ICP

IDAHO CLEANUP PROJECT

Non-Linear Seismic Soil Structure Interaction (SSI)

Method for Developing Non-Linear Seismic SSI Analysis Techniques

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SAFELY PLAN • MOTIVATE • DELIVER

Presentation Outline

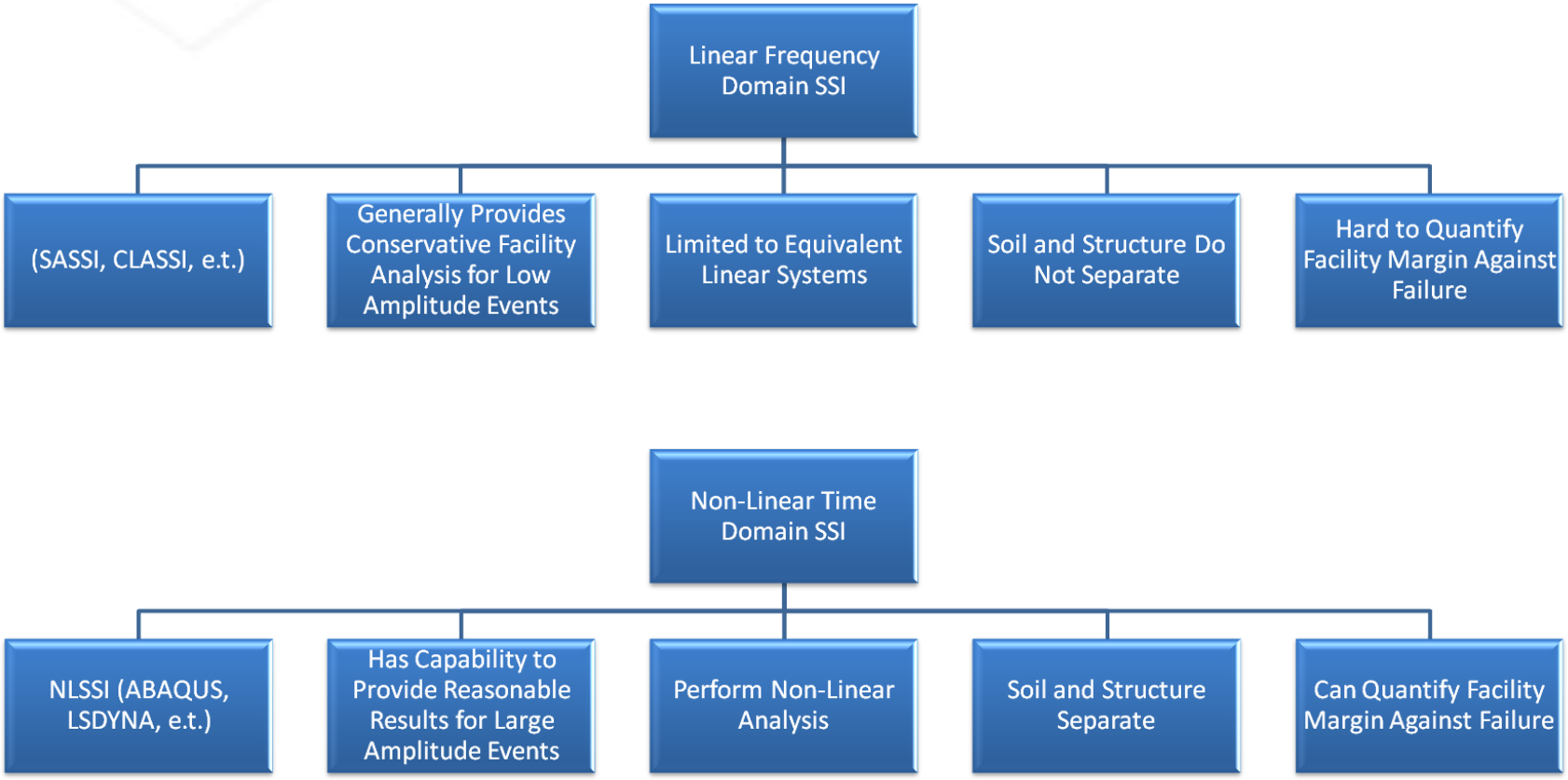
- Purpose of Presentation
- Linear versus Non-Linear Seismic SSI
- **N**on-**L**inear seismic **S**oil **S**tructure **I**nteraction (NLSSI) Studies
- The NLSSI Introduction
- Non-Linearity in Seismic SSI Analysis
- Commercial Software Elements
- Commercial Software Non-Linear Constitutive Models
- Non-Linear Seismic SSI Damping
- Demonstration of Time Domain 2D Model
- NLSSI Validation Approach
- NLSSI Implementation
- Need For NLSSI
- Conclusions

Purpose of Presentation

- The purpose of the presentation is to establish the need for using non-linear analysis software for performing NLSSI analysis

- Propose a method for implementing NLSSI analysis in nuclear facilities

Linear versus Non-Linear Seismic SSI



Non-Linear Seismic SSI Studies

- Studies indicate the need for performing non-linear analysis techniques
  - "EFFECT ON NON-LINEAR SOIL-STRUCTURE INTERACTION DUE TO BASE SLAB UPLIFT ON THE SEISMIC RESPONSE OF A HIGH-TEMPERATURE GAS-COOLED REACTOR (HTGR)" Kennedy, R.P. e.t. all. 1975
  - NUREG/CR-6957, CORRELATION OF ANALYSIS OF JNES SEISMIC WALL PRESSURE DATA FOR ABWR MODEL STRUCTURES, Xu et. all, 2008
  - "Three-dimensional nonlinear seismic ground motion modeling in basins," Xu et all, 2002

NUPEC Field Test Model of Reactor Building with Embedment

The NLSSI Introduction

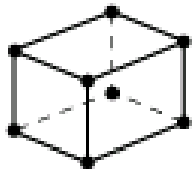
- **N**on-**L**inear **S**oil **S**tructure **I**nteraction analysis method (NLSSI)
- Utilize commercially available time domain explicit software to perform seismic SSI
- Commercially available non-linear analysis software GUI interfaces provide less user error.
- Commercial software packages with robust quality assurance programs provide software control
- Fast computer processors on multiple cores provides reasonable solving times for complex time domain problems.
- The NLSSI analysis approach potentially provides more realistic representation of facility response during earthquake motion
  - Better understanding of margin against failure
  - Provides a more accurate representation of the soil and facility

Seismic SSI Analysis Non-Linearity

- Types of non-linearity in SSI analysis
  - Geometric
    - Contact – Sliding and Separation
    - Non-linear springs
  - Material
    - Elastic/Plastic
  - Non-linear soil behavior
  - Non-linear behavior between soil and structure (i.e. the inability of soil to resist tension)
  - Non-linear behavior of the structure (i.e. steel and concrete)

Commercial Software Elements

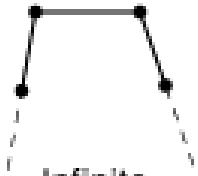
- Commercial software packages provide a large range of suitable structural elements
  - Solid element
  - Shell elements
  - 3D beam
  - Infinite Elements - Passes waves through boundaries.



Continuum (solid and fluid) elements

Shell elements

Beam elements

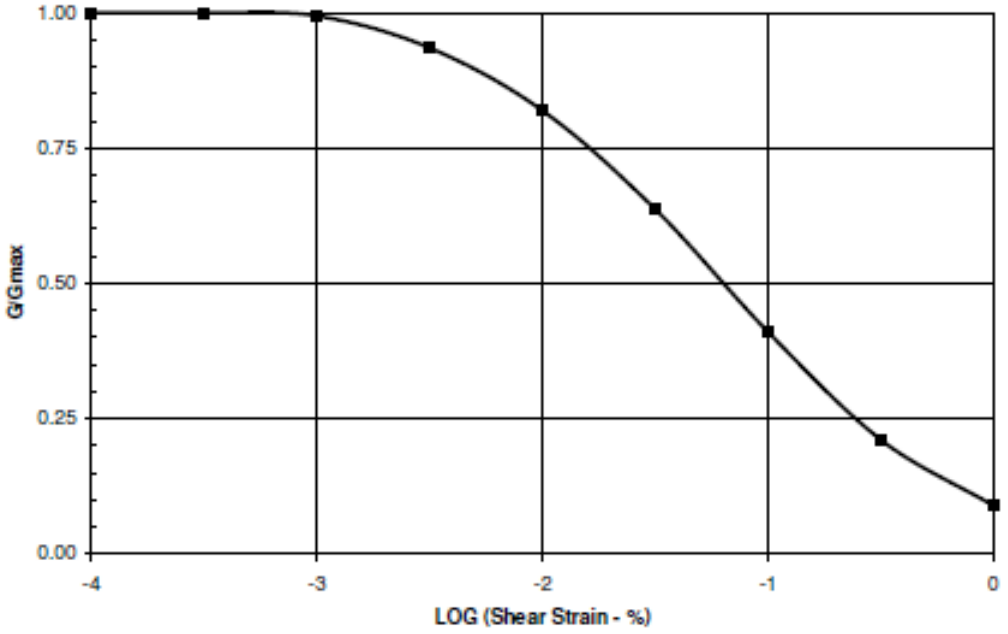


Infinite elements

Commercial Software Non-Linear Constitutive Models

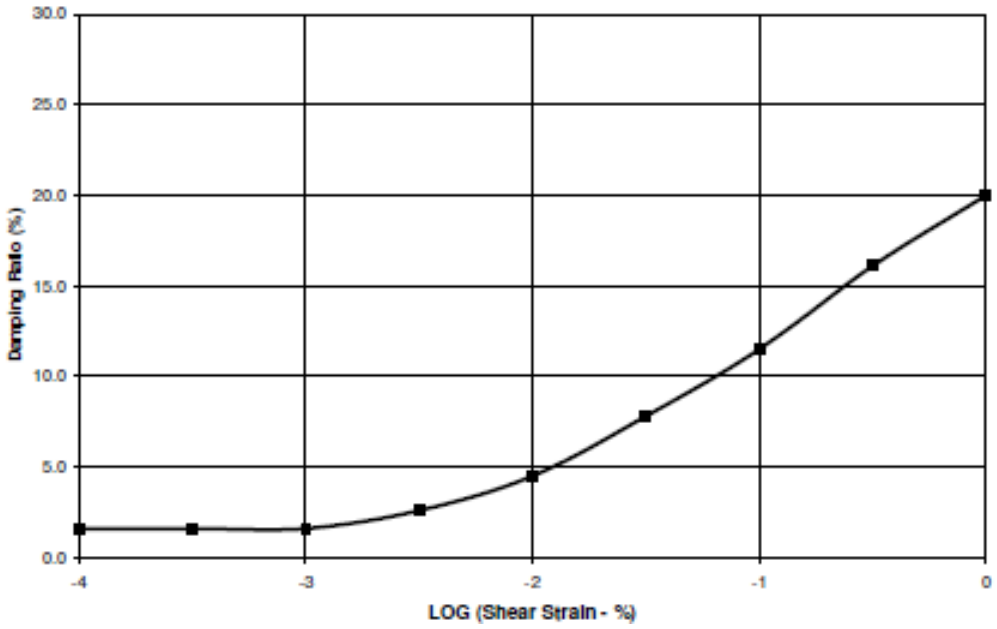
- Material Models for commercially available software:
  - Cracked Concrete Constitutive Models – Developed to match concrete stiffness reduction or load displacement curves
  - Soil Plasticity Constitutive Models
  - Metal Plasticity Definitions

Soil Shear Modulus Reduction Curve



Non-Linear Seismic SSI Damping

- In the Finite Element model damping is primarily from three sources:
  - Material damping – Choice of constitutive model
  - Numerical damping – Helps with stability of the solution
  - Boundary Conditions- Affect the way in which the numerical model transmits the specific energy of the stress waves.
    - Models the “contact” between the soil and structure

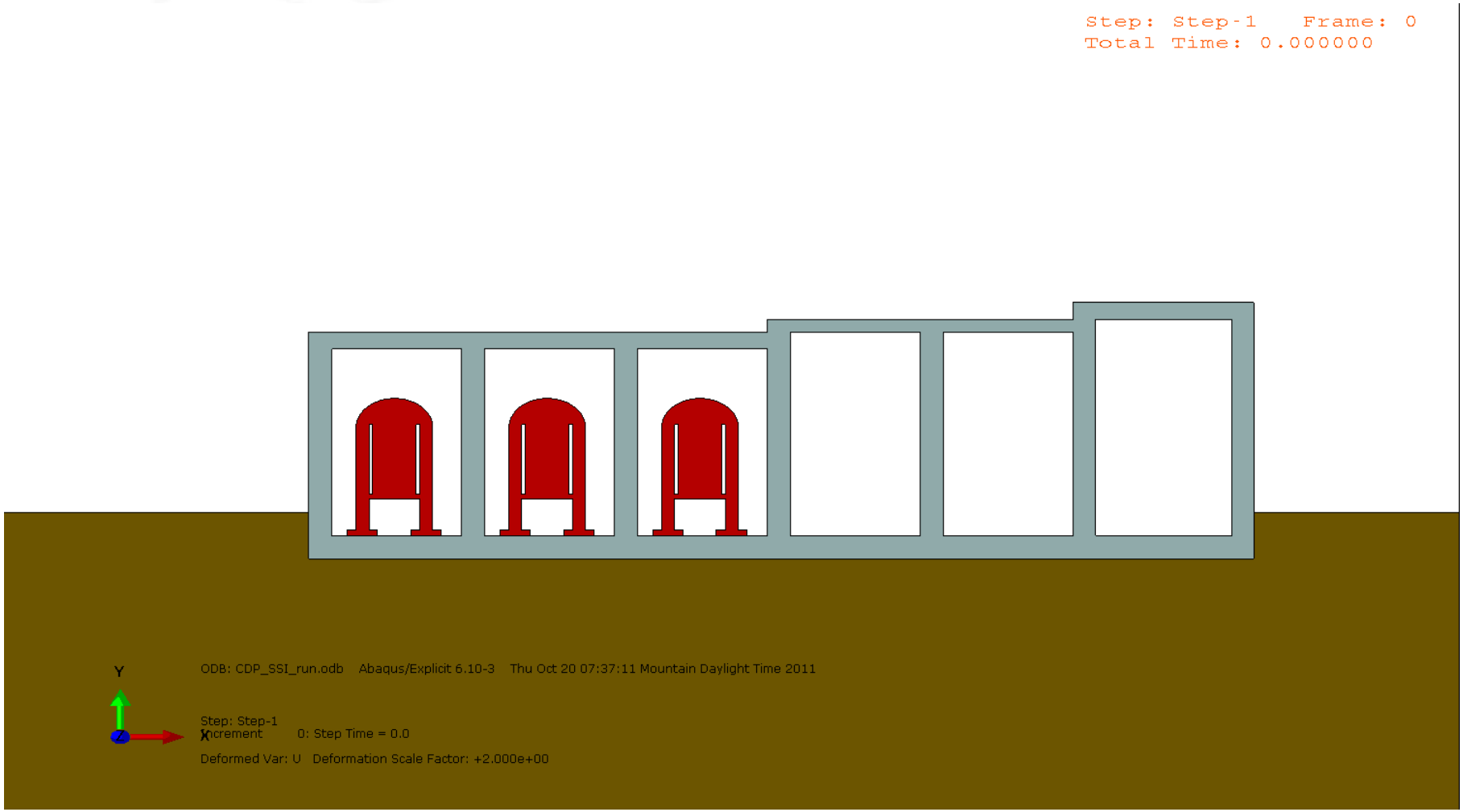


- Validation of the Constitutive models are necessary to assure the appropriate soil and structure response is captured
- Additional structural damping may be required

Demonstration of Time Domain 2D Model

- Demonstration of the explicit time domain capabilities using a 2D model of the Calcine Disposition Project (CDP) process in the existing IWTU cells
- This demonstrates the modeling capabilities of explicit time domain codes to model contact and allow waves to travel through soil and structure during earthquakes.
  - Demonstration Limitations:
    - HIP Unit Mass Not Representative
    - Concrete and Soil are modeled as linear elastic
    - Damping has not been Validated
    - Soil is modeled as one homogeneous layer
    - Cell geometry is simplified

Demonstration of Time Domain 2D Model



NLSSI Validation Approach

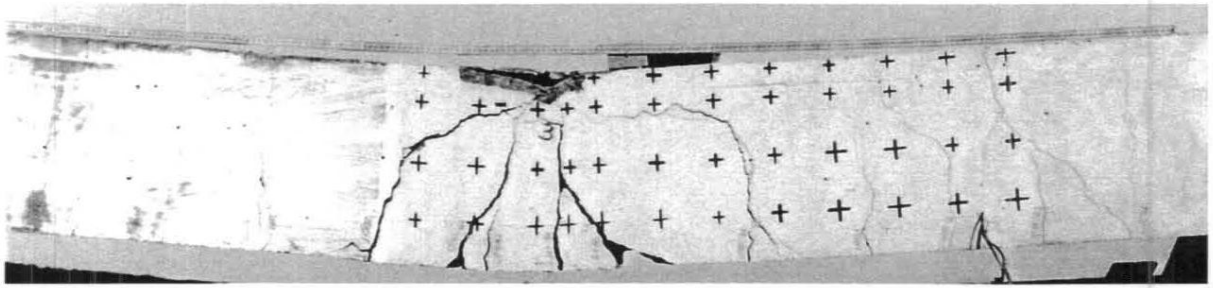
- Validation provides evidence that the correct model is solved.
- Component validation (material modeling, vibration analysis, soil pressures)
  - Constitutive (macroscopic material) behavior
  - Contact/interface behavior
  - Energy dissipation characteristics
- Complete system validation
  - Lotung (1/4 scale containment model) LSST tests
  - Fukushima-Daiichi NPP data
  - Japanese NUPEC tests

Slide from, **Jeremi´c, High Performance, High Fidelity Modeling and Simulation of Earthquake-Soil-Structure Interaction for Nuclear Power Industry Quake Summit 2011, NEES & MCEER Annual Meeting, Buffalo, NY, June 9-11, 2011**

NLSSI Validation Approach

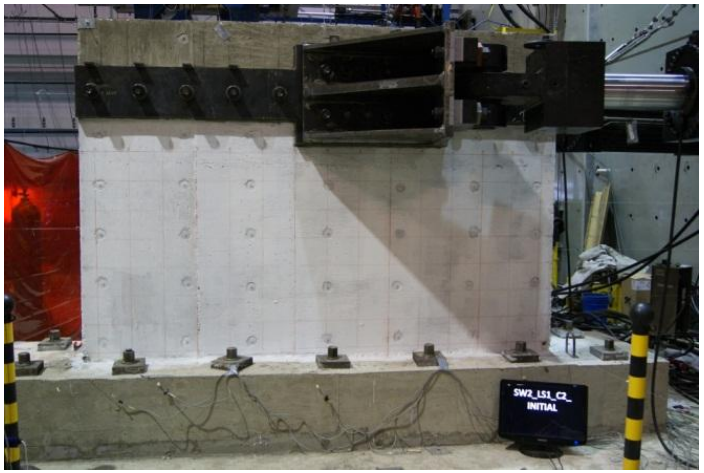
- Analyze simple models to validate the soil constitutive model and the structural constitutive model against experimental results

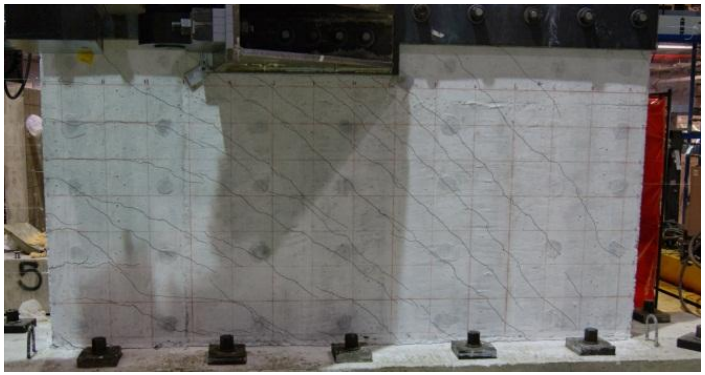
- Analyze the coupled SSI system and benchmark against experimental or actual results



NLSSI Validation Approach

- Validate the structure constitutive model by validating it against known results.
  - Performed impact modeling in non-linear software package
  - Use shear wall testing data from “Seismic Response of Low Aspect Ratio Reinforced Concrete Shear Walls,”
- Model and analyze coupled SSI system and benchmark against experimental and known results





NLSSI Proposed Development Approach

Model and Analyze Simple Linear Soil Columns

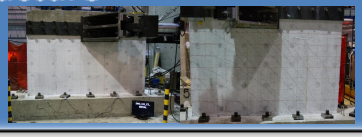
- Compare to Hand Calculated and Experimental Results

Model and Analyze Lotung SASSI Benchmark Problem as Linear SSI

- Compare Results to Experimental and SASSI

Release the tie between soil and structure and note difference

Model and Analyze Simple non-linear soil and structure experimental problems

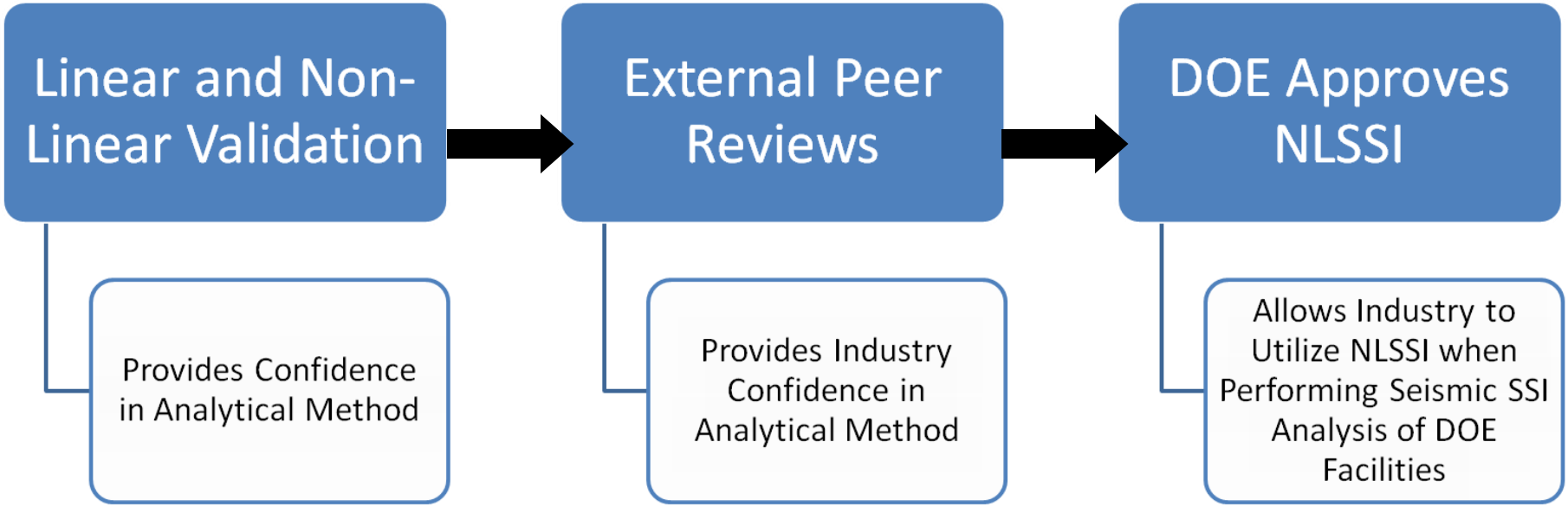


Implement non-linear constitutive models in Lotung problem

- Drive model with larger amplitude time histories and note the difference
- Compare to large amplitude event data, Japan Kishiwazaki, Japan Fukishima

NLSSI Proposed Method

NLSSI Implementation



Need For NLSSI

- Provides more accurate representation of seismic Soil Structure Interaction
- Increases DOE confidence in facilities margin against failure
- Potentially saves cost of construction
- Eliminates the need to utilize multiple software packages to perform the analysis; only one is needed

Conclusion

- Commercial software packages have capabilities for performing non-linear SSI methods
- Commercial software packages with robust quality assurance programs provide software control
- Commercial software packages provide user friendly Graphical User Interface that minimize input errors and maximize post processing capabilities
- NLSSI provides a more accurate representation of soil structure interaction during earthquake events
- NLSSI improves confidence in predicting nuclear facilities margin against failure
- DOE standardizes the NLSSI for Nuclear facility seismic analysis
- NSR&D funding needed for development of the NLSSI