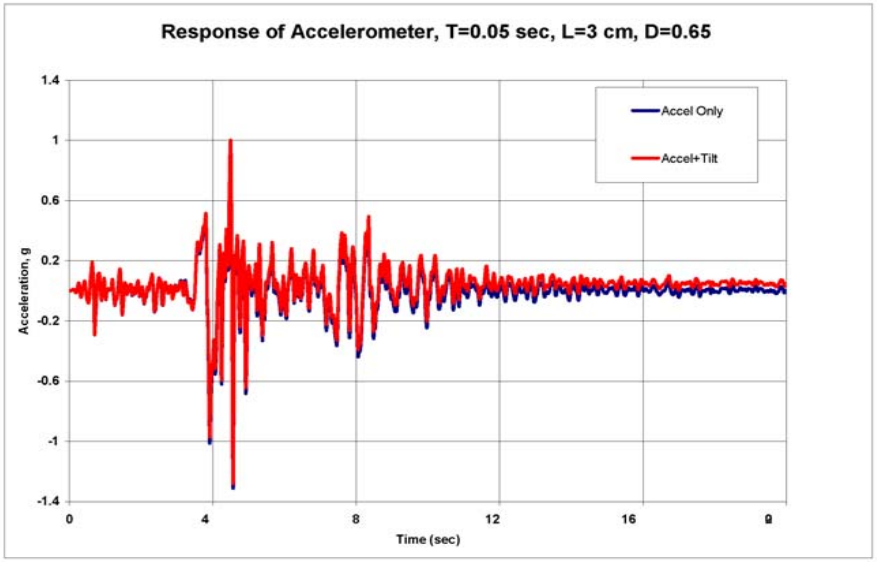


Comparison of Deck Displacement with and without Tilt Effects



Effect of cross-axis sensitivity and tilt

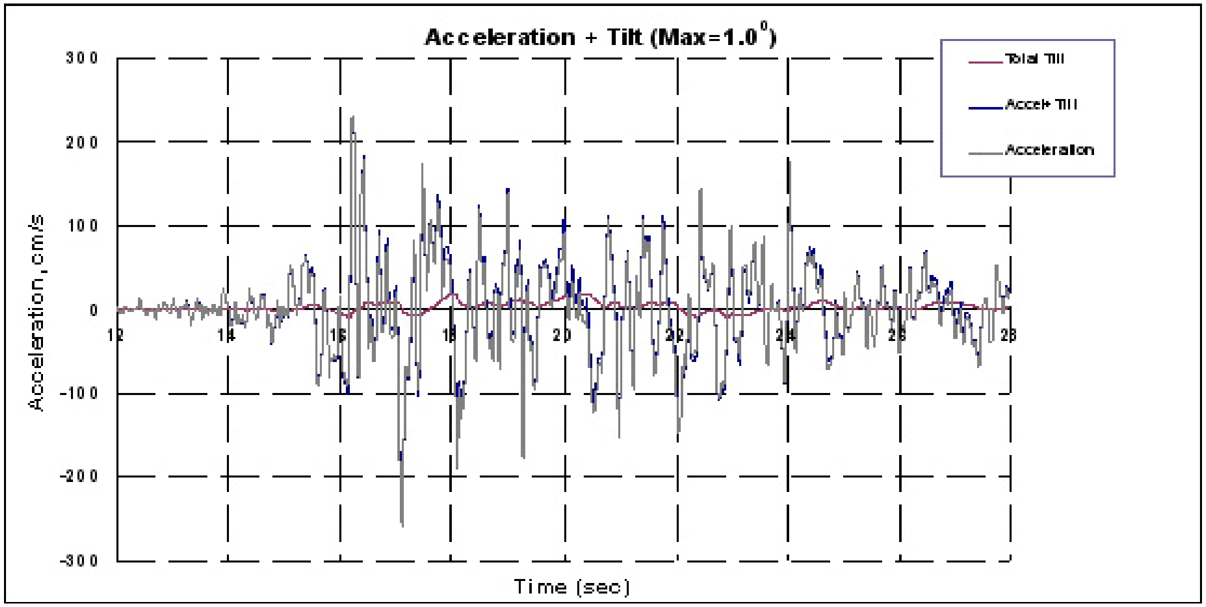


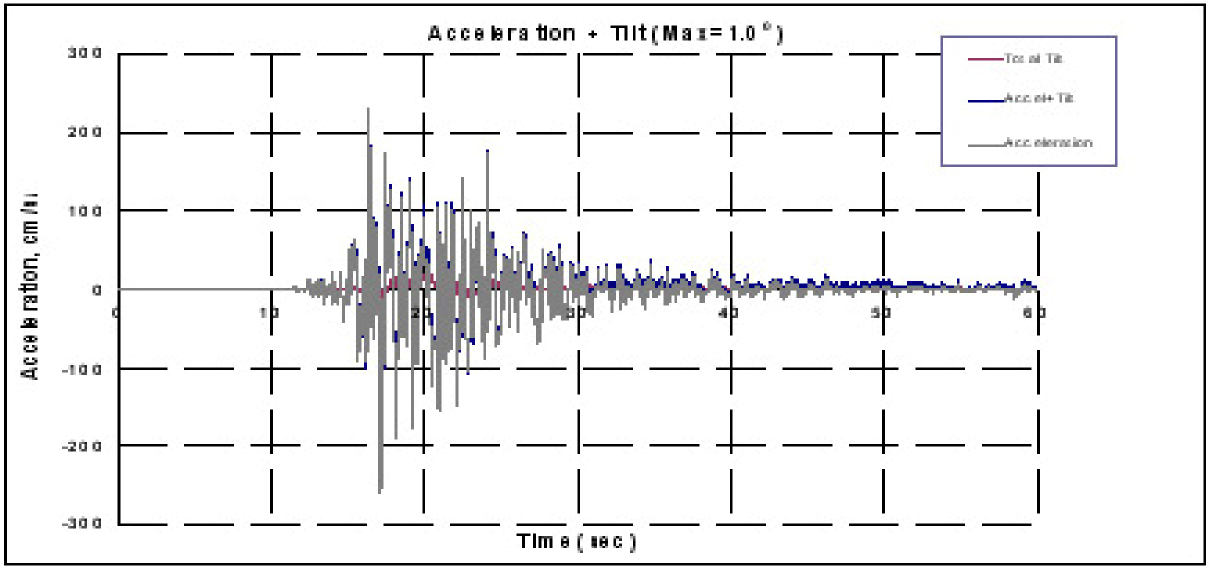


Effect of cross-axis sensitivity is generally negligible for recent accelerometers

Effect of tilt, especially residual can be very significant

Effect of tilt on the response of an accelerometer





Results

- Large tilts can produce significant errors in the recording of translational motion by pendulum accelerometers.

- Residual tilts in recordings of horizontal pendulum accelerometers can be easily recognized by the shift of “baseline”, and can be extracted.

- In case of tilting recorded acceleration should be corrected to allow reliable data interpretation.

Summary of major findings

- If the direction of dominant vertical pulses is in-phase with gravity, they may diminish the overall stiffness of system by increasing the contribution of geometric stiffness term. The associated enhanced P-D effects may create negative tangent stiffness in the post-yield deformation range by offsetting the effects of kinematic strain hardening. Hence, the bias towards increasing displacements in one direction becomes increasingly larger. This may create important practical consequences, such as dynamic instability (or collapse) can be initiated if the energy of multi-component excitations is large enough to carry the system inelastically in one direction.

- If the major pulses in vertical component are out-of-phase with respect to gravity, they act conversely and tend to minimize the destabilizing force. Same applies for tilt component: depending upon its phase difference with respect to horizontal motion, it may either remediate the system by offsetting the plastic rotations and reducing the overall inertia force, or it may act inline with horizontal motion and amplify the total inertia force.

Summary of major findings (cont.)

- Inclusion of vertical excitation modifies the geometric stiffness term which becomes time-variant. The instantaneous changes in geometric stiffness term create progressive modifications in overall stiffness. The intensity of these time-variant changes on force-deformation slope depends on the amplitude of vertical acceleration pulses. If the intensity of vertical acceleration pulses is large enough, the oscillator period may show noticeable variations. Under this circumstance, it is not possible to retain a constant period oscillation. Thus, linear-elastic oscillator may act as a nonlinear-elastic oscillator.

- Compared to vertical component, tilt component of motion has more impact on translational response of the system. Few degrees of dynamic ground tilting can easily double the overall system response. This difference will be more dramatic for tall structures since the inertia force due to angular acceleration is directly proportional to the effective height.

- The governing equation of motion considering multi-component excitation is derived based on equivalent-fixed-base oscillator, hence it provides directly the relative drift associated with the exact deformation. This interpretation provides ease in its implementation in computational frames.