

***2017 Pacific Rim Forum
Earthquake Resilience of Nuclear Facilities***

**Current SSI State-of-Practice and Future
Advancements:**

IAEA Technical Document

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IAEA Technical Document (Tecdod): SSI Methodologies Current Table of Contents

1. Introduction
 2. Elements of SSI
 3. Site configuration and soil properties
 4. Seismic hazard analysis (SHA)
 5. Seismic wave fields and free-field ground motion
 6. Site response analysis and seismic input
 7. Methods and models for SSI analysis
 8. Seismic response aspects for design and assessment
 9. Available software including V&V
 10. Sustainable capacity building
 11. References
- Appendices
Questionnaire



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1. INTRODUCTION

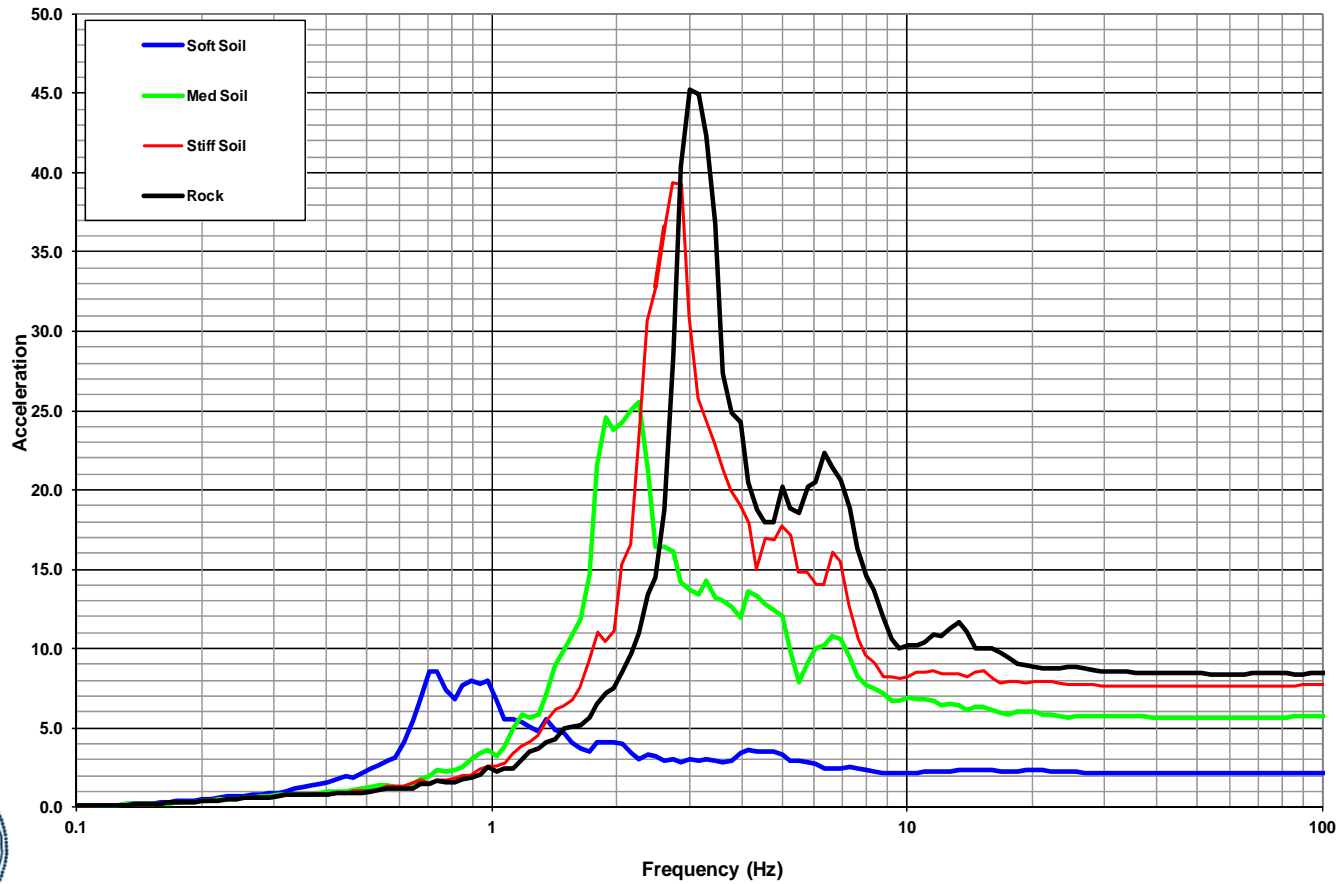
- Background
 - Importance of SSI to seismic response of structures
 - Historical perspective 1960s – present
- Objectives
 - Document state-of-practice and future vision of SSI analysis
 - Identify important aspects of site, structure, and ground motion to SSI
 - Provide guidance on applications
 - Identify and recommend treatment of uncertainties (aleatory and epistemic)



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1. INTRODUCTION

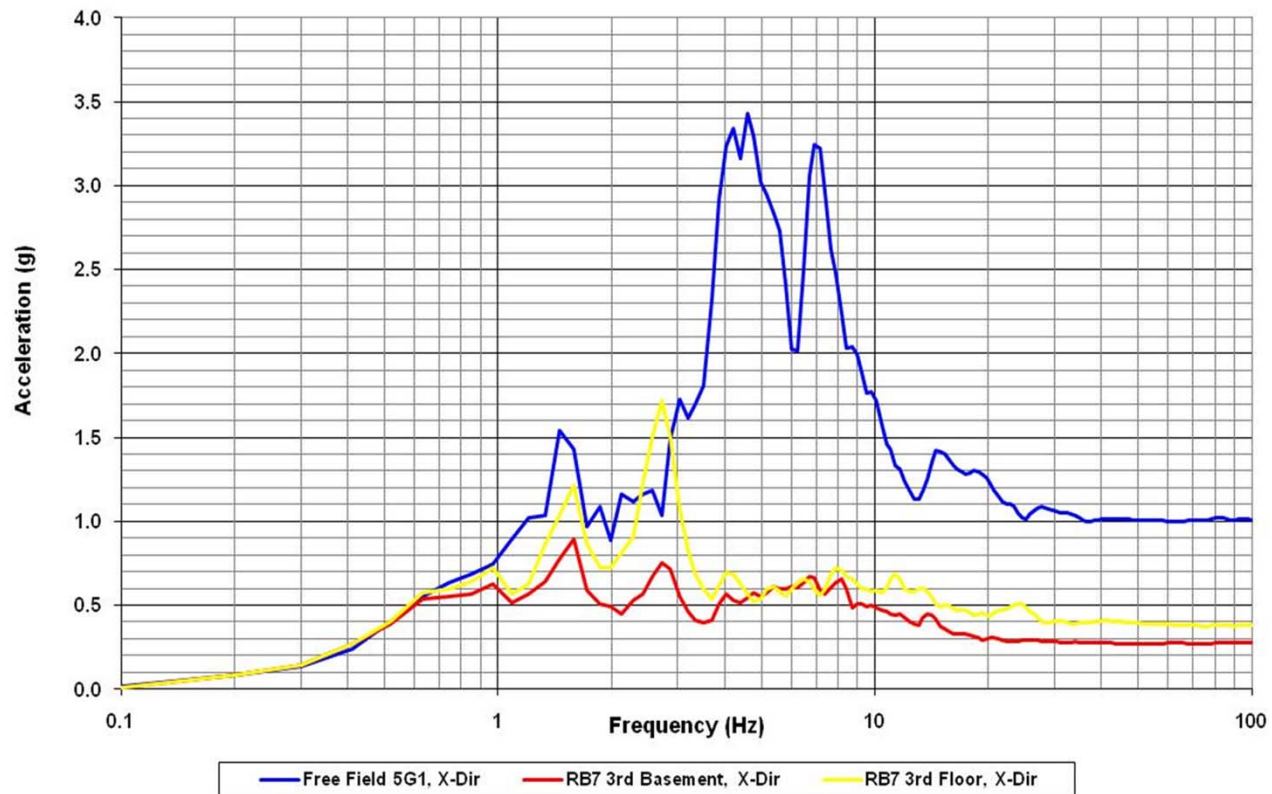
Response Spectra, Top of Shield Building, Horizontal-Direction



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1. INTRODUCTION

Task 1.1.2.C - Mainshock, 2007/07/16 10:13, Recorded Time Histories, Freefield 5G1, RB7 3rd Basement and RB7 3rd Floor, X-Direction (NS)



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1. INTRODUCTION

- Focus is design and assessments of nuclear installations
- Design
 - New installations
 - Nuclear power plants - Reference Designs, Certified Designs,
 - Other installations (e.g., U.S. DOE, Japan, other)
 - Retrofit and upgrades of existing installations
- Assessments
 - Beyond Design Basis Earthquakes
 - Seismic Probabilistic Risk Assessments (SPRAs)
 - Seismic Margin Assessments (SMAs)
 - Forensic analysis of installations that experienced earthquake ground motion



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1. INTRODUCTION

- Framework of SSI analysis in an overall design or assessment process
 - Design to be conservative – how conservative
 - Assessment to be realistic – how realistic
- Performance goals may be
 - Probabilistic or deterministic
 - Specified in terms of overall installation behavior or at the individual structure, system, and component (SSC) level
 - Coupled design and beyond design basis conditions
- Risk metrics (failure probability, CDF, LERF)



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1. INTRODUCTION

- Performance goals
 - U.S., Canada, U.K., and others – at the highest level risk-based
 - France and others – meet safety objectives
- Performance goals need to be tiered down to the level of seismic analysis, design, and qualification and to the level of seismic assessment of beyond design basis, including acceptance criteria
 - ASCE 4 + ASCE 43 – probability of unacceptable performance
 - <1% DBE
 - <10% 1.5 x DBE
 - All design procedures are deterministic



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2. ELEMENTS OF SSI: Roadmap to Succeeding Chapters

3. Site configuration and soil properties
4. Seismic hazard analysis (SHA)
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3. SITE CONFIGURATION AND SOIL PROPERTIES

- In-situ soil profiles and configurations
 - Field investigations – geological, geophysical, and geotechnical (GGG) – guidance from IAEA SSG-9 and other sources – low strain – assess site configuration for idealization (1D, 2D, 3D)
- Constitutive models – linear, equivalent linear, nonlinear – description – strain range of applicability – most general is nonlinear coupled bulk/deviatoric
- Field and laboratory measurements
- Calibration and validation



ncertainties

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4. SEISMIC HAZARD ANALYSIS (SHA)

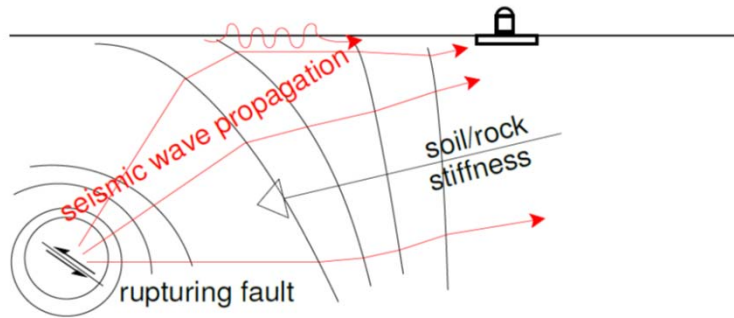
- Probabilistic and/or deterministic
 - Country specific approaches
- Focus on identifying the output requirements from the SHA for design and beyond design basis earthquake considerations
 - Function of analyses to be performed and their end products – e.g., end product of risk metrics requires PSHA and probabilistic quantities
- Focus on understanding what parameters are included in the SHA – e.g., site specific characteristics



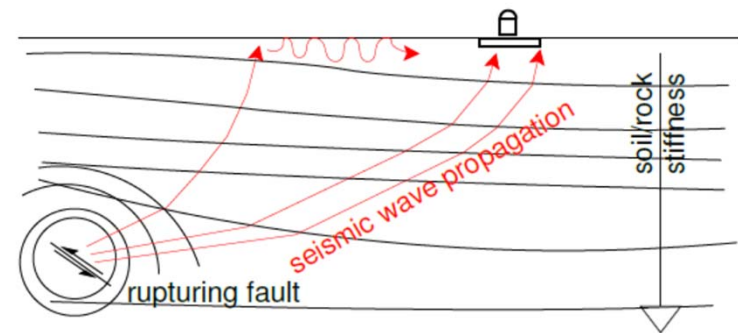
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5. SEISMIC WAVE FIELDS AND FREE-FIELD GROUND MOTION

Predominately 3D behavior



Simplified to 1D representation



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5. SEISMIC WAVE FIELDS AND FREE-FIELD GROUND MOTION

- Earthquake source, propagation path, and site near surface soil/rock material
- Free-field ground motion
 - Ground motion prediction equations (GMPE)
 - Large scale regional numerical simulations (source to site)
 - Site response analysis (Chapter 6)
- Spatial variation of ground motion
 - Over the width and depth of the structure foundation



Incoherence

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6. SITE RESPONSE ANALYSES AND SEISMIC INPUT

- Site response analysis considerations
 - One of the most important elements to defining the seismic input and soil material behavior in the process
 - Design (site independent or dependent ground motion) vs. assessment (SPRA-SMA-actual EQ)
 - Account for the physics of the wave propagation phenomena – spatial variation of motion
 - Define equivalent linear or nonlinear soil/rock behavior



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6. SITE RESPONSE ANALYSES AND SEISMIC INPUT

- Site response analysis considerations
 - Define seismic input motion to SSI model and analyses
 - Idealized soil profile and wave propagation mechanism—horizontal layers and vertically propagating body waves – when is it justified
 - Foundation Input Response Spectra (FIRS)
 - Non-idealized soil profile and 3D wave fields
 - Input motion of “soil island model” for nonlinear SSI
 - Methods of site response analysis dependent on SHA output quantities and requirements for the SSI model and analyses



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6. SITE RESPONSE ANALYSES AND SEISMIC INPUT

- Seismic Input – frequency characteristics
 - Standard response spectra
 - Site-specific response spectra based on PSHA or DSHA results, including design factors to achieve risk consistent definitions
 - Time histories



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7. METHODS AND MODELS FOR SSI ANALYSIS: Extensive Menu

- Basic Engineering Steps
 - Method and model selection
 - Method and model – V&V process
 - Execution
- Direct methods
 - Linear, equivalent linear, and nonlinear discrete methods
- Substructure methods
 - Classically considered to rely on super-position
 - Linear or equivalent linear



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7. METHODS AND MODELS FOR SSI ANALYSIS: Extensive Menu

- Aspects of SSI Computational Models
 - Soil rock linear/nonlinear modeling
 - Domain boundaries – hybrid linear/nonlinear
 - Seismic load input
 - Structure models
 - Contact/uplift/sliding
 - Buoyancy
 - Deeply embedded
 - Structure-soil-structure interaction
 - Probabilistic response analysis
 - More



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8. SEISMIC RESPONSE ASPECTS FOR DESIGN AND ASSESSMENT

- Decision-making –
 - Guidance on the selection and implementation of the elements of SSI analysis as described in Chapters 1-7 – dependent on purpose of analyses and physical conditions (site, structure, ground motion)
 - Accounting for uncertainties (aleatory and epistemic) that exist in all aspects of the models and modeling
 - Sensitivity studies to be performed



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CHAPTERS 9-11

9. AVAILABLE SOFTWARE INCLUDING V&V
 - Listing and availability
 - Tied to knowledge and experience of authors and results of the Questionnaire
10. SUSTAINABLE CAPACITY BUILDING
11. REFERENCES

Appendices – many examples

Questionnaire:

- Seek input on all aspects of SSI from Working Group Members concerning Chapters 1-11



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IAEA TEAM

- IAEA Coordinator
 - Mr. Jehad Haddad
- Task Leaders:
 - Mr Nebojsa Orbovic, CNSC
 - Mr Matthieu Caudron, EDF
- Principal Authors
 - Prof. Boris Jeremic
 - Dr. James J. Johnson
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WORKING GROUP MEMBER COUNTRIES

France

United States

Canada

Korea

Spain

Switzerland

China

Russia



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TIMELINE

- Planning prior to February 2016 – including first WG Meeting
- First meeting for CS writing – 23-26 February 2016
- Second meeting for CS writing – 3-5 October 2016
- Draft Rev. 0 of Chapters 1-7 complete
- Second WG Meeting – 13-15 December 2016
- External Review Panel – Dr. Robert P. Kennedy, Prof. Eduardo Kausel
- Draft Rev. 1 of complete document – June 2017
- Draft Final – end of 2017



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Questions and Discussion



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