Overview of Development of P-CARES: Probabilistic Computer Analysis for Rapid Evaluation of Structures

Jinsuo Nie, Jim Xu, Carl Costantino
Energy Sciences & Technology Department
Brookhaven National Laboratory

Vaughn Thomas
Office of Nuclear Regulatory Research
US Nuclear Regulatory Commission

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Background

- CARES, Computer Analysis for Rapid Evaluation of Structures, was developed by BNL for the NRC in late 1980's
  - To assist the staff as a tool to quickly check the validity and/or accuracy of the soil-structure interaction models and associated data in reviewing NPP applications
  - Use relatively simplified soil and structure models
  - Facilitate the sensitivity assessment of the computed seismic responses to a variety of controlling parameters
  - Deterministic site response and SSI analyses
- P-CARES, Probabilistic CARES, is the most recent successor of CARES

Timeline

- CARES Version 1.0, 1990
  - Combination of SLAVE (free-field) and SIM (SSI)
- CARES Version 1.1, 1992
  - Increased problem size, FFT, new soil degradation models, etc
- CARES Version 1.2, 1995
  - Added features: rigid links, composite damping, shear wall element, rectangular foundations, etc
- CARES Version 1.3, 2000
  - Kinematic interaction effects, improved structural damping models, etc
- P-CARES Version 2.0, 2007

Uncertainty Treatment

- Uncertainties are inherent in soils, structures, loadings, and modeling, and must be addressed appropriately
- The traditional deterministic bounding approaches, as in SRP 3.7 and ASCE 4-98, are widely considered conservative
- Recent advanced stochastic seismic analysis is shown to be more realistic
  - ASCE 43-05 utilizes a probabilistic approach for determining the design factors for soil site
  - ANSI/ANS-58.21 requires a probabilistic SSI response analysis for seismic PRA
  - Trend in industry practices for probabilistic site response analysis in Early Site Permit applications

Objective and Scope of P-CARES

- Uncertainty treatment
  - Uncertainties in structural properties are relatively small and not included
  - Uncertainties in ground motions are the greatest and however will be addressed in future development
  - Uncertainties in site soil properties are considered in the current development stage
- Usability and productivity enhancement
  - User friendly GUI

Uncertainties in P-CARES

- Site soil is modeled as a layered profile, as in CARES
- Random variables include soil density, low-strain soil shear modulus, and soil layer thickness
  - Material damping ratios are strain-compatible and are obtained using soil degradation models
  - A total of 3N variables (N is the number of layers)
- All random variables are modeled with lognormal distributions
  - Soil properties are all positive
  - Lognormal distribution is close to normal distribution if the variance is small
  - Convenient for correlation incorporation
  - An efficient implementation for the intended application of P-CARES
- Arbitrary feasible correlation can be specified
  - A quick exponential correlation rule is an option in P-CARES

Probabilistic Simulation

- CARES provides deterministic capability for site response and SSI analysis and works as the essential building block for probabilistic simulation in P-CARES
- Each sample in the probabilistic simulation corresponds to a soil-structure system realization and can be analyzed deterministically
- The fundamental simulation procedure to convert an independent standard normal random vector to a dependent lognormal random vector
- Simulation schemes differ only in how the independent standard normal vector is generated

Four Simulation Schemes

- Traditional Monte Carlo
  - Generate an independent standard normal vector directly
- Latin Hypercube (LHC) Sampling
  - Generate an independent uniform vector and then convert to an independent standard normal vector
  - A point is randomly generated in each interval
- Engineering LHC
  - Same as LHC except that the median point is used for each interval
- Fekete Point Set Method
  - A uniform point set is generated on a unit hypersphere
  - The set is then transformed into a unit hypercube
  - Each point in this set is then converted into a standard normal vector

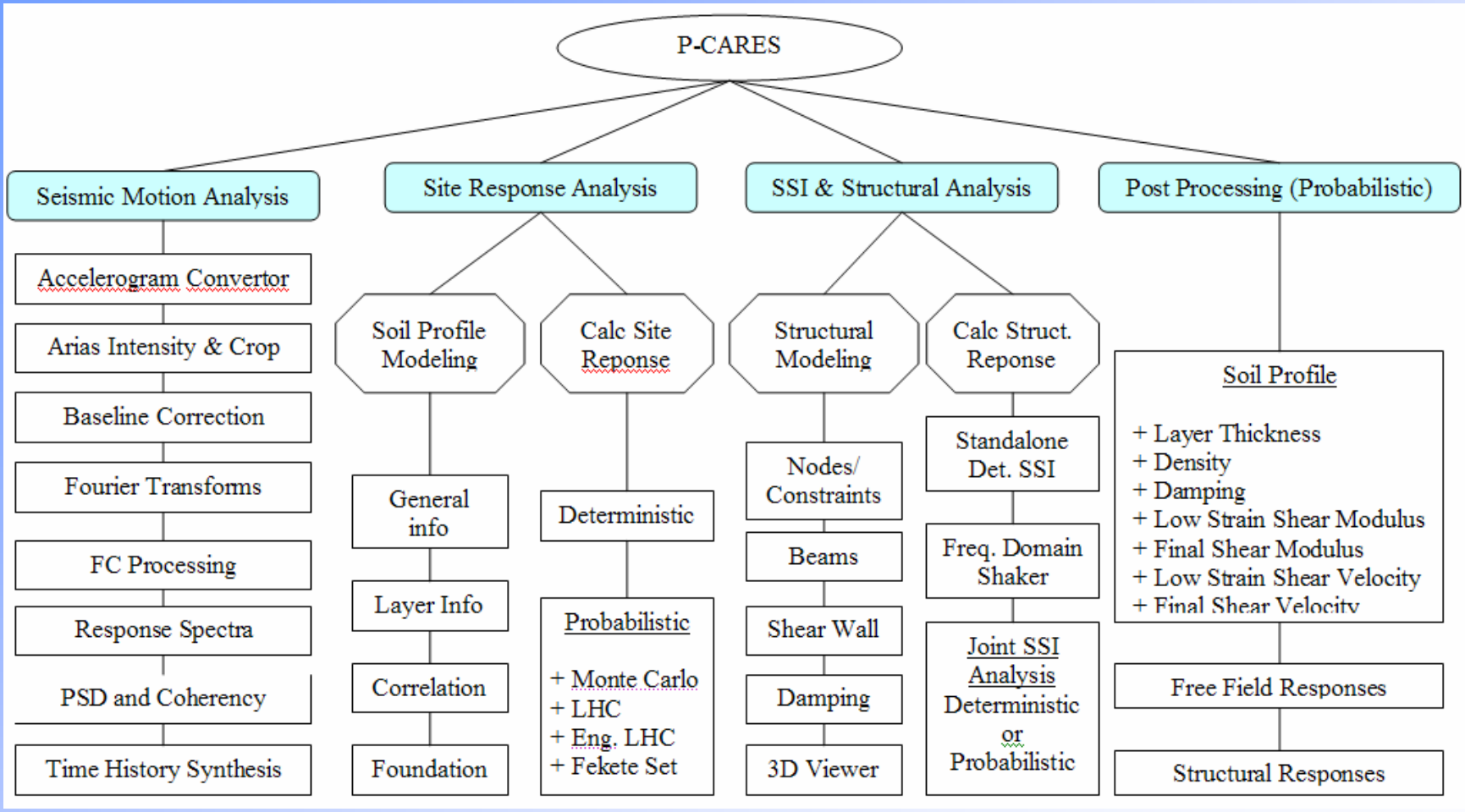
Design and Implementation

- Mixed programming technique typically used in rapid application development (RAD)
  - Fortran is used for heavy number crunching tasks
  - Python works as a glue language for system integration and computationally inexpensive tasks
- Fortran codes
  - CARES (upgraded to Fortran 95)
  - FFT, Smoothing, response spectra, baseline correction, etc
- Python codes
  - GUI (forms and plots)
  - Simulation and data management
  - Interaction between Fortran codes
- An single integrated package

Design and Implementation

- Object-oriented programming for better maintainability
- Extensive usage of open source packages
  - Python
  - Numarray / Numeric (for efficient data processing)
  - wxPython (for GUI)
  - Matplotlib (for 2D plots)
  - Vtk (for 3D structural model viewer)
  - F2py (to compile Fortran codes to Python modules)
  - Py2exe (to convert Python program to exe)
- Free software (not open source)
  - Inno Setup (to create the installer)

P-CARES Components



Major Features

- Seismic motion analysis tools
  - Arias intensity, chopping and zero-padding of time history
  - Baseline correction
  - Forward and inversion FFT
  - Fourier spectra processing
  - Response spectra
  - Power spectra and coherency
  - Time history synthesis
- Post-processing of simulated site and structural properties and responses

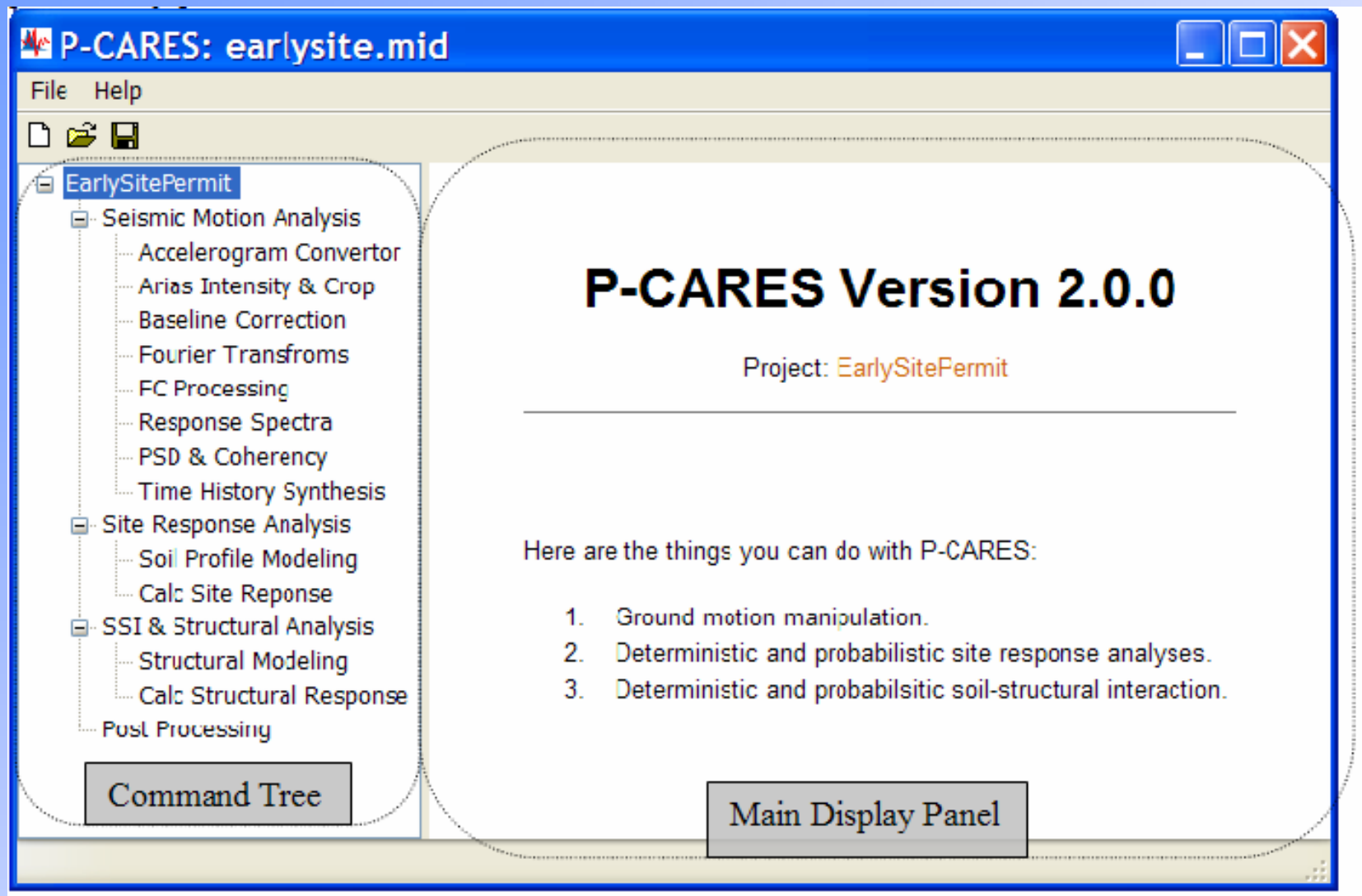
Major Features

- Site response analyses
  - Deterministic and probabilistic analyses of site response
  - Soil profile can be defined through the convenient forms
  - Option to generate SSI spring properties and SSI motions to the structure
  - Selection of analysis type and simulation schemes
  - Allow arbitrary number of samples in the simulation

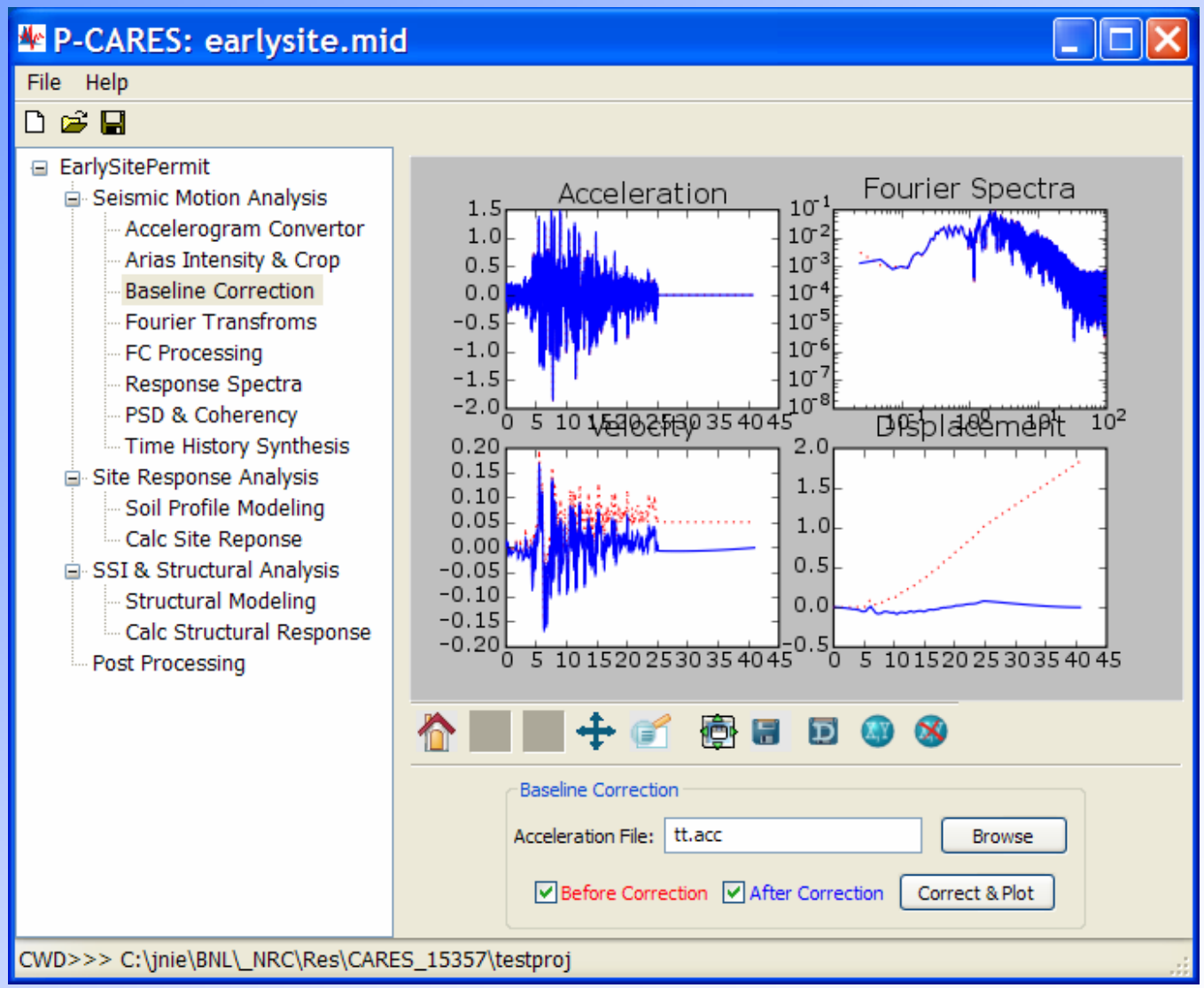
Major Features

- SSI and Structural Analyses
  - Lumped mass structural model
  - Element types for beams, springs, shear walls, rigid links
  - Various damping models
  - Structural definitions by forms
  - 3D Structural model viewer
  - Standalone deterministic SSI analysis
  - Frequency domain shaker analysis
  - Joint deterministic and probabilistic SSI analyses (requires site response analyses)

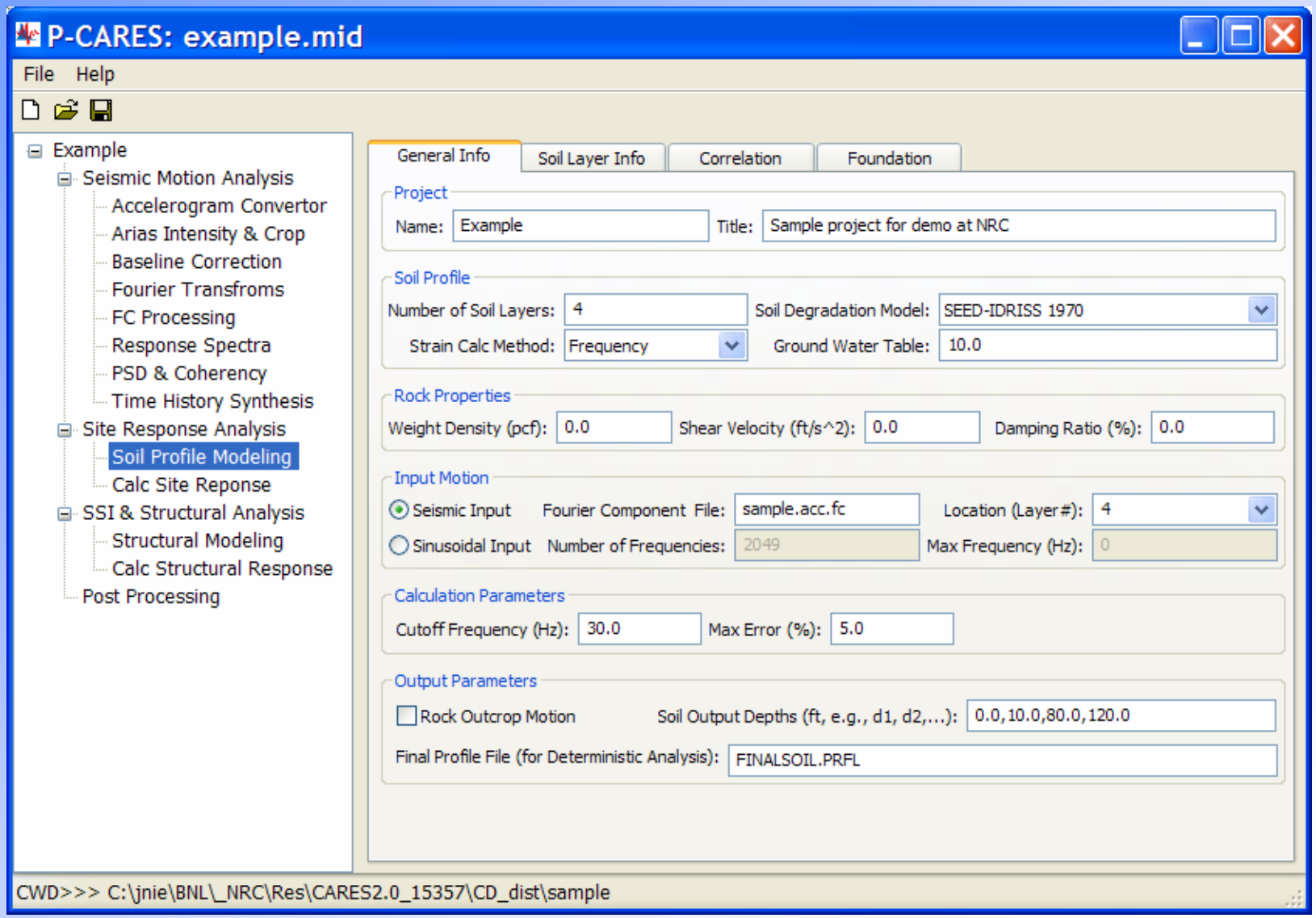
P-CARES Main GUI



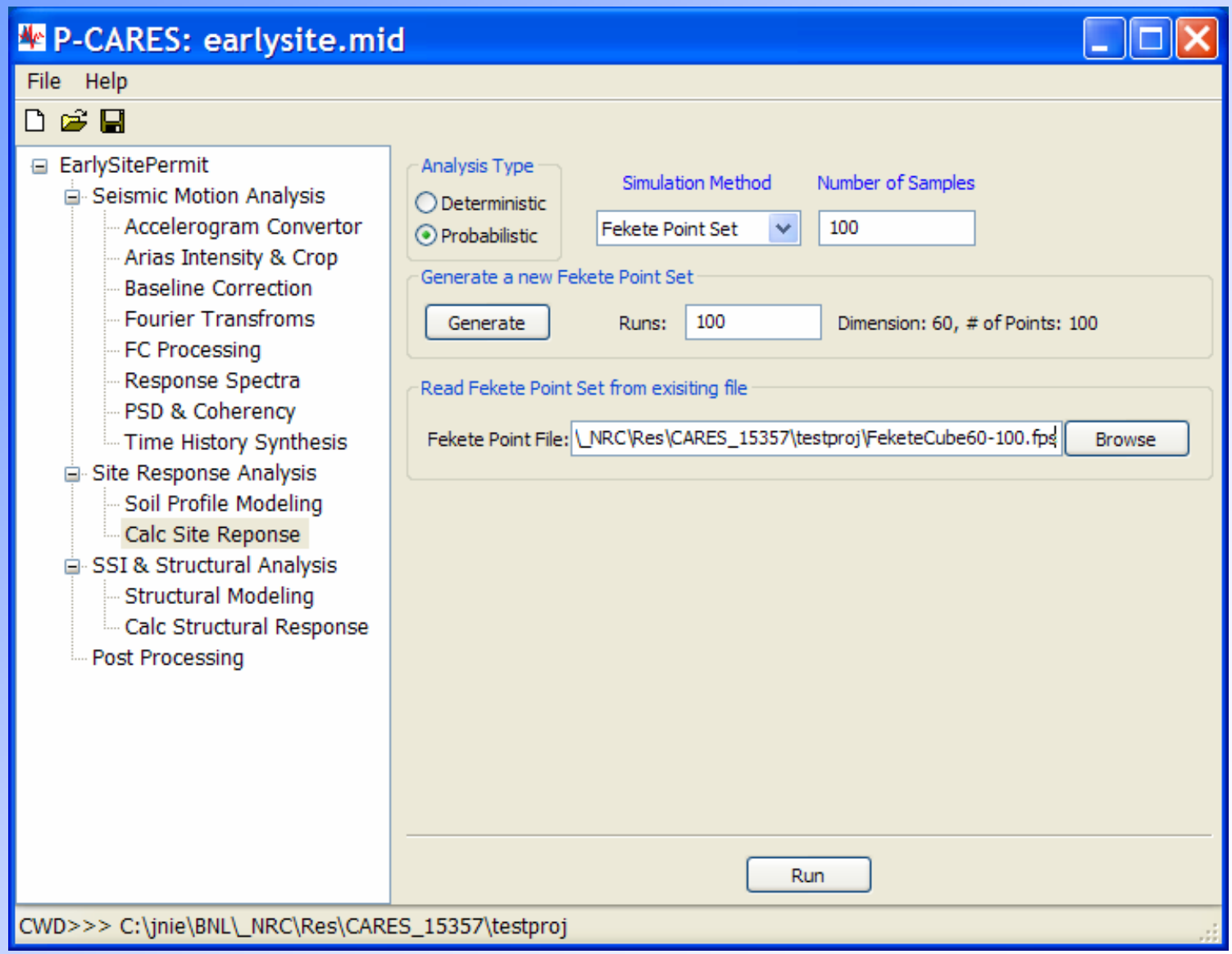
GUI Example – Baseline Correction



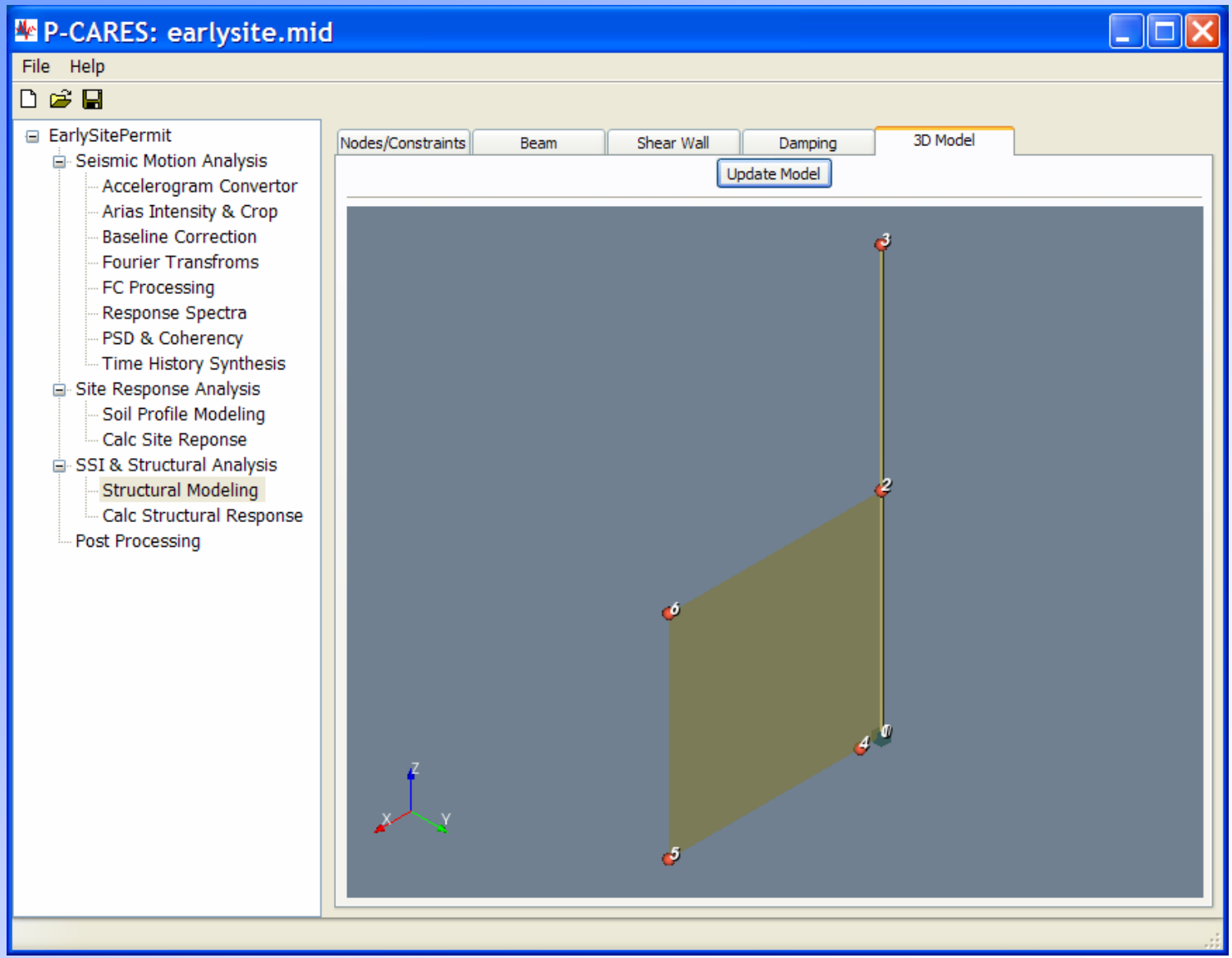
GUI Example – Soil Profile Forms



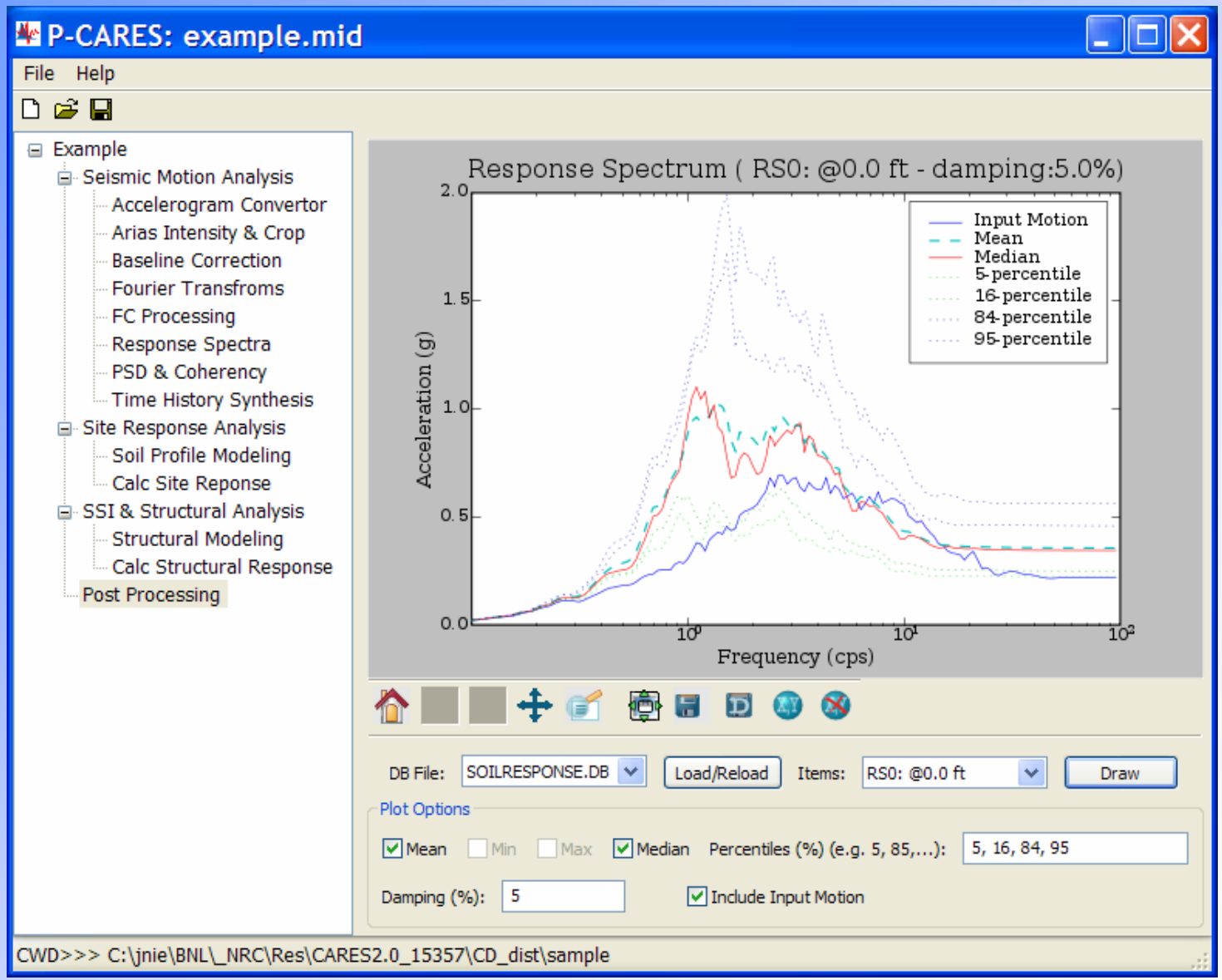
GUI Example – Simulation Schemes



GUI Example – 3D Model Viewer



GUI Example – Post Processing



Summary of P-CARES Development

- Implementation of probabilistic simulation capability for uncertainty treatment for site response and SSI analyses
- A very user friendly GUI for an coherent and integrated package
- Greatly enhanced maintainability for future improvement and functionality additions
- Use of open source packages as a cost-effective and robust non-time-consuming algorithms (e.g. GUI and plots)
- A demonstrated approach to revamp valuable historical Fortran codes