Downstream Uses

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NRC Site Response SSHAC Level 2 Workshop

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TI TEAM QUESTIONS

1. Please provide a brief description of the current process for integrating or utilizing the results of the site response analysis (SRA) into the SSI analysis.
   a. Briefly describe the flexible volume method and how sub-structuring is used to solve the SSI problem.
   b. Why is the input motion generally defined at the foundation level (FIRS) for an SSI analysis?
   c. How do you determine what strain compatible properties you will use for the SSI analysis (best estimate, upper and lower)?
2. How should uncertainty in the SRA be incorporated into the SSI analysis in current practice? Consider sharing insights from the current NRC study on probabilistic SSI.
3. What is the expectation for future directions in SRA-SSI analysis?

Topics

- Downstream Uses of Site Response Results
  - Probabilistic Evaluation of Liquefaction Potential and Effects
  - Deterministic SSI Analyses – Frequency & Time Domain
  - Probabilistic SSI Analyses
  - Non-linear SSI Analyses – Time Domain
- Current and Emerging Issues

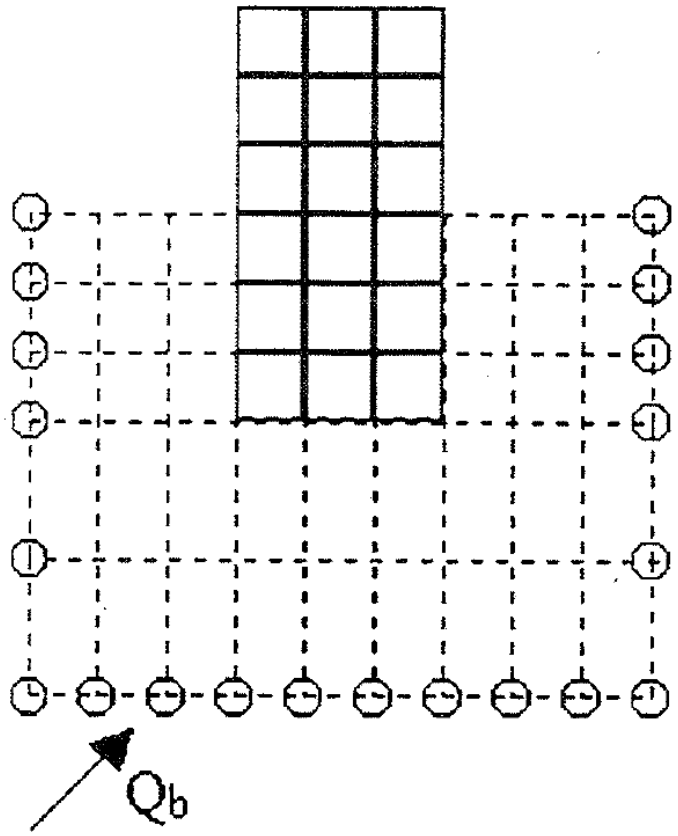
Downstream Uses of Site Response Results

- Probabilistic Evaluation of Slope Stability & Liquefaction Potential and Effects
  - Strain Compatible Soil Properties
  - Definition of GMRS & FIRS
    - Response Spectra
      - » Horizontal (& Vertical for Slopes)
    - M & D of Characteristic Events
    - Strong Motion Duration
  - Preferably, Sets of Time Histories Consistent With the PSHA (GMRS -- Surface)
    - The Number of Sets are Dependent Upon Whether MCS or LHS is Used for the Project

Liquefaction

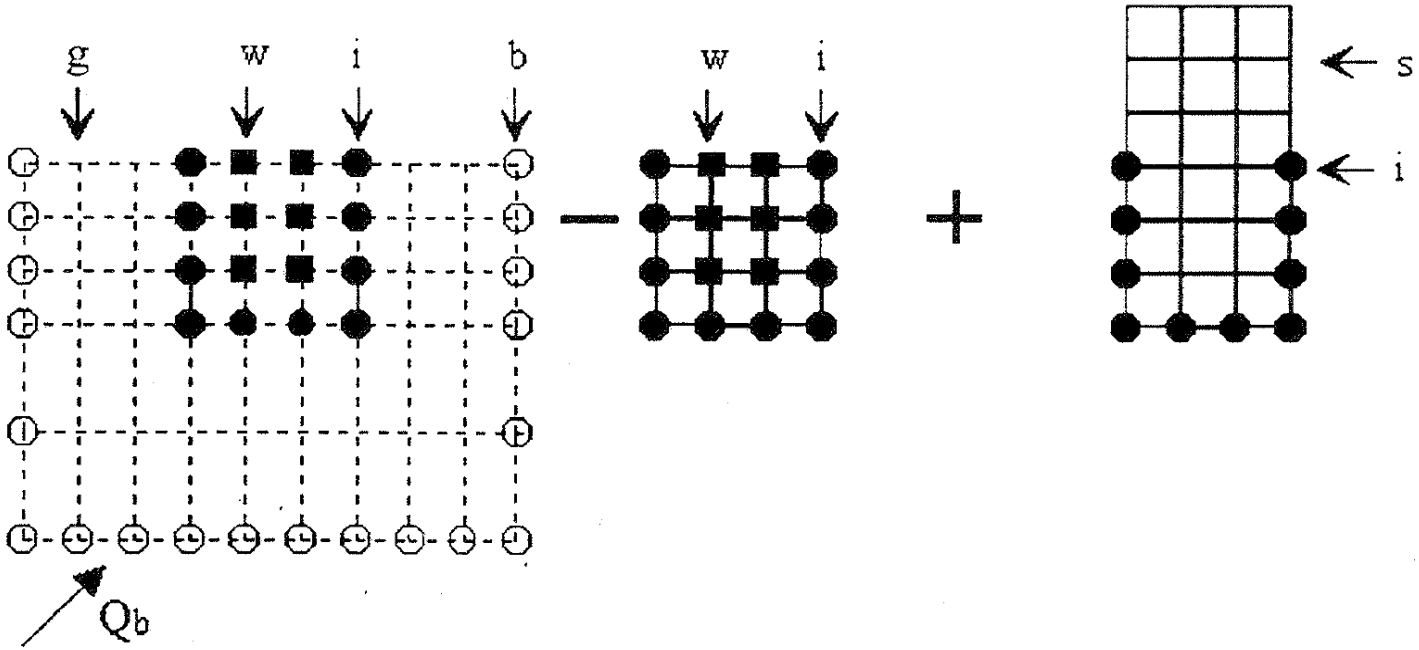
- Empirical Liquefaction Assessments --Inputs
  - PGA
  - PGV
  - T_S <- From V_S profiles
  - Tm <- ground motion period
  - Mw & R <- deaggregated
    - If deaggregation is at rock, then need SAFs for PGA & PGV
  - More Sophisticated Models
    - Youssef?
    - Katerina?

Overview of Flexible Volume Method



(a) Total System

Overview of Flexible Volume Method

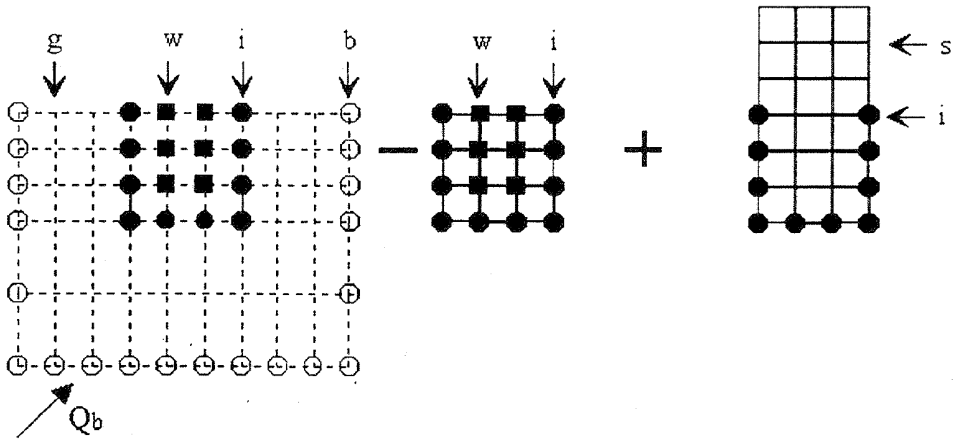


(b)
Substructure I
Free-Field Site

(c)
Substructure II
Excavated Soil Volume

(d)
Substructure III
Structure

Overview of Flexible Volume Method



(b) Substructure I Free-Field Site

(c) Substructure II Excavated Soil Volume

(d) Substructure III Structure

Soil properties developed in SRA used to compute X and U

$$\begin{bmatrix} C_{ii}^{III} - C_{ii}^{II} + X_{ii} & -C_{iw}^{II} + X_{iw} & C_{is}^{III} \\ -C_{wi}^{II} + X_{wi} & -C_{ww}^{II} + X_{ww} & 0 \\ C_{si}^{III} & 0 & C_{ss}^{III} \end{bmatrix} \begin{Bmatrix} U_i \\ U_w \\ U_s \end{Bmatrix} = \begin{Bmatrix} X_{ii}\, U_i' + X_{iw}\, U_w' \\ X_{wi}\, U_i' + X_{ww}\, U_w' \\ 0 \end{Bmatrix}$$

Where:

[X] is the impedance matrix (complex stiffness) in free-field soil medium

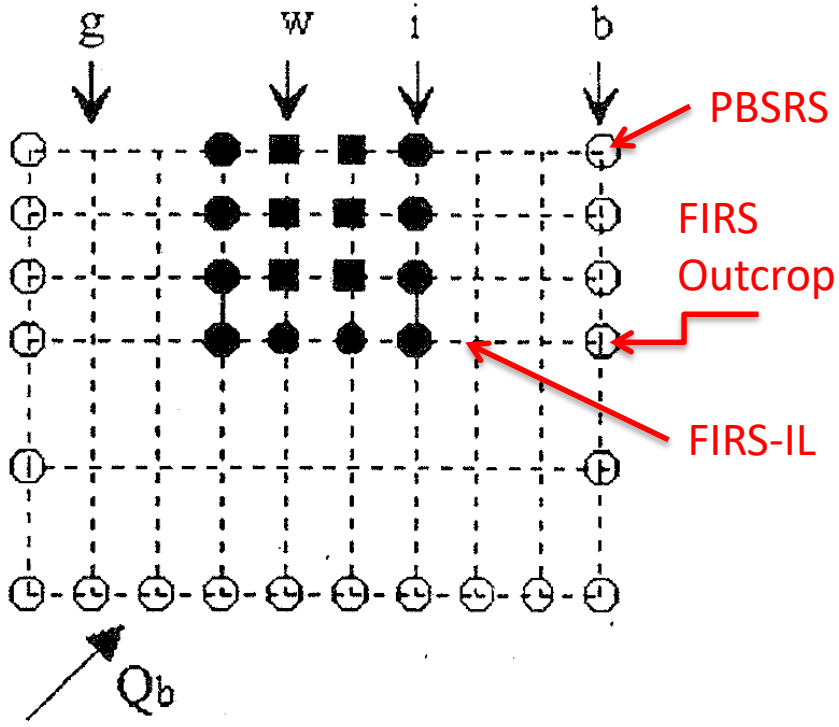
[C] is a complex frequency-dependent dynamic stiffness matrix

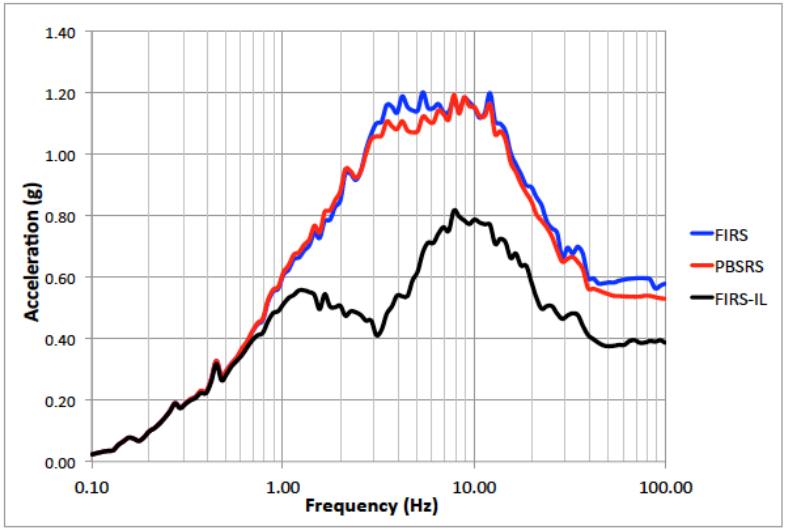
Defining Input Motion at Foundation Level – FIRS

- Specifying the seismic input at locations other than the FIRS can lead to unrealistic response spectra at the foundation level (either seriously unconservative or unrealistically high)*

- *NEI White Paper, “Consistent Site-Response/Soil-Structure Interaction Analysis and Evaluation,” NEI, June 12, 2009. (ADAMS Accession No. ML091680715)

Defining Input Motion at Foundation Level – FIRS





Soil Properties Used for SSI Analysis

- Three Soil Columns Are Used in Deterministic SSI Analysis – Data obtained from the PSHA (SRA)
  - Best Estimate (BE) V_S
    - Usually the mean from the SRA results, consistent strain levels associated with the definition of the GMRS
  - Lower Bound (LB) V_S
    - 16^{th} percentile Vs and 84^{th} percentile soil damping

      => Not larger than BE÷(1+COV)
  - Upper Bound (UB) V_S
    - 84^{th} percentile Vs and 16^{th} percentile soil damping

      $\Rightarrow$Not less than BE x (1+COV)
  - COV == 0.5 for Well Characterized Sites and 1.0 for Poorly Characterized Sites
- Results From the Three Soil Columns are Enveloped

Soil Properties Used for SSI Analysis

- V_P Computed Using Low Strain Poisson's Ratio
- P-wave Damping Taken as Equal to S-wave Damping
- Additional Soil Profiles Added as Required to Meet the Criteria That the Envelop of the Surface Spectra from the Columns Used in the SSI Analyses Envelope the PBSRS
  - Alternatively, the FIRS input motion may be scaled
- Soil Density is Taken From the SRA to Ensure That the Motions Throughout the SASSI Model Free-Field are Consistent with the PSHA Motions

Incorporating Uncertainty in SRA into SSI Analysis

- Uncertainty in SRA Primarily Affects the SSI Response in the Following Areas:
  - Estimate of Mean and Standard Deviation in Strain Compatible Soil Properties
  - Spatial Variation of Soil Properties and Ground Motions
  - Wave Propagation Characteristics of the Seismic Motion – Vertical vs. Inclined Waves.
  - Directional Variability of GMRS

Incorporating Uncertainty in SRA into SSI Analysis

- Preferred Treatment is Using Probabilistic Techniques
  - ASCE 4-16 Provides Recommended Distributions for Variables Important to Response
- Deterministic Approaches Address the Uncertainty by:
  - Design Using the Envelope of 3 Soil Cases (BE, UB, LB)
  - Including an Accidental Torsion Equal to 5% of the Plan Dimension in the Analyses
  - Peak Broadening the In-Structure-Response Spectra

Downstream Uses of Site Response Results

- Deterministic SSI Analyses – Frequency & Time Domain
- Probabilistic SSI Analyses

Downstream Uses of Site Response Results

- Probabilistic SSI Analyses
  - Strain Compatible Soil Properties
  - Definition of GMRS & FIRS
    - Response Spectra (Horizontal and Vertical)
    - Directional Variability of Ground Motion
    - M & D of Characteristic Events
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Downstream Uses of Site Response Results

- Deterministic SSI Analyses – Frequency & Time Domain
  - Strain Compatible Soil Properties
  - Definition of GMRS & FIRS
    - Response Spectra (Horizontal and Vertical)
    - M & D of Characteristic Events
    - Strong Motion Duration
  - Preferably, 5 sets of time histories consistent with the PSHA (FIRS and GMRS)

Current and Emerging Issues

- When empirical relationships are used in the PSHA (i.e. V/H ratios), the finite element constitutive models can't reproduce the responses from the PSHA throughout the soil profile
- For Direct Solutions, the ground motions have to be specified at the base and sides of the model. When non-linear models other than equivalent linear are used, the mapping of those boundary motions onto a 3-D representation of the SSI problem is essentially a trial and error process

Current and Emerging Issues

- Site Specific Randomization if we are using Toro models <-- what is distribution for high strain?
- V/H at depth vs V/H at surface
- If we base sigma on AF rather than Vs, then we need a mapping scheme to get SSI model properties correct

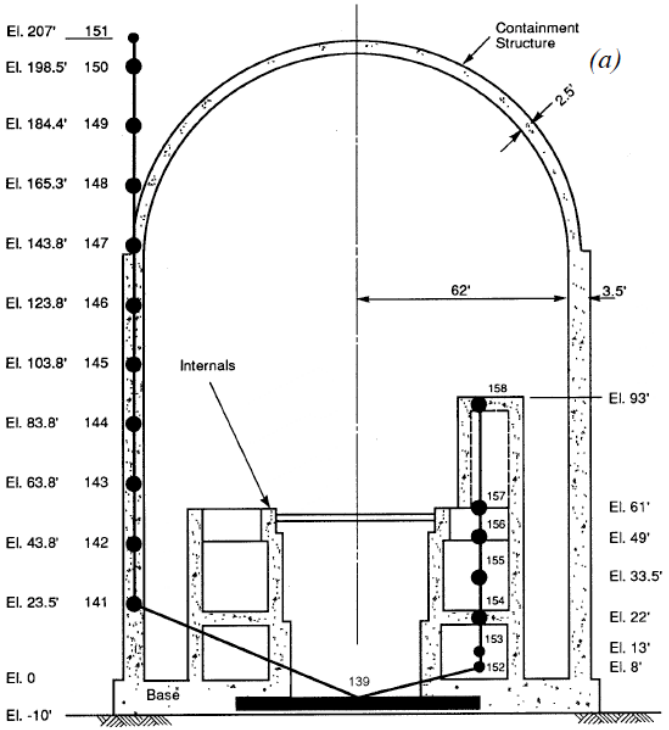
Expectation for Future Directions in SRA-SSI Analysis

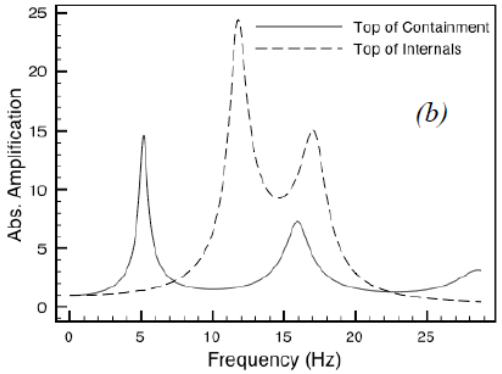
- Currently, there is an effort to modify SASSI software to accommodate the differences between motions developed using V/H ratios and the motions that are currently computed based on the constitutive models.
- Probabilistic SSI Analyses Are Becoming More Common as Computational Capabilities are Expanded
- There Continues to be a Significant Push Toward Using Non-Linear SSI Analyses

Expectation for Future Directions in SRA-SSI Analysis

- Non-linear SSI Analyses – Time Domain
  - Incorporating Constitutive Models Consistent with Assumptions Used to Perform SRA
  - Compatibility Between "Free-field" Motions and Properties (Often Equivalent Linear) and Properties Used for Soil in the Models
    - Motions Around the Boundaries of the Soil Model Have to be Defined
  - Appropriate Representation of Damping in the Model can be Difficult
    - Usually Rayleigh Damping Combined with Hysteretic Behavior of the Constitutive Model
  - Verification and Validation of the Approach is Needed
    - Requires Data from Observed Responses → Both Site Response and Structural SSI Responses

Insights from Current NRC Study on Probabilistic SSI
Surface Founded Model (Lysmer 2000)





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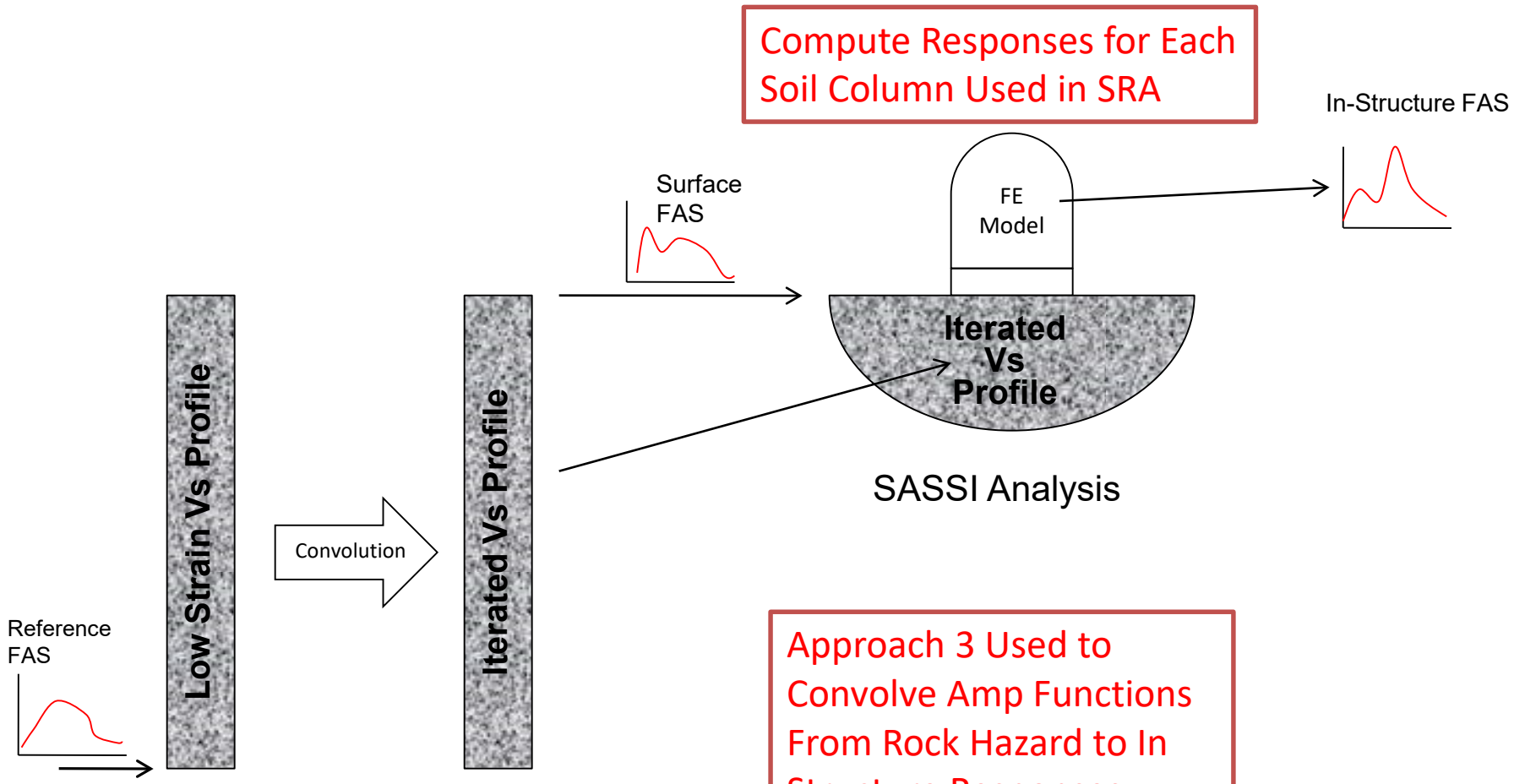
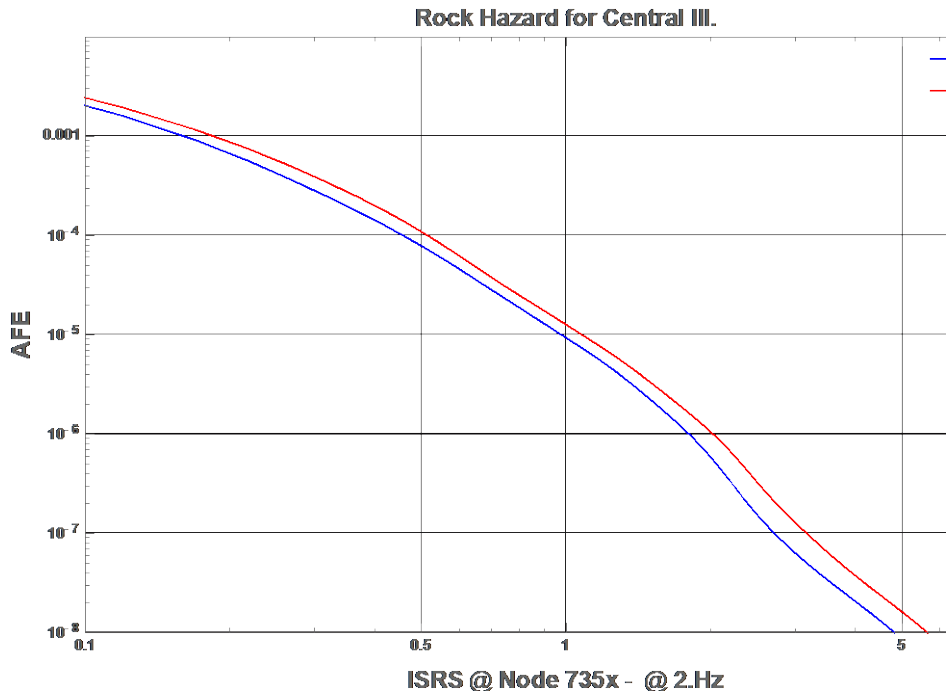


Hazard-Consistent Soil Structure Interaction Analyses from Probabilistic Seismic Hazard Studies at Nuclear Facilities -- Preliminary Results (ISRS)
Site: SRS



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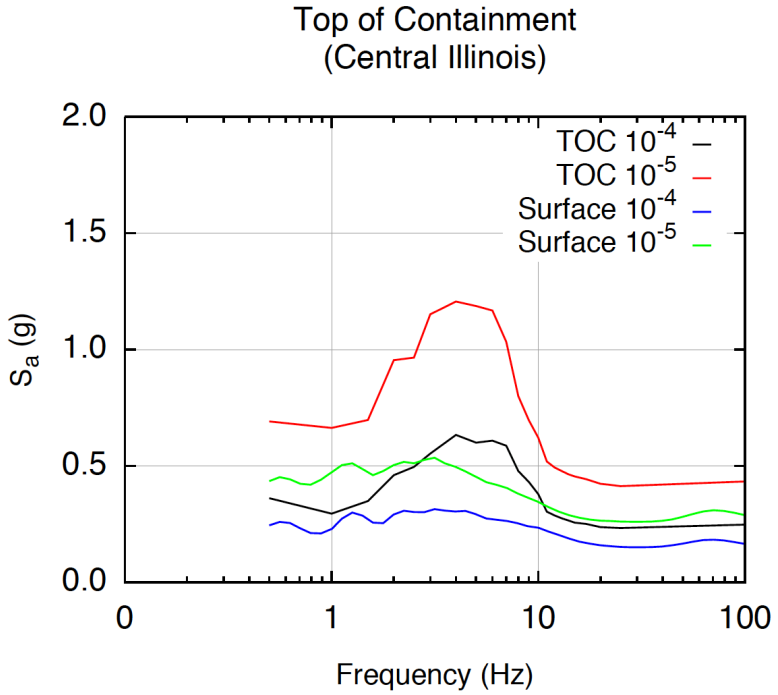

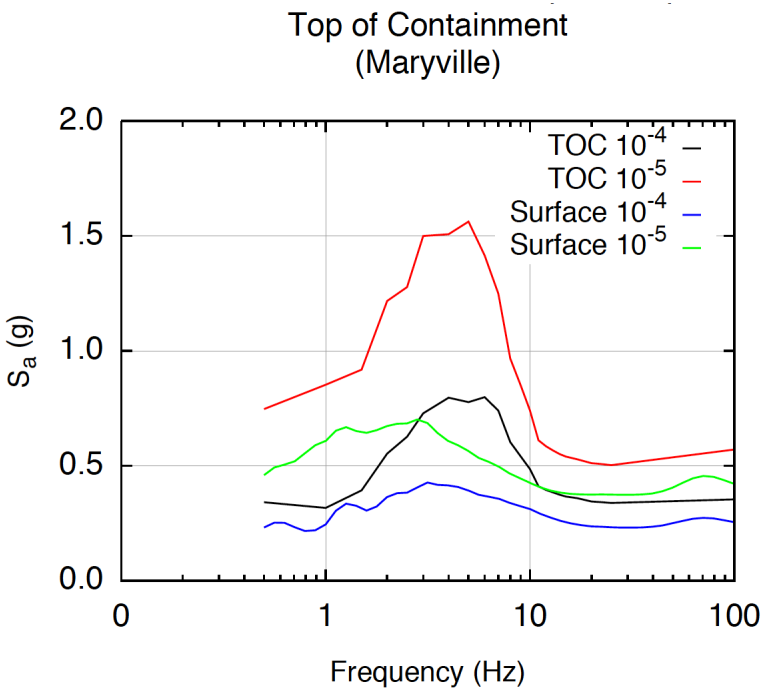

Insights from Current NRC Study on Probabilistic SSI -- Preliminary

- ASCE Approach Generally Exceeds 80th Percentile Response Given Mean Input Motion
  - Exception appears to be near base mat for embedded structures
- Once the GMRS/FIRS is Defined, Local Variations in the Site Soil Properties (V_S) Have Little Effect on Computed Response
- For Deterministic Analyses, SSI Responses Appear Stable for Soil Properties Selected Consistent with the Hazard Level (e.g. surface pga acceleration) Most Similar to the GMRS are consistent with using properties selected based on contribution of each rock hazard to the GMRS
- Uncertainty in Structural Response is Primarily Correlated to Uncertainty in the Site Response (Rock Hazard to In Structure Responses)

References

- NEI White Paper, “Consistent Site-Response/Soil-Structure Interaction Analysis and Evaluation,” NEI, June 12, 2009. (ADAMS Accession No. ML091680715)
- ASCE 4-16, “Seismic Analysis of Safety-Related Nuclear Structures”