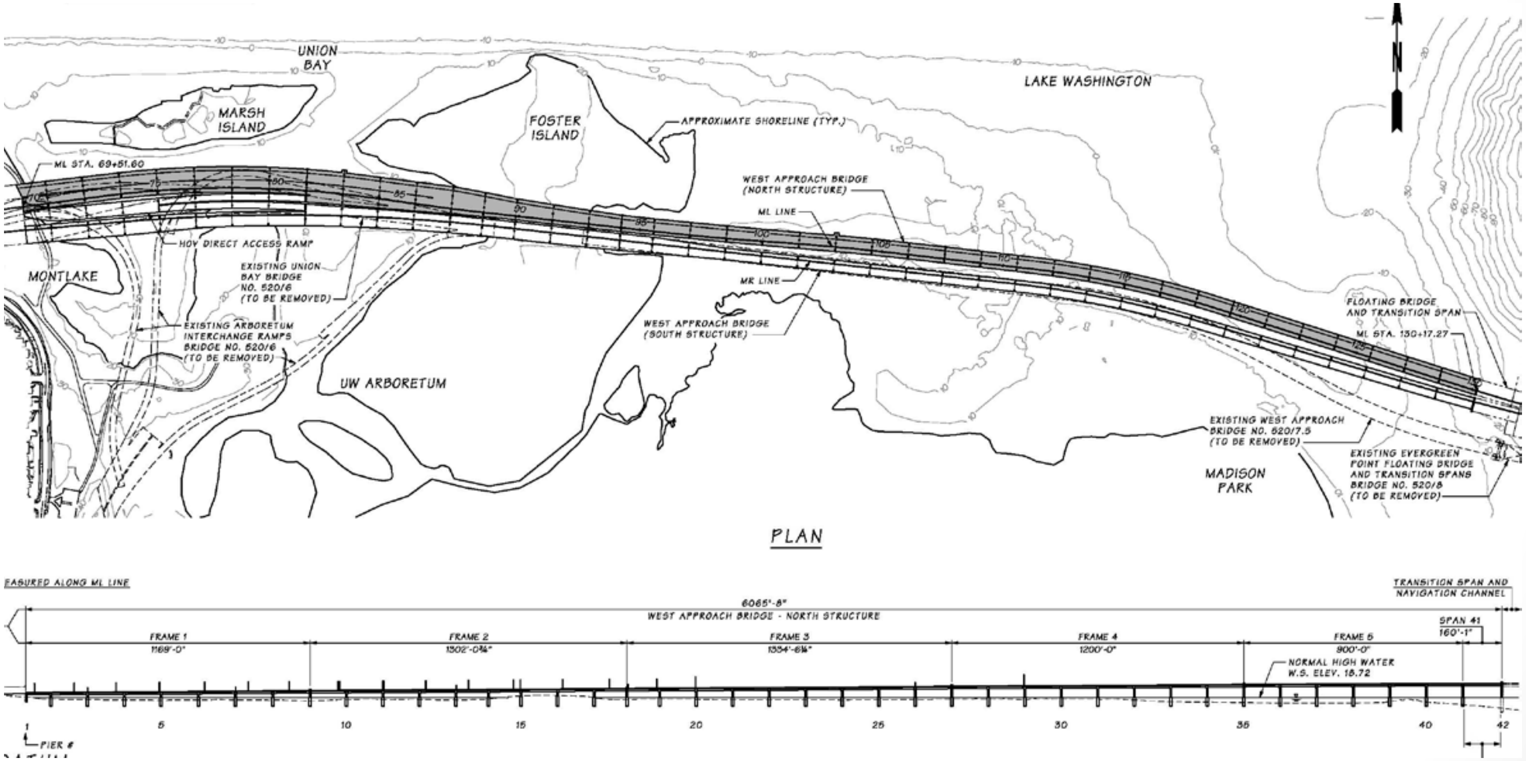
The Importance of Considering Column Top Rotations in the displacement of Triple Friction Pendulum Isolators for Tall Column Structures

Eric Abrahamson, PhD, PE
Fletcher Waggoner, PE

SC Solutions, Inc., Sunnyvale, CA

The SR 520 West Approach Bridge (WAB) in Seattle:
40 seismically isolated spans
1 navigation span (traditional bearings)
1 transition span connecting the shoreline to the new Lake Washington floating bridge.



TFPB Isolator System

One isolator system considered was Triple Friction Pendulum Bearings (TFPB) from EPS of Vallejo, CA.

The SCS independent analysis was performed as design check of the main design performed by HDR Engineering, Inc. (HDR).

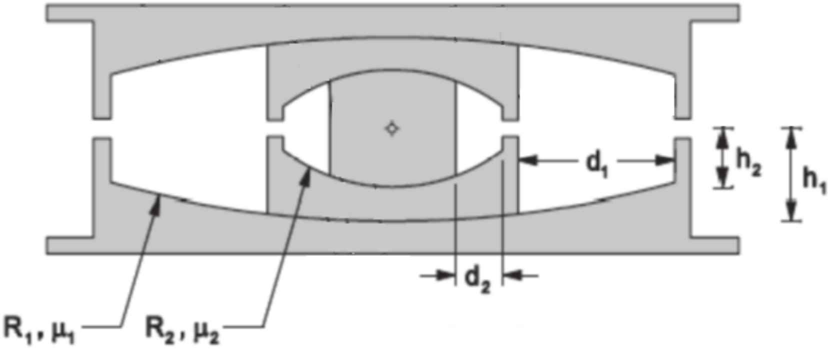
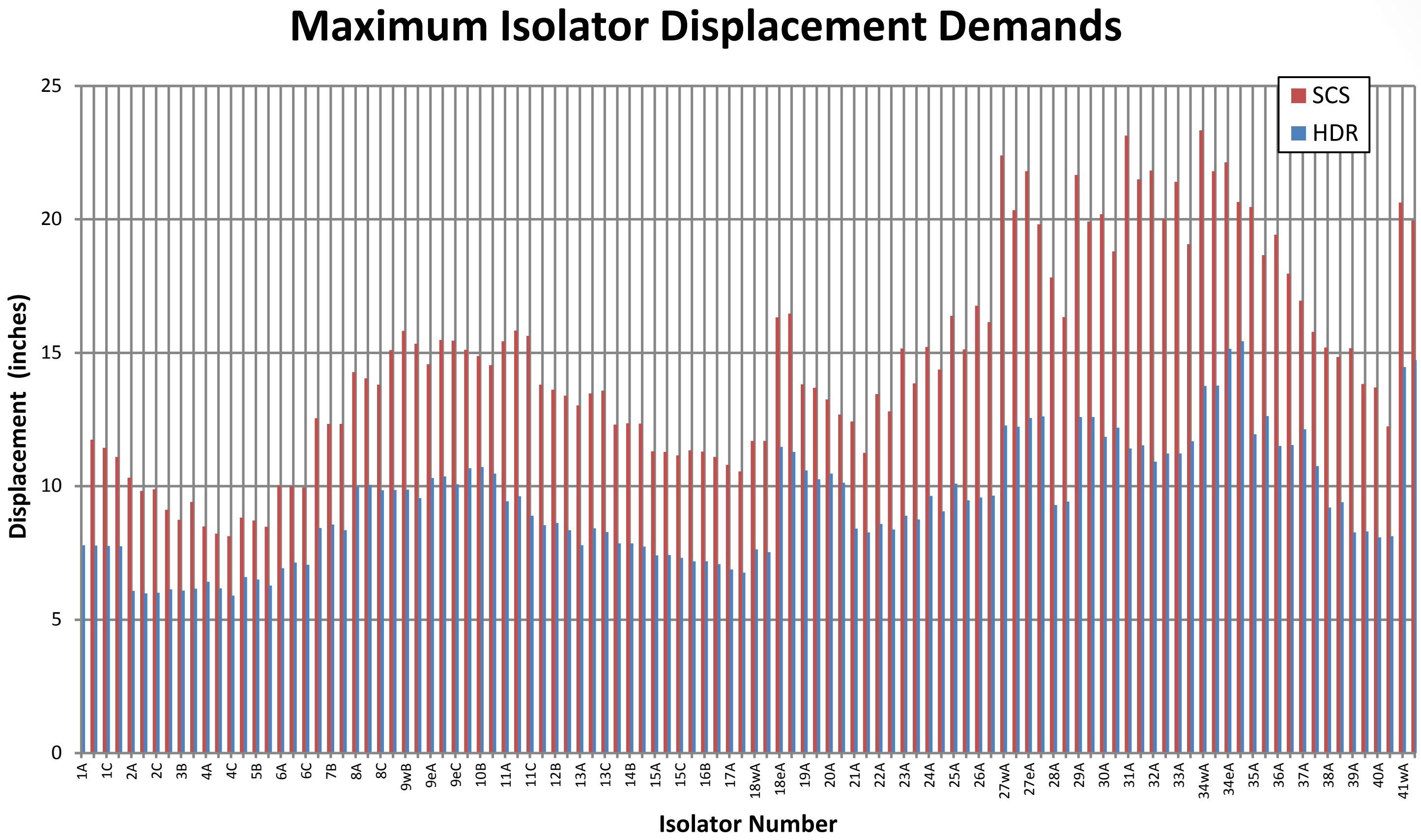


Figure from "Modeling Triple Friction Pendulum Isolators in Program SAP2000" by Sarlis & Constantinou

WAB Isolator Displacement Summary



Maximum Isolator Displacement Demands

Peak isolator displacement demands computed by SCS were significantly larger than those computed by HDR

TFPB Modeling

- HDR performed their analysis using CSiBridge, with the TFPB's idealized as 2 FPB elements in parallel, as recommended. This element does not consider rotation of the base of the bearing.

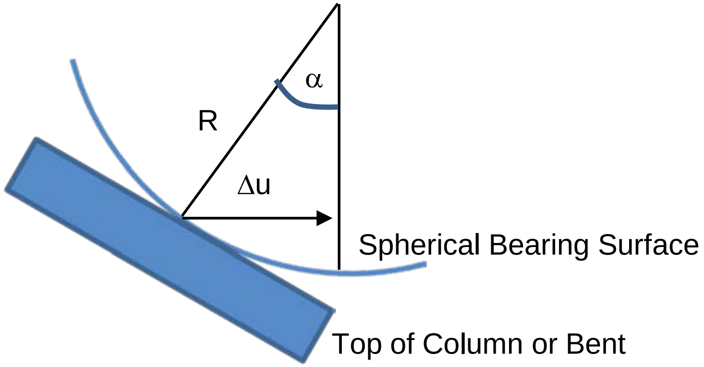
- SCS used ADINA for the analysis. The TFPB's were represented using a proprietary SCS developed "user supplied" element. This element models the TFPB as a nested pendulum system having 4 spherical surfaces.

- Each spherical surface is assigned a velocity dependent frictional coefficient, which produces a transverse restoring force opposite to the direction of the instantaneous relative velocity.

- The element is formulated for large displacements, and the local element stiffness matrix is recomputed at each time step based upon the updated relative position of the four surfaces, including the effects of isolator base rotation. P-Δ effects are included as part of the large displacement formulation.

TPFB Rotation Effects

Isolator base rotations are considered. As the base rotates, the equilibrium position shifts.



The effective additional displacement caused by the shift in equilibrium position is

$$\Delta u = R \sin \alpha$$

TPFB Rotational Restoring Force

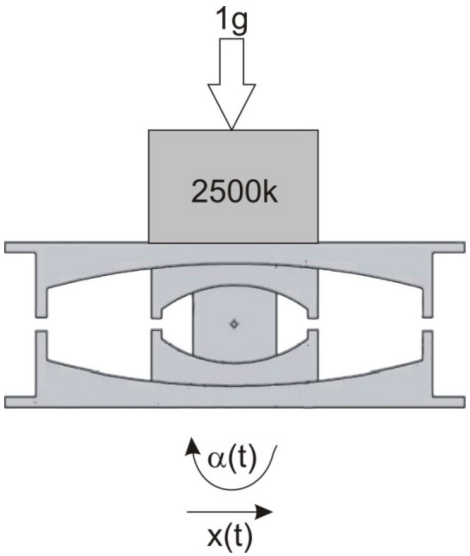
Each sliding surface has a friction force and a restoring force. The restoring force for the lower slider is found from

$$\mathrm{F} = \mathrm{N}\left(\frac{\mathrm{u}}{\mathrm{R}} + \sin(\alpha)\right)$$

The base rotation causes a change in the restoring force in the lower sliding surface.

For the WAB analysis, the column top rotation reached about 4°, and the radius of curvature of the outer surfaces were about 12 feet, resulting in a shift in the equilibrium position by about 10 inches

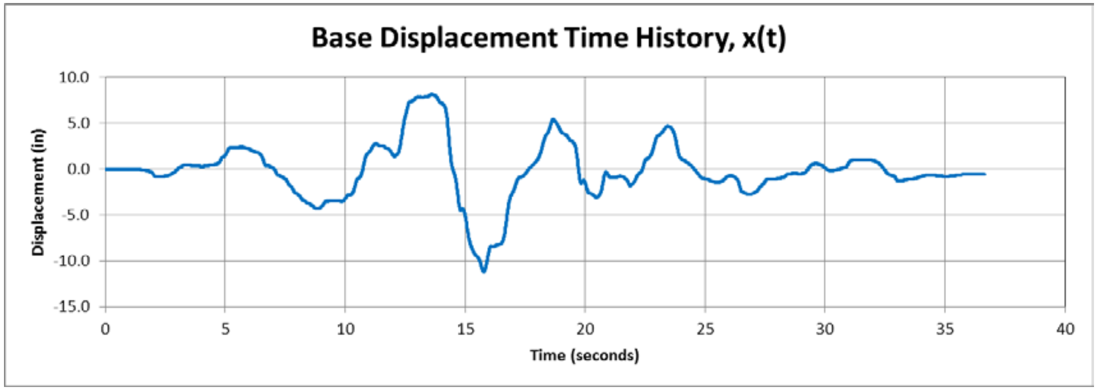
Simplified Example

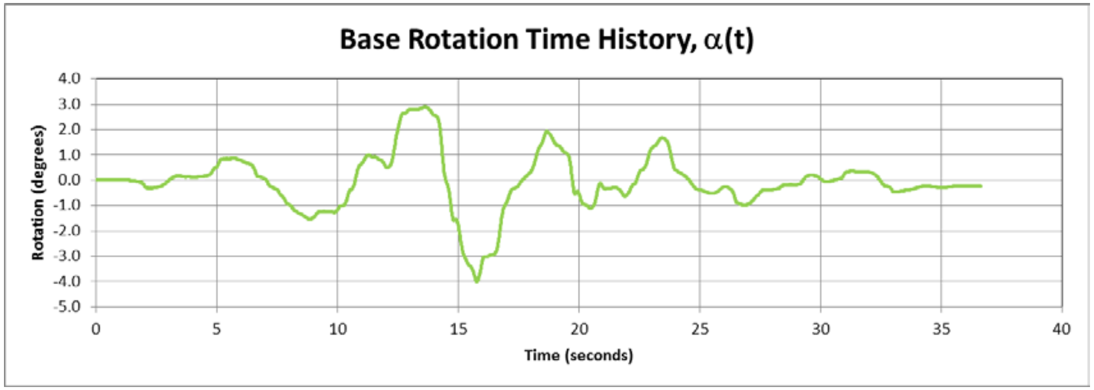


Variable	Value	Description
R_1	156”	Outer slider radius ($R_{eff1} = R_1 - h_1 = 151”$)
R_2	14”	Inner slider radius ($R_{eff2} = R_2 - h_2 = 11”$)
μ_1	0.03-0.06	Velocity dependent friction for outer sliders
μ_2	0.02-0.04	Velocity dependent friction for inner sliders
d_1	17.5”	Distance to ring stop, outer slider
d_2	1.5”	Distance to ring stop, inner slider

- Case 1: no base rotation, only x(t) applied, $\alpha(t) = 0$.
- Case 2: with base rotation, both x(t) and $\alpha(t)$ applied

Motion Inputs





The base rotation input is in phase and the same shape as the base displacement input

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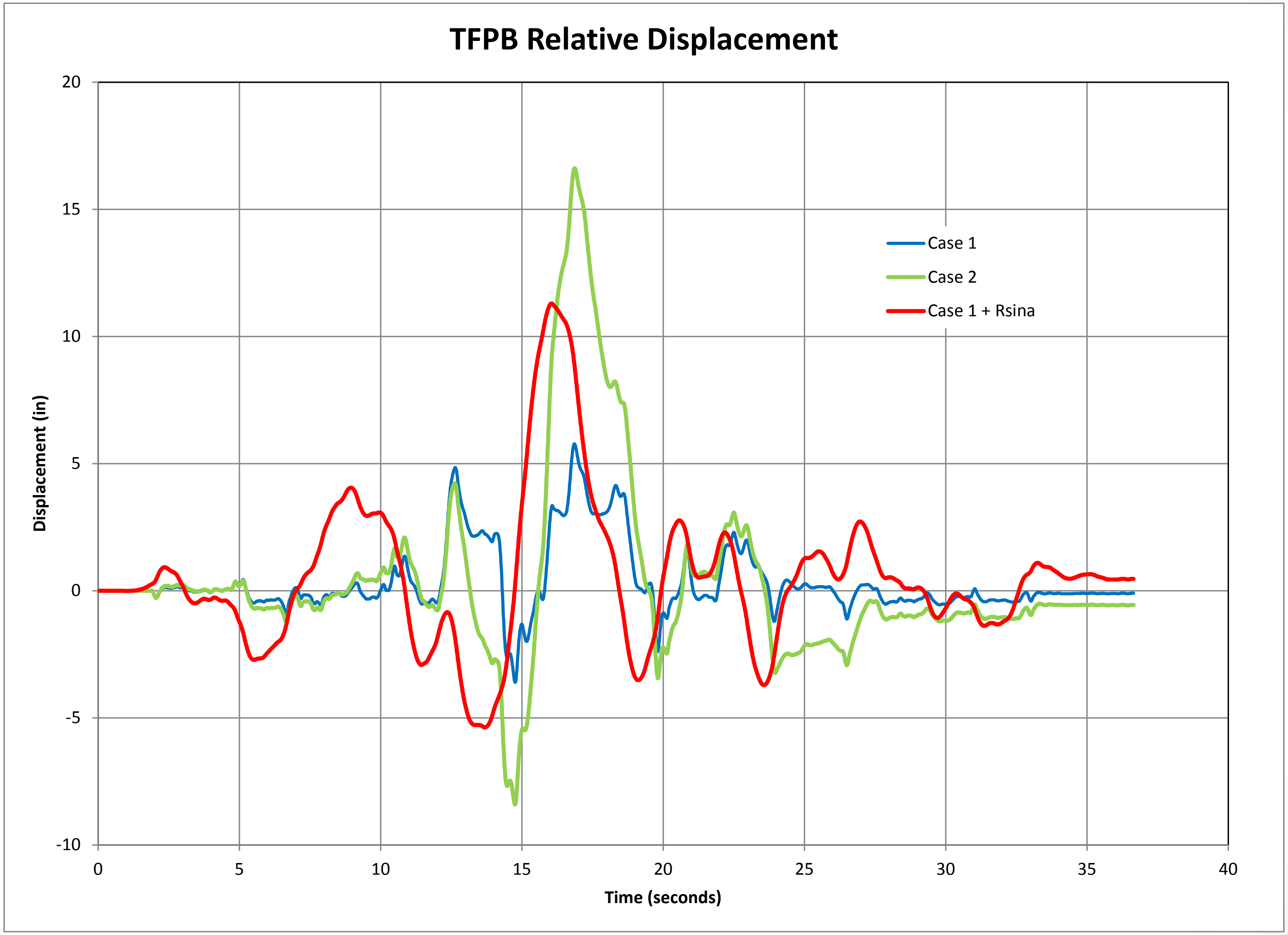
Displacement Results



Conclusions

- Rotation of the column top can cause significant increases in the displacement of the TPFB isolation bearing.

- Neglecting this effect can result in a bearing without sufficient displacement capacity for the design earthquake.

- The addition of a correction factor is not sufficient, as it is a static correction on the equilibrium position, and does not reflect the dynamic response of the isolator.