Upgrades of Seismic Design Standards for Nonstructural Components and Nonbuilding Structures in MOTEMS

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Objectives

- Provide background for MOTEMS provisions
- Highlight underlying assumptions
- Provide observations based on results from analytical study

ASCE 7 Provisions

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

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

$$\text{or } 0.3 < \frac{0.4 a_p \left(1 + 2z/h\right)}{R_p} < 1.6$$

Lower and upper limits based on judgement

ASCE 7 Provisions

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

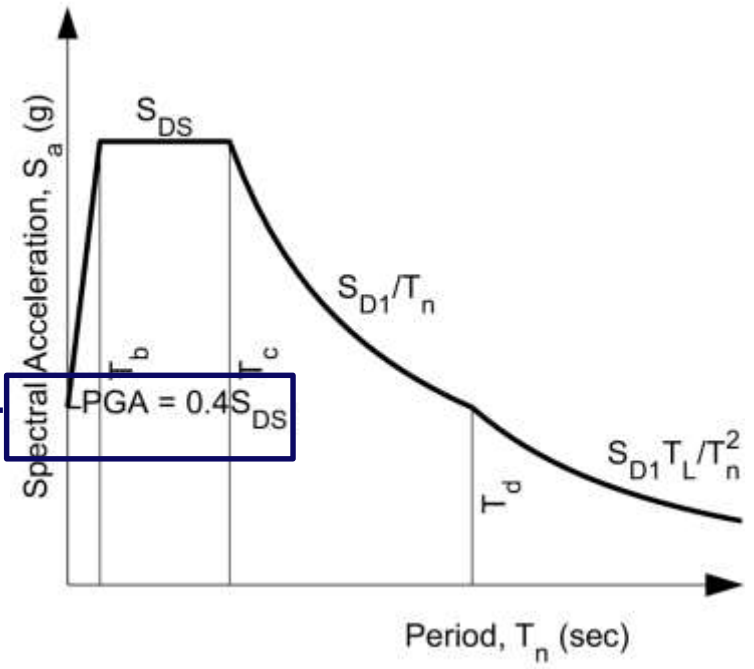
z = height in structure of point of attachment of component with respect to base

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

ASCE 7 Formula Background

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

Design Peak Ground Acceleration

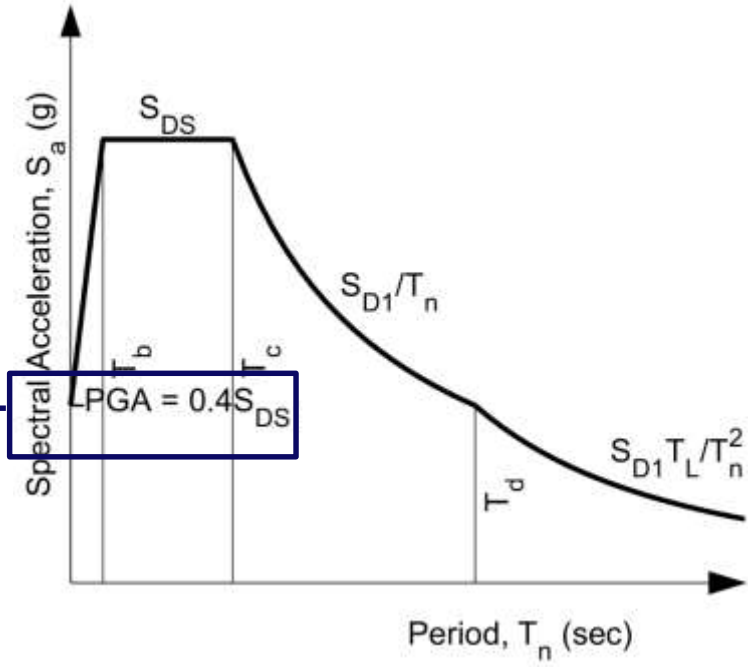


ASCE 7 Formula Background

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

Amplification of PGA to Bottom of Nonstructural Component

Peak Ground Acceleration



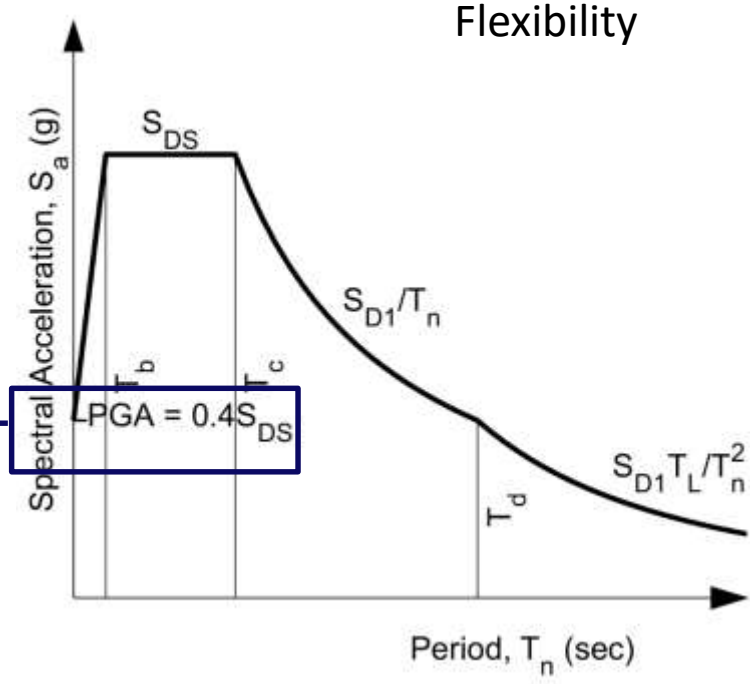
ASCE 7 Formula Background

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

Amplification of PGA to Bottom of Nonstructural Component

Amplification of Acceleration due to Component Flexibility

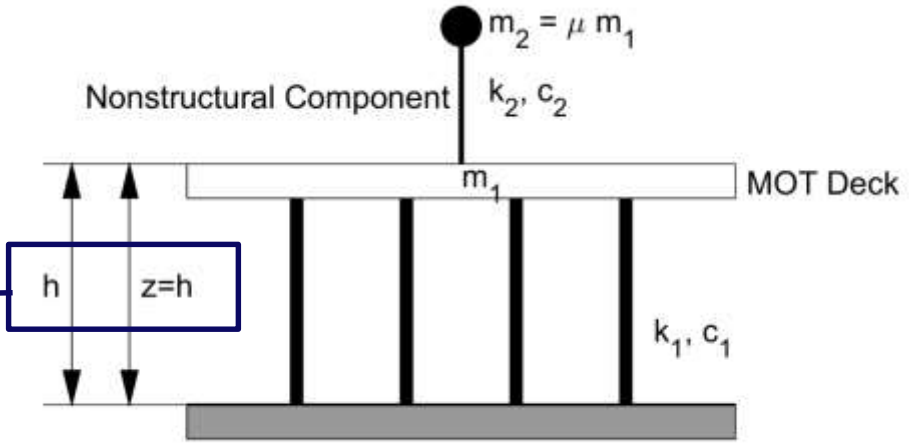
Peak Ground Acceleration



MOT Application

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

(1+2z/h) = 3



MOTEMS Formula

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

$$= \frac{(0.4S_{XS})(3)a_p I_p W_p}{R_p}$$

$$= \frac{1.2S_{XS}a_p I_p W_p}{R_p}$$

MOTEMS Formula

$$F_p = \frac{1.2 S_{XS} a_p I_p W_p}{R_p}$$

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

$$\text{or } 0.3 < \frac{1.2 a_P}{R_P} < 1.6$$

MOTEMS Formula

- a_p = 1.0 for rigid components (period < 0.06 sec) or rigidly attached components
- a_p = 2.5 for flexible components (period > 0.06 sec) or flexibly attached components
- I_p = 1.5 for critical components
- I_p = 1.0 for other components
- R_p = Value listed in Table 31F-4-5
  - R_p generally based on some testing, some observations on performance during past earthquakes, and a lot on judgement

ASCE 7 Alternate Equation

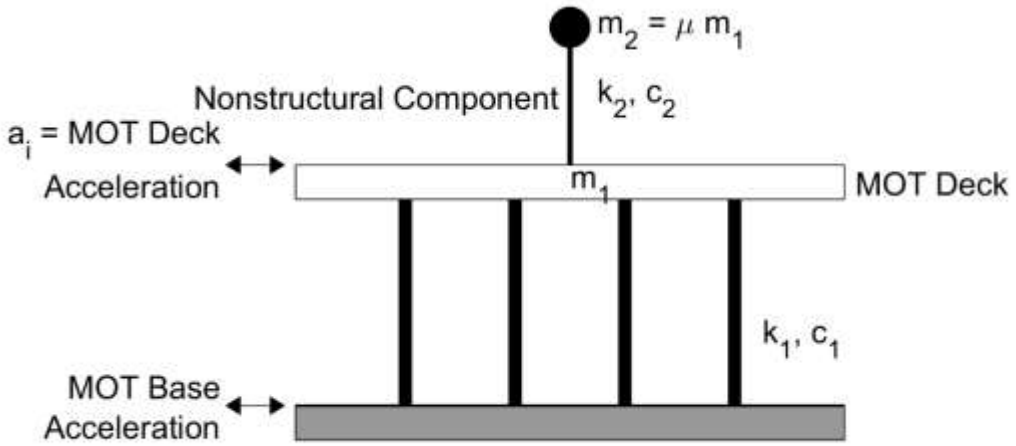
- If acceleration, a_i, at the point of attachment of the component is known

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

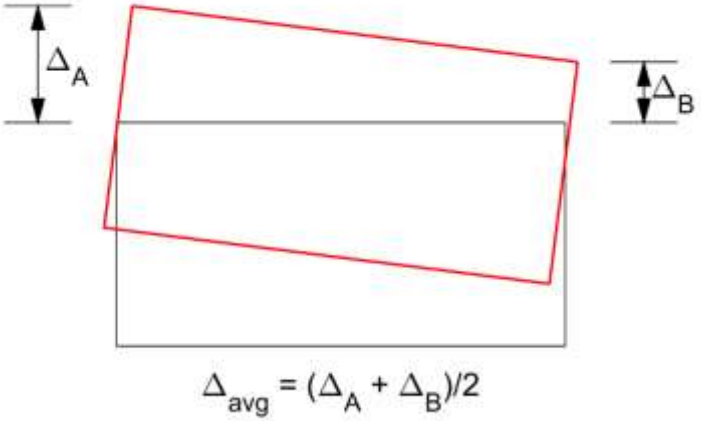
$$0.3 S_{DS} I_p W_p < F_p < 1.6 S_{DS} I_p W_p$$

MOT Application

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



Acceleration at Point of Attachment of Nonstructural Component



$$\Delta_m = \max\{\Delta_A \text{ or } \Delta_B\}$$

$$A_x = \left(\frac{\Delta_m}{1.2\Delta_{avg}}\right)^2$$

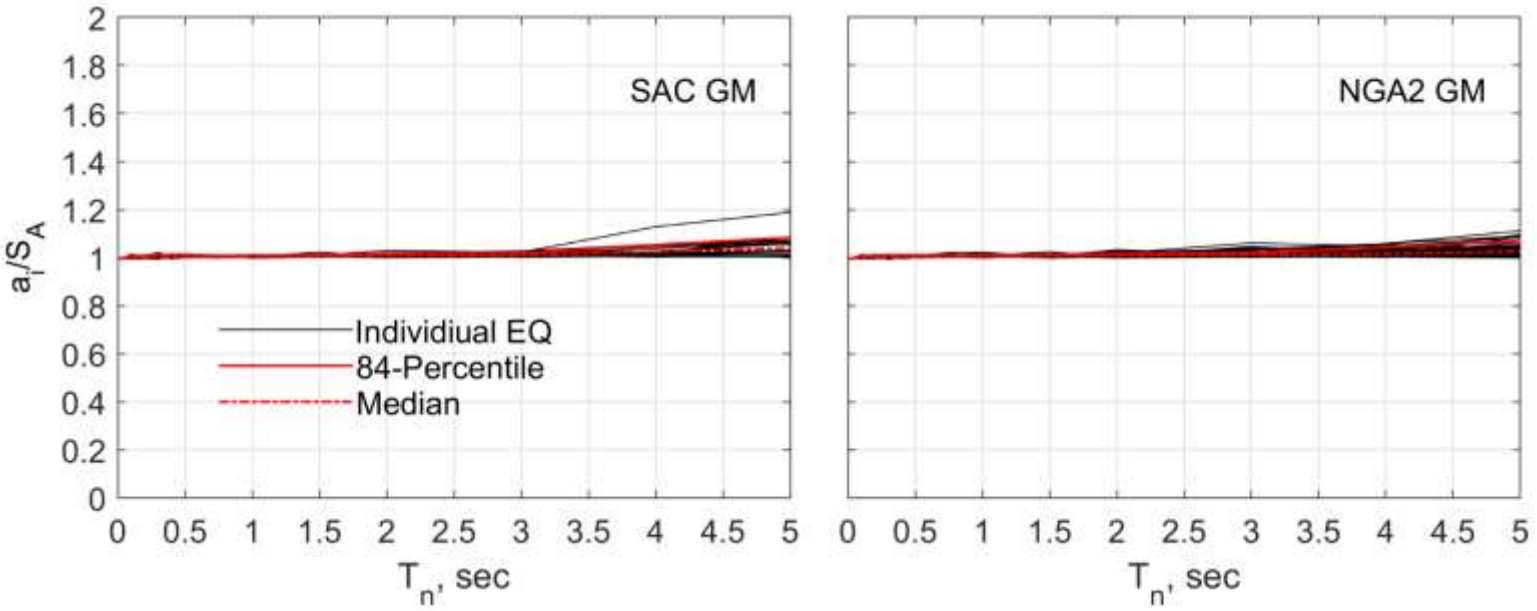
Torsional Amplification

Estimation of a_i

- Marine Oil Terminals are, in most cases, similar to single-degree-of-freedom (SDF) systems
- Damping is typically low (5%)
- For such cases, a_i = spectral acceleration for design earthquake

Relationship between a_i and S_A

- For low damping values (e.g., 5%), a_i for a SDF system is essentially equal to spectral acceleration, S_A



MOTEMS Alternate Equation

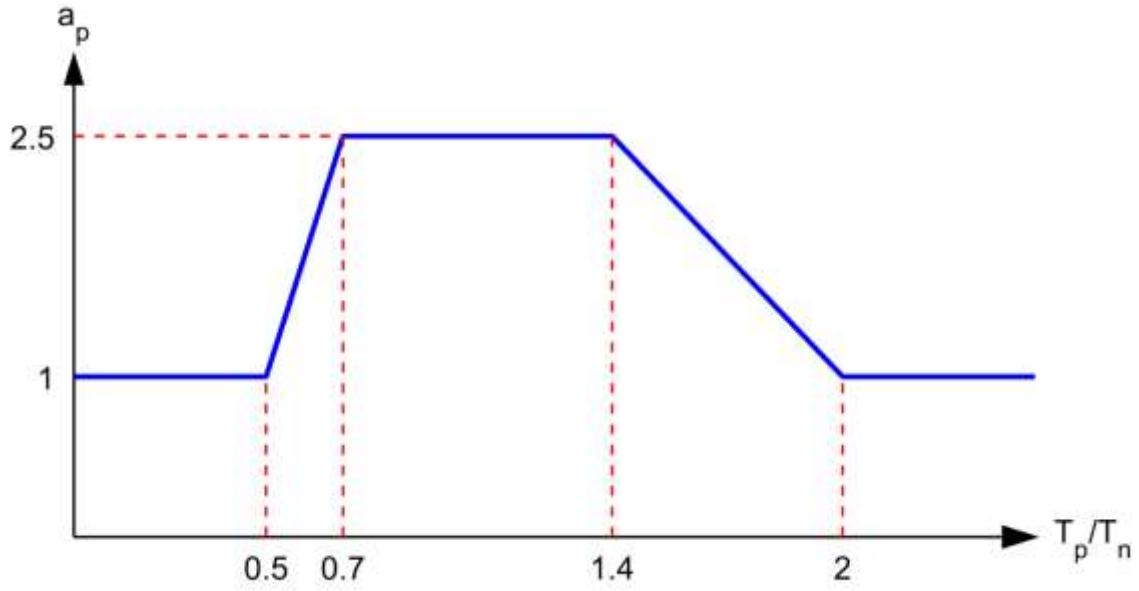
$$F_p = \frac{a_p S_A I_p A_x W_p}{R_p}$$

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

S_A = Spectral acceleration at period equal to elastic fundamental period of the MOT structure

Alternate Procedure to Estimate a_p

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



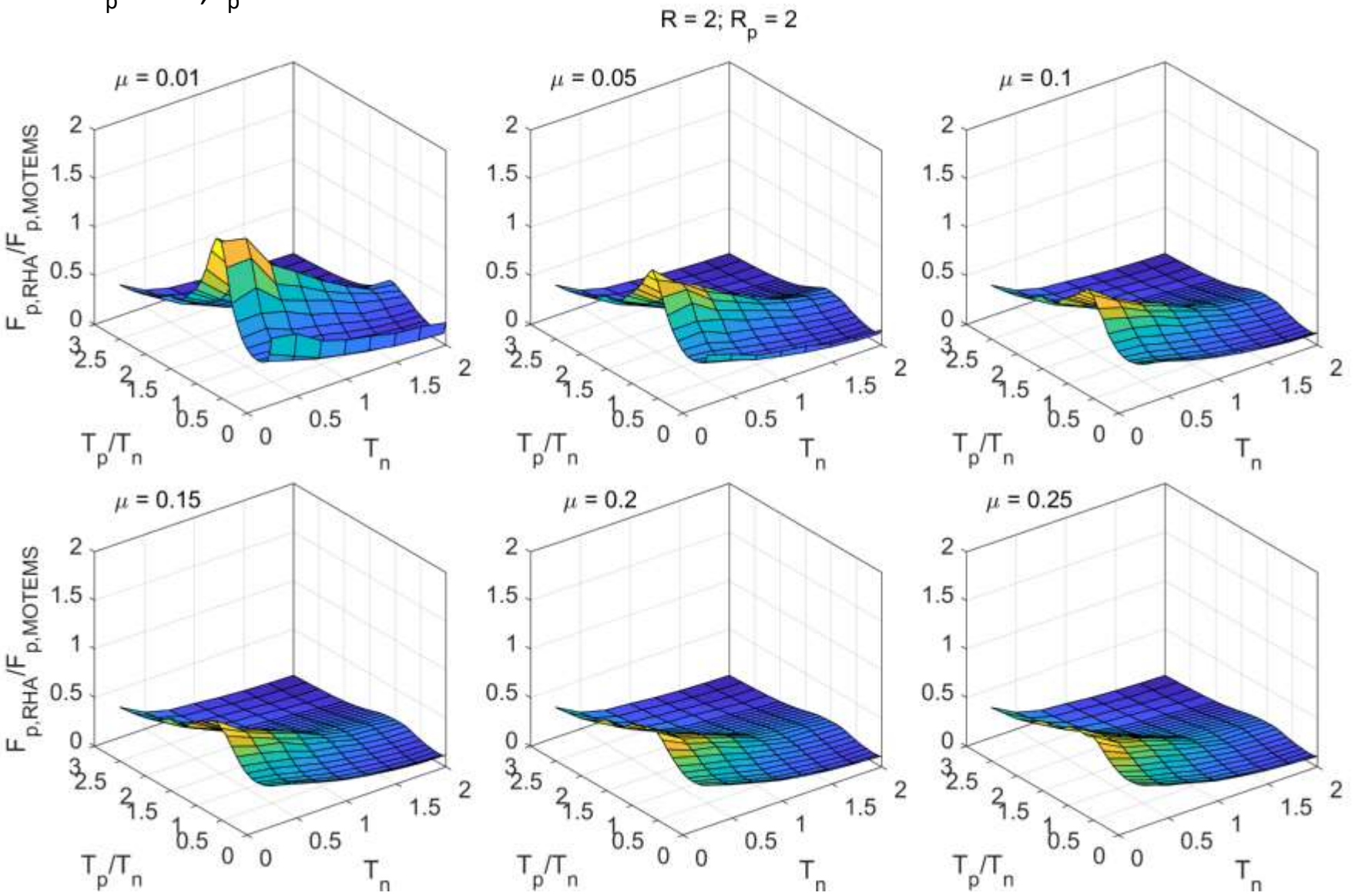
Underlying Assumptions

- Calculation of forces only for Level 2 design earthquake
- Formula for F_p is developed primarily based on linear-elastic studies
- Formula for F_p does not take into consideration possible nonlinearity of the MOT at design-level earthquake
  - Accelerations transmitted from base to top of the MOT deck are expected to reduce due to system nonlinearity

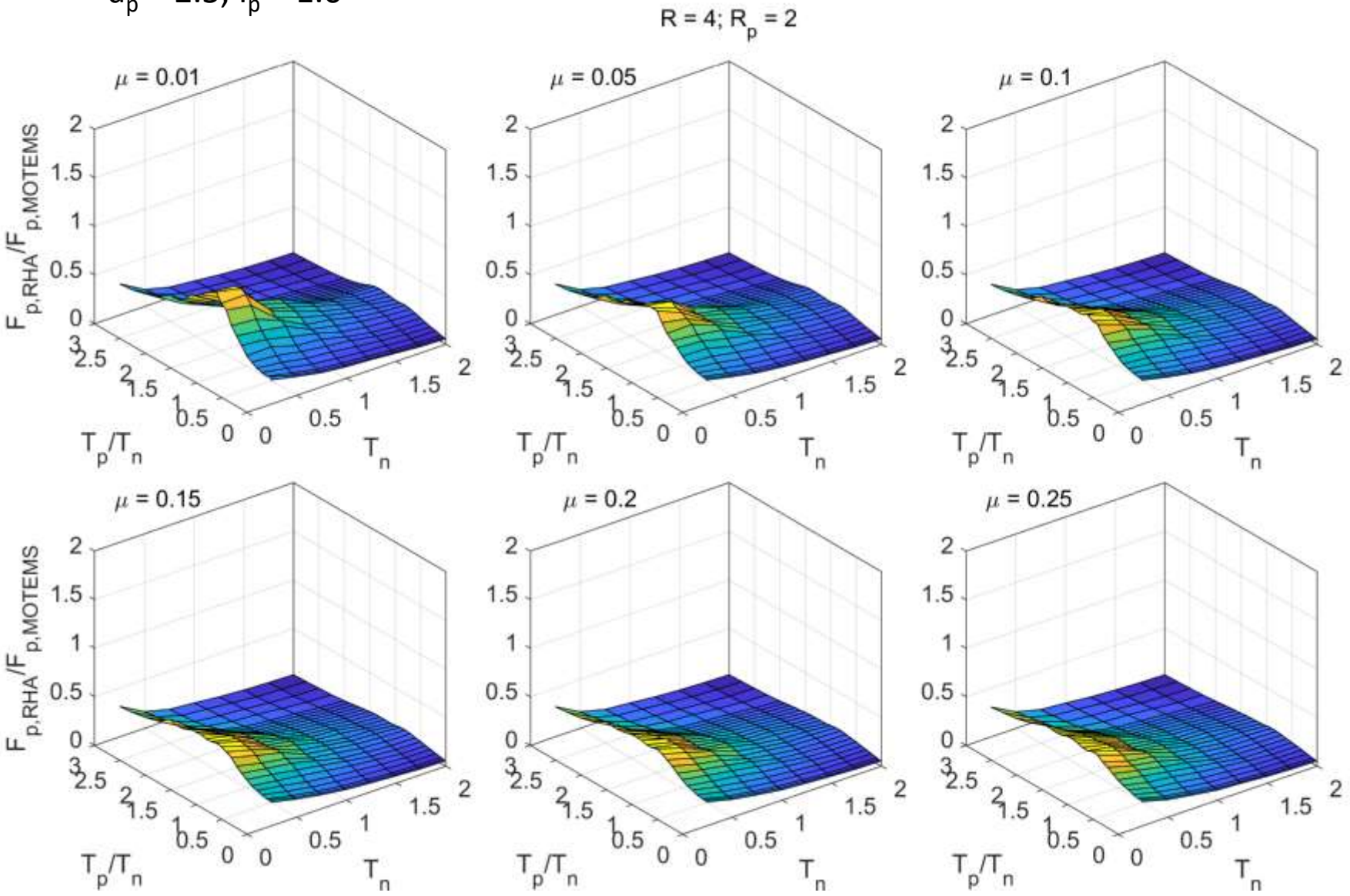
Limits of MOTEMS Procedure

- MOTEMS procedure is not applicable for nonstructural component or nonbuilding system
  - Supported by other nonstructural system permanently attached to MOT,
  - Supported by other structure permanently attached to MOT,
  - Attached to multiple MOTs,
  - Attached to structure and ground.
- Use rational approach subject to division approval.

$a_p = 2.5$, $I_p = 1.0$



$a_p = 2.5$, $I_p = 1.0$



Summary

- MOTEMS presents a simple formula for estimating seismic forces in nonstructural components and nonbuilding structures supported on MOT structure
  - Based on ASCE 7 provisions
  - Does not consider nonlinearity in the primary system
- Analytical study suggests that MOTEMS will provide conservative estimate of forces when primary system is deformed beyond linear elastic limit