LONG PERIOD BASIN RESPONSE IN DOWNTOWN LOS ANGELES AND LONG BEACH FROM POSTULATED EVENTS ON THE ELYSIAN PARK THRUST AND PALOS VERDES/TORRANCE WILMINGTON FAULT SYSTEM

Final Report

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LONG PERIOD BASIN RESPONSE IN DOWNTOWN LOS ANGELES AND LONG BEACH FROM POSTULATED EVENTS ON THE ELYSIAN PARK THRUST AND PALOS VERDES/TORRANCE WILMINGTON FAULT SYSTEM

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Technical Abstract

Part 1 of this report gives an overview of the staggered-grid finite-difference method for simulating wave propagation in 3D elastic media. In this overview, we introduce a memory optimization procedure which allows large-scale 3D finite difference problems to be computed on a conventional, single-processor desktop workstation. With this technique, model storage is accommodated using both external and internal memory. To reduce system overhead, a cascaded time update procedure is utilized to maximize the number of computations performed between I/O operations. We also describe the extension and implementation of a stable and accurate free-surface boundary condition to the case of 3D media, as well as presenting an approximate technique for the inclusion of spatially variable anelastic attenuation within the finite-difference computation. We conclude with some examples which demonstrate the capabilities of the staggered-grid approach.

In part 2 of this report, we apply the 3D FD technique to model the strong ground motions recorded in the Los Angeles basin during the 1987 Whittier Narrows earthquake. Evidence for basin generated effects are clearly seen in the ground motion recordings of this event. In addition, since the event was recorded at a number of sites located both inside and outside of the Los Angeles basin, it is particularly well suited for use in validating the 3D velocity model of the LA basin.

Part 3 of this report describes the application of the 3D FD technique to model ground motions for a large, hypothetical earthquake on the San Andreas fault. This exercise is necessary to quantify the sensitivity of the long period ground motion response to the parameterization of the earthquake source. We use a finite fault representation with various choices of seismic moment, slip rise time, and slip heterogeneity. Our results indicate that the accurate simulation of long period ground motions requires a realistic source parameterization, including appropriate choices of seimic moment and rise time, as well as the use of spatial and/or temporal variations in slip distribution.

The final section of this report presents an analysis of ground motion amplification and associated damage in the Santa Monica area during the 1994 Northridge earthquake. We find that the shallow (1 km deep) basin edge structure created by the active strand of the Santa Monica fault is primarily responsible for the amplification effect. This basin edge amplification effect is quite similar to that which occurred during the 1995 Kobe earthquake, and which

resulted in tremendous structural damage within the Kobe City area. Using existing geological and seismological constraints, we developed a set of 2D velocity models that satisfactorily explain both the long period (T > 1 sec) mainshock strong motion recordings, as well as the high frequency (2-6 Hz) amplification ratios determined from aftershock observations. These validated 2D models form the basis for developing a more comprehensive 3D model of this region that can then be used in the simulation of expected ground motions for future earthquakes in the LA region.

Non-Technical Abstract

Studies of recent earthquakes in California and Japan have shown a strong correlation between the presence of sediment filled valleys and the amplification of earthquake ground shaking. The objective of this project is to understand and quantify the effect that lateral variations in shallow geologic structure will have on expected levels of earthquake ground motions in the Los Angeles region of southern California. We first used observations of recent earthquakes, along with available geologic information, to develop three-dimensional models of the subsurface structure beneath the LA region. Using these geologic models, we then employ sophisticated computer simulations to predict the ground shaking that is to be expected for future large earthquakes. During the course of this project, we have developed an extremely efficient computer algorithm, which allows large scale earthquake simulations to be computed on a conventional desktop workstation. Previous calculations of this type could only be performed using very expensive supercomputers, and thus were relegated to just a few experiments of primarily academic interest. In addition to this newly developed computation methodology, this project has also led to the development of a more comprehensive three-dimensional geologic model of the LA region, and an increased understanding of the effects that subsurface geologic structure can have on ground motion amplification during large earthquakes.

Publications from this Award

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Graves, R. W. (1996). Simulating realistic earthquake ground motions in regions of deep sedimentary basin, in *Proc. 11th World Conf. Earthquake Engineering*, Acapulco, Mexico, June 23-28, 1996.

Graves, R. W. (1998). Three dimensional finite difference modeling of the San Andreas fault: source parameterization and ground motion levels, *Bull. Seism. Soc. Am.*, **88**, 891-897.

Graves, R. W., A. Pitarka, and P. G. Somerville (1998). Ground motion amplification in the Santa Monica area: effects of shallow basin edge structure, *Bull. Seism. Soc. Am.*, **88**, in press.

Simulating Seismic Wave Propagation in 3D Elastic Media Using Staggered-Grid Finite-Differences

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Abstract

This paper provides an overview of the application of the staggered-grid finite-difference technique to model wave propagation problems in 3D elastic media. In addition to presenting generalized, discrete representations of the differential equations of motion using the staggered-grid approach, we also provide detailed formulations which describe the incorporation of moment tensor sources, the implementation of a stable and accurate representation of a planar free surface boundary for 3D models, and the derivation and implementation of an approximate technique to model spatially variable anelastic attenuation within time-domain finite-difference computations. The comparison of results obtained using the staggered-grid technique with those obtained using a frequency-wavenumber algorithm shows excellent agreement between the two methods for a variety of models. In addition, this paper also introduces a memory optimization procedure which allows large-scale 3D finite-difference problems to be computed on a conventional, single-processor desktop workstation. With this technique, model storage is accommodated using both external (hard-disk) and internal (core) memory. To reduce system overhead, a cascaded time update procedure is utilized to maximize the number of computations performed between I/O operations. This formulation greatly expands the applicability of the 3D finite-difference technique by providing an efficient and practical algorithm for implementation on commonly available workstation platforms.

Introduction

Modern computational efficiency has advanced to a state where we can begin to calculate wave field simulations for realistic 3D models at frequencies of interest to both seismologists and engineers. The most general of these numerical methods are grid-based techniques which track the wave field on a dense 3D grid of points, eg., the finite-difference (FD), finite-element (FE), and pseudo-spectral (PS) methods. Various algorithms have been developed to implement these techniques, and while there will always be debate as to which one is the "best" technique, each method has its merits and pitfalls.

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SIMULATING REALISTIC EARTHQUAKE GROUND MOTIONS IN REGIONS OF DEEP SEDIMENTARY BASINS

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ABSTRACT

We have developed a workstation based numerical simulation technique to model seismic wave propagation in arbitrarily complex 3D elastic media. The technique uses a staggered-grid finite-difference approach and is capable of generating highly accurate results. Due to the substantial storage requirements needed for the 3D finite-difference models, we have designed a memory optimization algorithm which reduces system overhead to a manageable level and allows the code to be implemented on a workstation platform. The method has been successfully applied to model the long-period (T>1 sec) ground motions for several recent earthquakes, including the 1987 Whittier Narrows, 1994 Northridge, and 1995 Kobe events. This workstation based technique provides an efficient and practical method to calculate the seismic response for large-scale, 3D geologic models.

KEYWORDS

Finite-difference simulations, workstation, basin response, Whittier Narrows, Kobe

INTRODUCTION

Many urban regions, including Los Angeles and Seattle in the United States, Osaka and Tokyo in Japan, and Mexico City in Mexico are located above large sedimentary basins. The conventional engineering approach to estimate earthquake ground motions is to assume that the near-surface geology can be characterized by a horizontally stratified medium, and that only the shallowest few tens of meters influence the ground motion characteristics. However, this simple approach may significantly underestimate the amplitudes and durations of strong ground motions, especially at periods of about one second and longer, where seismic energy can become trapped within the dipping sedimentary layers due to critical reflections that are set up at the edges of the basin. These effects are due to the geometry of the interface between the sedimentary materials and the underlying crystalline rocks, and cannot be explained by the shallow soil profile alone. Many elements of the urban infrastructure, such as bridges, multi-story buildings, dams and storage tanks, are susceptible to long-period ground motions.

Recently, much interest has been generated concerning the simulation of earthquake ground motions in realistic 3D geologic structures. The most general simulation methods are grid based techniques, which typically require substantial computational resources in order to produce results of practical interest. One way to handle this computational demand is to utilize the resources of a multi-processor supercomputer. However, these types of machines are extremely expensive and their use can require a significant amount

3D Finite Difference Modeling of the San Andreas Fault: Source Parameterization and Ground Motion Levels

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Abstract

Olsen et al. (1995) recently simulated a M_w 7.75 earthquake on the San Andreas fault, predicting long period (T > 2.5 s) ground velocities of 140 cm/s in the Los Angeles basin, about 60 km from the fault. These motions are much larger than estimates derived from empirical relations or other numerical simulations. Standard area-magnitude relations predict the 170 km × 16 km fault used in the simulations would produce a M_w 7.5 earthquake, giving a moment of 2.0×10^{27} dyne-cm, which is 2.4 times smaller than the moment used by Olsen et al. (1995). Further, self-similar scaling predicts a rise time of 3 s for a M_w 7.75 event and 2.2 s for a M_w 7.5 event. The filtered impulse slip function used by Olsen et al. (1995) has an effective rise time of 1.6 s, yielding a response that is about 2 times larger than expected for periods less than 5 seconds. This combination of high seismic moment and short rise time, along with the use of a uniform slip distribution, leads to the extreme ground motion levels predicted by Olsen et al. (1995).

To quantify the sensitivity of the long period ground motion response to source parameterization, we have performed 3D finite difference simulations using various combinations of seismic moment, source rise time, and slip heterogeneity. These calculations incorporate the same grid dimensions, fault size, and bandwidth employed by Olsen et al. (1995). With a moment of 2.0×10^{27} dyne-cm, a rise time of 2 s, and a smoothly heterogeneous slip distribution, we simulate peak long period ground velocities of 155 cm/s in the near-fault region, and 40 cm/s in the Los Angeles basin. These values are much closer to (although still higher than) empirical predictions. A uniform slip distribution produces the largest peak motions, both in the near-fault region and in the Los Angeles basin, whereas a rough asperity slip distribution noticeably reduces the maximum near-fault ground velocities. Our results indicate that the accurate simulation of long period ground motions requires a realistic source parameterization, including appropriate choices of seismic moment and rise time, as well as the use of spatial and/or temporal variations in slip distribution.

Ground Motion Amplification in the Santa Monica Area: Effects of Shallow Basin Edge Structure

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Abstract

The 1994 Northridge earthquake produced ground motions in the northwest portion of the Los Angeles basin that were significantly larger than rock site motions observed at locations just north of the basin. The Santa Monica area was hit particularly hard, with numerous structures being damaged or destroyed by the strong ground shaking. In this region, the basin edge geology is controlled by the active strand of the east-west striking Santa Monica fault, and virtually all of the structural damage occurred at or south of the fault location. We have used 2D finite difference ground motion simulations to investigate the effect of the basin edge structure in amplifying ground response. Constraints on the basin edge structure come from geologic cross sections, geophysical data, and seismological observations. Our simulations indicate that the shallow basin edge structure (1 km deep) formed by the active strand of the Santa Monica fault creates a large amplification in motions immediately south of the fault scarp, in very good agreement with mainshock damage patterns, recorded ground motions and locations of elevated site response. This large amplification results from constructive interference of direct waves with the basin edge generated surface waves and is quite similar to the basin edge effect associated with the 1995 Kobe earthquake. In addition, we find that focusing effects created by the deeper basin structure (3-4 km deep), cannot explain the large motions observed immediately south of the fault scarp. This strongly suggests that the deep-basin focusing models proposed by Gao et al. (1996) and Alex and Olsen (1998) are not likely explanations of the observed pattern of ground motion amplification in the Santa Monica area.

Introduction

At the time of its occurrence, the 1994 Northridge earthquake produced the most comprehensive set of strong ground motions observed to date, including some of the largest earthquake ground motions ever recorded instrumentally. Several stations in the near source region measured peak ground accelerations at or near 1 g, and a number of stations recorded peak ground velocities well over 100 cm/s (eg., Shakal et al., 1994; Porcella et al., 1994).