Overview on BNL Assessment of Seismic Analysis Methods for Deeply Embedded NPP Structures

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BACKGROUND

Need for the Research:

- Several Conceptual Designs of Advanced Reactors Proposed Deeply Embedded and/or Buried (DEB) Features for NPP Structures
- Understanding of Effects of DEB Features on Seismic Analysis Methods
- Evaluation of Current Seismic Criteria for Soil-Structure Interaction (SSI) Pertaining to DEB Structures

PROGRAM OBJECTIVE AND TASKS

Objective:

- Investigate and Evaluate the Applicability of Existing Seismic SSI Practice, Regulatory Guidance and Computer Codes for DEB NPP Structures.
- Develop insights to be used for the safety evaluation of deeply embedded and/or buried (DEB) structures

Tasks:

- Perform Literature Review of Existing Practices and Guidelines and Identify Potential Seismic Issues Requiring Further Study
- Evaluation of Simplified vs. Detailed Methodologies for SSI Spectrum Computations (CARES versus SASSI).
- Evaluation of Methods for Computing Seismic Induced Pressures for DEB Structures

SCOPE OF LITERATURE REVIEW

- Reviewed the open literature to determine the state-of-the-art for performing seismic analyses of DEB NPP structures
- Performed search on a broad range of literature using keywords such as: SSI, Kinematic, Wall pressures, Embedded, Earthquake measurements.
- The search yielded hundreds of abstracts related to the subject
- Reviewed more than 100 references

LITERATURE REVIEW OF SEISMIC ANALYSES AND PRACTICE

- SSI phenomenon: kinematic and inertia interaction effects are well studied for embedded structures:
  - Analytical efforts (authors such as Pais and Kausel, Iguchi, Roesset, Luco, etc.)
  - Numerical efforts: SASSI, CLASSI, FLUSH, CARES
- Seismic induced pressures
  - Mononobe-Okabe (M-O) method for earth retaining walls
  - Elastic solution by wood (ASCE 4)
  - Others such as studies by Veletsos, Ostadan, etc., for seismic-induced pressure calculations of buried structures.
  - Japanese studies using field tests and shake table tests.

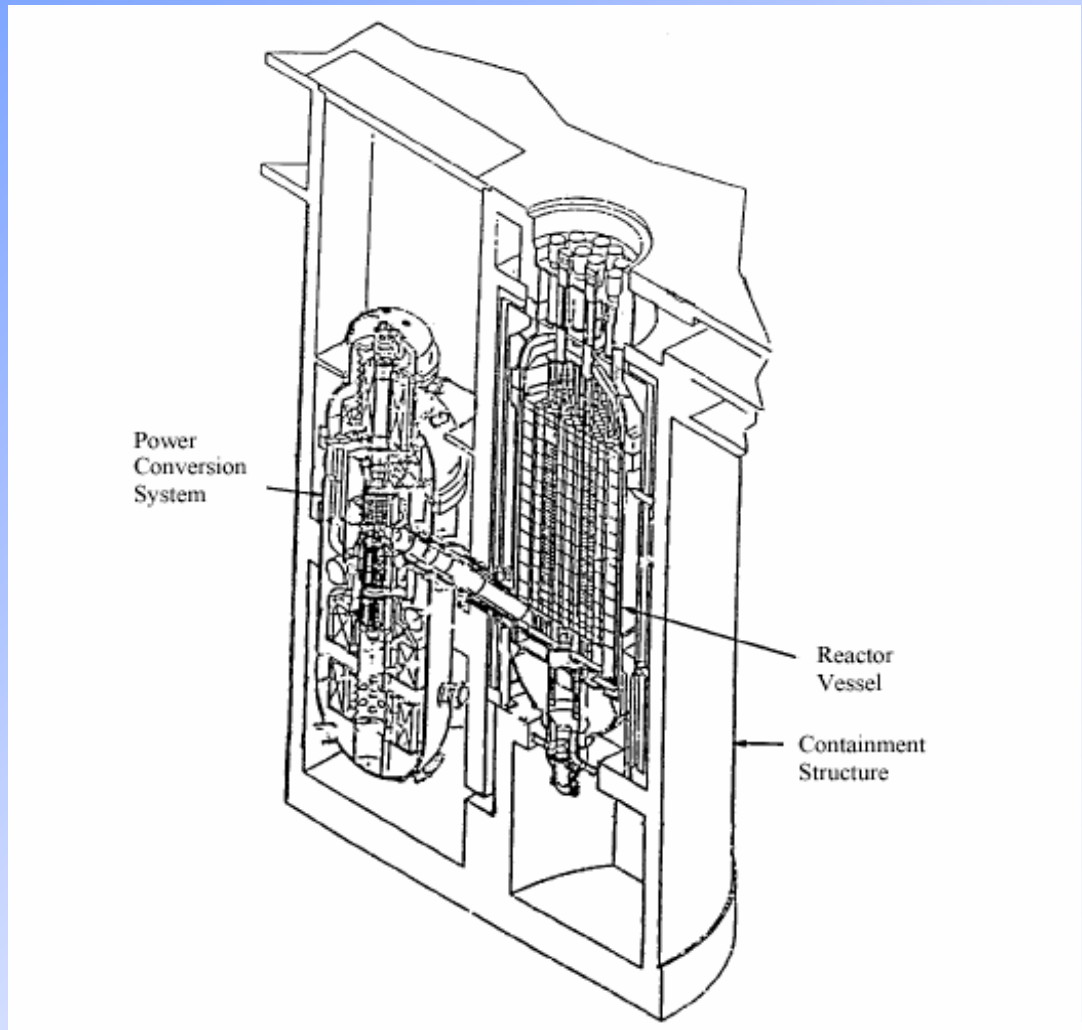
KEY ISSUES IMPORTANT TO DEB SSI

Key Issues	Attributes of Importance	Current Computational Capability
Kinematic Interaction (KI)	Rigid foundation modifies free-field motion	Incorporated into codes such as SASSI SASSI for linear SSI response.
Free-Field Seismic Motions	P, SH or SV waves in free field motions need to be defined for computing SSI response	All computer codes typically utilized to address SSI response issues can address the issue of free-field input motion characteristics associated with various wave types.
Wall Pressures and Other Nonlinear Effects	Nonlinear effects are important in determining seismic wall pressures.	The SASSI Code can only treat the equivalent linear problem. Nonlinear effects can currently only be treated in time-domain codes having this capability (LS-DYNA, ABAQUS). The codes require the definition of various input parameters to properly incorporate these effects within the model.
Sidewall Interaction	Kinematic interaction effect needs to be considered in simplified lump mass SSI models.	The SASSI Code can treat this problem correctly for a given free-field configuration and input motion. Simplified SSI codes (e.g., CARES) make use of parameters from a library of solutions available in the literature.
Ground Motion Incoherence	High frequency (greater than 10 Hz) SSI response, which is important for facilities sited on hard rock.	The codes typically available to evaluate these effects are currently in their developmental stage. In addition, the data used to develop the incoherence parameters is relatively restricted.

EVALUATION OF SIMPLIFIED VS. DETAILED METHODOLOGIES FOR SSI

- Evaluation of Simplified vs. Detailed Methodologies for SSI Spectrum Computations for DEB Structures
- CARES was Used for Simplified Method (NUREG/CR-6922)
- SASSI for Detailed Method (SASSI 2000, UC Berkeley)

STRUCTURAL CHARACTERISTICS



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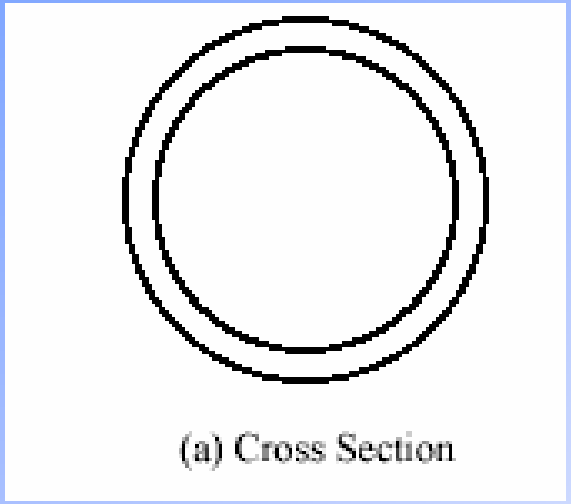
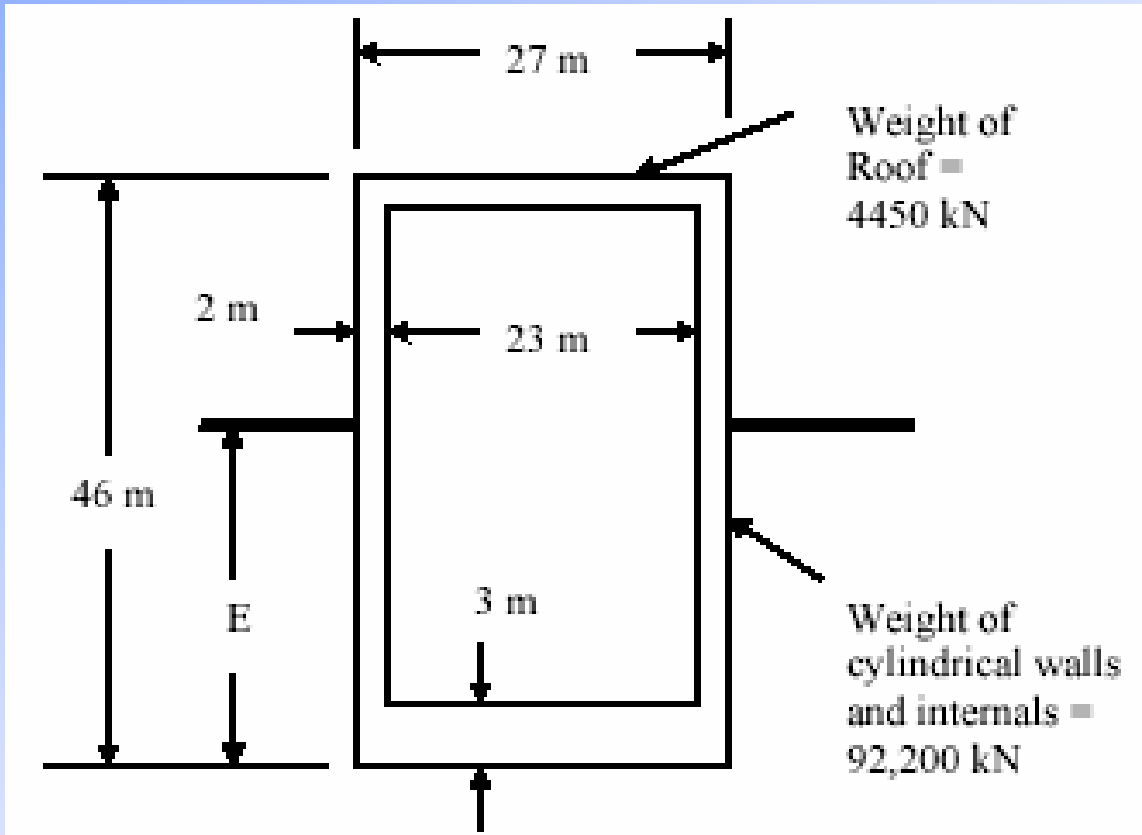
STRUCTURAL CONFIGURATION



(a) Cross Section



(b) Elevation

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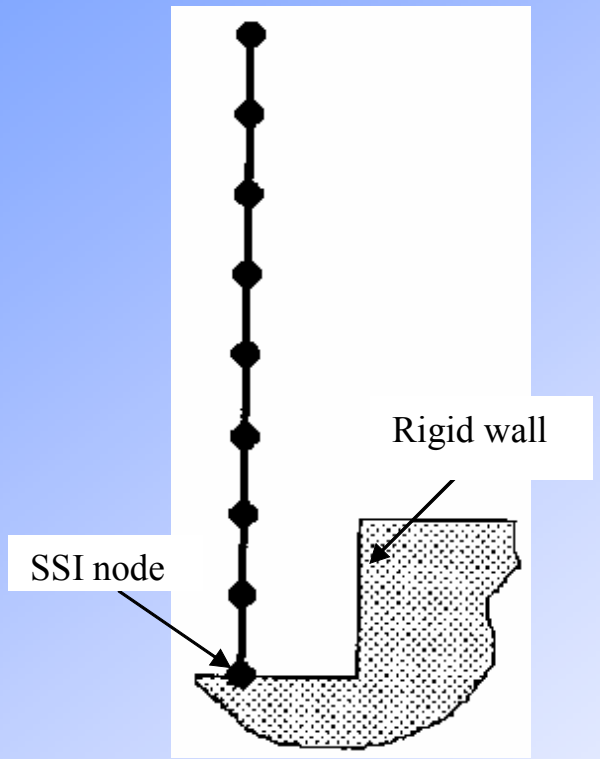
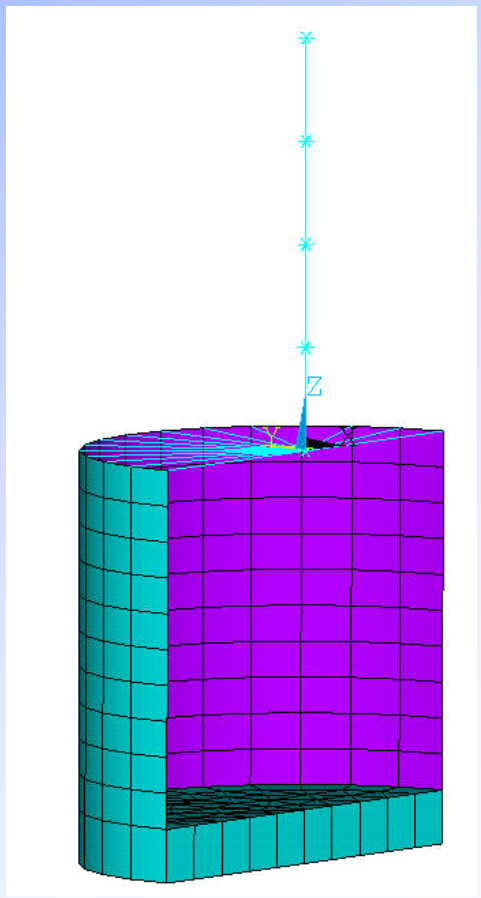
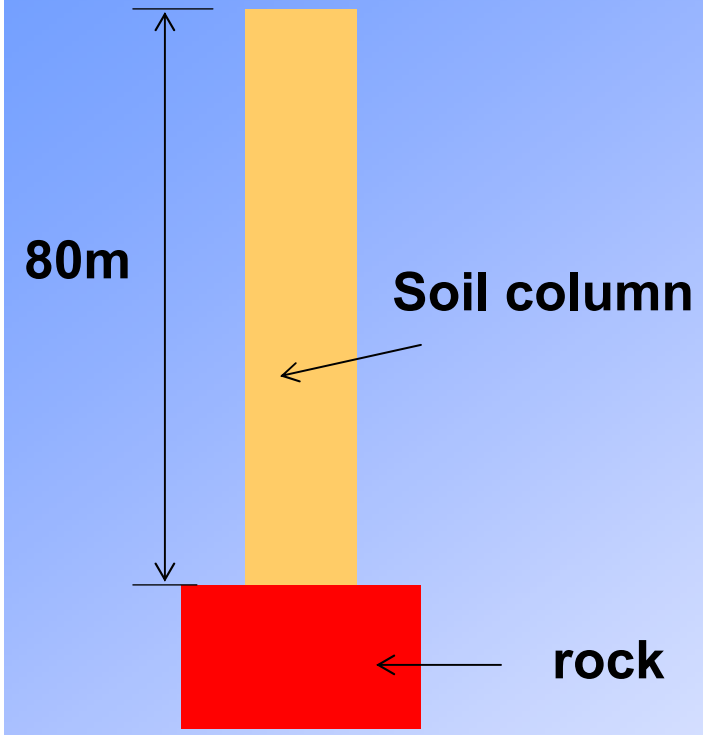
CARES AND SASSI Models

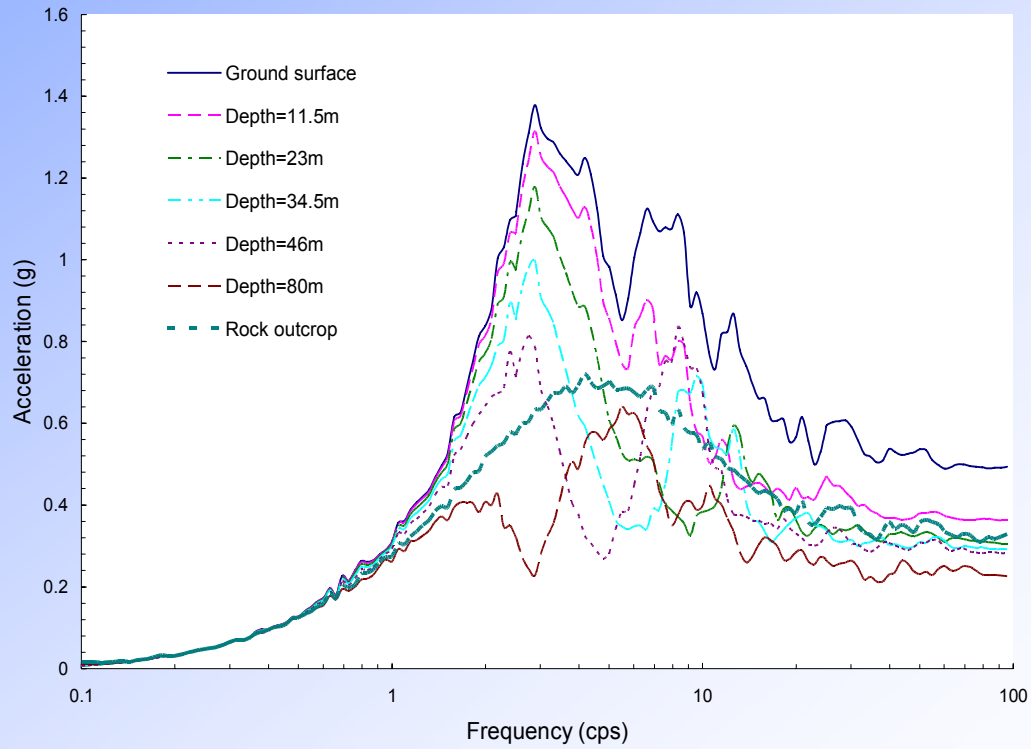




Free Field Response



Free Field Soil Column



Free Field Response Spectra

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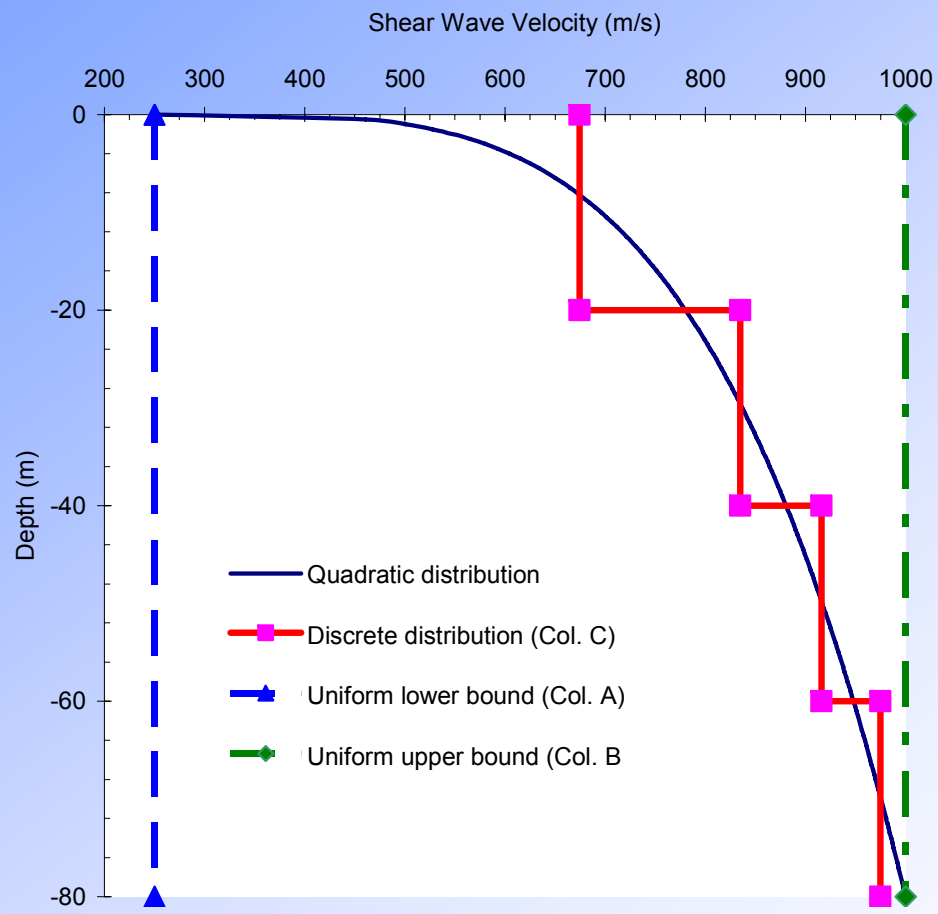
Soil Profiles



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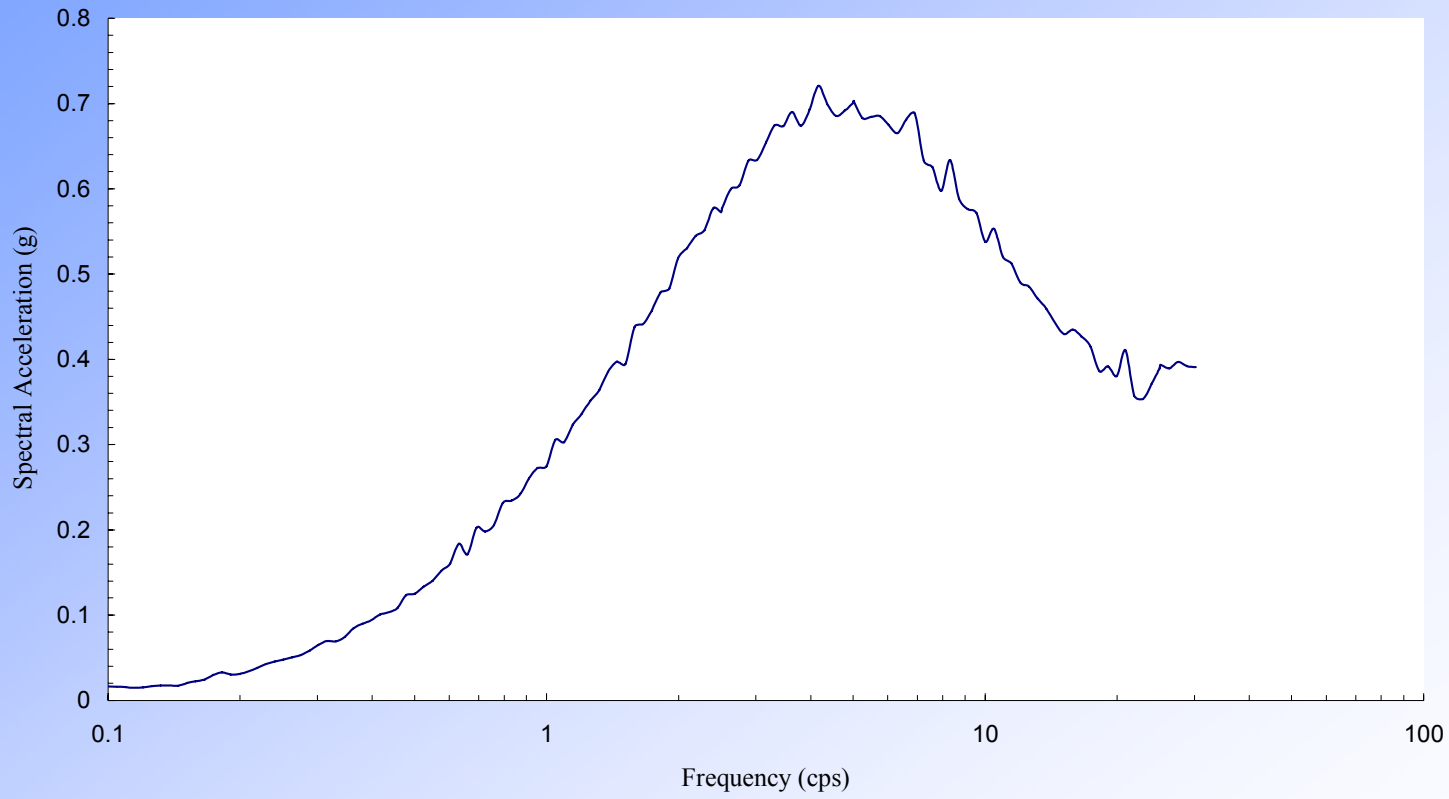
Rock Outcrop Motion



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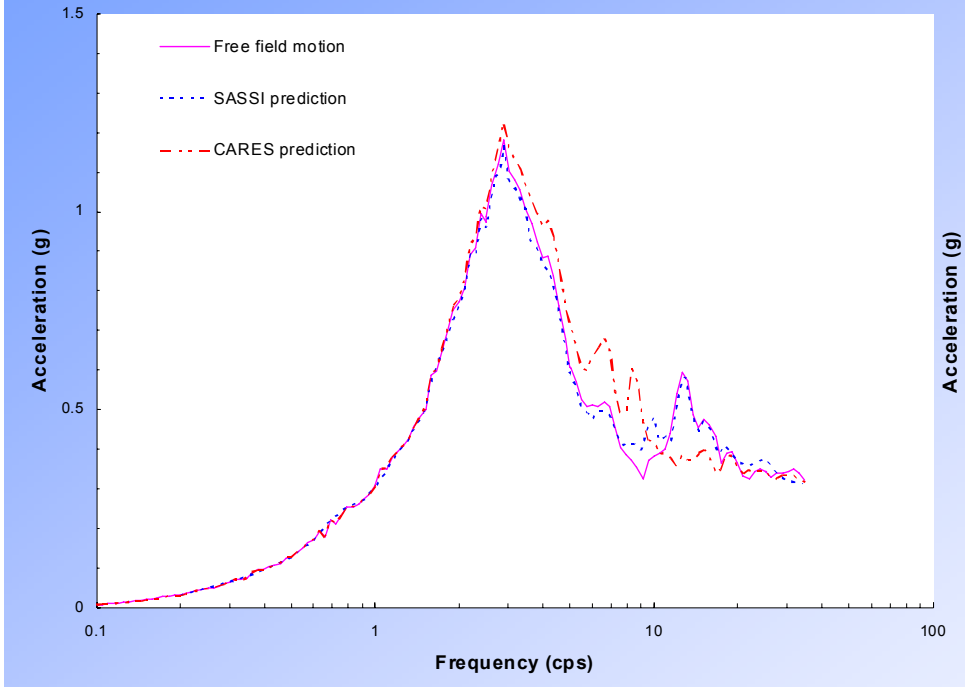
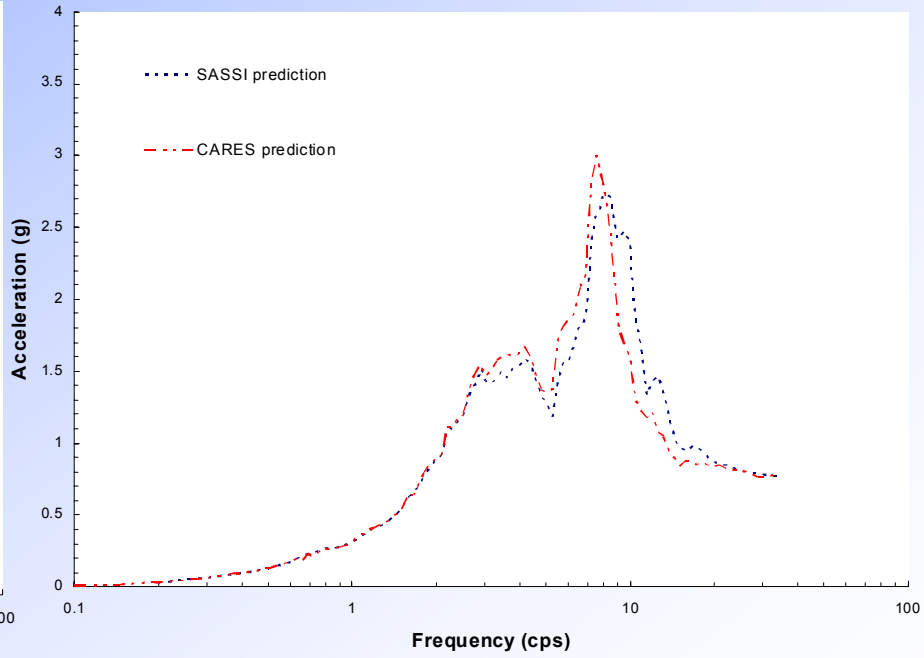
Comparison of Response Spectra DOB = 23 m, Soil Column C

Base



Roof



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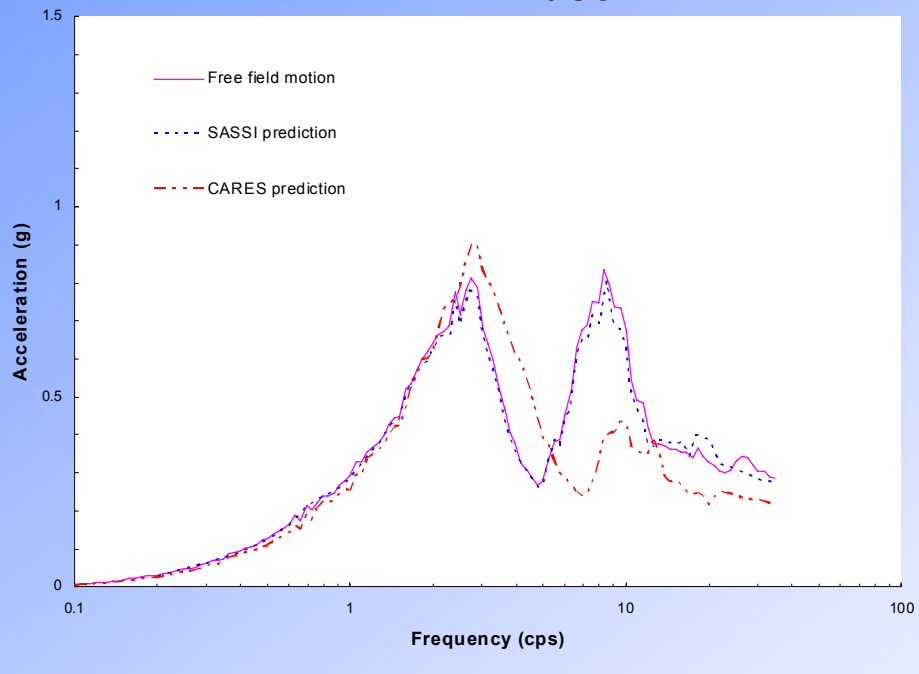
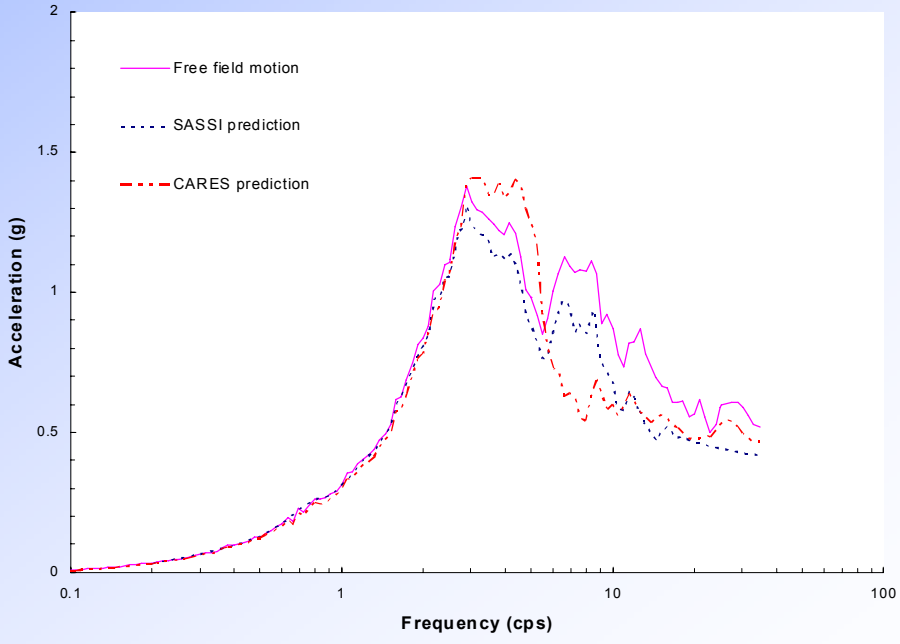
Comparison of Response Spectra
DOB = 46 m, Soil Column C

Base



Roof



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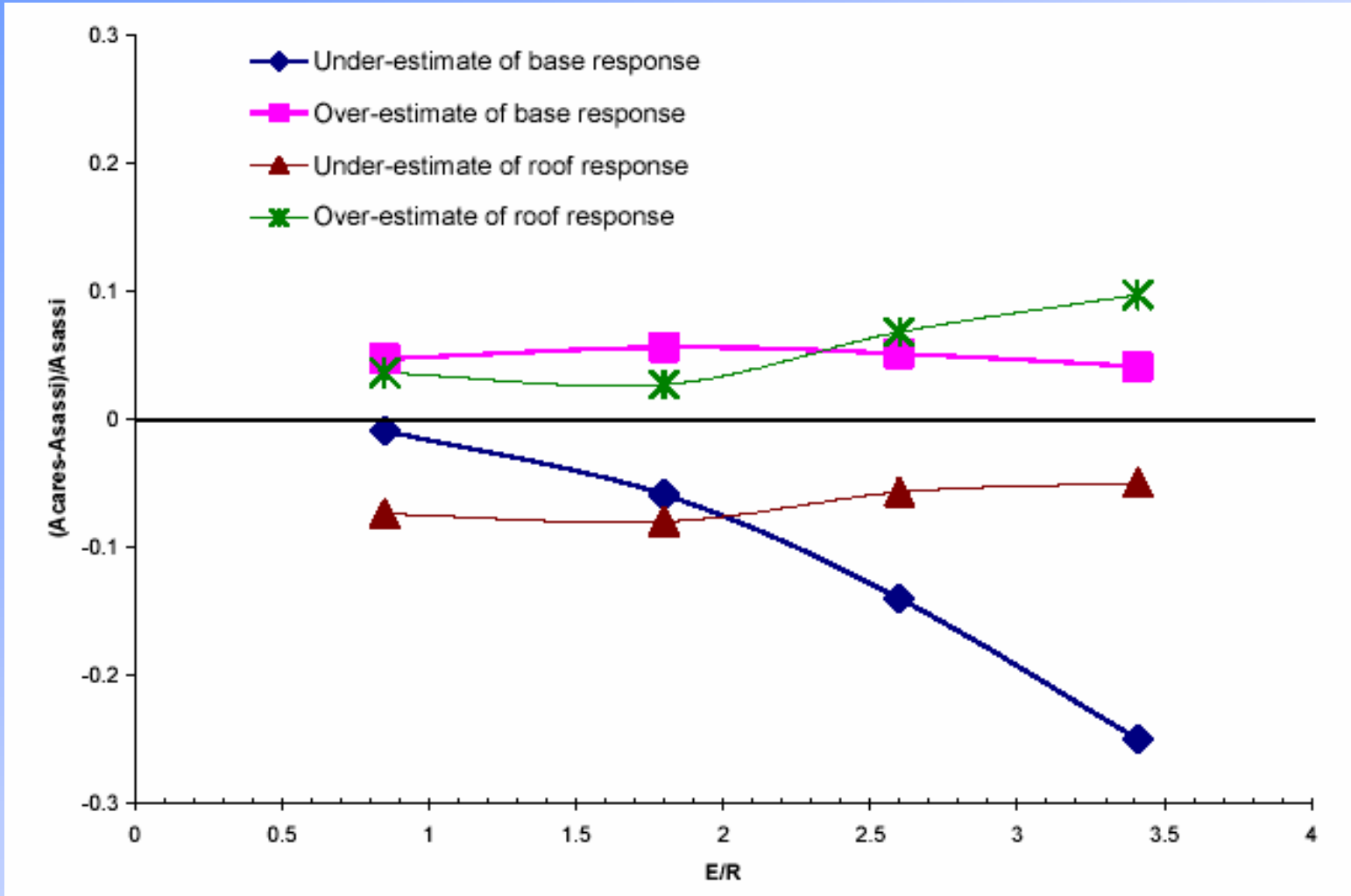
Performance Evaluation for SSI Analyses, Soil Column C--- Area Differences



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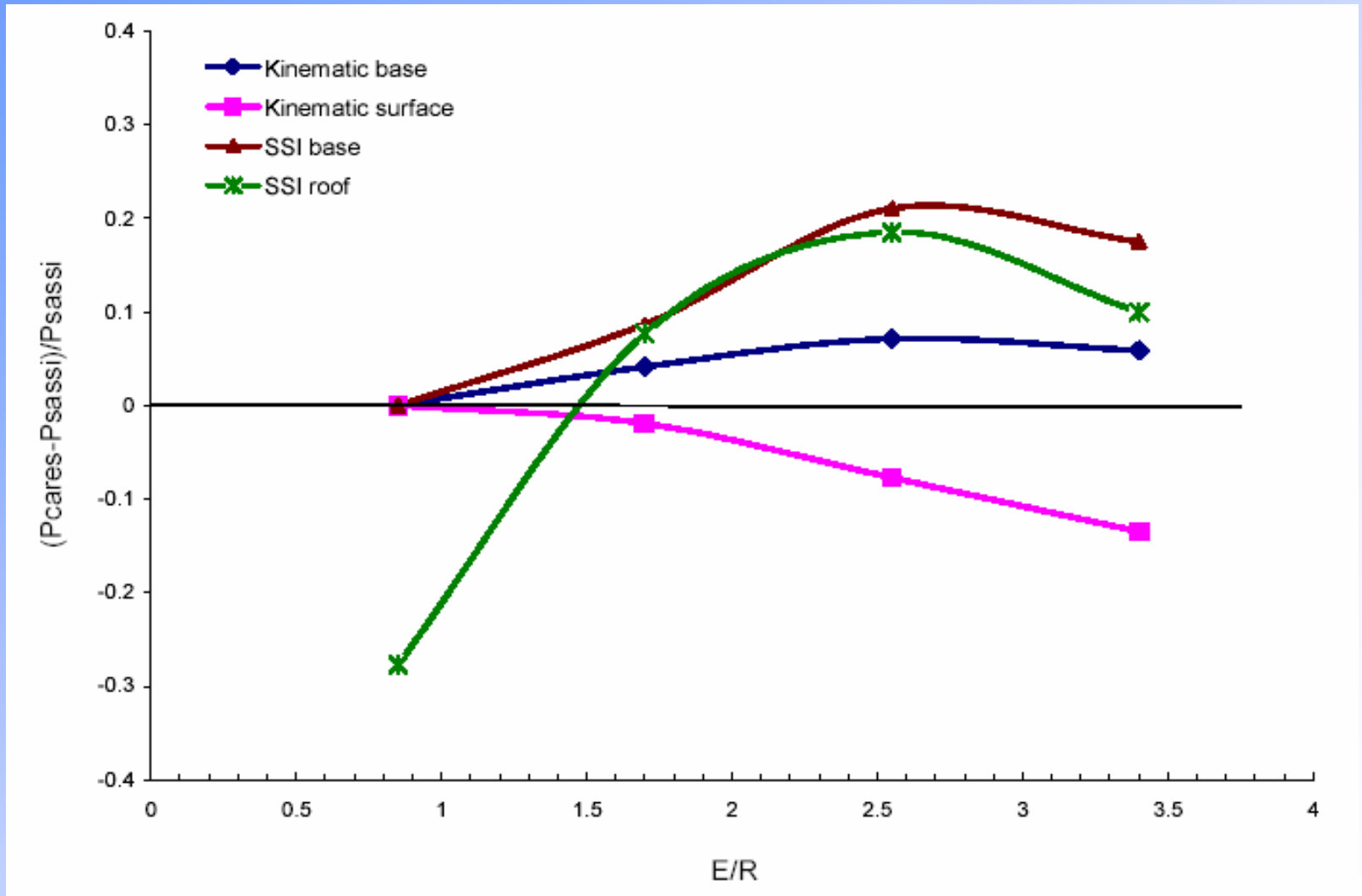
Performance Evaluation for SSI Analyses, Soil Column C--- Peak Spectral Differences



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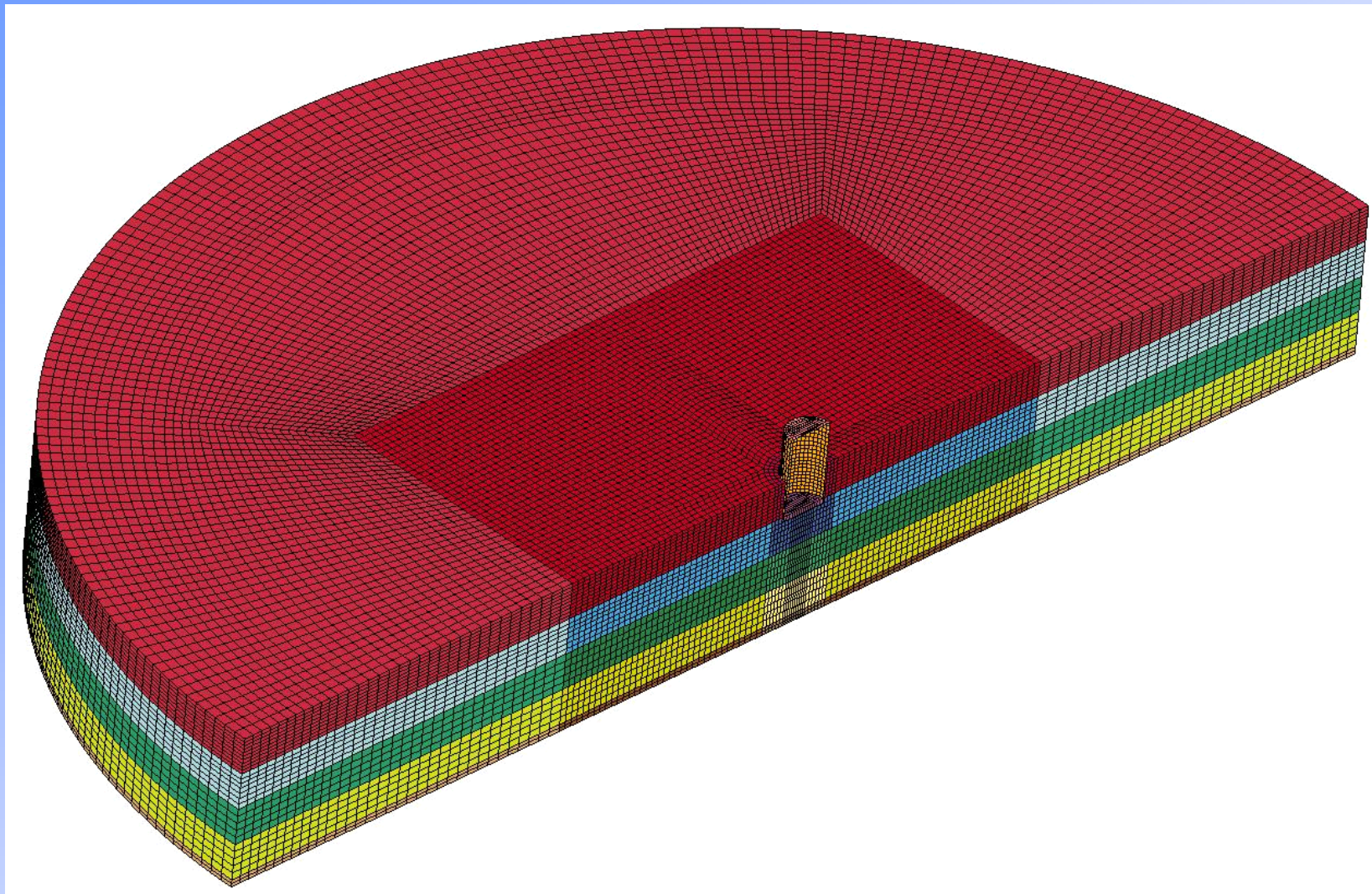
SEISMIC SOIL PRESSURE CALCULATIONS

- Evaluation of Methods for Computing Seismic Induced Pressures for DEB Structures
- SASSI
- LS-DYNA: Explicit Finite Element Program
- Assumption of Linearity applied in both analyses

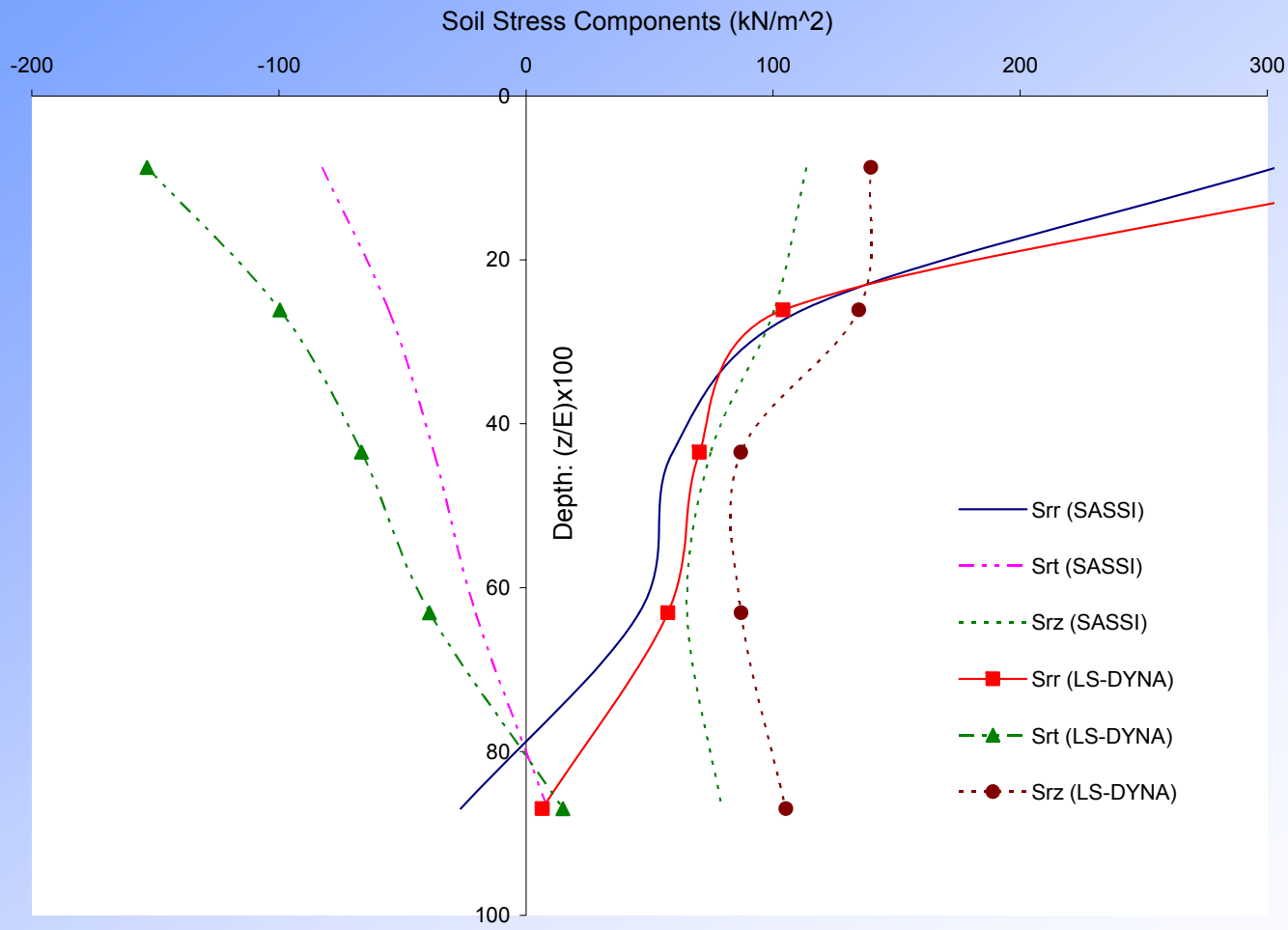
CALCULATION OF SOIL PRESSURES (Cont'd)

- Soil pressures computed for four depths of burial (11.5m, 23m, 34.5m, and 46m)
- Circumferential variation of pressures are found to be either sine or cosine as expected
- Vertical distribution of pressures shows strong SSI effect which is predominantly inertia interaction for shallow embedded structures to principally kinematic interaction for deeply embedded structures

LS-DYNA MODEL FOR 50% DOB



VERTICAL DISTRIBUTION OF SOIL PRESSURE FOR 25% DOB



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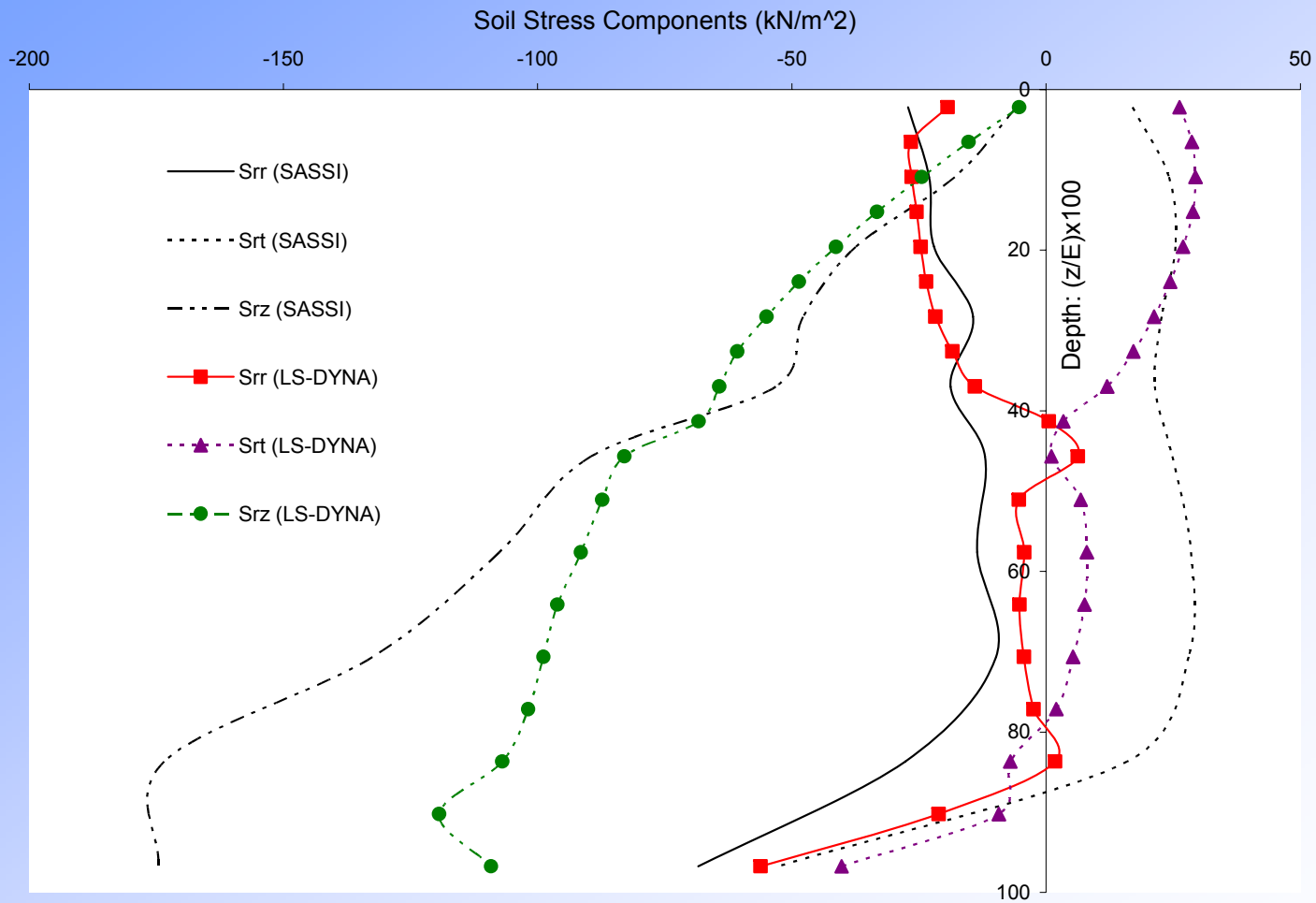
VERTICAL DISTRIBUTION OF SOIL PRESSURE FOR 100% DOB



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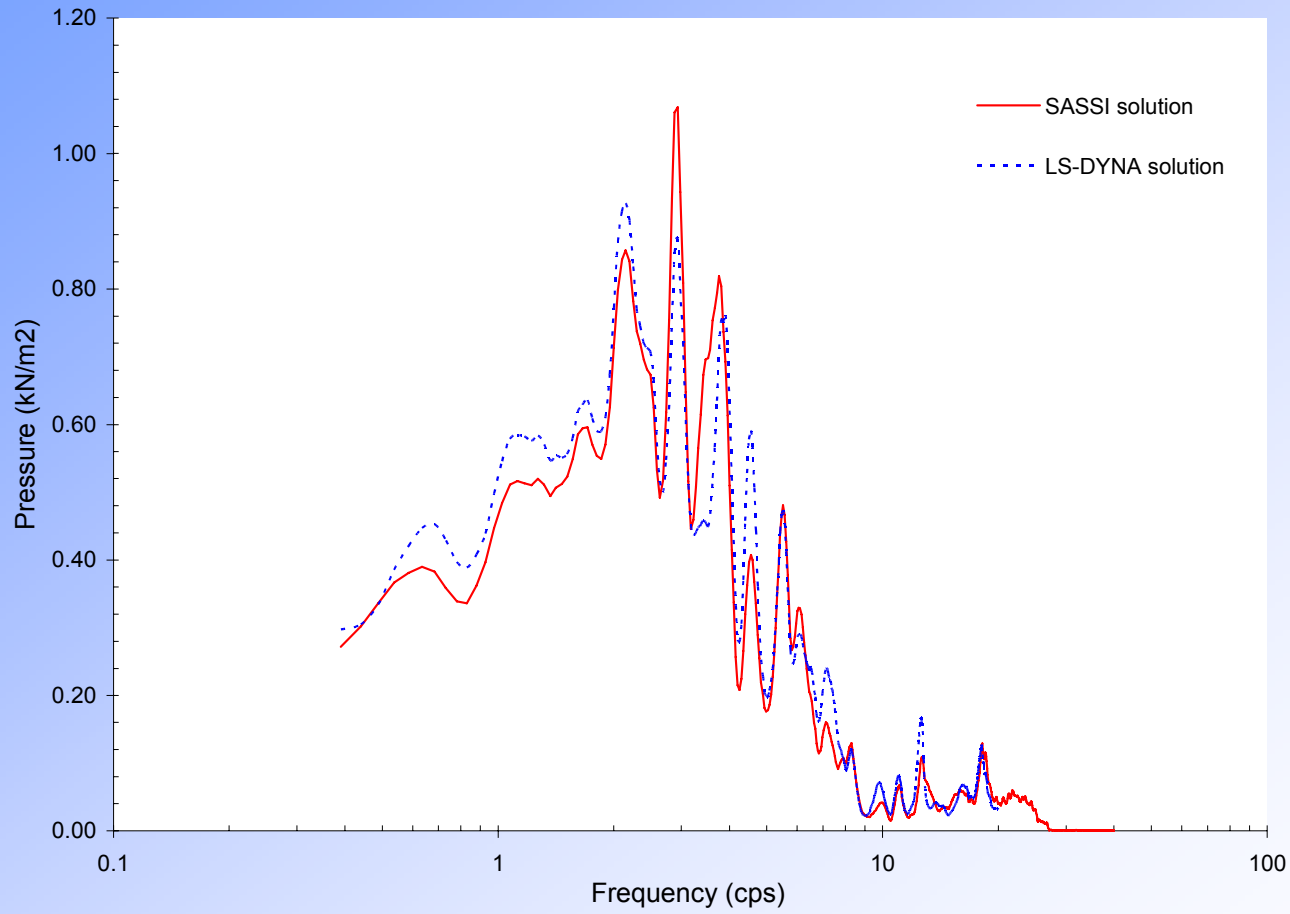
Fourier Spectra of Soil Pressure for 75% Depth of Burial



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Conclusions

- Assessed the state-of-the-art (current analyses methods acceptable for ground motions that do not result in non-linear SSI response).
- For SSI spectrum computation, both CARES and SASSI compare comparably; simplified approach mostly predicted slightly higher responses
- For wall pressure calculation, reasonably close comparisons were shown between SASSI and LS-DYNA (linear domain).
- When non-linearity is modeled (no discussion was made in this presentation; detailed analysis can be found in NUREG/CR-6896), such as contact area between foundation and soil, and nonlinear soil models, the wall pressure distributions would be vastly different from linear analysis.