2025 SCEC Annual Progress Report

Feature Enhancements to the Broadband Platform: Site Response Modules and Ground Motion Models

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1. Background

The SCEC Broadband Platform (BBP) (Maechling et al. 2014) is an open-source computational system developed by the Statewide California Earthquake Center (SCEC) for generating synthetic broadband earthquake ground motions using 1D velocity models. BBP supports physics-based simulations for historical and scenario earthquakes across multiple tectonic regions, including California, Japan, and eastern North America, producing seismograms spanning 0-20+ Hz. It combines rupture generation using multiple rupture generator methods, low-frequency and high-frequency wave propagation, and optional site response adjustment. Since its release, BBP has undergone continuous development through successive versions, with the most recent release being version 22.4.0 in September 2022.

BBP consists of science modules which handle the physical simulation of earthquake rupture and wave propagation and utility modules which provide post-processing capabilities for validating and analyzing simulated seismograms. The site response (SR) module is an optional science module that modifies simulated seismograms to account for local site conditions that differ from those assumed in the 1D velocity model used for simulation.

The current BBP version 22.4.0 has limitations on its SR and utility modules. The SR module supports two methods: GP and PySeismoSoil. The GP method performs site adjustments for both low-frequency and broadband seismograms using only site-specific V_{S30} values. PySeismoSoil adjusts broadband seismograms based on V_{S30} and $z_{1.0}$ values. However, the station file (.stl) format does not support $z_{1.0}$ as a direct input, requiring PySeismoSoil to estimate $z_{1.0}$ from V_{S30} and reducing the accuracy of site-specific adjustments. Additionally, PySeismoSoil is limited to high-frequency ground motion adjustment and does not support low-frequency seismograms. Incorporating additional site response methods such as the Bayless and Abrahamson (2019) frequency-based approach, which uses both V_{S30} and $z_{1.0}$ to adjust low-frequency and broadband seismograms would expand the available options, enable users to assess performance across methods, and support uncertainty quantification in simulated seismograms.

The utility modules have two related limitations. The BBP currently uses an older version of the BSSA14 Ground Motion Model (GMM) that does not incorporate the Southern California basin model (Nweke et al. 2022), limiting its applicability for basin sites in Southern California. Furthermore, the platform does not include an EAS-based GMM, such as the BA19 model of Bayless and Abrahamson (2019), preventing users from directly comparing simulated ground motions with empirical predictions based on the Effective Amplitude Spectrum (EAS).

This project, supported by SCEC Awards #25052, aims to develop and integrate these capabilities into BBP so that future users can perform all necessary analyses within a single platform.

2. Project Objectives

The project endeavors worked to enhance the BBP Site Response and utility modules through three objectives:

1. Improve accuracy of the SR module by integrating site-specific $z_{1.0}$ values into the input station file (.stl) format and expanding PySeismoSoil to support site adjustment for low-frequency seismograms.

2. Integrate Bayless and Abrahamson (2019) frequency-based site response analysis method as an additional SR option in BBP, alongside existing GP and PySeismoSoil methods.

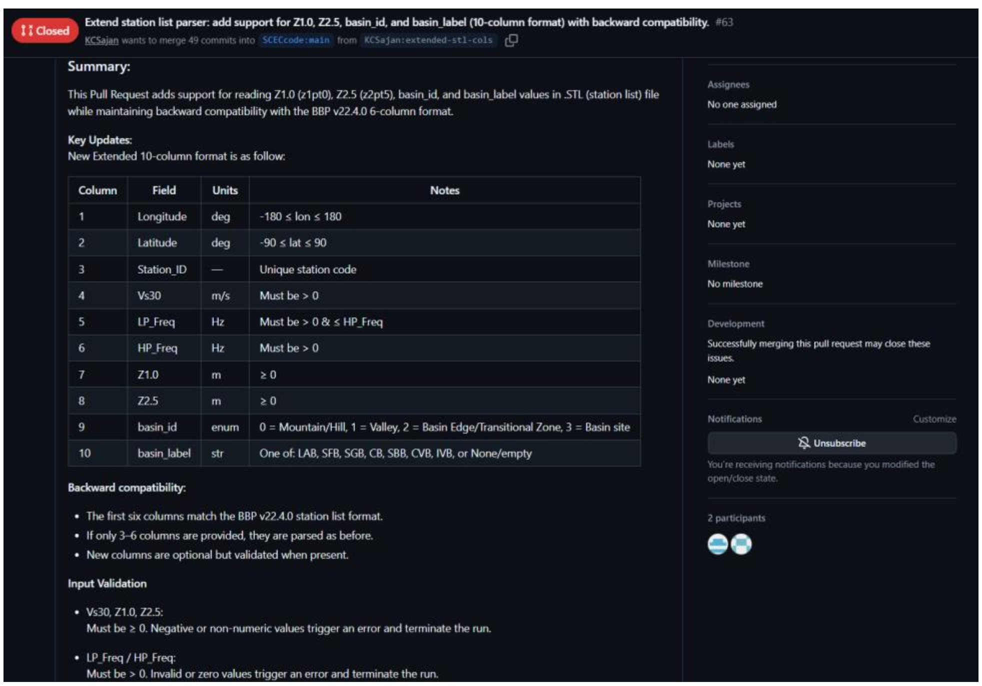
3. Update utility modules by incorporating the latest BSSA14 GMM with the Southern California basin model (Nweke et al. 2022) and adding an EAS-based GMM (Bayless and Abrahamson 2019) to enable comparison of simulated seismograms with EAS-based empirical predictions.

3. Work Completed

The following tasks have been added, tested, and are currently in active communication with BBP lead development team (Fabio Silva and Phil Maechling) regarding further validation requirements and integration into a future BBP release.

3.1 $z_{1.0}$ Integration and Update PySeismoSoil SR Method

- **Station file (.stl) format update:** The station file reader code has been modified to include an additional field for station-specific $z_{1.0}$ values as the 7th column (Figure 1). The updated format is backward compatible with existing station files that do not include $z_{1.0}$.



Closed
Extend station list parser: add support for Z1.0, Z2.5, basin_id, and basin_label (10-column format) with backward compatibility. #63
KCSajan wants to merge 49 commits into SCECcode:main from KCSajan:extended-stl-cols

Summary:

This Pull Request adds support for reading Z1.0 (z1pt0), Z2.5 (z2pt5), basin_id, and basin_label values in .STL (station list) file while maintaining backward compatibility with the BBP v22.4.0 6-column format.

Key Updates:
New Extended 10-column format is as follow:

Column	Field	Units	Notes
1	Longitude	deg	-180 ≤ lon ≤ 180
2	Latitude	deg	-90 ≤ lat ≤ 90
3	Station_ID	—	Unique station code
4	Vs30	m/s	Must be > 0
5	LP_Freq	Hz	Must be > 0 & ≤ HP_Freq
6	HP_Freq	Hz	Must be > 0
7	Z1.0	m	≥ 0
8	Z2.5	m	≥ 0
9	basin_id	enum	0 = Mountain/Hill, 1 = Valley, 2 = Basin Edge/Transitional Zone, 3 = Basin site
10	basin_label	str	One of: LAB, SFB, SGB, CB, SBB, CVB, IVB, or None/empty

Backward compatibility:

- The first six columns match the BBP v22.4.0 station list format.
- If only 3–6 columns are provided, they are parsed as before.
- New columns are optional but validated when present.

Input Validation

- Vs30, Z1.0, Z2.5:
  Must be ≥ 0. Negative or non-numeric values trigger an error and terminate the run.
- LP_Freq / HP_Freq:
  Must be > 0. Invalid or zero values trigger an error and terminate the run.

Assignees
No one assigned

Labels
None yet

Projects
None yet

Milestone
No milestone

Development
Successfully merging this pull request may close these issues.
None yet

Notifications Customize
Unsubscribe
You're receiving notifications because you modified the open/close state.

2 participants

Figure 1. Screenshot of the GitHub Pull Request (#63) submitted to the SCEC BBP development team proposing an extended 10-column station file (.stl) format with backward compatibility, adding support for $z_{1.0}$, *basin_id*, and *basin_label* fields required for the updated site response modules and BSSA14 GMM with Southern California Basin Model.

- **PySeismoSoil update:** The PySeismoSoil SR module has been updated to read and utilize station-specific $z_{1.0}$ values for site response analysis and apply site adjustments to low-frequency seismograms. Previously, PySeismoSoil was limited to broadband (high frequency) seismogram adjustments. The updated module supports both low-frequency and broadband seismograms, consistent with the GP SR module.

3.2 Integrate Bayless and Abrahamson (2019) Frequency Based SR Method.

- **Implementation:** The Bayless and Abrahamson (2019) frequency-based site response analysis method has been added as a new SR module within BBP. The module accepts V_{S30} and $z_{1.0}$ as inputs and applies frequency-dependent site adjustments to both low-frequency and broadband seismograms. The V_{S30} based site adjustment works for both northern and southern California, whereas $z_{1.0}$ integration is available for southern California region only.

- **Selection interface:** A user selection interface has been proposed allowing users to choose between GP, PySeismoSoil, and Bayless and Abrahamson methods for site response analysis within a BBP simulation run. Moreover, if the SR method is Bayless and Abrahamson, the interface asks if the study is southern California or northern California.

3.3 Addition of EAS-Based GMM

- **EAS GMM integration:** The EAS-based ground motion model of Bayless and Abrahamson (2019) (BA19) has been integrated into the BBP utility module. Users can now obtain EAS-based GMM prediction directly within the platform and compare against simulated seismograms-based EAS for California earthquakes

4. Work In Progress

4.1 Updated BSSA14 with Southern California Basin Model

The update of the BSSA14 GMM to the version including the Southern California basin model (Nweke et al. 2022) is the remaining incomplete deliverable. Significant progress has been made in understanding the implementation requirements, but the task has encountered a technical complexity that has not yet been resolved.

Challenge: The updated BSSA14 GMM requires additional site and basin characterization parameters (specifically the Nweke et al. (2022) basin id and basin labels for Southern California). Incorporating these additional parameters requires two coordinated challenges: modifying the .stl file reader to recognize and pass the new fields, and developing a mechanism to automatically populate basin id and basin labels from the existing geospatial models based on the user provided station location coordinates when the study region is southern California. However, the latter has proven to be primary source of complexity.

Expected resolution: We anticipate resolving the implementation approach in the near term and completing this deliverable following the station file design decision. The GMM computation itself is ready to be implemented and tested. The remaining work is the integration of the parameter inputs.

5. Coordination with the SCEC BBP Development Team

All completed work described in Section 3 has been developed outside of the main BBP codebase and verified against research results from SCEC Awards #22160 and #24062. Integration into BBP requires coordination with Fabio Silva and Phil Maechling to:

- **Validate implementations** against the BBP testing framework and existing benchmark simulations.
- **Establish pull-request and code review procedures** consistent with BBP development standards.
- **Agree on station file format extensions** for $z_{1.0}$ and basin parameters that maintain backward compatibility.
- **Plan a release schedule** for incorporating the new features into a future BBP version.

Active communication with the BBP team is ongoing. The completed implementations are ready for review, and we expect the pull-request and validation process to proceed in the near term.

6. Planned Timeline for Remaining Work

Task	Description	Target
Basin parameter addition decision	Agree with BBP development team on the approach for automatically populating basin identifiers and labels from geospatial models based on station coordinates and finalize the .stl file extension for the new fields	Near term
BSSA14 with southern California basin model implementation	Implement the updated BSSA14 with Nweke et al. (2022) basin model and integrate the basin parameter inputs once the design decision is finalized.	Following design decision
Full BBP integration testing	Test all completed modules (SR-Z1.0, BA19 SR, EAS GMM, updated BSSA14) within the BBP framework against existing benchmark simulations	Following PR acceptance
User testing, documentation and release	Conduct user testing with select researchers, gather feedback. Update BBP user manual, develop tutorials and example workflows for all new features, and support formal release in a future BBP version	Final phase

7. Summary

This project focused on enhancing the SCEC Broadband Platform by improving the Site Response (SR) module and updating the utility modules. Three of the four planned deliverables have been finalized and are in active communication with the BBP development team for validation and integration into a future release. Specifically, the station file format has been updated to support station-specific $z_{1.0}$ values, PySeismoSoil has been expanded to support low-frequency seismogram adjustment, the Bayless and Abrahamson (2019) frequency-based site response method has been integrated as a new SR option alongside GP and PySeismoSoil, and the EAS-based BA19 GMM has been added to the utility module.

The remaining deliverable, updated BSSA14 GMM with the Southern California basin model (Nweke et al. 2022), is in progress. The GMM computation is ready; the outstanding challenge is developing a mechanism to automatically populate basin identifiers and labels from existing geospatial models based on user-provided station coordinates, which requires a coordinated design decision with the BBP development team regarding the station file format extension.

Upon full integration and release, these enhancements will enable BBP users to perform more accurate site-specific ground motion simulations and directly compare simulated seismograms with EAS-based empirical predictions within a single platform.

References

Bayless, J., and Abrahamson, N. A. (2019). Summary of the BA18 ground-motion model for Fourier amplitude spectra for crustal earthquakes in California. *Bulletin of the Seismological Society of America*, 109(5), 2088-2105.

Boore, D. M., Stewart, J. P., Seyhan, E., and Atkinson, G. M. (2014). NGA-West2 equations for predicting PGA, PGV, and 5% damped PSA for shallow crustal earthquakes. *Earthquake Spectra*, 30(3), 1057-1085.

Maechling, P. J., Silva, F., Callaghan, S., and Jordan, T. H. (2014). SCEC Broadband Platform: System architecture and software implementation. *Seismological Research Letters*, 86(1), 27-38.

Nweke, C. C., Stewart, J. P., Wang, P., and Brandenberg, S. J. (2022). Site response of sedimentary basins and other geomorphic provinces in Southern California. *Earthquake Spectra*, 38(4), 2341-2370.

Xia, F. (2024). Improving site response analysis for earthquake ground motion modeling. Zenodo. https://doi.org/10.5281/zenodo.13833723.