Numerical Modeling of Concrete Building Pounding During Seismic Events - A Case Study

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INTRODUCTION

Potential Consequence of Seismic Impact

- **Structural Damage**
  - Local structural failure
  - Consequence of local failure
  - Global structural failure

Typically addressed by sizing the gaps to eliminate impact at SSE level earthquake altogether.

Jankowski, Engineering Structures, 2009

- **Non-Structural Damage**
  - High-frequency spectral acceleration due to impact/pounding
  - Chatter-sensitive components
  - Cosmetic or non-load bearing failures.

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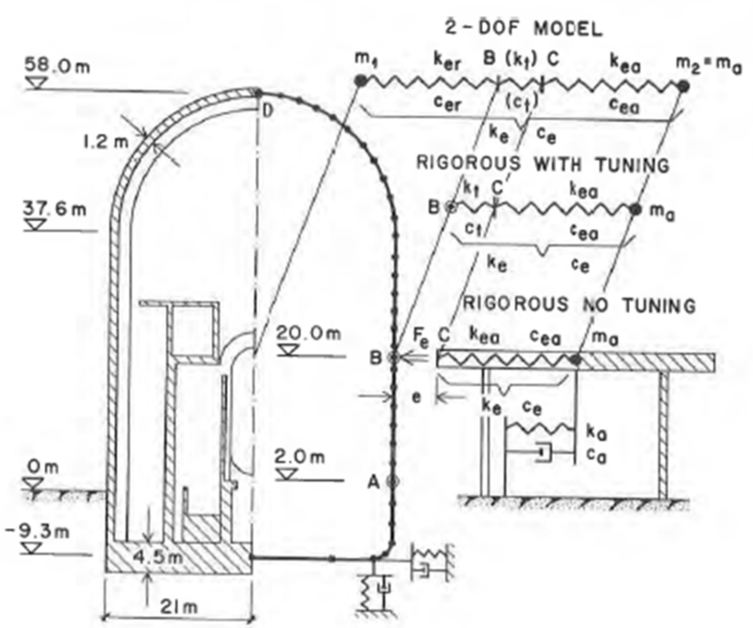
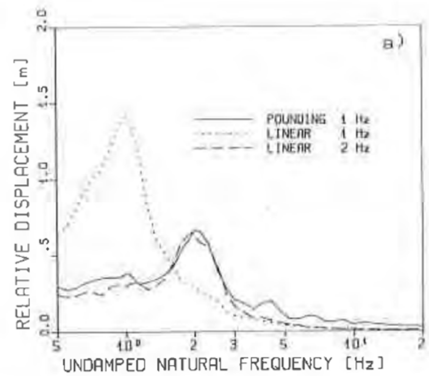
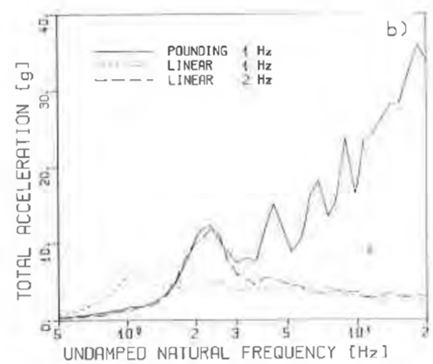
Background

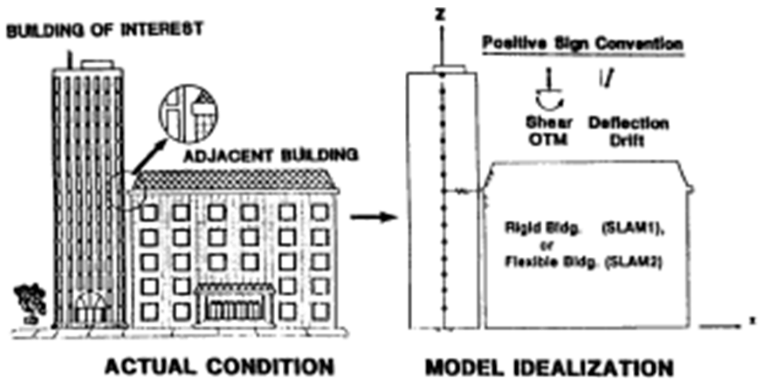


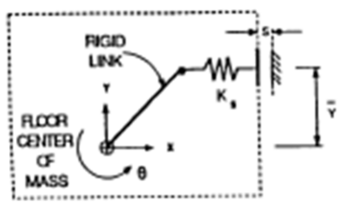




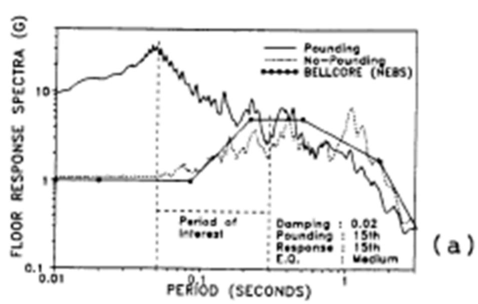
Wolf and Skrikerud (Nuclear Engineering and Design 1980)

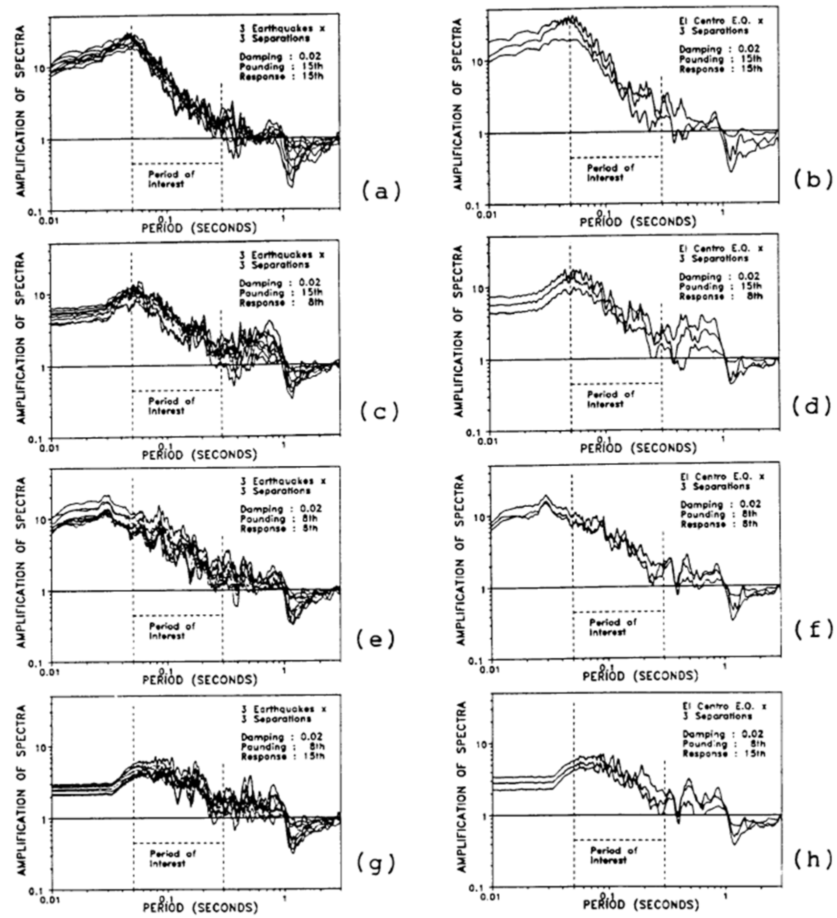
Background





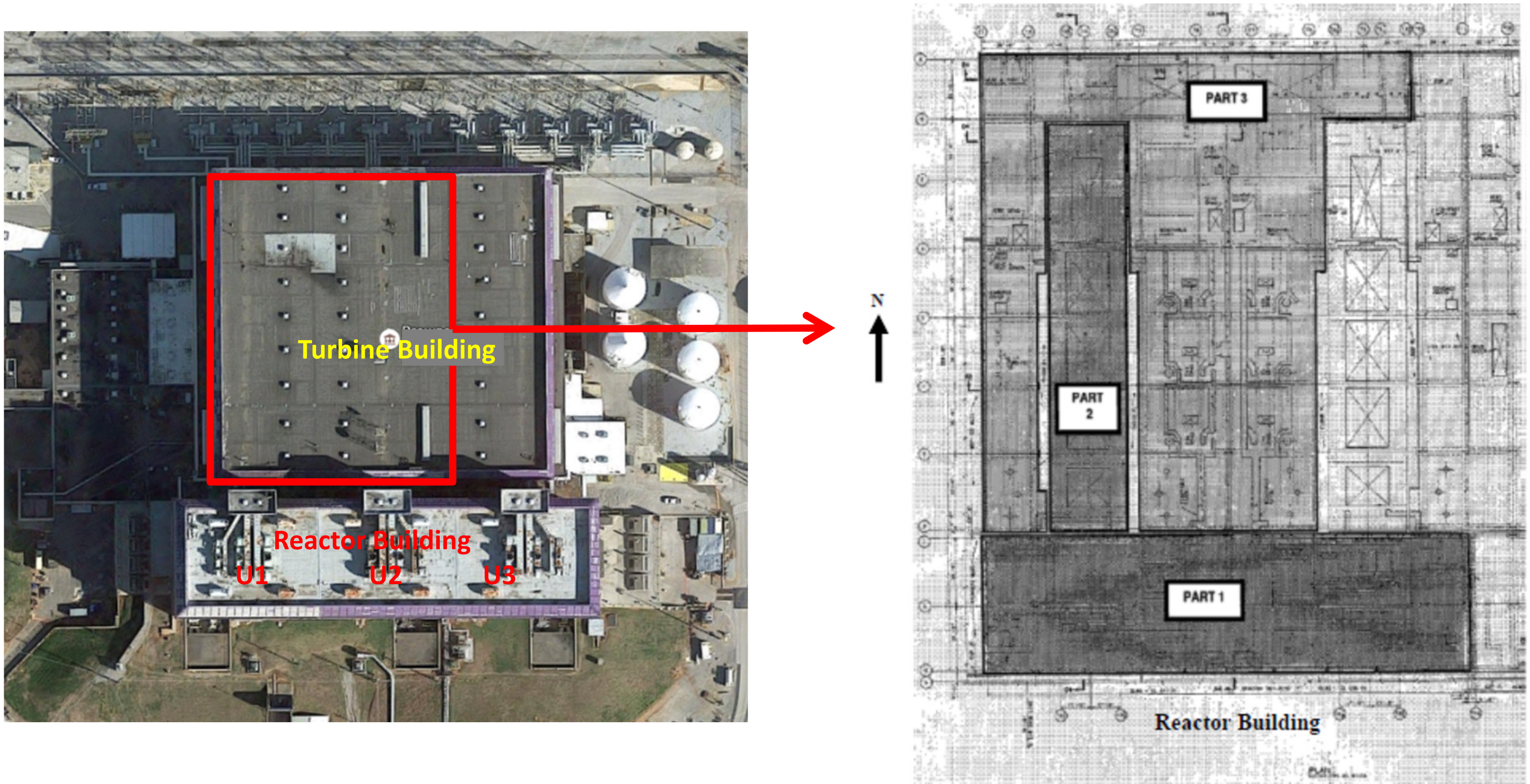
Plan View
Pounding Floor Level





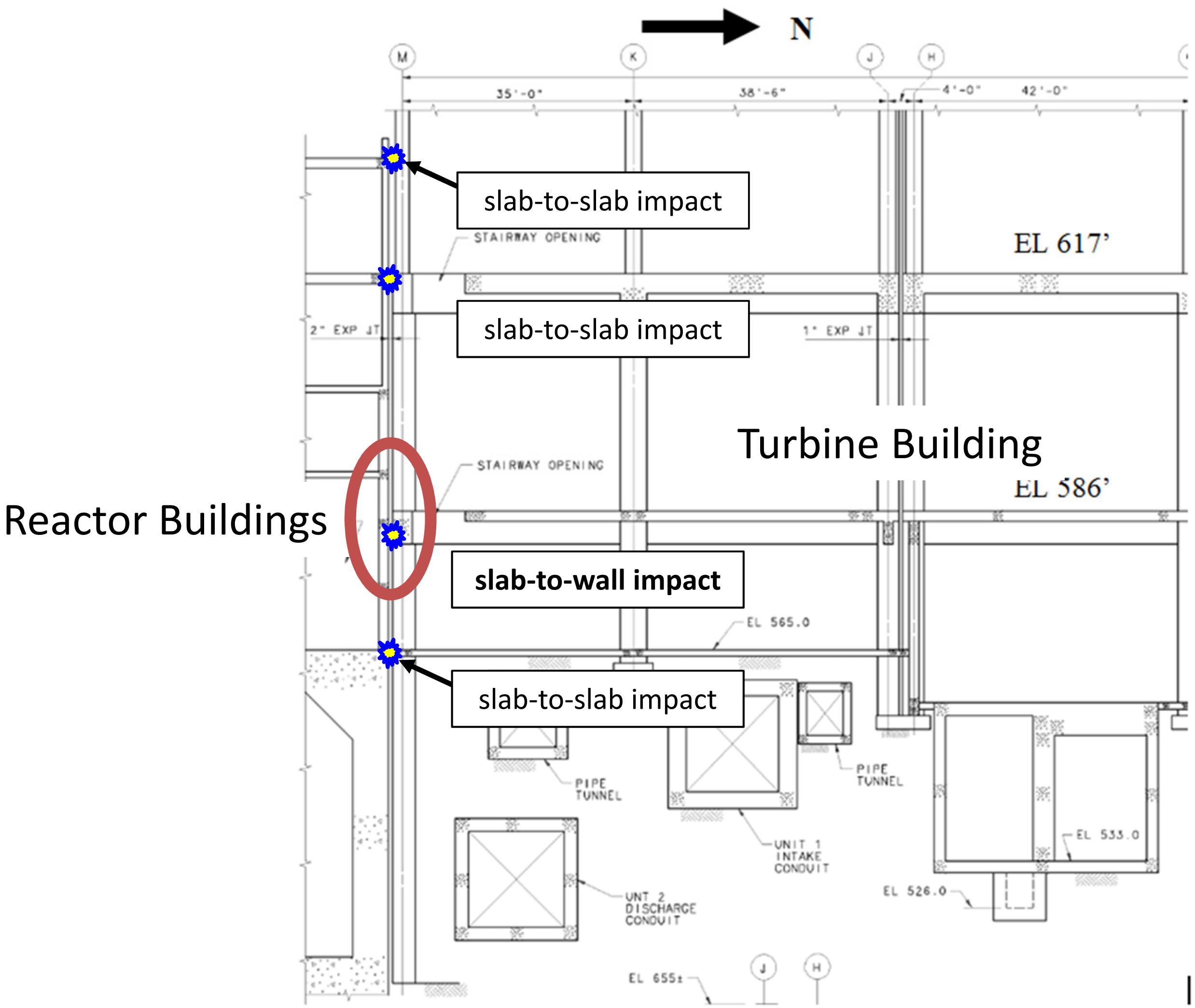
Kasai, Jeng, & Maison (Earthquake Engineering 1992)

Motivation



Turbine Building
Reactor Building
U1
U2
U3
N
PART 3
PART 2
PART 1
Reactor Building

Motivation



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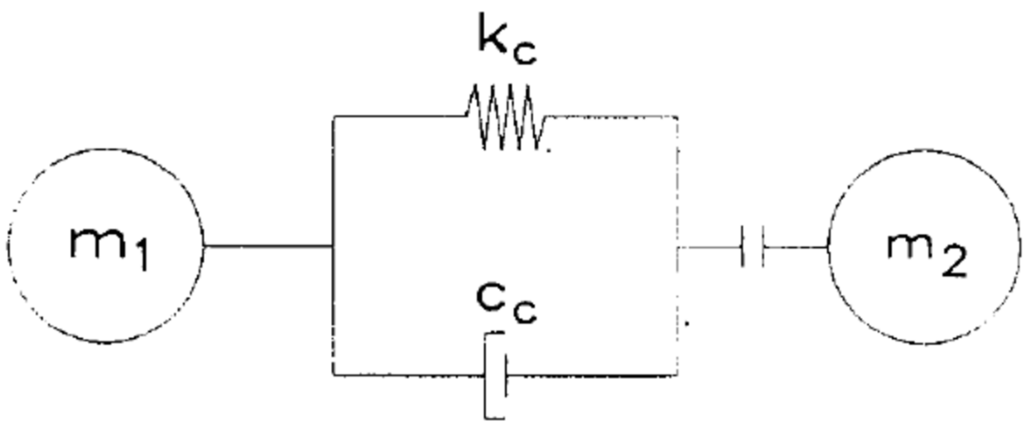
METHODOLOGY

Modeling of Impact



Modified (Hybrid) Contact Laws:

$F(t) = K_e \delta^{\frac{3}{2}}(t) + C(t)\dot{\delta}(t)$	$\dot{\delta}(t) > 0$	(approach period)
$F(t) = K_e \delta^{\frac{3}{2}}(t)$	$\dot{\delta}(t) \leq 0$	(restitution period)
$F(t) = 0$	$\delta(t) \leq 0$	(separation period)

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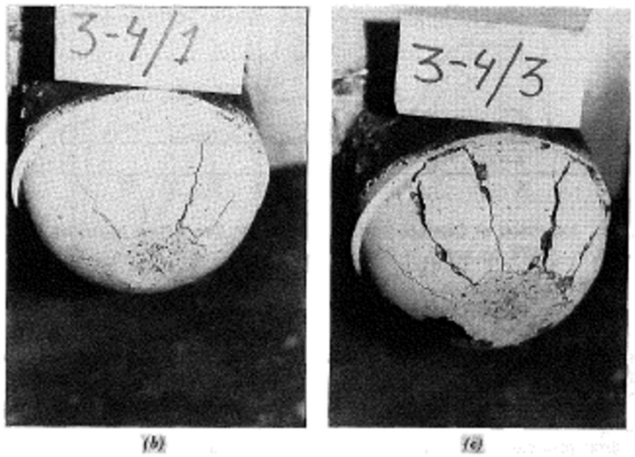
Impact Stiffness

$$F(t) = K_e \delta^{\frac{3}{2}}(t) + C(t)\dot{\delta}(t)$$

$$K_e = f(m_1, m_2, \rho, E, \nu)$$

Contact stiffness approximated as the stiffness of impact neighboring FE elements



$K_e \cong 10^6 kip/ft^{1.5}$

Goldsmith, W., (1960) Impact: the theory and physical behavior of colliding solids,

$K_e \cong 10^7 kip/ft^{1.5}$

Kawashima, K., and Penzien, J., EERC Report 76-26, 1976

$K_e \cong 10^5 kip/ft^{1.5}$

van Mier, J. G. M., et al., ASCE Journal of Structural Engineering, 1991

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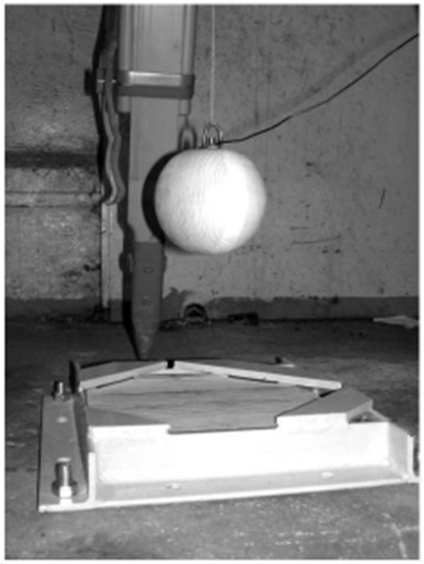
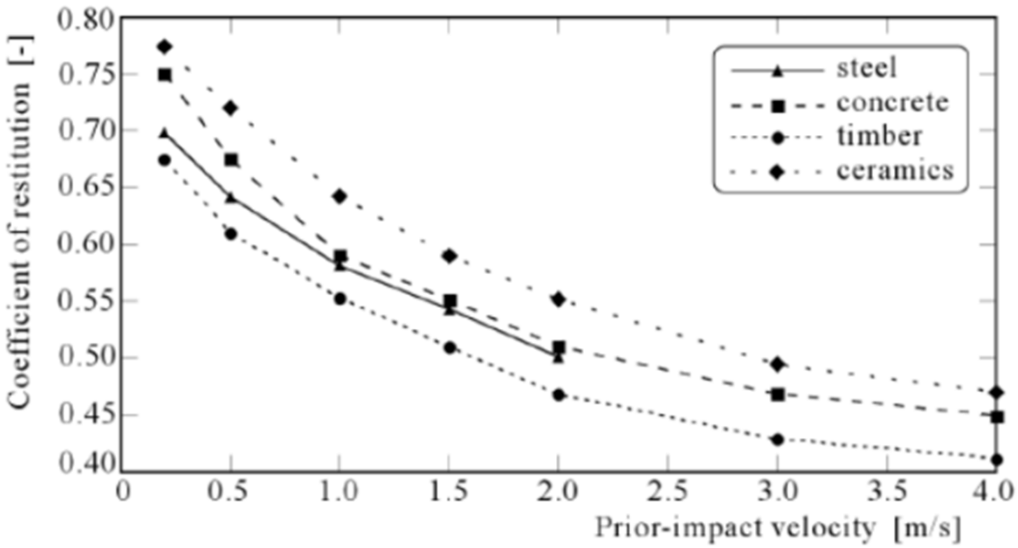
Impact Damping

$$F(t) = K_e \delta^{\frac{3}{2}}(t) + C(t)\dot{\delta}(t)$$

$$C(t) = f(m_1, m_2, K_e, \delta(t), C_r)$$

Jankowski, R., Key Engineering Materials., 2005





Jankowski, R., Theoretical and Applied Mechanics, 2007

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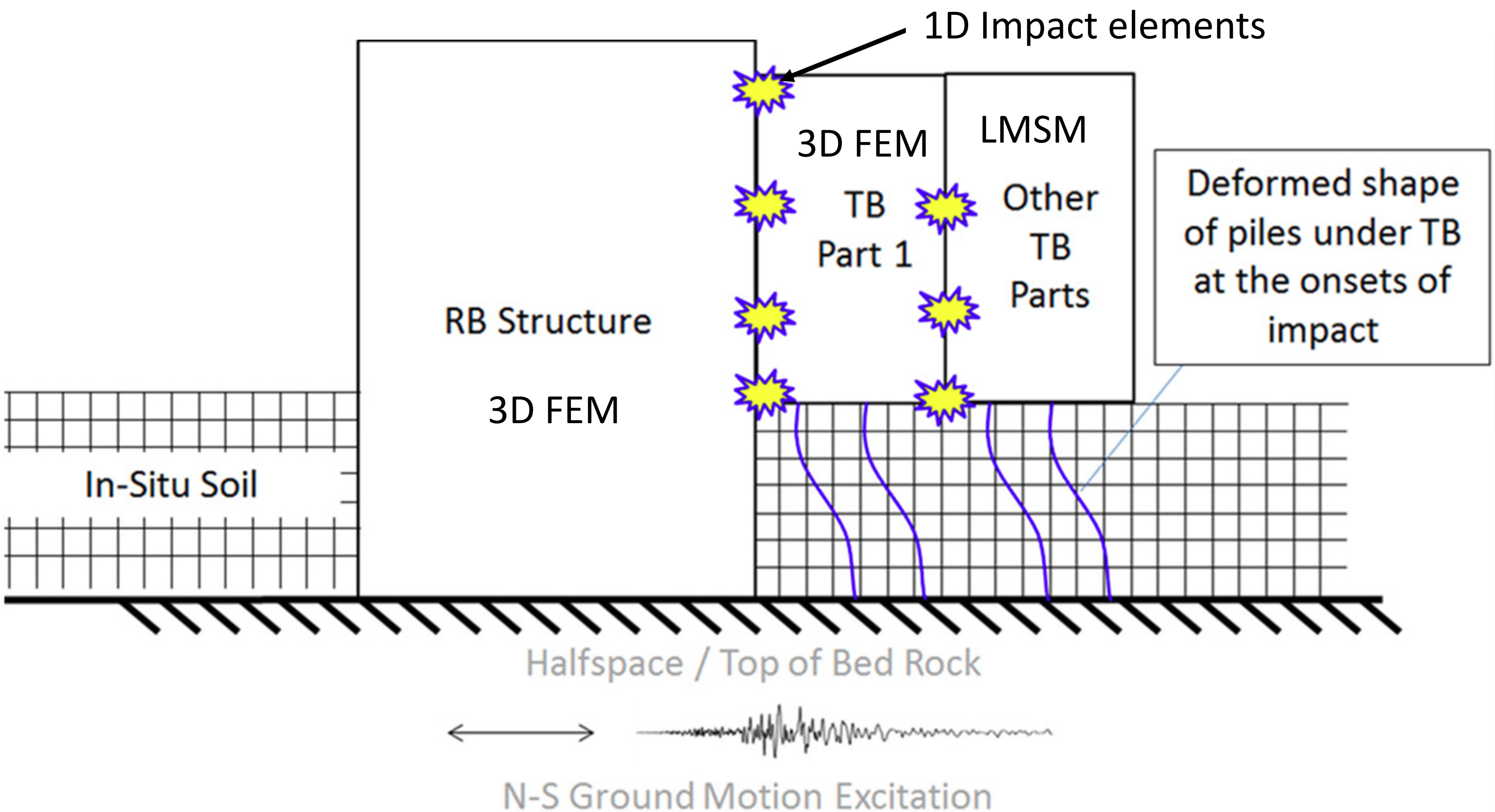
MODELING DETAILS

Detailed Modeling Strategy



Five spectrally matched ground motions

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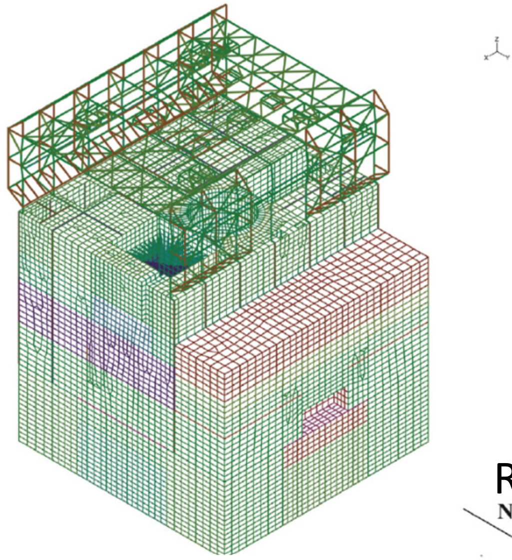
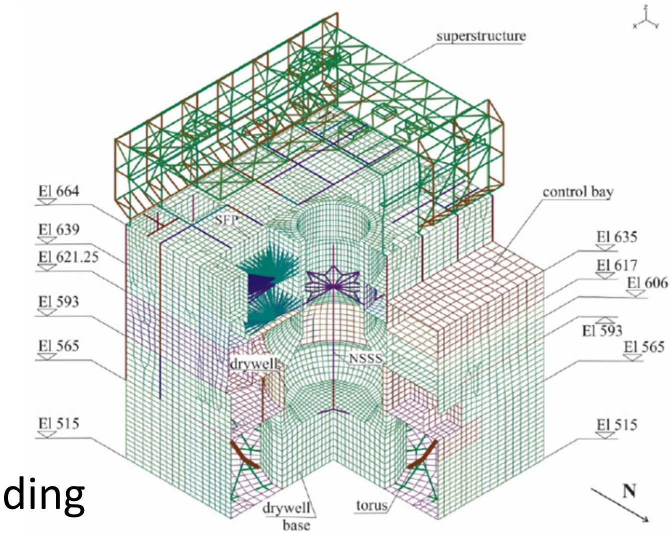
3D Finite Element Models





Reactor Building

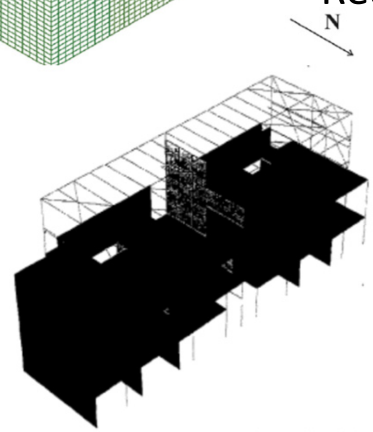
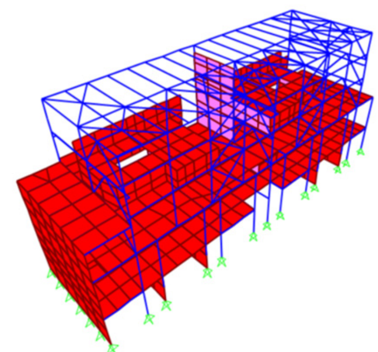


Figure 5: Portion between Lines J and M - Full Model



Turbine Building Part 1

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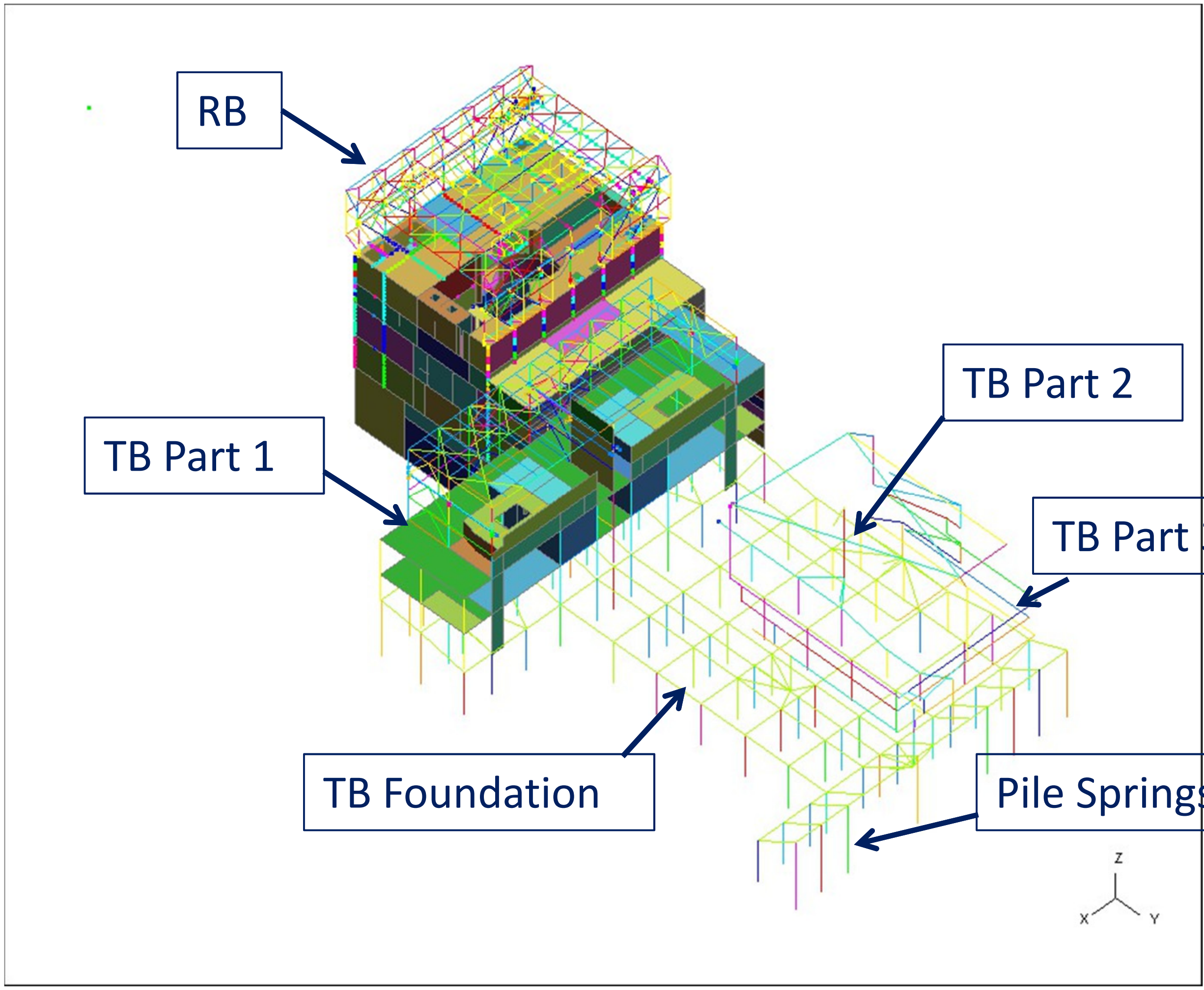
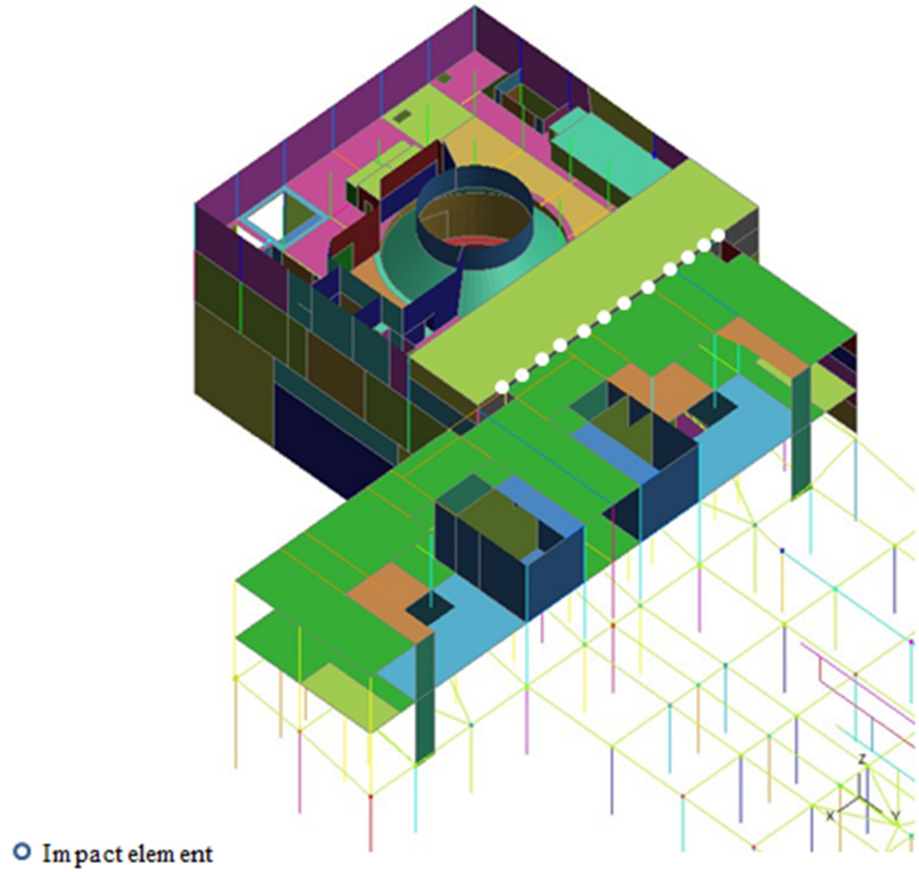
Combined Finite Element Model



Combined Finite Element Model



Location of impact elements at RB-TB Part 1 at a typical elevation

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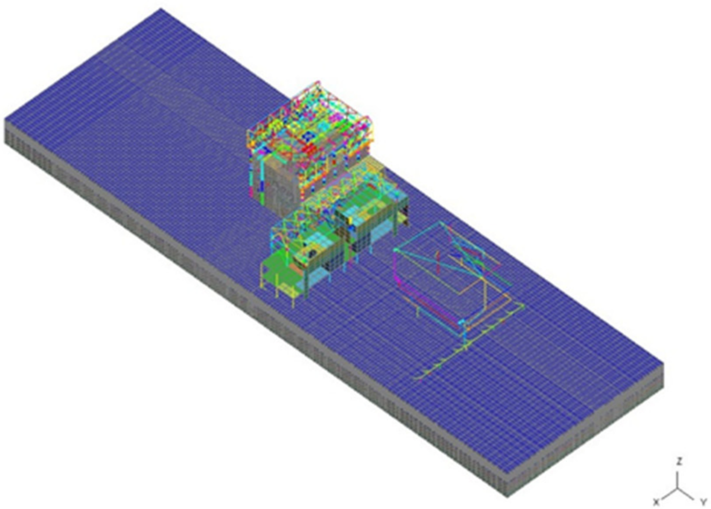
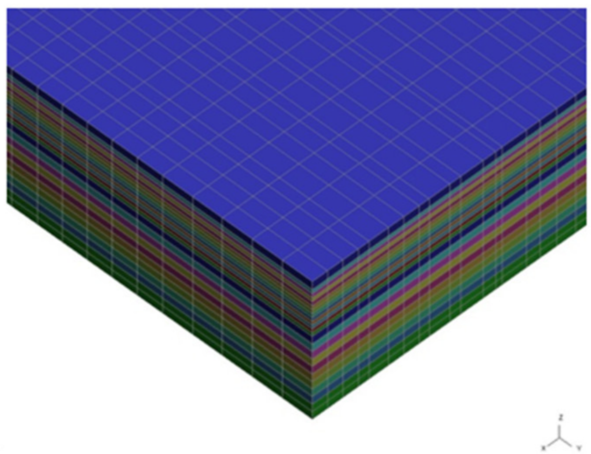
FE Model Including Soil





- The soil medium explicitly modeled with solid finite elements.
- A hysteretic viscoelastic material model used for modeling both soil and structure to achieve nearly frequency independent viscoelastic behavior.
- Analyses were performed using the explicit time domain in LS-DYNA

INVESTIGATION OF IMPACT BEHAVIOR

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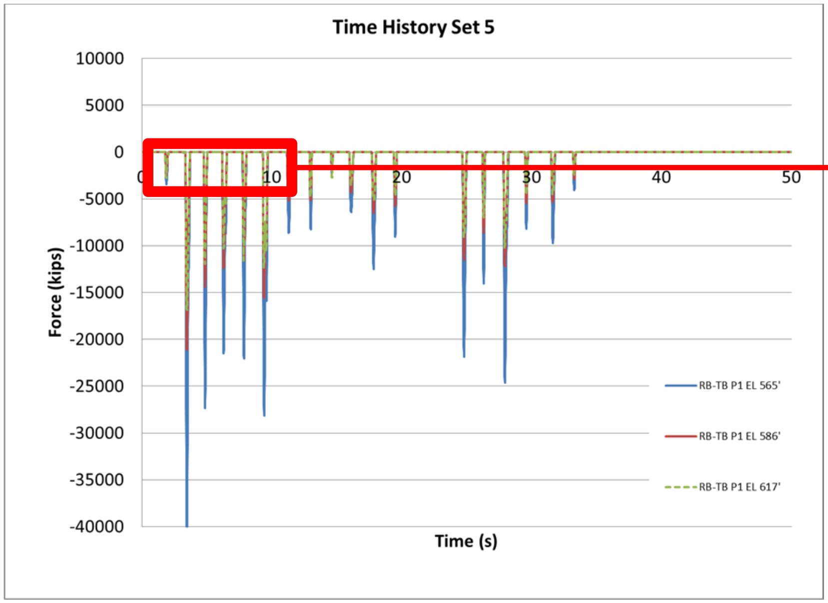
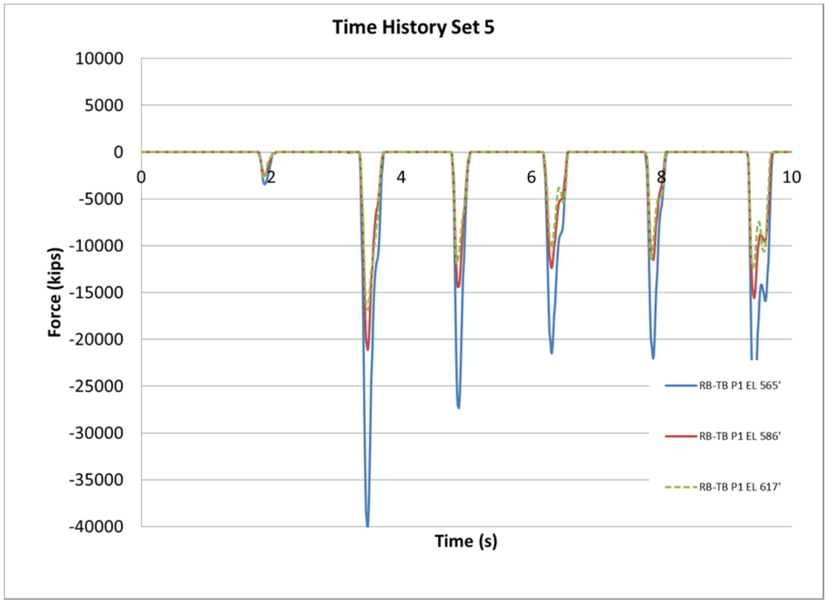
Impact Forces





$$duration_{avg} = 0.25s \cong T_{RB}$$

$$\Delta T_{avg} = 1.8s \cong T_{TB}$$

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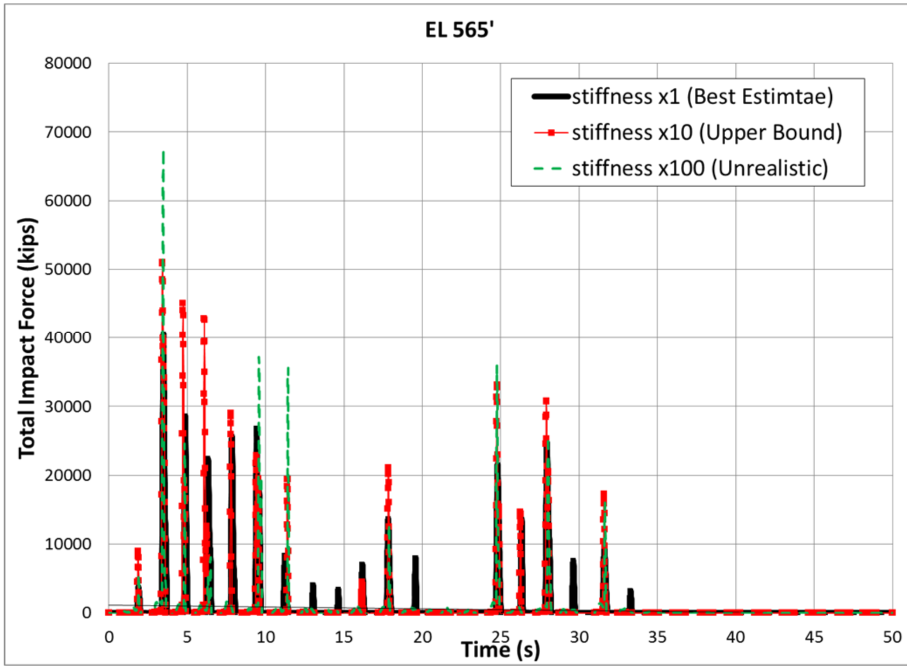
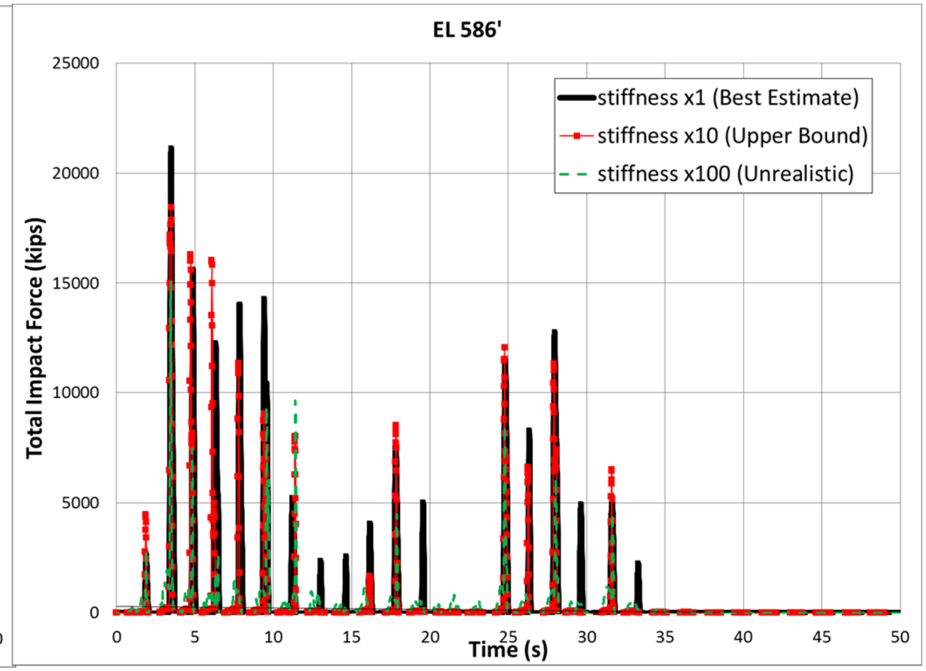
Variation of Impact Forces with Impact Stiffness





- No specific trend due to impact element stiffness. The impact force results vary by ±20% depending on the choice of impact stiffness.

- The impact forces are highly dependent on the local building stiffness

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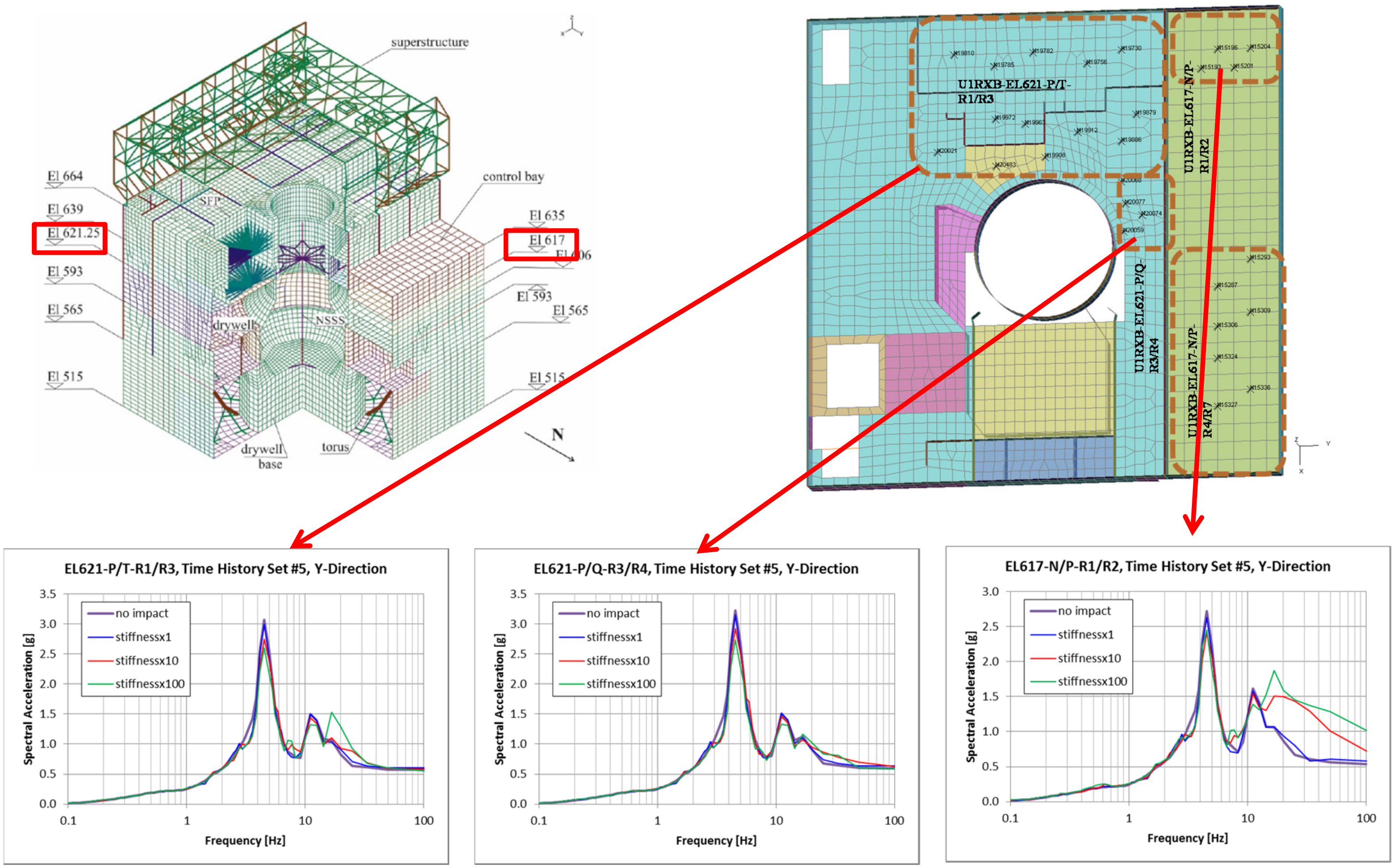
Variation of ISRS with Impact Stiffness

Selected Areas for ISRS Generation at RB EL 617’ and 621’ Slabs



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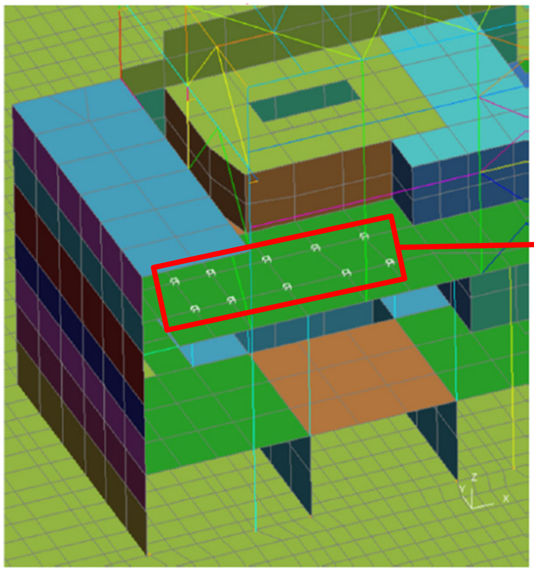
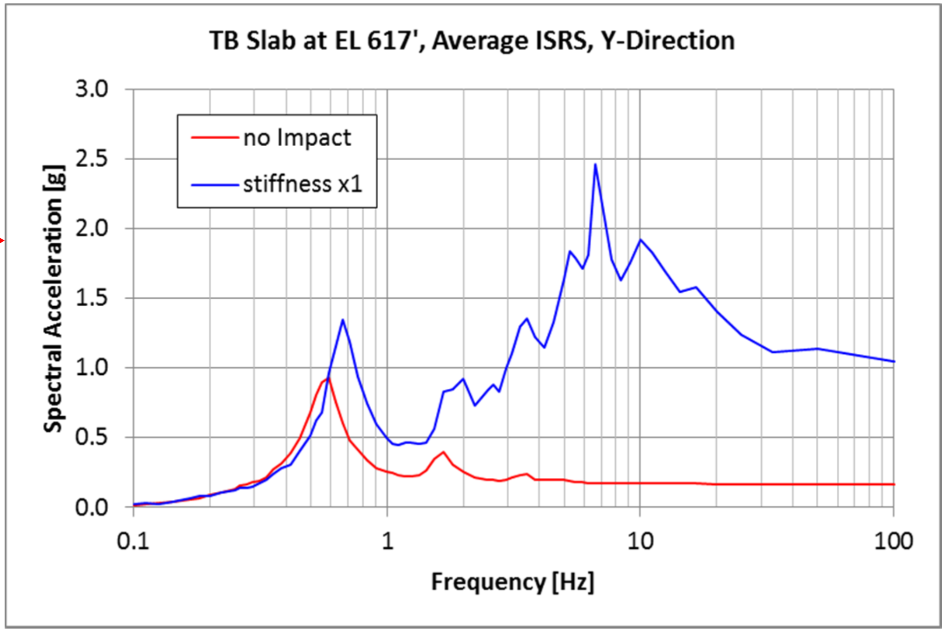
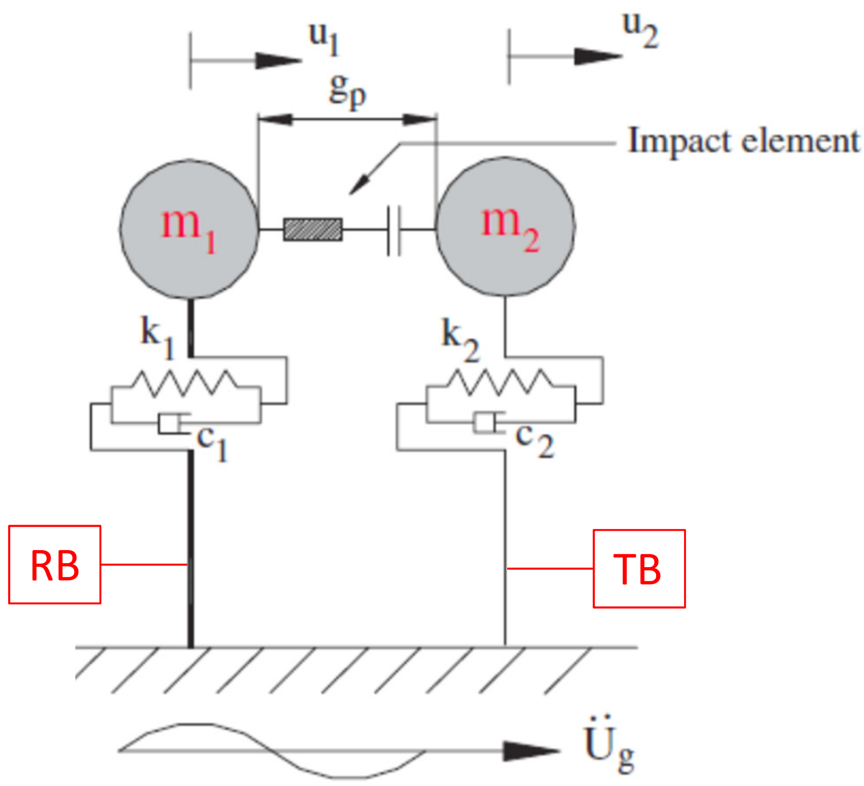
TB ISRS

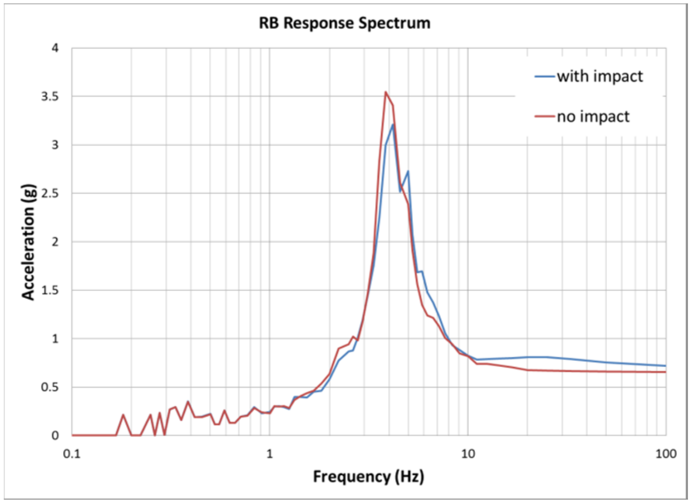


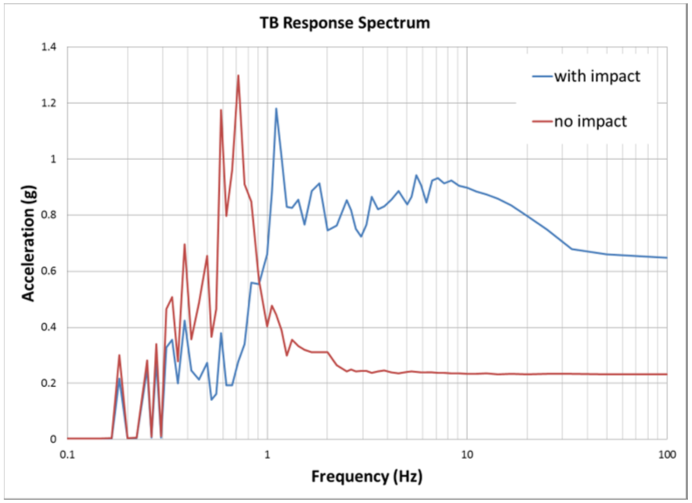


TB Slab at EL 617', Average ISRS, Y-Direction
no Impact
stiffness x1
Spectral Acceleration [g]
Frequency [Hz]
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.1
1
10
100

ISRS Results From SDOF Model







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CONCLUSION AND SUMMARY

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Conclusion and Summary

- The effect of building impact between two concrete structures with fairly different flexibilities was investigated in this studies.
- The effect of impact on the ISRS in the more flexible structure was found significant while it was found insignificant in the stiffer structure.
- The impact forces were highly dependent on the local structural stiffness of the impacting buildings but not very sensitive to the selection of the impact stiffness in the realistic range.
- The ISRS results from simplified SDOF model show consistent behavior with the detailed model.

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THANK YOU! QUESTIONS ?

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