CITY UNIVERSITY LONDON

RESEARCH CENTRE FOR CIVIL ENGINEERING STRUCTURES

INVESTIGATION OF THE INELASTIC RESPONSE OF STRUCTURAL SYSTEMS VIA INCREMENTAL DYNAMIC ANALYSIS TO INFORM PRACTICAL ASEISMIC STRUCTURAL DESIGN SCENARIOS

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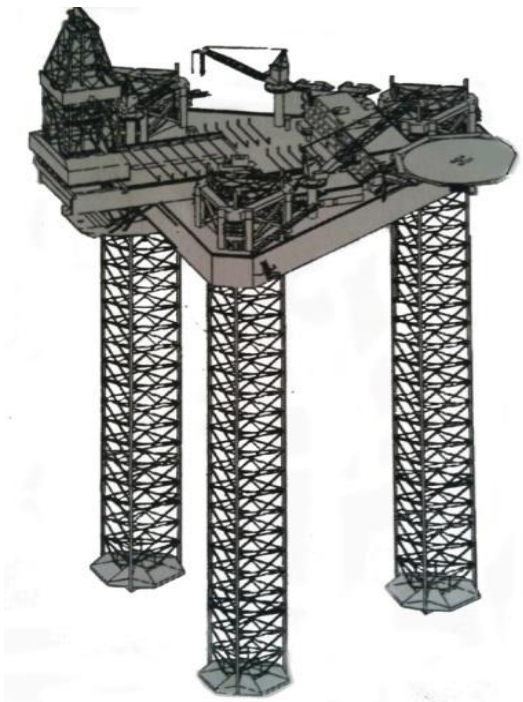
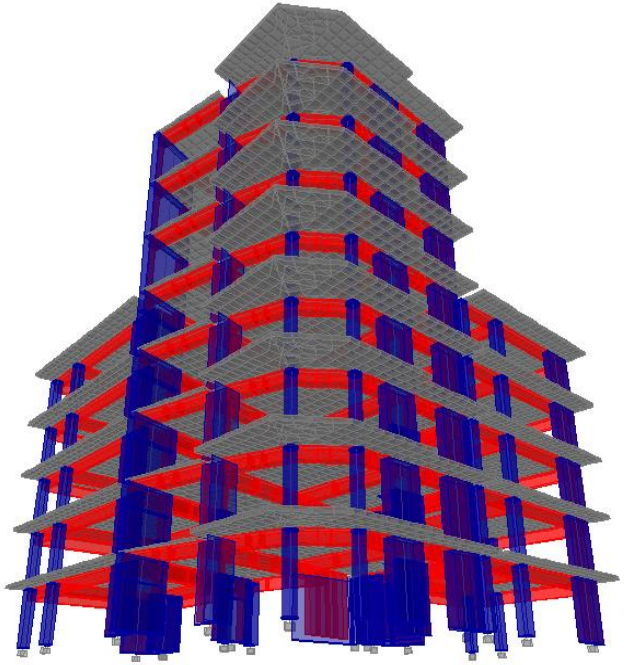
PhD SCOPE

ASSESSMENT OF FIXED BASED OFFSHORE STRUCTURES ← → INCREMENTAL DYNAMIC ANALYSIS ← → INFLUENCE OF POUNDING ON ADJACENT RC STRUCTURES





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THE PBEE LOSS ESTIMATION FRAMEWORK

THE FOUR STAGES OF THE PBEE FRAMEWORK

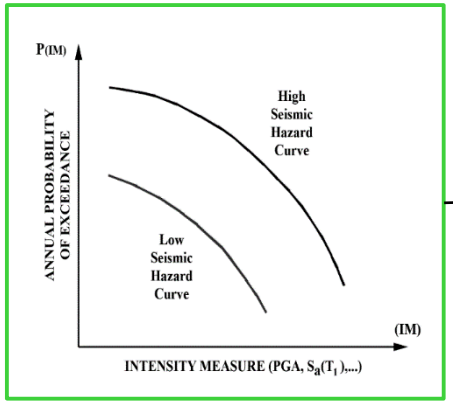
1. Seismic Hazard Analysis
   $\lambda(im)$
   im: intensity measure
→
2. Response Analysis
   G(edp|im)
   edp: engineering demand parameter
→
3. Damage Analysis
   G(dm|edp)
   dm: damage measure
→
4. Loss Analysis
   G(dv|dm)
   dv: design variable

ANALYTICAL EXPRESSION OF THE PBEE FRAMEWORK

$$\lambda(dv<DV)=\int_{im}\int_{dm}\int_{edp} G(dv|dm)\cdot\left|dG(dm|edp)\right|\cdot\left|dG(edp|im)\right|\cdot\left|d\lambda(im)\right|$$

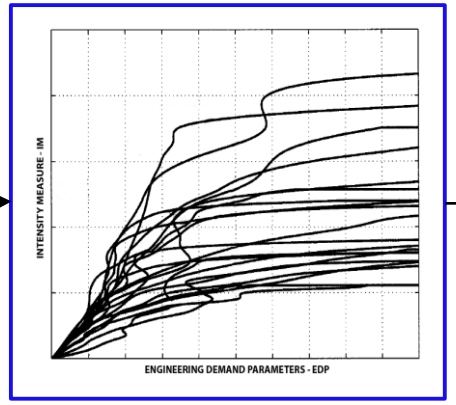
PROBABILISTIC SEISMIC HAZARD ANALYSIS

- ANNUAL PROBABILITIES OF EXCEEDANCE OF VARIOUS LEVELS OF SEISMIC INTENSITY **λ(IM)**.
- IDENTIFY GROUND MOTIONS OF INTEREST.



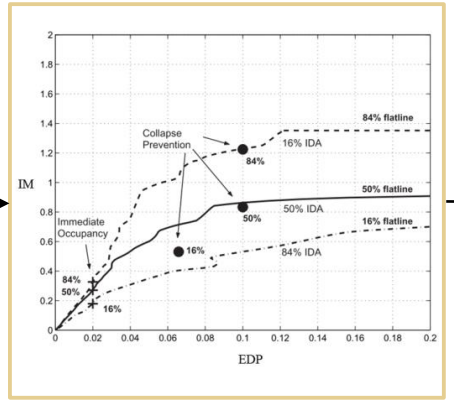
PROBABILISTIC SEISMIC DEMAND ANALYSIS

- PERFORM RESPONSE HISTORY ANALYSES FOR THE PRE-IDENTIFIED GROUND MOTIONS.
- OBTAIN RESPONSE CURVES AS A FUNCTION OF THE **IM** AND AN **EDP**



DAMAGE ANALYSIS

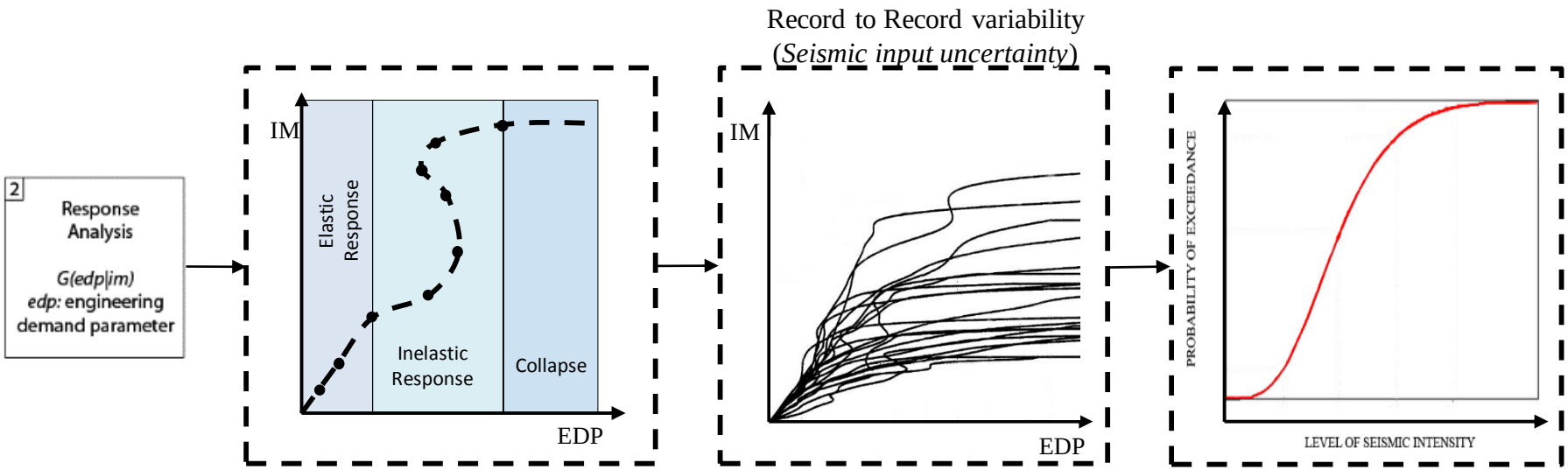
LIMIT STATE VALUES THAT CORRELATE WELL WITH VARIOUS DAMAGE STATES ARE IDENTIFIED ON THE IM-EDP RESPONSE CURVE.



LOSS ANALYSIS

THE OBTAINED DAMAGE VALUES ARE TRANSLATED INTO LOSS QUANTITIES OF INTEREST.

INCREMENTAL DYNAMIC ANALYSIS (IDA) FOR PROBABILISTIC SEISMIC DEMAND ANALYSIS



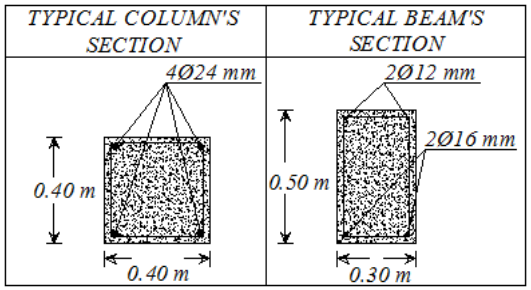
- Vamvatsikos, D. & Cornell, C.A. (2002). Incremental dynamic analysis. Earthquake Engineering and Structural Dynamics, 31, 491-514.
- Vamvatsikos, D. & Cornell, C.A. (2004). Applied incremental dynamic analysis. Earthquake Spectra, 20, 523-553.

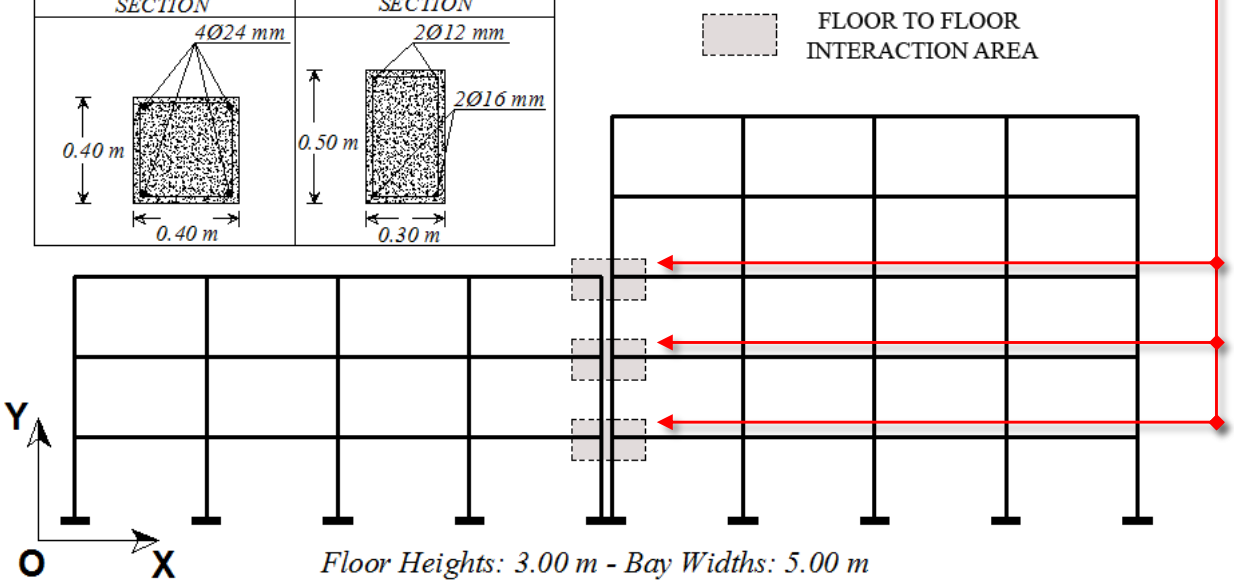
IMPACT OF THE POUNDING MODELING PARAMETERS ON THE SEISMIC PERFORMANCE OF ADJACENT RC FRAMES WITH EQUAL STOREY HEIGHTS

FINITE ELEMENT MODELS

Modelling Assumptions

- 2D Distributed plasticity RC Frames & P-Delta phenomena
- Columns share the same section
- Beams share the same section
- 5% Structural Damping
- Fixed Boundary conditions

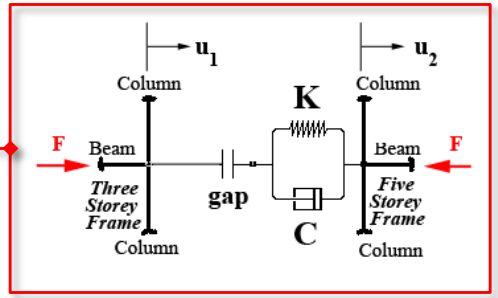




T=0.64 sec

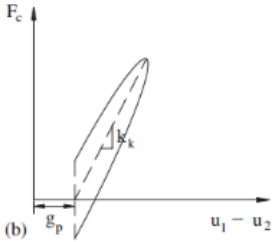
T=0.84 sec

Contact model



$$F = \begin{cases} Kx + C\dot{x}, \delta > 0 \\ 0\,, otherwise \end{cases}$$

Where: δ=u1-u2-gap

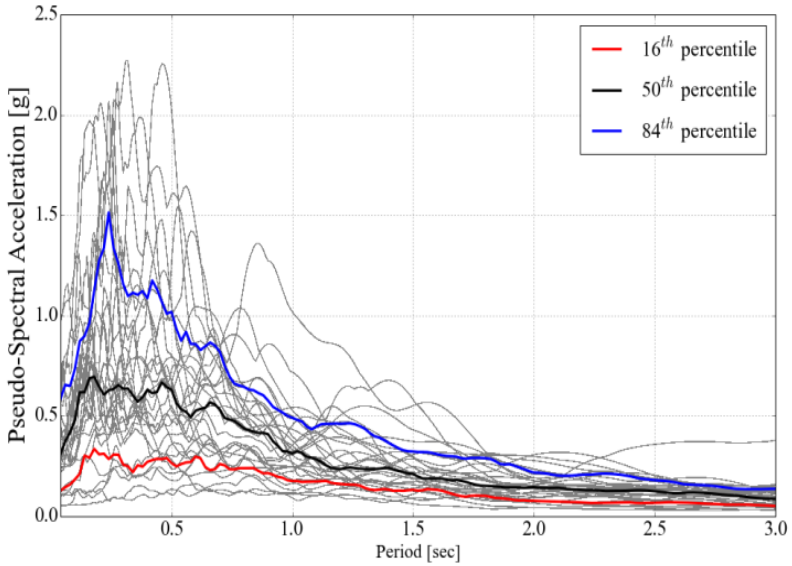


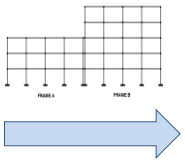
METHODOLOGY

IDA BASED SENSITIVITY ANALYSIS (Vamvatsikos and Fragiadakis, 2009)

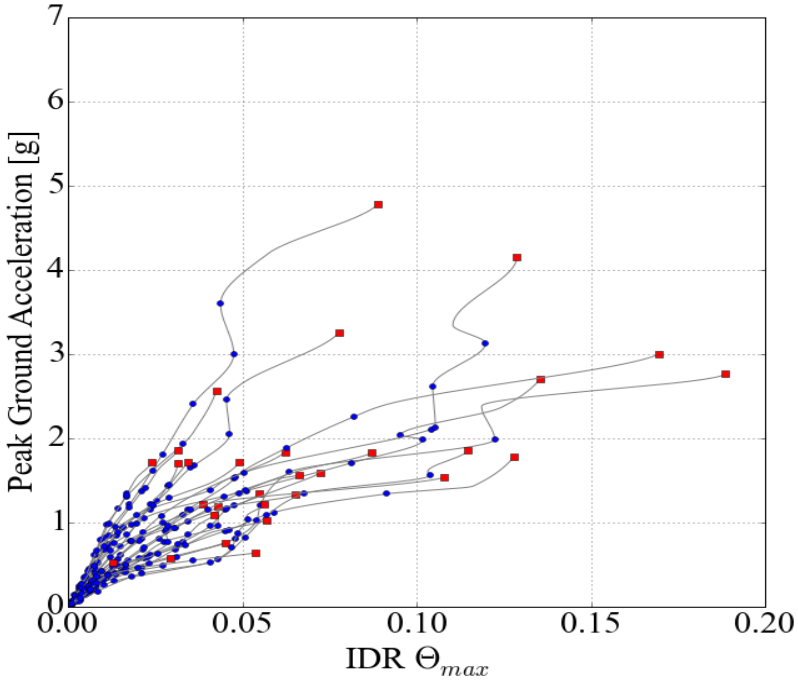
1. Incremental Dynamic Analysis (Vamvatsikos and Cornell, 2002)

ENSEMBLE OF 30 GROUND MOTIONS





IDA CURVES



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- Vamvatsikos D. And Fragiadakis M., (2009), "Incremental Dynamic Analysis for estimating seismic performance sensitivity and uncertainty", *Earthquake Engineering and Structural Dynamics*, **39**(2), 141-163

METHODOLOGY

IDA BASED SENSITIVITY ANALYSIS (Vamvatsikos and Fragiadakis, 2009)

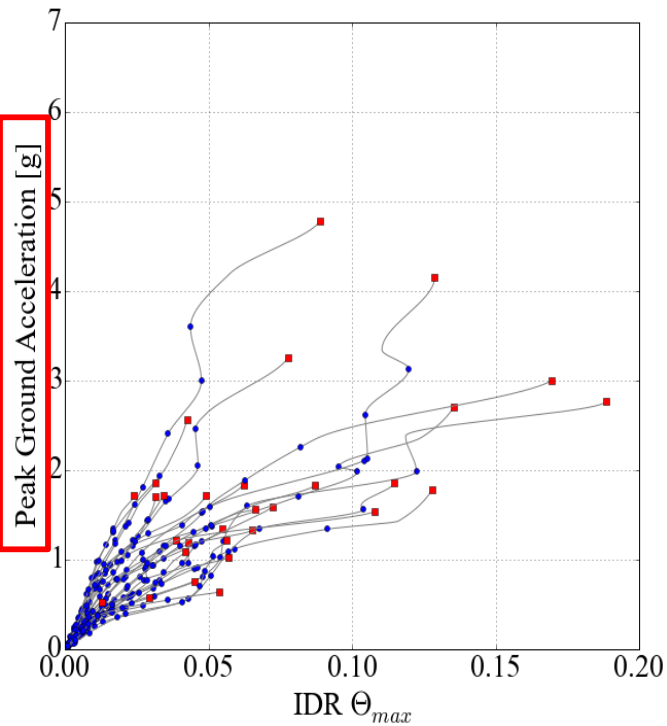
2. Efficient IM for Structural Pounding/Interaction Studies (vs. PGA)

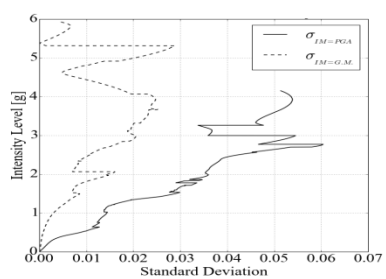
"Linear" Geometric Mean

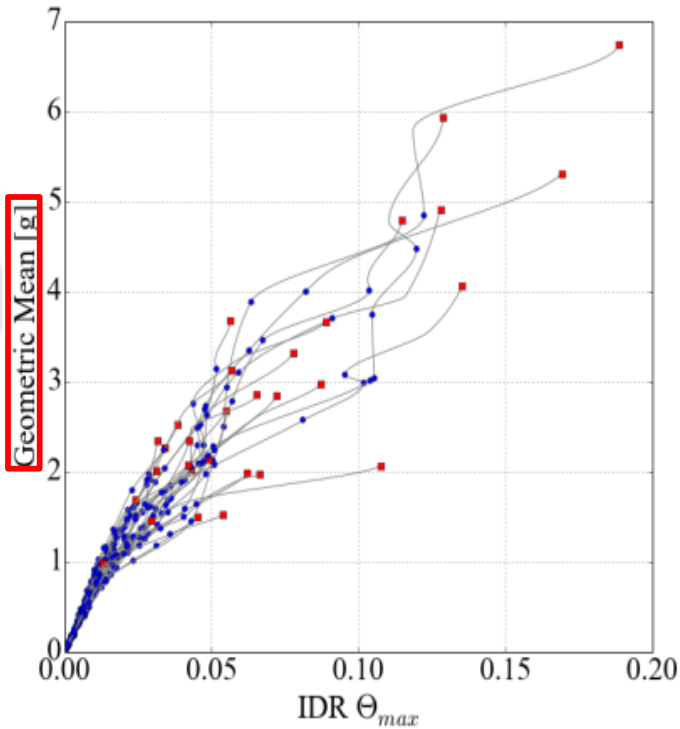
$$\sqrt{Spa_{A,T_1} \times Spa_{B,T_1}}$$

K number of interacting structures

$$\sqrt[K]{Spa_{1,T_1} \times Spa_{2,T_1} \times \ldots \times Spa_{K,T_1}}$$





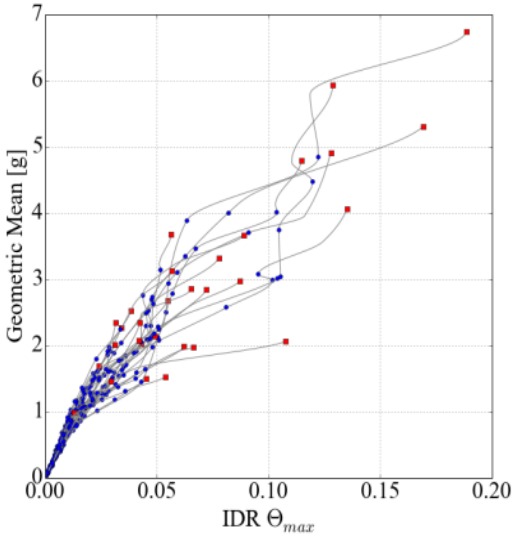


METHODOLOGY

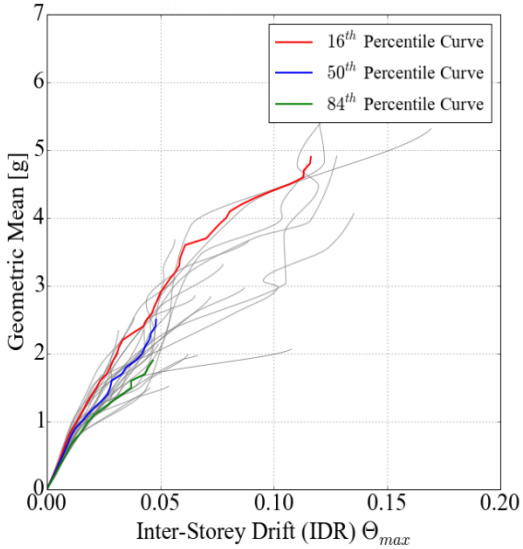
IDA BASED SENSITIVITY ANALYSIS (Vamvatsikos and Fragiadakis, 2009)

3. Statistical Analysis of IDA Curves

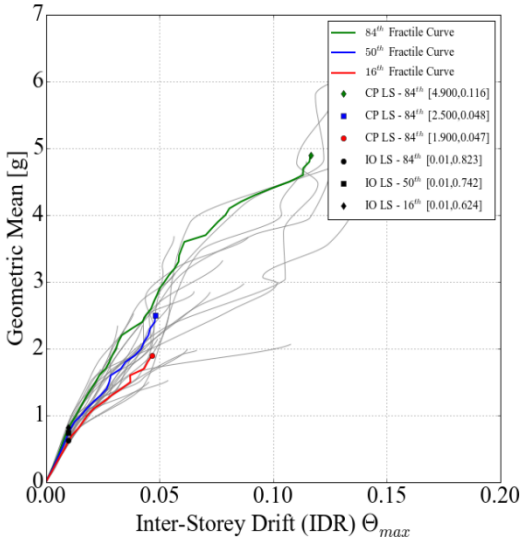
IDA Curves



Summarized IDA Curves



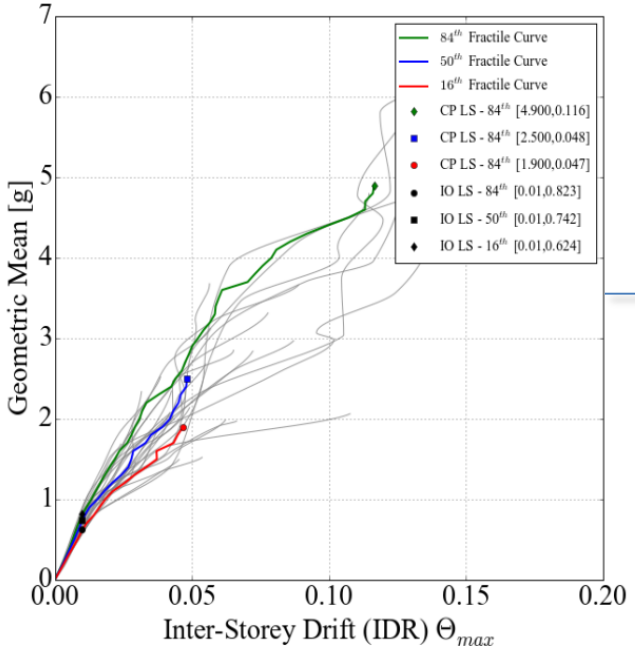
Fractile IDA Curves



METHODOLOGY

IDA BASED SENSITIVITY ANALYSIS

5. Fragility Functions



Limit State:
Immediate Occupancy

Lognormal Distribution

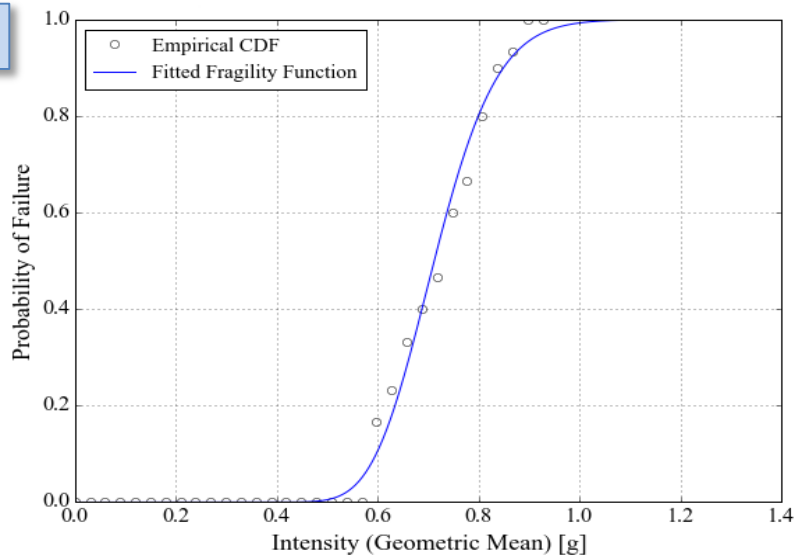
Mean

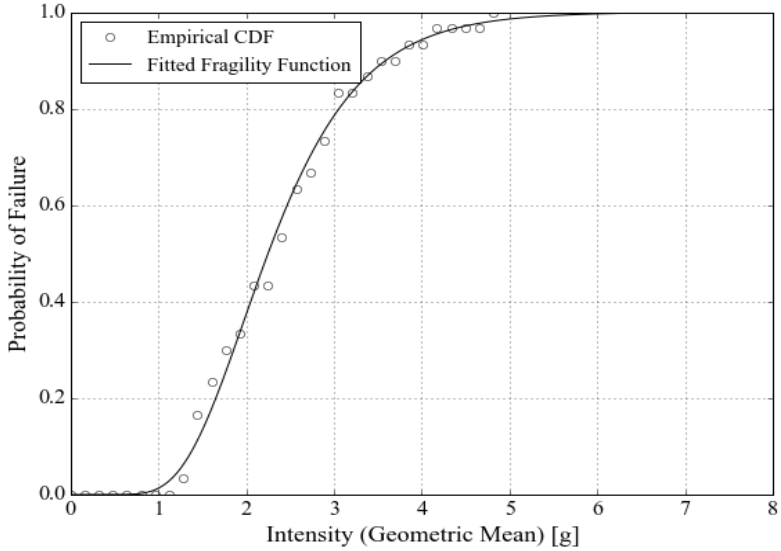
$$\ln \hat{\theta} = \frac{1}{N}\sum_{i=1}^{k} \ln(\mathrm{IM}_k)$$

Std

$$\hat{\beta} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{k} (\ln(\mathrm{IM}_k / \theta))}$$

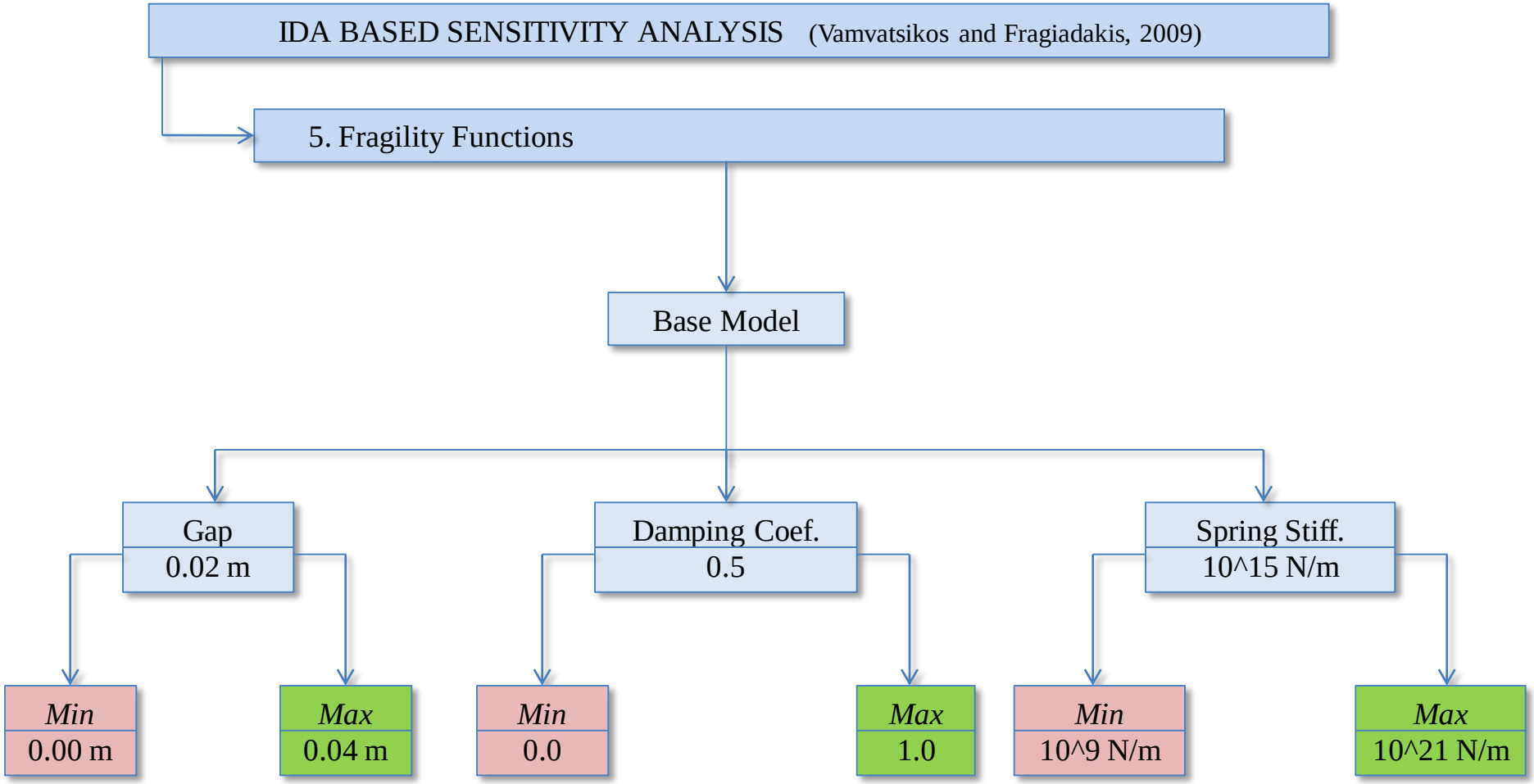
Limit State:
Global Instability





Ibarra, L. F., and Krawinkler, H. (2005). "Global collapse of frame structures under seismic excitations" *John A. Blume Earthquake Engineering Center*, Stanford, CA, 324.

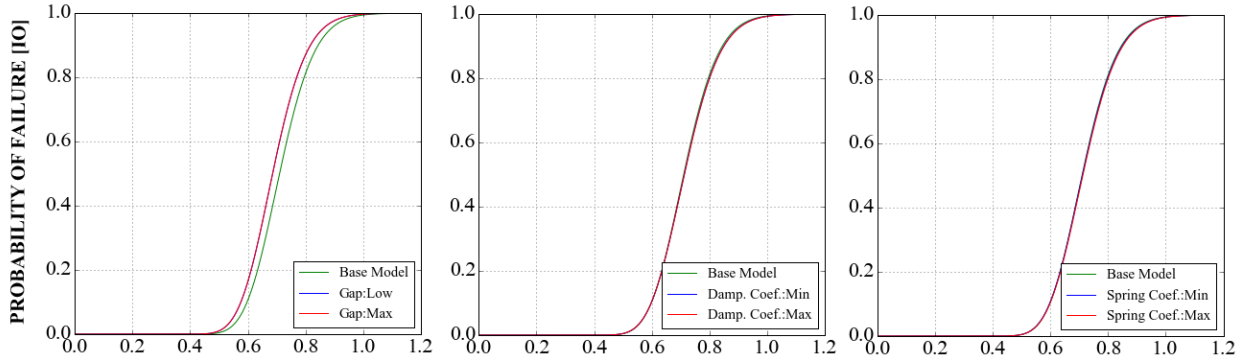
METHODOLOGY



DISPERSION OF FRAGILITY CURVES

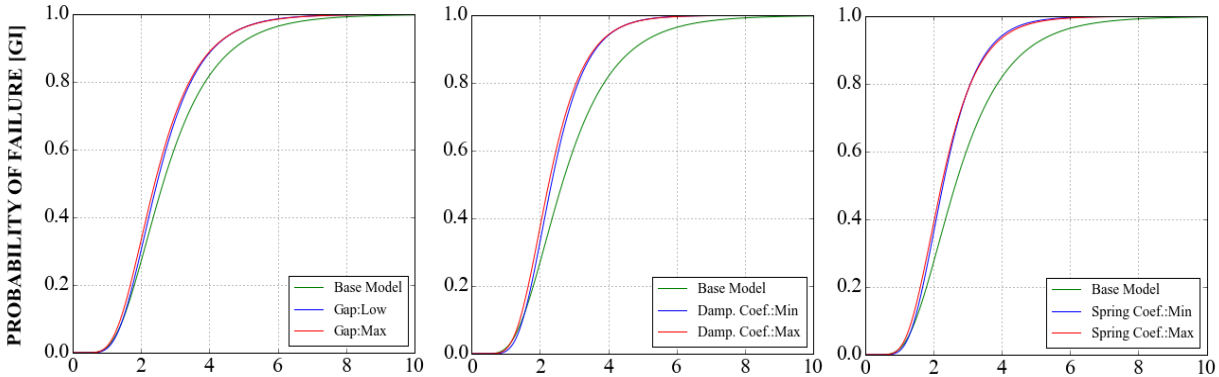
Limit State:
Immediate Occupancy

Gap | Damping Coeff. | Spring Stiffness



Limit State:
Global Instability

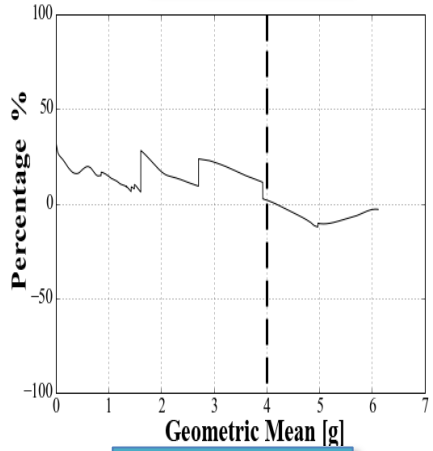
Gap | Damping Coeff. | Spring Stiffness

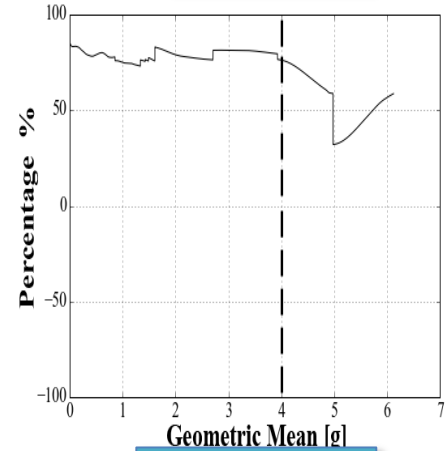


COMPARISON BETWEEN THE MEAN SHEAR FORCES FOR THE COUPLED AND UNCOUPLED STRUCTURES

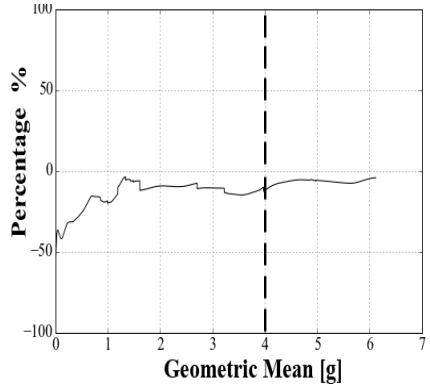
$$\frac{MEAN\ SHEAR\ FORCES_{COUPLED} - MEAN\ SHEAR\ FORCES_{UNCOUPLED}}{MEAN\ SHEAR\ FORCES_{COUPLED}} \times 100$$

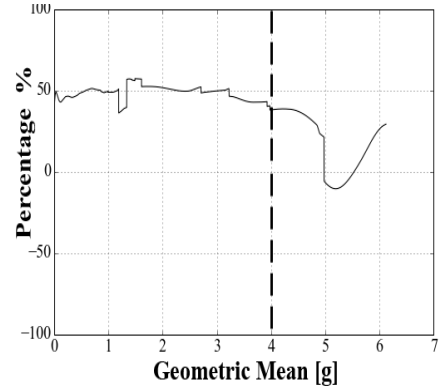
FRAME A → Columns → Beams





FRAME B → Columns → Beams



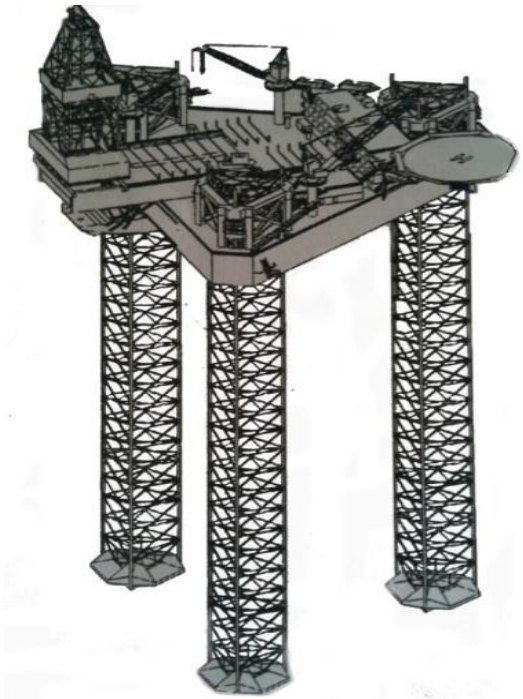


CONCLUDING REMARKS

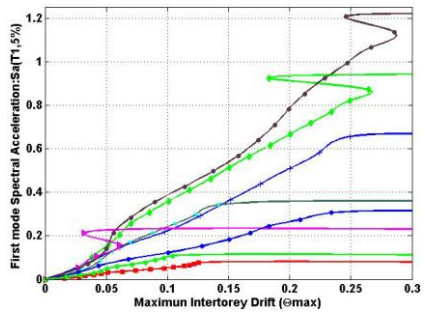
- Conclusions
  - Low Seismic Intensity
    - The coupled structural system is marginally sensitive to the separation distance
    - The coupled structural system is insensitive to the spring stiffness and damping coefficient
  - High Seismic Intensity
    - The coupled structural system is sensitive to all three modelling parameters
  - We need Shear Sensitive Damage Indices

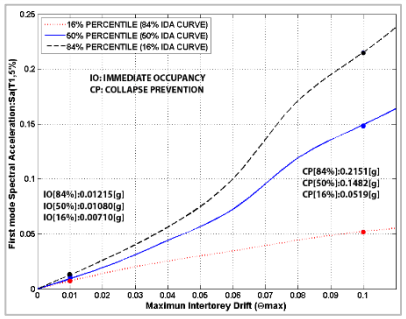
SOME MORE RESULTS-1

ASSESSMENT OF FIXED BASED OF OFFSHORE STRUCTURES

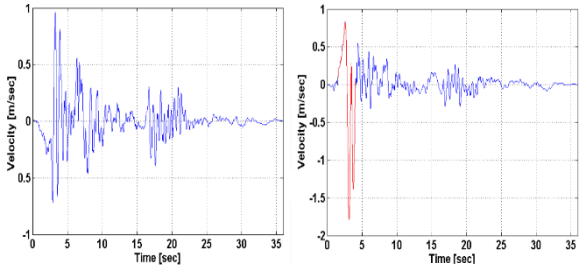


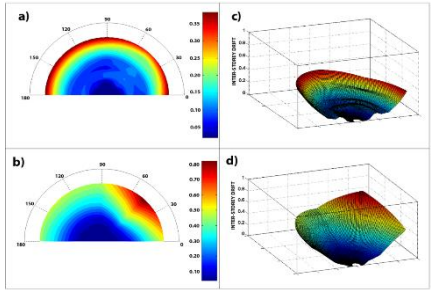
FAR-FIELD GROUND MOTION EXCITATION





NEAR-FIELD GROUND MOTION EXCITATION





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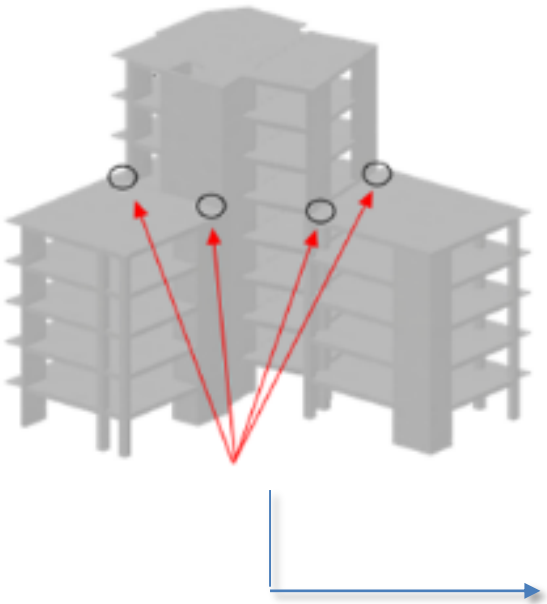
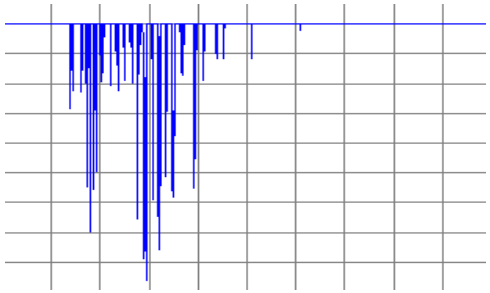
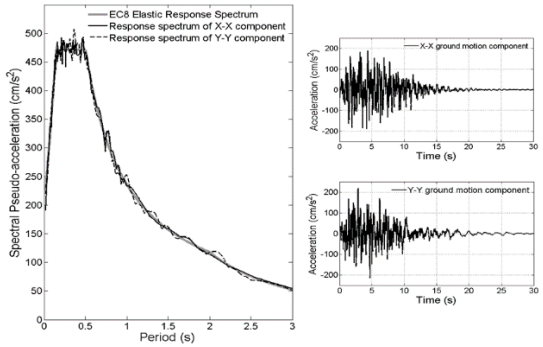
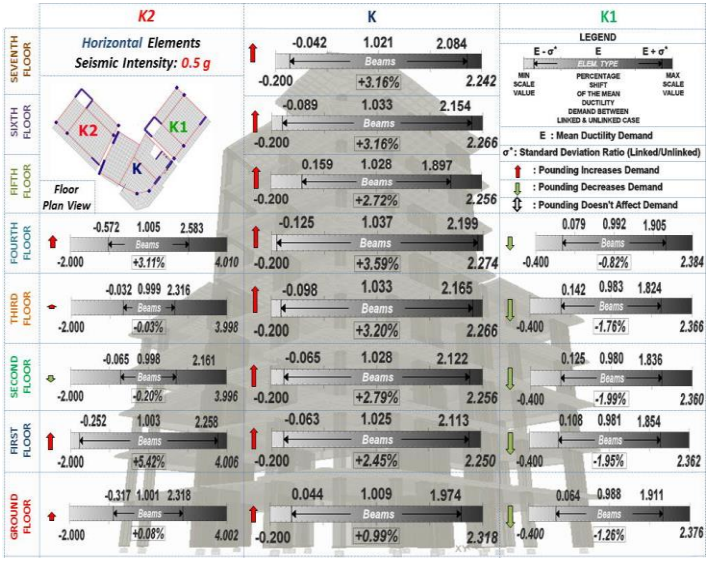
SOME MORE RESULTS- 2

SEISMIC PERFORMANCE ASSESSMENT OF RC STRUCTURES SUBJECTED TO SEISMICALY INDUCED POUNDING









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THANK YOU