IMPROVED PROCEDURE TO ESTIMATE SEISMIC FORCES IN ANCILLARY SYSTEMS SUPPORTED ON PIERS AND WHARVES: INSPIRATION FROM PROFESSOR CHOPRA

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PIERS AND WHARVES

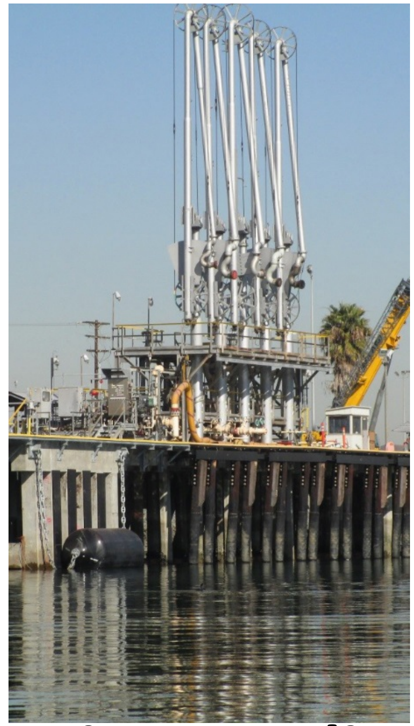
Marine Oil Terminal Plan

Marine Oil Terminal Elevation

Pictures Courtesy William Bruin and Gayle Johnson, SGH

ANCILLARY SYSTEMS

Hose Tower



Marine Loading Arms

Sign Board

Hose Cranes

Pictures Courtesy William Bruin and Gayle Johnson, SGH

ASCE 7-10 FORMULA

Amplification Within Component

PGA

$$F_p = \frac{\boxed{0.4S_{DS}}\,\boxed{a_p}\,W_p}{R_p / I_p}\boxed{\left(1 + 2\frac{z}{h}\right)}$$

Amplification Within Structure

$$0.3S_{DS}I_pW_p < F_p < 1.6S_{DS}I_pW_p$$

ASCE 7-10 FORMULA

S_{DS} = Short period spectral acceleration

a_p = Component amplification factor

I_p = Component importance factor

R_p = Component response modification factor

W_p = Component operating weight

z = height in structure of point of attachment of component with respect to base

h = average roof height of structure with respect to the base

ASCE 7-10 FORMULA

- R_p and a_p values are provided in tables
- a_p = 1 for rigid components;
- a_p = 2.5 for flexible components
  - Lower value permitted if justified by detailed dynamic analysis

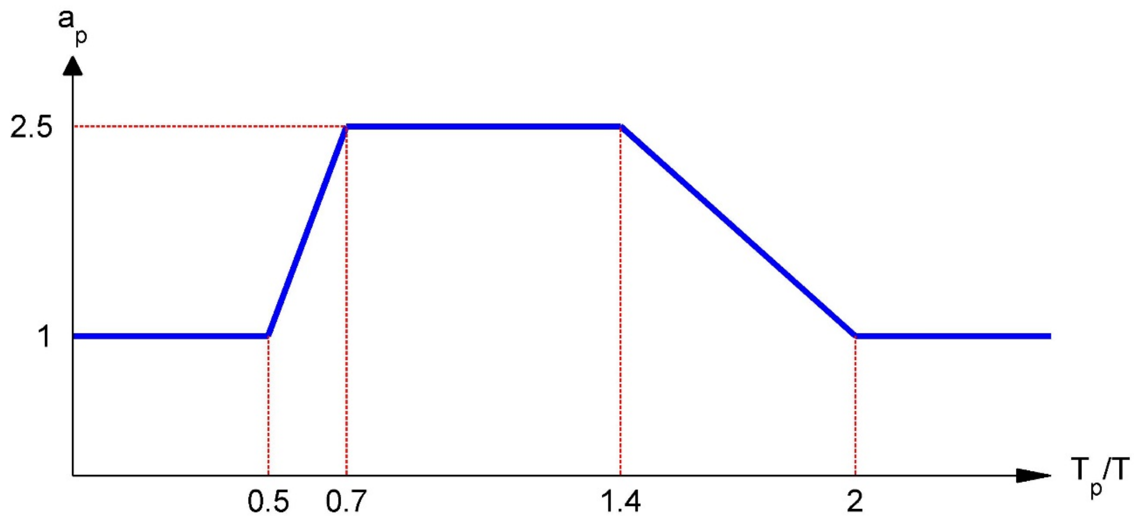
ALTERNATE FORMULA

- If acceleration, a_i, at the point of attachment of the component can be computed from modal (or response spectrum) method

$$F_p = \frac{a_i a_p W_p}{R_p / I_p} A_x$$

ALTERNATE ESTIMATE FOR a_p

- If fundamental period of the structure, *T*, and of the component, T_p, are know, a_p may be estimated from



ACCELERATION AT POINT OF ATTACHMENT

- Current Formula
  - Ancillary components are attached at deck level of piers & wharves
  - z = 1 and (1+2z/h) = 3
  - Acceleration at point of attachment = 3 times PGA
  - Independent of primary system period
  - Is this appropriate?

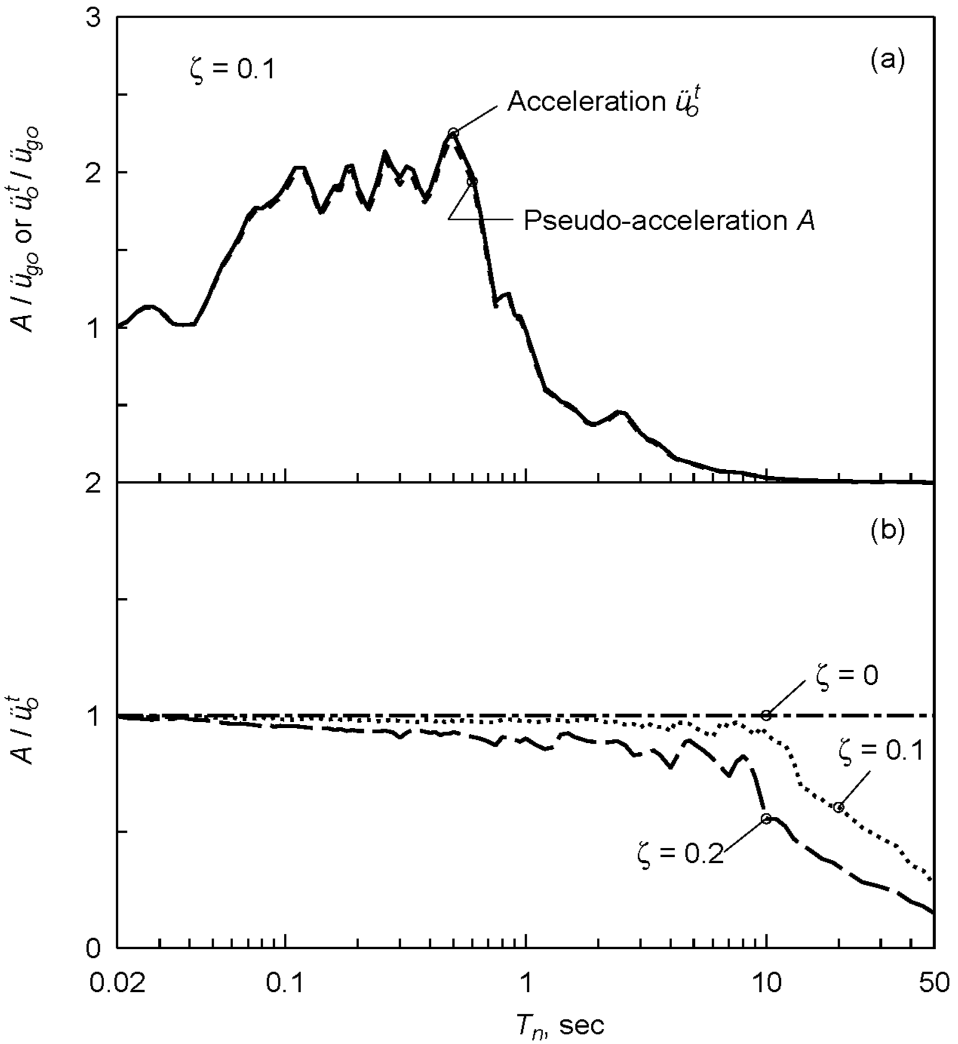
$$F_p = \frac{0.4 S_{DS}\, a_p\, W_p}{R_p / I_p}\left(1 + 2\frac{z}{h}\right)$$

ACCELERATION AT POINT OF ATTACHMENT

- Alternate approach to estimating a_i in piers and wharves
  - Typically one-level structures
  - Most can be idealized as single-degree-of-freedom system in direction under consideration
  - a_i is total acceleration in the SDF system

$$\boxed{F_p = \frac{a_i a_p W_p}{R_p / I_p} A_x}$$

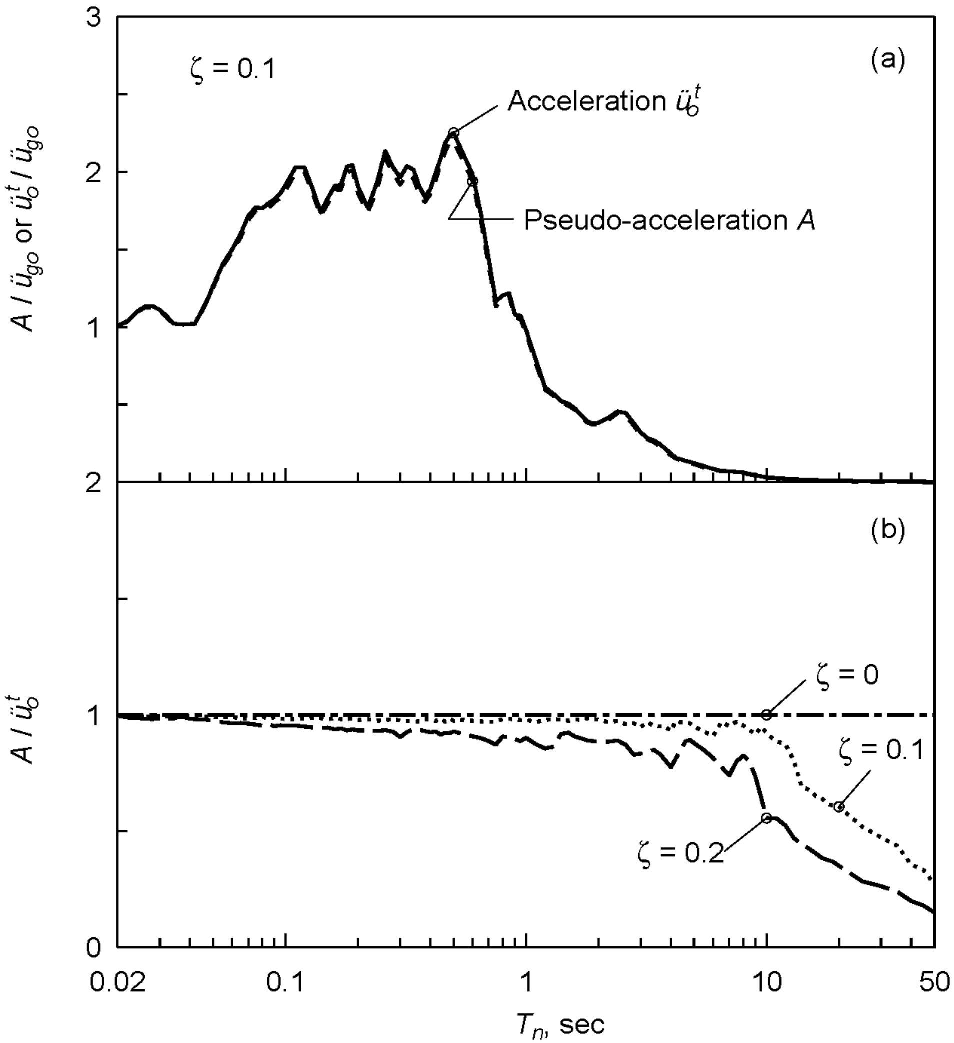
INSPIRATION FROM PROF. CHOPRA



Comparison between pseudo-acceleration (or spectral acceleration) and total acceleration in SDF systems

Figure 6.12.2 from Dynamics of Structures: Theory and Applications to Earthquake Engineering, 5th Edition, Anil K. Chopra, PEARSON

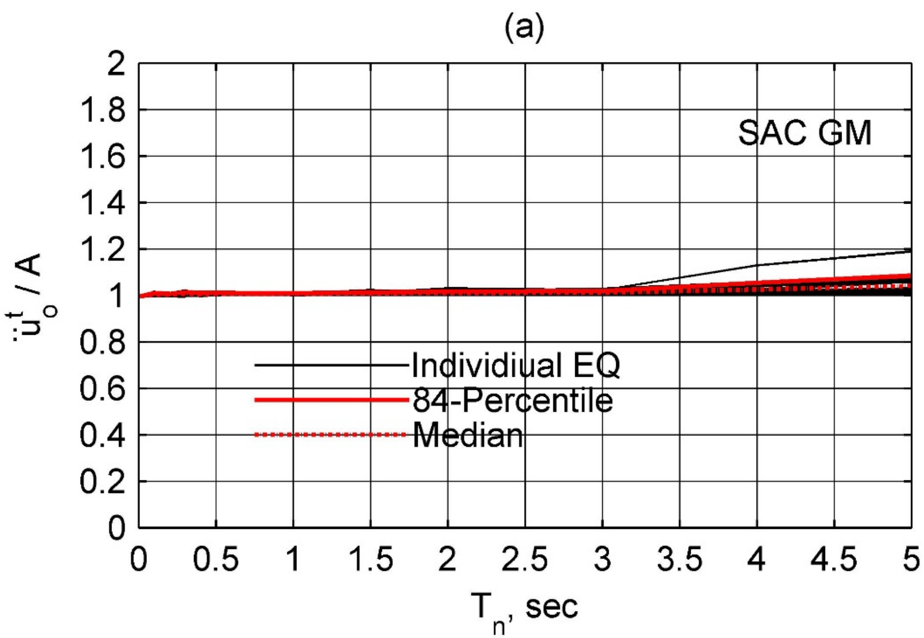
INSPIRATION FROM PROF. CHOPRA



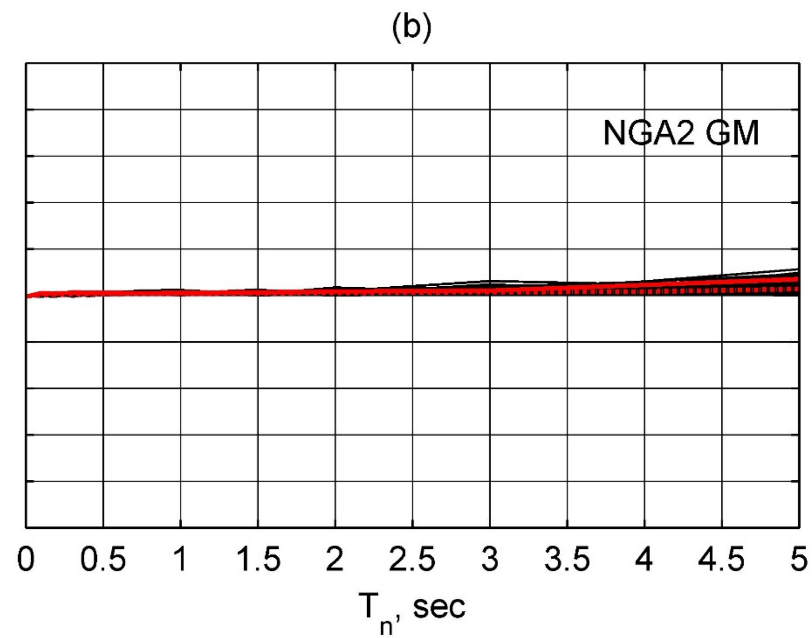
- Total acceleration and spectral acceleration are theoretically the same for zero damping
- **Total acceleration is approximately equal to spectral acceleration for low damping**

Figure 6.12.2 from Dynamics of Structures: Theory and Applications to Earthquake Engineering, 5th Edition, Anil K. Chopra, PEARSON

VERIFICATION

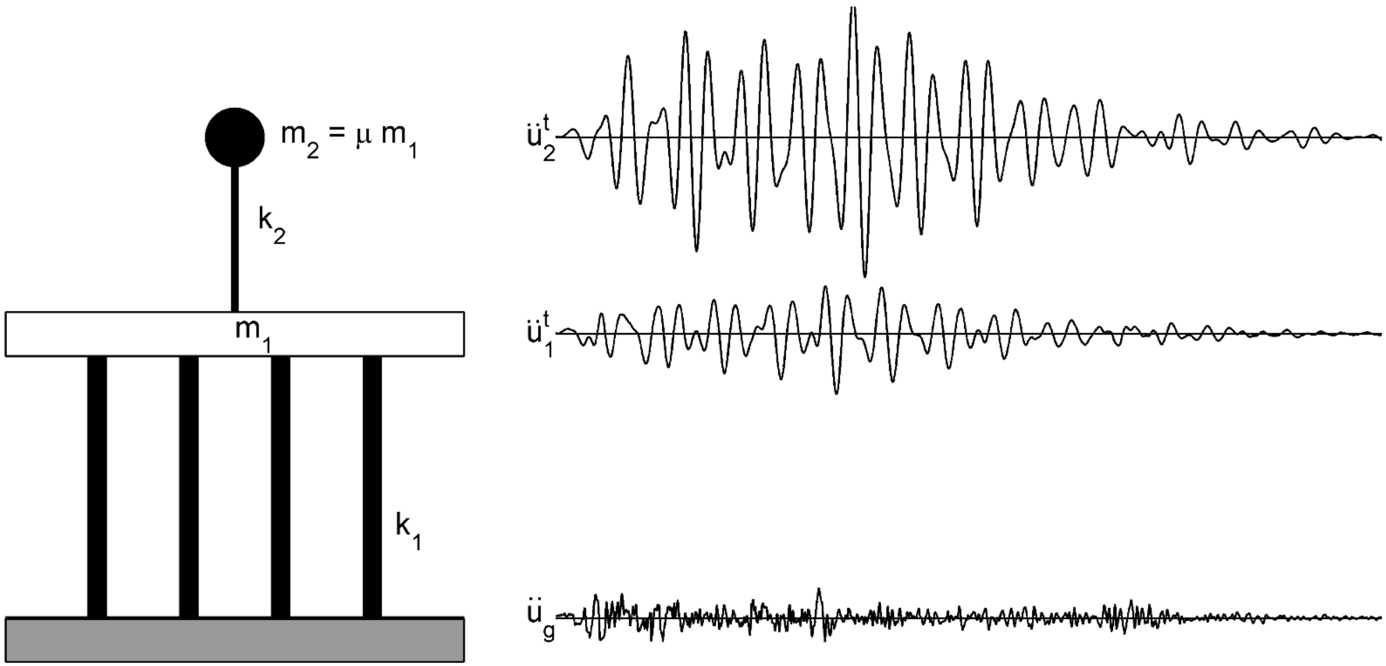


Suite of 20 SAC Ground Motions
5% Damping



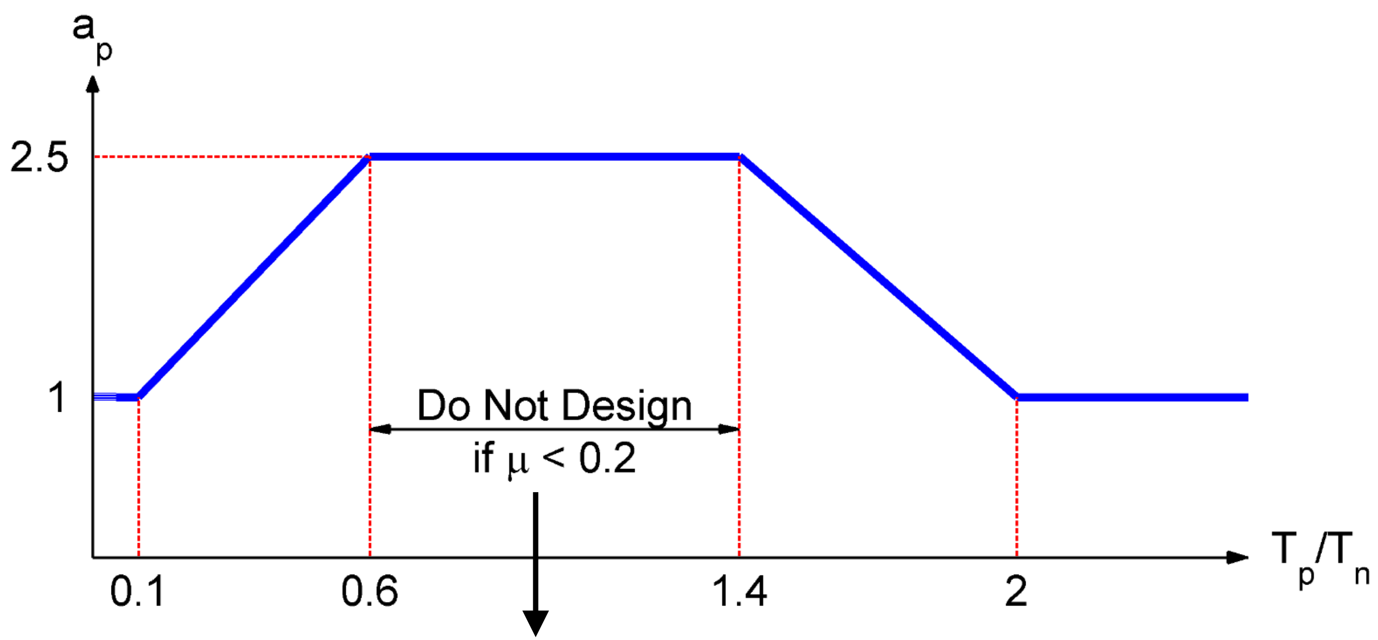
Suite of 80 NGA 2 West Ground Motions
5% Damping

AMPLIFICATION FACTOR a_p



A Simple 2 DOF Model to Study Amplification of Acceleration within Component

RECOMMENDATION FOR AMPLIFICATION FACTOR a_p



Not permitted because ancillary component will act like tuned-mass damper and will experience excessive motions

PROPOSED PROCEDURE FOR PIERS AND WHARVES

$$F_p = \frac{a_p A I_p A_x W_p}{R_p}$$

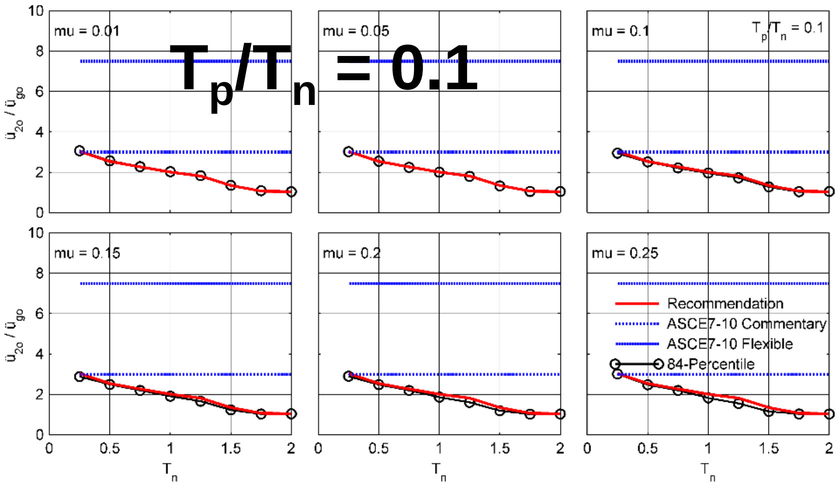
Revised amplification factor

Spectral acceleration at fundamental period of the pier/wharf in direction under consideration

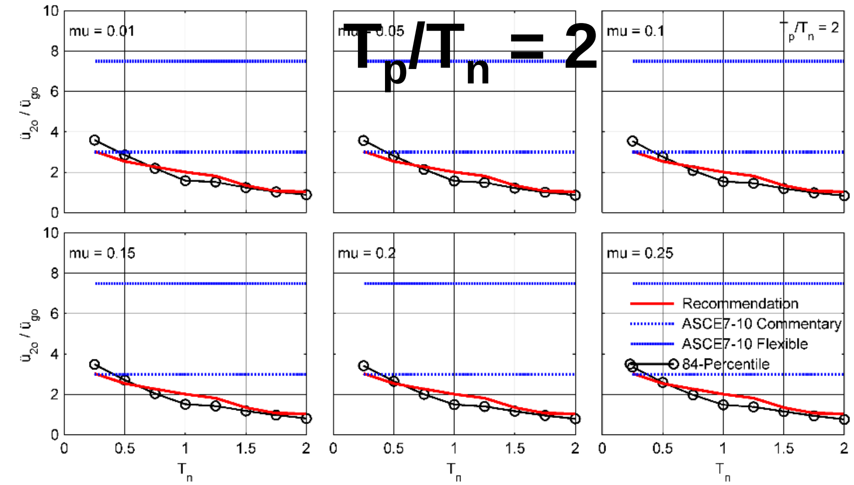
$$0.3 S_{DS} I_p W_p < F_p < 1.6 S_{DS} I_p W_p$$

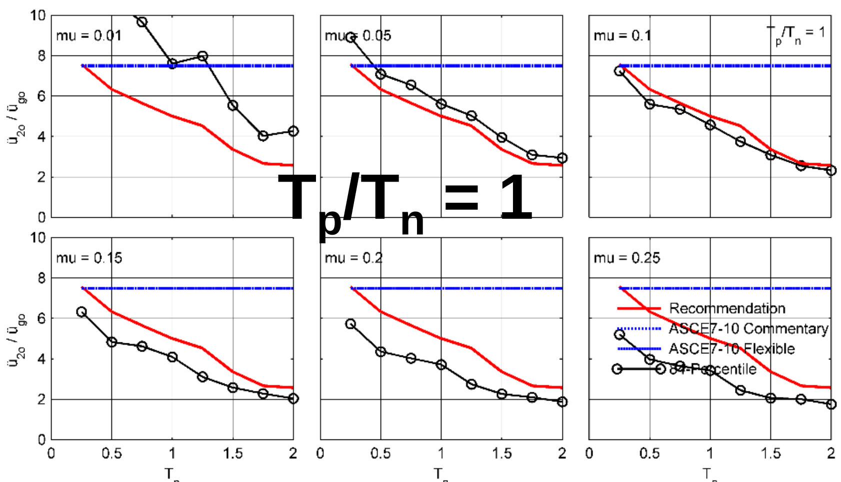
VERIFICATION

Excellent Estimate



Excellent Estimate





Better than ASCE 7-10 but not very good estimate for light secondary systems with period close to primary system

SUMMARY

- Inspired by work by Prof. Chopra, a simple procedure has been developed to more-accurately estimate forces in ancillary components supported on piers and wharves
  - Total acceleration approximated by spectral acceleration
  - Utilizes simplicity of piers and wharves as SDF systems