LACK OF CORRELATION (INCOHERENCE) MODELING AND EFFECTS FROM REALISTIC 3D, INCLINED, BODY AND SURFACE SEISMIC MOTIONS

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ABSTRACT

In this paper we explore the issue of realistic, 3D, inclined, body and surface wave seismic motions that are used as an input to 3D, time domain, nonlinear analysis of NPPs, and lack of correlation (incoherence, as it is known in the frequency domain). One of the main issues addressed here is the development of un-correlated (incoherent) motions for a full 3D case.

INTRODUCTION

Modeling of un-correlated seismic motions (aka incoherent motions, if they are modeled in the frequency space) is drawing significant attention of the engineering community because of the effects such motions could have on the seismic response of NPPs. Of interest here is the development of such motions for a full 3D time domain simulations.

A number of interesting and important issues need to be addressed. First, can synthetically produced ground motions (using Green's function program, (Hisada and Bielak, 2003)) produce lack of correlation at the surface and depth? Second, How should those synthetic motions be changed to include lack of correlation (incoherence) effects? Third, how important are those lack of correlation (incoherence) effects for a soil-structure interaction modeling? This paper will, in a limited space allocated, present some of our recent work in this area.

Synthetic seismic motions, produced using Green's functions approach (Hisada and Bielak, 2003), modeling Northridge earthquake, were analyzed for lack of correlation (incoherence). Those motions were then enriched with lack of correlation (incoherence) motions developed using model described below.

Ground motion incoherence affects both the Fourier amplitude and phase of the recorded motions. The three main sources of incoherence modeled herein are (a) stochastic Fourier amplitude and phase variations due to scattering, (b) deterministic Fourier phase variation due to the wave passage effect, and (c) stochastic Fourier phase variations around a plane wave passage effect called 'arrival time perturbations' by Zerva (2009). The method of introducing incoherence is performed using the method developed by Abrahamson (1992a). Stochastic phase (which includes the arrival time perturbations) is modeled with plane wave coherency functions from Abrahamson (2005, 2007) developed for soil and rock sites. Stochastic amplitude is modeled with functions from Abrahamson (1992b) and Abrahamson (2005) developed for soil and rock sites.

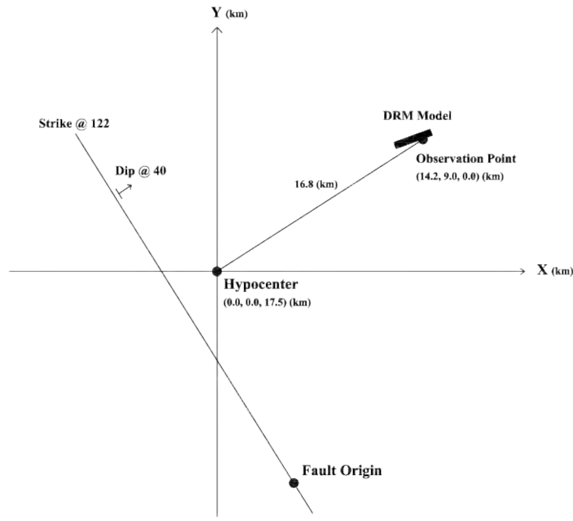
New method of developing Spatially Variable Ground Motions (SGVM) is used (as explained in accompanying references). In addition to that, depending on how well the initial synthetic motions incorporate incoherence target, slight or large variations are introduced. The lack of appropriate incoherence is most likely to be due to the limitation within the method to introduce necessary scattering effect. Motion developed using this methodology will be analyzed for effects on dynamics of an NPP and results presented at the conference.

SEISMIC MOTION MODELING FROM THE SEISMIC SOURCE

Seismic motions were developed using an analytic solution through Green's functions, developed and implemented in a program by Hisada (1994) and Hisada and Bielak (2003). The method takes into account fault slip mechanism, and propagates the wave through elastic half space layered medium to the surface. The fault rupture mechanics was chosen to be similar to Northridge slip mechanics, which generated an earthquake with a moment magnitude of 6.7. Fault rupture is modeled using Boore's source model, while the seismic waves propagating from that source are modeled using Green's functions for layered or homogeneous half space. As presently implemented, this model can model a minimum period of $T = 0.06$s (corresponding to the frequency of $f = 16.67$Hz). Rupturing fault parameters include: fault length of 18km, fault width of 24km, number of sub-faults along the length and width is 14×14, strike of 122^o, and the dip is 40^o. Figure 1 (upper) shows ground motion model setup, while Figure 1 (lower) shows location of observation points that were used to assess current and develop new uncorrelated (incoherent) motions for simulations.

The actual fault, in this case, was placed at the depth of approximately 17km[1], while the NPP site (the soil/rock model) was placed at approximately 17km away from the earthquake epicenter. The main motivation for a chosen setup was to have a rupturing fault (hypocenter and epicenter) fairly close to the NPP, as was the case of recent earthquake at the Kashiwazaki NPP in Japan. Moreover, close proximity (in relative terms) of the seismic source will results in the development of significant 3D seismic effects, with both horizontal and vertical motions. The actual NPP site (3D model), was oriented in such a way to pick up highest horizontal motions in local X direction, as shown in Figure 1.

[1]In the case of Northridge earthquake, the source was shallower than that, at approximately 6km.



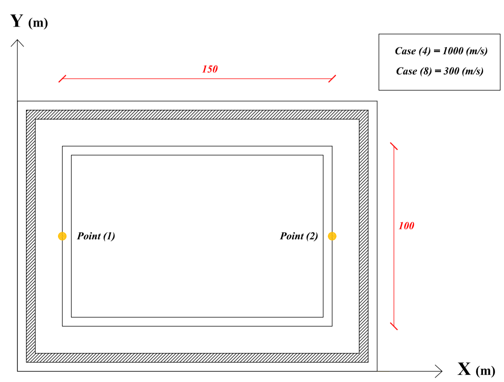


Figure 1: Upper: Analytic model (Green's functions) setup, with locations of hypocenter, epicenter and the DRM model; Lower: Location of observation points 1 and 2, at the edge of foundation model.

UN-CORRELATED MOTIONS DEVELOPMENT

Lack of Correlation (Incoherence) for the Original Seismic Motions

Figure 2 show the analysis of analytically developed seismic motions (using Green's functions for layered half space) with incoherence function developed from the Lotung LSST site in Taiwan by Abrahamson et al. (1991); Abrahamson (1992b, 2005, 1992a). The incoherency is observed at points 1 and 2, separated by 150m, see Figure 1 (lower). Lagged coherency of the strong motion window between the pairs of the synthetic motions are biased higher (i.e. more coherent) at frequencies up to approximately 7 Hz as shown in Figure 2. The large spike in lagged coherency at 16 Hz is due to a 16 Hz frequency limit of the synthetic motions developed using layered half space model.

It is interesting to note that even a model with quite regular layering, simulated over half space was able

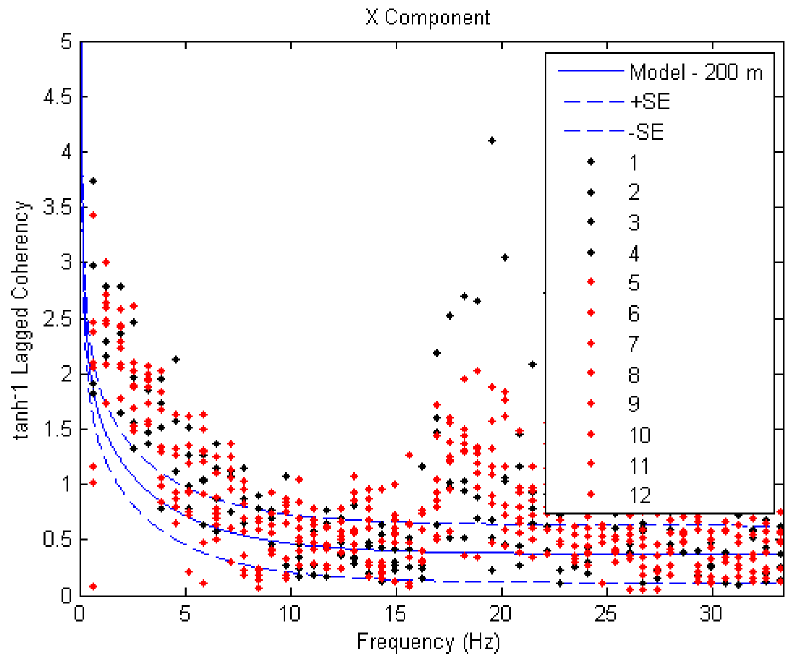


Figure 2: A comparison incoherence of analytically developed seismic motions (using Green's functions for layered half-space) with incoherence model by Abrahamson, from Lotung LSST site, for all twelve soil/rock profiles, grouped as soil and rock profiles.

to predict incoherence, although to a smaller degree than what the extrapolated model from Lotung LSST site shows. This result signifies that a dimension of the model (in this case half-space) plays an important role in development of the incoherence, since it was shown by Walling (2009), that a limited size model (a block with sides of 1km) cannot account of majority of incoherence.

Lack of Correlation (Incoherence) for the Abrahamson Model Motions

In addition to incoherent motions developed using layered half space simulations, a different set of incoherent motions was developed in order to test the effects incoherency has on NPP response. In order to introduce appropriate amount of variability over the bandwidth due to incoherence effects, each point was used as a seed motion to generate a new motion across the grid at a separation distance of 200 meters. In other words, point 1 is modified to generate a ground motion at point 2 and vice versa. The method is a non-stationary simulation routine that utilizes short time windows of various lengths where the length of the window controls the frequency band over which spectral modifications are made consistent with a selected coherency (γ) and random Fourier amplitude model ($\sigma_{\Delta A}$). Synthetic models created by analytic solution for layered half space, with different profiles but similar source were used as seed motions for incoherence motion development. Soil/Rock profiles as described in Soils/Rock were grouped as rock cases with

$V_s \geq 760$m/s and soil cases with $V_s < 760$m/s.

Separate coherency and random Fourier amplitude models are selected for rock and soil profiles separately. For rock cases, a plane wave coherency (γ_{pw}) and $\sigma_{\Delta A}$ developed by Abrahamson (2007) from the Pinyon Flat array recordings located in California was used. For soil cases, a lagged coherency ($|\gamma|$) and $\sigma_{\Delta A}$ developed by Abrahamson (1992a) from the Lotung LSST (Large Scale Seismic Test).

Range of Model Applicability Based on a report by Abrahamson (2007) the incoherence models developed from the Pinyon Flat array appear to applicable to separation distances of 5 to 150 meters and a frequency range of from 5 to 40 Hz. Since the model is developed from Pinyon Flat recordings alone is it unknown how well this model fits similar rock site array recordings or possible future array recordings located in the eastern North America region. The incoherence models developed by Abrahamson (1992a) are applicable to separation distances of 6 to 85 meters and frequencies greater than 1 Hz.

Model Validation Figures 3 and 4 show the validation of developed incoherent seismic motions. It

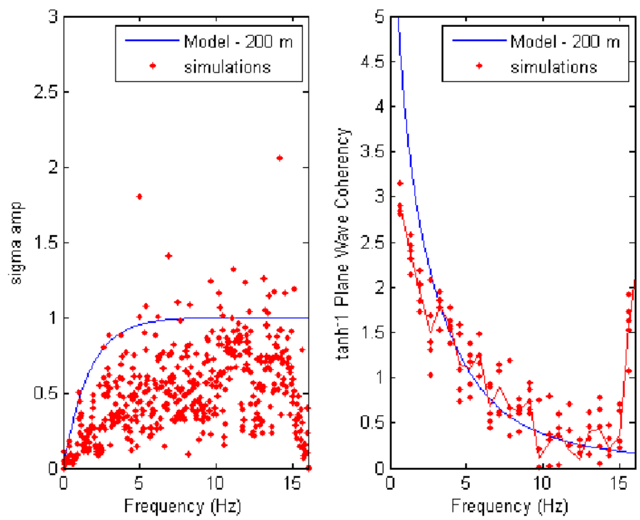


Figure 3: Validation of case 1 (rock) using location 1 as a seed against the selected $\sigma_{\Delta A}$ (left) and γ_{pw} (right) models. Solid blue lines are the selected $\sigma_{\Delta A}$ and γ_{pw} models. Red dots are the estimate of the metric comparing the seed to the 5 simulations. The solid red line on the right is a running mean of the estimated plane wave coherency.

is interesting to compare newly developed, incoherent seismic motions with the original (also somewhat incoherent) motions shown in Figure 2. It is noted that both the original and newly developed incoherent motions do follow mean fairly well.

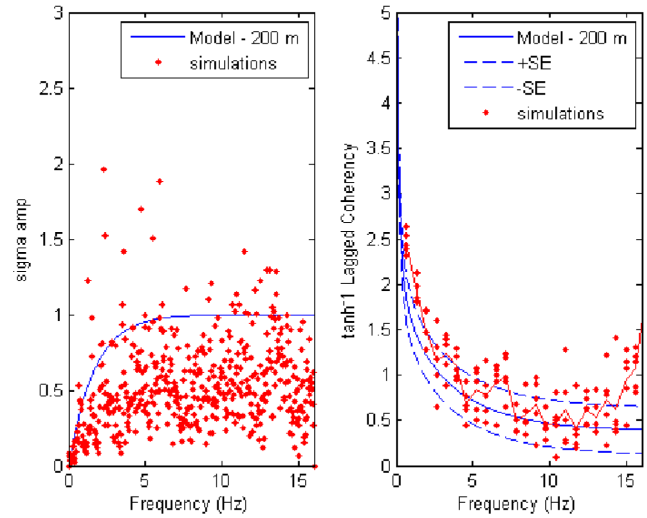


Figure 4: Validation of case 5 (soil) using location 1 as a seed against the selected $\sigma_{\Delta A}$ (left) and γ_{pw} (right) models. Solid blue lines are the selected $\sigma_{\Delta A}$ and γ_{pw} models, while dashed lines on the right are model $\pm\sigma$ Red dots are the estimate of the metric comparing the seed to the 5 simulations. The solid red line on the right is a running mean of the estimated plane wave coherency.

Development of Un-Correlated Motions in 3D

Un-correlated motions in full 3D can be developed by realizing that all three spatial axes (main, radial horizontal direction, along the principal direction of wave propagation motions, in our case X, transverse horizontal direction, in our case Y and the vertical direction) do exhibit lack of correlation (incoherence). This existence of three spatial directions of lack of correlation requires existence of data and models for all three directions. Abrahamson (1992a) concluded that there was little difference in the radial and transverse lagged coherency computed from the LSST array selected events. Therefore, the horizontal coherency models by Abrahamson (1992b) and subsequent models Abrahamson (2005, 2007) assumed the horizontal coherency model may apply to any azimuth. Coherency models using the vertical component of array data are independently developed from the horizontal.

ACKNOWLEDGMENT

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References

Abrahamson, N. (1992a). Generation of spatially incoherent strong motion time histories. In A. Bernal (Ed.), *Earthquake Engineering, Tenth World Conference*, pp. 845–850. Balkema, Rotterdam. ISBN 90

5410 060 5.

Abrahamson, N. (1992b). Spatial variation of earthquake ground motion for application to soil-structure interaction. *EPRI Report No. TR-100463, March.*.

Abrahamson, N. (2005). Updated coherency model. *Report Prepared for Bechtel Corporation, April*.

Abrahamson, N. A. (2007). Hard rock coherency functions based on Pinyon Flat data. unpublished data report.

Abrahamson, N. A., J. F. Schneider, and J. C. Stepp (1991). Empirical spatial coherency functions for applications to soil–structure interaction analysis. *Earthquake Spectra 7*(1), 1–27.

Hisada, Y. (1994). An efficient method for computing Green's functions for a layered half-space with sources and receivers at close depths. *Bulletin of the Seismological Society of America 84*(5), 1456–1472.

Hisada, Y. and J. Bielak (2003). A theoretical method for computing near–fault ground motions in layered half–spaces considering static offset due to surface faulting, with a physical interpretation of fling step and rupture directivity. *Bulletin of the Seismological Society of America 93*(3), 1154–1168.

Walling, M. A. (2009, Spring). *Non-Ergodic Probabilistic Seismic Hazard Analysis and Spatial Simulation of Variation in Ground Motion*. Ph. D. thesis, University of California at Berkeley. Under guidance of Professor Norman Abrahamson.

Zerva, A. (2009). *Spatial variation of seismic ground motions: modeling and engineering applications*. CRC Press.