Site amplification quantification through simulation of ground motion

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Abstract

The level of the earthquake hazard is strongly modified by local geological structure which can act to amplify ground motion substantially. The capability of simulating seismic waves propagating through complex 2D and 3D earth models provides a direct means to quantify this effect when the subsurface structure is well known. It also provides a means to study the reliability of field approaches to estimate site amplification, and a test-bed from which to develop improved field methods. Simulation studies of seismic waves entering simple structures using a pseudo-spectral approach indicate that a frequently applied microtremor method to estimate site amplification generally yields unreliable or incorrect results except when subsurface structure is present. Large scale 3D simulations of waves in the Brisbane basin illustrate the feasibility of using the simulation-based approach to quantify local site amplification effects in real cases provided subsurface structure is well known.

Introduction

It is well recognized that local site conditions can vary greatly over short distances. This variability in the local geology can have a major influence on the level of ground shaking during an earthquake. An ability to predict, by computer simulation, ground motion during strong earthquakes, provides a means to study the seismic response of large basins.

The study of site effects requires curved interfaces and free surface topography to be taken into account. The pseudospectral method is an attractive approach for modelling wave propagation through these complex realistic models, particularly in view of its ease of implementation. This method formulated in cartesian coordinates is not well suited to such models because the sharp interfaces and free surface do not coincide with grid lines, leading to numerical artifacts. Such problems may be overcome through the use of curved grids whose lines follow sharp interfaces and whose density increases in the vicinity of these interfaces (Komatitsch, et al., 1996[1]). One approach is to solve the wave equation in cartesian coordinates by using the chain rule to express the cartesian partial derivatives in terms of derivatives computed in the new coordinate system. However, it is more natural to directly solve the tensorial form of the wave equation in the desired curvilinear coordinate system, making use of a transformation of a square grid onto the curved grid. While the tensorial approach is less computationally expensive than the chain rule method, it requires more memory. In practice, it is preferable to use the chain rule approach for smooth topographies.

Studies of the reliability of field methods for site amplification

Synthetic data have been generated with the pseudospectral method (Komatitsch, et al., 1996[1]) and used to compare four site-response estimation techniques (Coutel and Mora, 1998[2]). The limits of applicability of each method were determined by modelling microtremors and incoming SV waves (with different incidence angles) and analysing the site amplifications. The first two techniques investigated consist of dividing the spectrum of the horizontal motion at a site by that of a reference site using either incident S waves or microtremors. The latter was unable to reveal either the resonant frequencies or peak amplitudes in any cases. The two other techniques are based on the horizontal-to-vertical (H/V) spectral ratio using S-waves or microtremors. These techniques were found to reveal at least the fundamental resonant frequency and amplitude (former method only) within a 10% error, in the case of simple geology (flat layers). However, the results show that these techniques are unable to take into account 2D effects such as focusing effects and basin-edge effects and yield unreliable or incorrect results in such cases.

Influence of 3D structure and source type on site response spectra

Three-dimensional simulations using different types of sediment-filled basins were performed (Coutel, 1998[3]). The influence of the dimension of the model, the addition of a surface topography, and the source parameters (type and position of the source) are studied. The modelling results indicate that the geometry of the basin strongly influences the site response. Complicated interactions, such as focusing effects, are observed between the structure of the basin and the incoming waves. Significant differences are found in amplitude and position of the resonant peaks for equivalent 1-D, 2-D and 3-D models, confirming the important role of structure. A small hill placed on top of a 3D basin nearly doubles the amplification factor, due to stronger focusing effects.

Three types of source (S wave, P wave, and seismic noise) yield different site responses. The largest amplification is obtained by using an S wave source. The use of the H/V ratio, based on seismic noise to compute the site response, does not detect amplifications due to focusing effects by the basin shape.

Illustration of large scale simulation to quantify basin response

A simplified model of the Brisbane basin was developed using geological, geophysical and geotechnical input (Figure 1). This model is not an accurate representation of the subsurface so it is not possible to draw detailed conclusions pertaining to the local amplification effects in the Brisbane basin. However, simulations of seismic waves through this model (Coutel, 1998[3]) illustrate the feasibility of large scale computer simulation studies to quantify the spectral response of a basin.

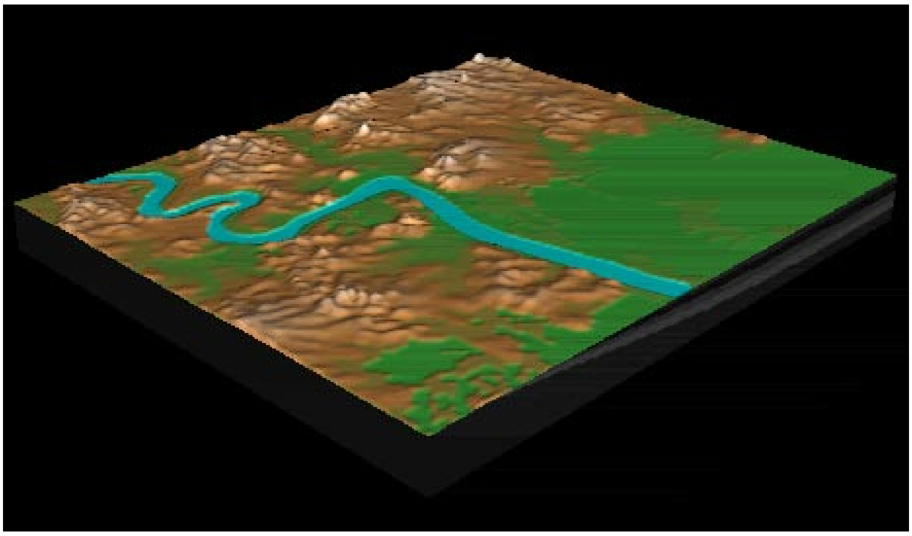

Figure 1: Illustrative model of the Brisbane basin based on surface topography data and a simplified subsurface structure developed from geological, geophysical and geotechnical data.

Figure 2 depicts snapshots of a vertically incident plane shear wave entering the Brisbane model. Figure 3 shows the spectral response of the basin computed at two specified frequencies. The availability of such information would be of great significance for engineering purposes, particularly for design of major or sensitive structures.

The results show that for the simplified Brisbane model, site amplification occurs in the north-west above the sedimentary basin (right side of Figure 1 = upper right of Figure 3), and that there are also site amplification effects induced by surface tomography on some rock sites (light areas in the lower left part of the plots in Figure 3).

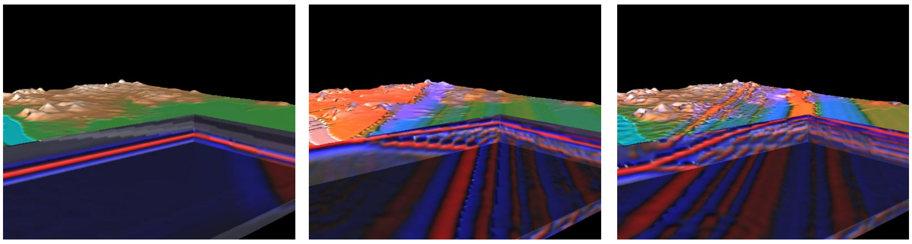

Figure 2: Snapshots of an incident plane shear wave entering the Brisbane model showing the reverberation phenomenon and site amplification effects.

This example shows how the site amplification factor as a function of space and frequency could be mapped for any given incident wave provided a detailed subsurface model is available, and represents an illustration of how supercomputer simulation studies could be used to provide information of practical significance in the immediate

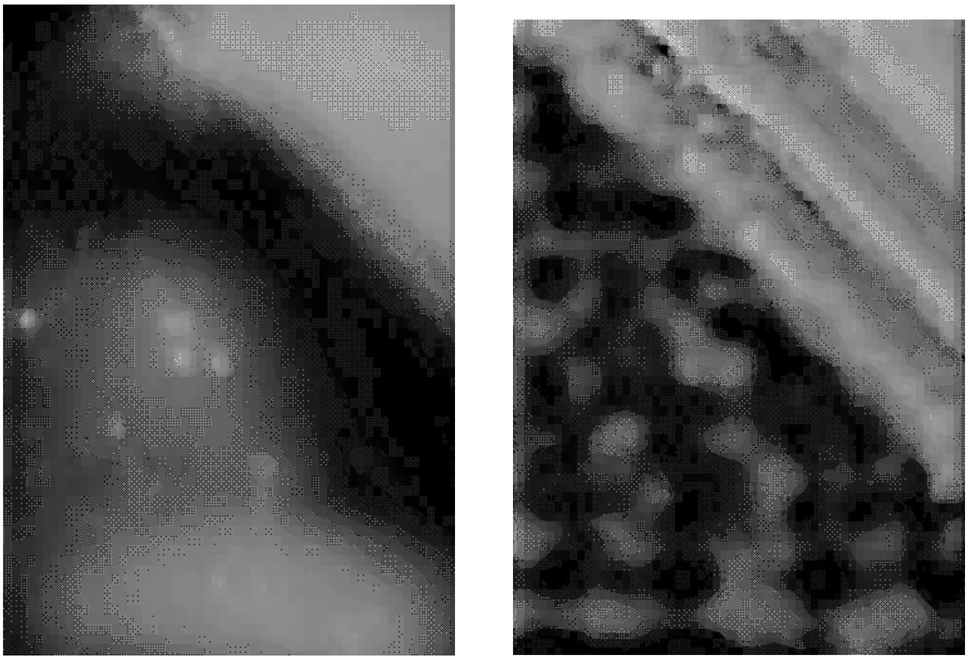

Figure 3: Resulting amplification as a function of position (lightest grey = an amplification factor of 4, darkest greys = amplification factor of 1 = no amplification). **Left:** at 0.5 Hz, **Right:** at 2.0 Hz.

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References

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