SCEC Report: Proposal 20067

A Technical Activity Group (TAG) for the coordination of SCEC5 research activities on nonlinear effects in the shallow crust: Progress and Future Plans

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Introduction

We report the progress and future plans of the TAG for the coordination of SCEC5 research activities on nonlinear effects in the shallow crust. Our TAG's mission is to develop, verify and validate a robust family of computational tools that will advance the capabilities of SCEC ground motion simulation frameworks to capture anelastic effects in the shallow crust. To achieve these goals, our TAG coordinates efforts in: (i) constitutive modeling and simulation of nonlinear effects; (ii) development and validation of semi-empirical and synthetic nonlinear site factors; and (iii) physics-based modeling of crustal heterogeneity and scattering attenuation. More specifically, our efforts focus on extending the capabilities of the SCEC Broadband Platform and of the 3D physics-based ground motion simulation codes. This report summarizes ongoing research efforts pertinent to the TAG's mission, and outlines target milestones for the next fiscal cycle.

Year 4 Research Coordination Plan

Over the past four years, the TAG identified research problems as priorities to be coordinated; these problems are briefly described below. In each category, we outline both the long term research goals and the submitted proposals that aligned with associated milestones set for the 2021 fiscal cycle. The PIs originally planned to organize an all-day workshop at the 2020 Annual Meeting, to summarize the findings of the TAG participants throughout SCEC5, including the verification and validation statistics of the various modules and tools currently in progress. COVID19 interruptions prevented us from doing so, but we are planning to distribute a summary of

the TAG outcomes during the forthcoming 2021 SCEC Annual Meeting, in the form of a TAG wrap-up meeting, a poster and a white paper on future challenges in the realm of nonlinear effects in the shallow crust.

1. Evaluation of site-response modules

The TAG has been coordinating two families of nonlinear site response modules for the BBP over the past three years. Upon completion of the development and subsequent implementation of all modules, the TAG plans to spearhead a revised BBP validation exercise. The two families of site modules are summarized below:

1.1 Fourier-based site factors: Under Project 19097, the PIs (Jeff Bayless and Jonathan Stewart) developed a region specific Fourier-based amplification model (Vs_{30} scaling and nonlinearity) which is developed from ground motion recordings and is dependent on the Vs_{30}, PGA_r, region, and frequency. The model is applicable over the frequency range 0.1-100 Hz and the Vs_{30} range 180-1500 m/s, although it is not well constrained for Vs_{30} values greater than 1000 m/s. The model does not have magnitude or distance dependence. At the 2020 SCEC Annual Meeting, the PIs showed comparison of the Bayless and Abrahamson (2019) FAS model against 3 empirical EAS databases: NGA-West2, Wang and Stewart (2019), Buckreis et al. (2019). Wang and Stewart (2019) extends the NGA-West2 database with earthquakes and recordings in California and northern Mexico since 2011. This database includes 29 new events with 6,584 three-component ground motion recordings. Buckreis et al (2019) further supplements the NGA-West2 data, mostly with recordings in central and northern California. This database includes 39 events (5 already existing in NGA-West2 and 34 new additions) with 3,721 new three-component ground motion recordings. Overall, the linear V_{s30} scaling models compare favorably with other empirically-based models (e.g. Bora et al. 2019; Seyhan and Stewart, 2014); especially at low frequencies. For the nonlinear term, the Bayless and Abrahamson (2019) suggests generally weaker nonlinear effects than both Hashash et al. (2018) and Seyhan and Stewart (2014), except at the highest frequencies, where the proposed model exhibits stronger nonlinearity than H18 but weaker nonlinearity than SS14.

1.2 Nonlinear site-specific response: A finite element module, on the other hand, was developed under proposal 20205 (PIs: Arduino, Taciroglu). A workflow was developed and implemented to modify the BBP simulated ground motions on reference site conditions, by generating Vs30–dependent soil profiles, prescribing the BBP

output as rock outcrop input motion, and computing the site-specific nonlinear site response at each ground surface receiver node. The workflow was validated as part of These modules are also available as open-source standalone software on `github`.

2. Modeling and Effects of Stochastic Media

The TAG has been coordinating the development of new methods to model wave propagation scattering due to structural complexities in deterministic ground motion simulations. Topics in this realm include: i) parameterization of correlation functions for the statistical representation of small-scale velocity variations, characteristic of Southern California; ii) validation of the stochastic models using recorded data; iii) efficiency assessment of the stochastic models using wave propagation modeling for recorded small earthquakes ($<$ M5); and iv) investigation of the effects of crustal small-scale heterogeneities on the spatial variability of surface ground motions. Under Proposal 20064, the PIs (Elnaz Seylabi, David McCallen, and Arben Pitarka) used physics-based ground motion simulations to numerically study the complexity of ground motion coherency as a function of physical parameters, i.e., distance, frequency, heterogeneity, and source properties. Although their focus was on Northern California, using the SW4 finite difference code (Petersson and Sjögreen, 2015) to perform earthquake simulations, the approach can be directly implemented in Southern California using Cybershake simulations. To model small scale heterogeneity, the PIs perturbed the background velocity model stochastically using the Von Karman distribution. Their preliminary results showed that lagged coherency functions across the area of interest are likely correlated to local site conditions.

3. Verification and Validation of Nonlinear Constitutive Models in 3D Simulations

The TAG has been coordinating the development, optimization, verification and validation plan of soil plasticity models implemented in SCEC physics-based ground motion simulation platforms. This year was dedicated to the verification and validation of 3D nonlinear codes using site characterization data and strong motion records from the Garner Valley Downhole Array site. The following ongoing research projects are aligned with the priorities of the TAG in this research thrust. Specifically, research under Proposal 19128 focuses on the development and optimization of a nonlinear constitutive model for large-scale ground motion simulations; while research under Proposal 19056 initiated a multi-year verification and validation exercise for available nonlinear models on SCEC simulation platforms. Both projects

were delayed due to COVID-19 pandemic-related issues, and have requested no-cost extensions with expected completion in March 2022.

Coordination Efforts (2020-2021)

The TAG organized one remote meeting in the past year. Participants included members of the SCEC funded research community with interest in contributing to the TAG activities, USGS researchers who provided insight in the architecture of the BBP and the site characterization data availability across Southern California, and interested users of the Community Modeling Environment software relevant to the developments planned by the TAG. The participants outlined research plans to reach the TAG goals through concretely identified milestones through the end of SCEC5. The TAG was planning an in-person meeting to synthesize SCEC5 results and outline future research goals at the 2020 SCEC Annual Meeting, and has now extended the target date to the 2021 SCEC Annual Meeting.