# Incorporation of Local Site Effects in Broadband Simulations of Ground Motions: Case Study of the Wildlife Liquefaction Array in Southern California

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## ABSTRACT

The principal objective of this research is to explore the most efficient approach to incorporate local site effects in Broadband (BB) simulations of ground motions and include the nonlinear soil behavior in the overall response. The recorded data by a geotechnical downhole array in California will be utilized to validated and evaluate the proposed approaches.

The geotechnical downhole array data could be extremely valuable for verifying and validating simulation-based predictions of strong ground motions that incorporate site response. We have reviewed available data from downhole arrays in California and selected Wildlife Liquefaction Array (WLA) in Southern California as our top candidate site for the purpose of this research. This research is divided into three tasks as indicated hereafter.

- Task 1: Compilation and Selection of Recorded Data at WLA
- Task 2: Incorporating Local Site Effects in BB Simulations
- Task 3: Evaluation

Further information about the details of these tasks are provided in subsequent the sections. We also present some preliminary results to illustrate the effects of local site conditions on simulated ground motions.

## ACKNOWLEDGEMENT

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## TASK 1: COMPILATION OF WLA RECORDS

We have reviewed available data from downhole arrays in California and evaluated with special attention given to non-basin sites where large amplitude ground motions have been recorded. In our preliminary research, we have reviewed the data recorded by California Strong Motion Instrumentation Program (CSMIP) [1] as well as NEES@UCSB [2]. Considering the number of geotechnical downhole arrays in California (i.e. around 40 arrays), we have carried out a screening procedure to select one array that has records pertinent to the expectations herein such as

- Recorded bi-directional shakings
- Recorded both small-to-moderate and large-amplitude motions (PGA<0.15g and PGA>0.2g).
- Recorded ground motions are regarded as free-field motions and are not affected by an adjacent structure
- The site geology is relatively simple (i.e. minor basin or topography effects).
- Well documented subsurface soil information such as laboratory and in-situ test data are available.

We have identified Wildlife Liquefaction Array (WLA) in Southern California which is operated by NEES@UCSB as our top candidate downhole array and will utilize it in this research. Figure 1 illustrates the soil profile and the existing instrumentations at WLA.

Our first task focuses on compilation and selection of recorded data at WLA. Considering the large number of events recorded by WLA, we will review available records and select at least 10 seismic events recorded by this array. The selected data will be grouped into two categories: (1) Category 1 which will include small-to-moderate ground shakings which initiated negligible excess pore water pressure, and (2) Category 2 which consists of strong motions producing significant excess pore water pressure. In our initial assessment, we have identified the following two events for our preliminary analysis in near future:

- 05/21/2015 M4.1, 13km WNW of Calipatria, CA as a Category 1 event
- 08/27/2012 M4.9, 5km NNE of Brawley, CA as a Category 2 event

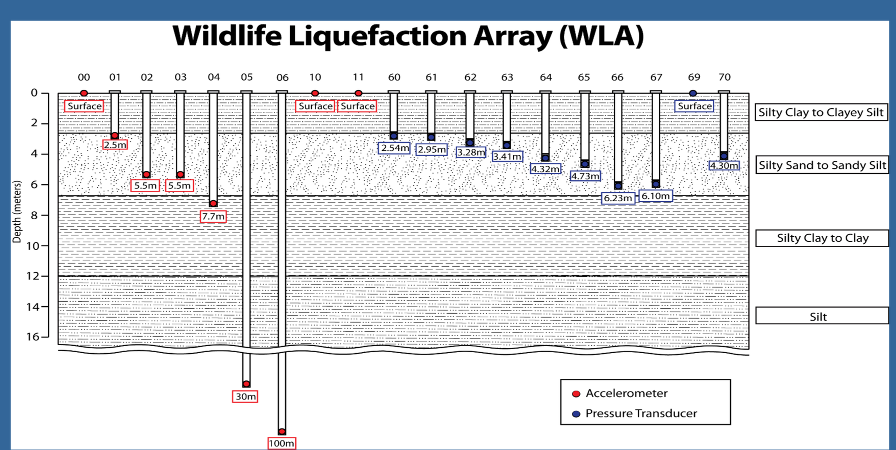


**Figure 1.** Instrumentations and simplified soil profile [2]

## TASK 2: BROADBAND SIMULATIONS

This study will explore different approaches in incorporating local site effects in the BB simulations. The methods which will be explored in this research include:

1. Direct inclusion of local site effects in the BB simulations: in this method, the subsurface soil properties are explicitly incorporated in the BB simulations. An equivalent linear approach is possible in this alternative, at least with the Composite Source Model approach (Anderson, 2015) [3] since this model retains a full wave propagation solution at high frequencies.
2. A two-stage simulation consisting of the BB simulations for predicting motions for some horizon beneath the surface and then calculating the soil response using one of the Site Response Analysis (SRA) programs such as Deepsoil or D-MOD2000. Both programs are capable of analyzing 1-dimensional SRA based on equivalent linear as well as nonlinear methods. In addition, both computer programs are able to carry out total stress and effective stress analyses. Key issues to be addressed for this class of approaches are appropriate selection of the horizon, which affects the relative amount of the body and surface waves in the synthetics, and selection of the soil response method.
3. Because in many cases, less information is available than what is known of WLA, our experiences with the above approaches will be used to evaluate the use of transfer functions, including phase, that can be applied to surface synthetics.

## TASK 3: EVALUATION

We will evaluate the efficiency of different methods in inclusion of local site effects in the BB simulations using the Goodness-of-Fit (GOF) concept described in Anderson (2004) [4]. The GOF method is a unique methodology that uses a similarity-based scoring system to quantify the quality of the fit. This comprehensive evaluation provides a quantitative measure of the quality of the predicted ground motions in a systematic framework.

## PRELIMINARY RESULTS

In order to demonstrate the feasibility of this study, we have carried out a numerical experiment to investigate how local site effects can be manifested in the BB simulations. Synthetic seismograms were generated using the CSA Model [3] for an earthquake with magnitude Mw=7.65 on a vertical strike-slip fault with rupture length 146 km. The average slip on the fault is 3.0 m. Stations were chosen at random on two racetracks, at distances of 20 km and 50 km from the fault, as shown in Figure 2. There are 15 stations on the 20 km racetrack, and 13 stations on the 50 km racetrack. The calculations were performed with three different velocity models in the upper 100 m, an example is shown in Figure 3. The three models all have $V_{S30}$=250 m/s, but they were designed to give distinctively different site resonance periods at about 0.36s, 1.0s, and 1.4s. Example synthetic accelerograms at site with period of 1.4 s is illustrated in Figure 4.

We calculated synthetic seismograms for 50 different source realizations for each of the stations in Figure 2, for the three different velocity models. Next, we calculated geometric mean response of the horizontal components of PSA response (damping 5%) for all seismograms. We also calculated an overall mean response spectrum from these synthetics by averaging the mean of the three different site periods which are presented in Figures 5 and 6.

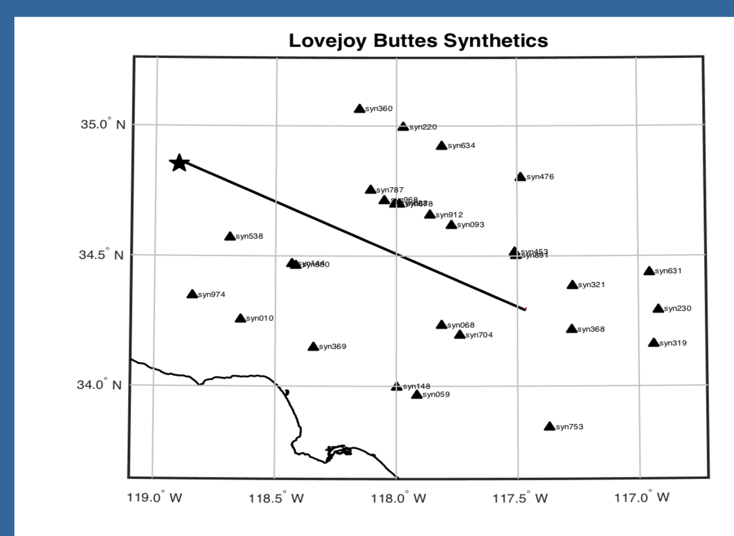


**Figure 2.** Map showing location of fault and locations of stations.

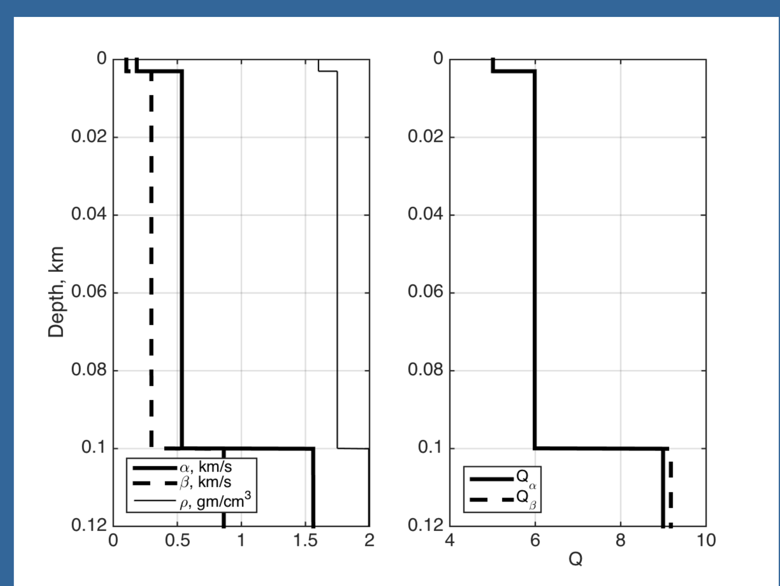

**Figure 3.** Near-surface velocity model for site condition 3 ($V_{S30}$= 250 m/s, T=1.4 s)

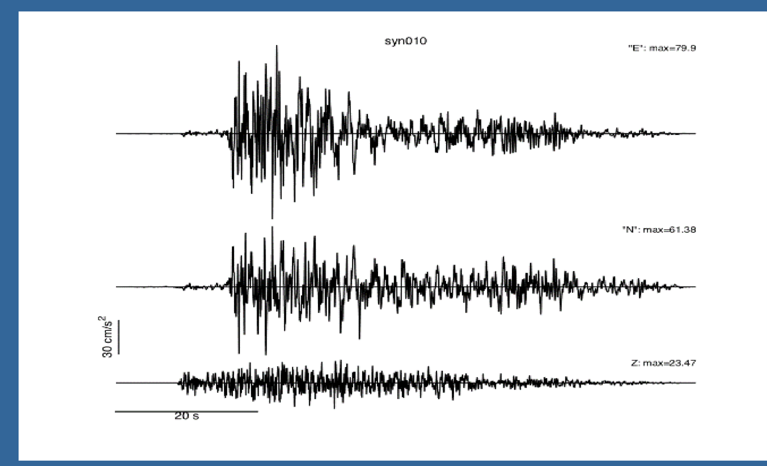

**Figure 4.** Synthetic accelerograms at one of the 50 km sites for site condition 3 (T=1.4s)

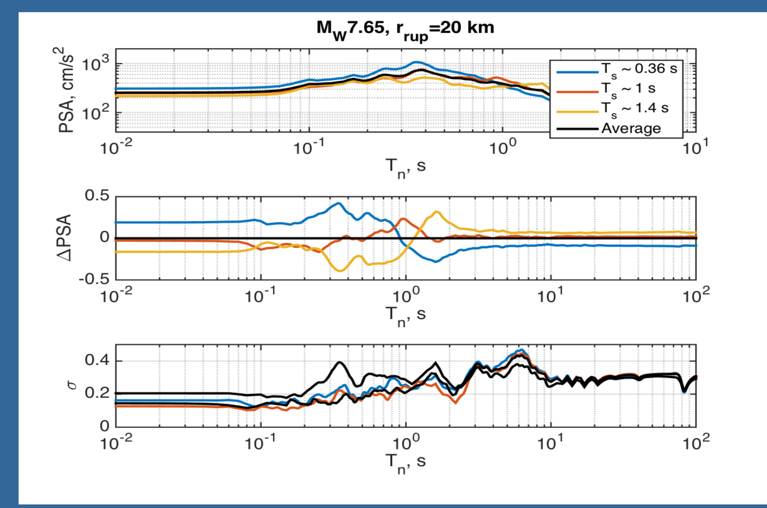

**Figure 5.** Top: Average PSA response for the three site conditions, and the average over all site conditions, for stations at 20 km. Center: Natural log of the ratio of the average spectra for the individual site conditions to the average over all sites. Bottom: Standard deviation of the site response for the individual site conditions and for the average over all site conditions.

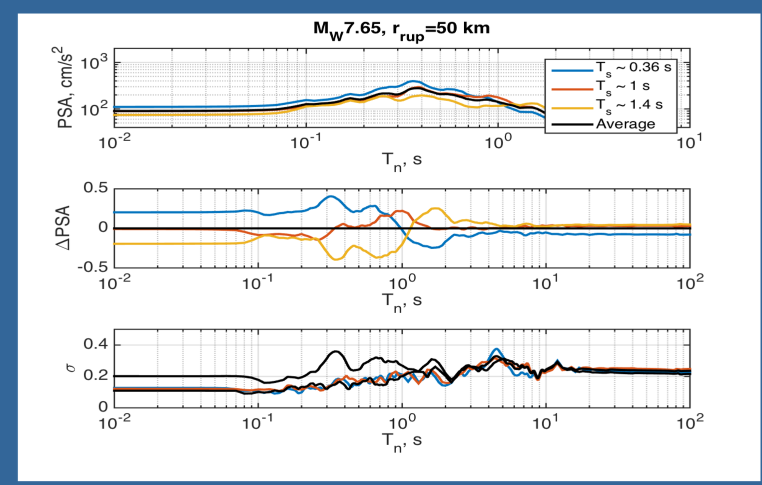

**Figure 6.** Equivalent of Figure 5, for stations at 50 km.

## CONCLUSIONS

1. The WLA site appears to include recorded ground motions pertinent to this research. These records will be utilized to evaluate the accuracy of our BB simulations.
2. Our preliminary BB simulation results from three hypothetical sites with distinctly different shallow Vs profiles have demonstrated the capabilities of the CSM method in capturing the local site effects.
3. In the next 6 months, we will carry out BB simulation of at least 10 events recorded at WLA and quantify the simulation results using the GOF method.

## REFERENCES

1. California Engineering Strong Motion Database (CESMD). *www.strongmotioncenter.org.*
2. NEES@ UCSB website. *nees.ucsb.edu.*
3. Anderson, J. (2015) "The composite source model for broadband simulations of strong ground motions" Seismological Research Letters, Vol. 86, No. 1, 68-74.
4. Anderson, J. (2004) "Quantitative Measure of the Goodness-of-Fit of Synthetic Seismograms" World Conference on Earthquake Engineering, paper no. 243.