



NUMERICAL SIMULATION OF WAVE PROPAGATION IN REALISTIC 3D BASIN MODELS

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Abstract

The importance of long period motions on the response of large-scale structures (such as high-rise buildings, fluid-storage tanks, suspension bridges, etc.) has been well recognized by the earthquake engineering community. However, such long period motions are usually associated with surface waves, their incorporation in analysis procedures is not systematically performed. Furthermore, selection of strong motion records containing surface waves with particular characteristics (e.g. Rayleigh waves vs. Love waves) is not a trivial process. Also, techniques to synthesize strong motion records that contain surface waves with particular characteristics, are not widely available.

This work is concerned about the analysis and modelling of long period motions. The impact of buried geomorphology on both the elongation of the synthetic motions and the generation of surface waves will be studied. Numerical simulations of wave propagation in a 3D randomly heterogeneous soil basin, embedded in the surrounding outcropping bedrock was performed. The Argostoli city located at Kefalonia Island was selected as studied site because it is well characterized by several geological and geophysical campaigns.

According to the obtained results, the introduction of heterogeneous fluctuations of the mean geological properties increase the apparition of Rayleigh waves at the surface of the basin.

Keywords: Physics-based 3D simulation; alluvial basin; surface waves; heterogeneous soil properties;



1. Introduction

The importance of long period motions on the response of large-scale structures (such as high-rise buildings, fluid-storage tanks, suspension bridges, etc.) has been well recognized by the earthquake engineering community. However, such long period motions are usually associated with surface waves, their incorporation in analysis procedures is not systematically performed. Part of this problem is the fact that surface waves are described by more complicated characteristics (e.g. dispersion) that may not be well understood among earthquake engineers. Furthermore, selection of strong motion records containing surface waves with particular characteristics (e.g. Rayleigh waves vs. Love waves) is not a trivial process. Also, techniques to synthesize strong motion records that contain surface waves with particular characteristics, are not widely available.

In addition, earthquake engineers are becoming increasingly aware of the importance of rotational motions (i.e. rocking and torsion), associated with long periods, for the dynamic response of long period structures. Analysts develop all the necessary techniques to incorporate rotational motions in the excitation of the structural models, however, recordings of such motions are not always available and their estimation from the records of translational motions, whenever this is feasible, is not an easy task.

This work is concerned about the analysis and modelling of long period motions. Intense long-period ground motions are usually generated at large distances from the source and consist primarily of surface waves that arise when seismic waves encounter sedimentary deposits. The impact of buried geomorphology on both the elongation of the synthetic motions and the generation of surface waves will be studied. Numerical simulations of wave propagation in a 3D randomly heterogeneous soil basin, embedded in the surrounding outcropping bedrock was performed. This work is in the framework of both the MODULATE project (Modeling lOng-perioD groUnd motions, and assessment of their effects on Large-scale infrAsTructurEs - ANR-18-CE22-0017) and the SINAPS@ project (ANR-11-RSNR-0022). The developments to generate seismic signals that rigorously describe the presence of basin-generated surface waves, will be used later to study the seismic behaviour of large-scale structures through the framework of Performance-Based Earthquake Engineering (PBEE).

2. Case study and numerical model

In this section, the case study is illustrated briefly, providing some information about the geological context and the available in situ data and the resulting geotechnical model. The Argostoli-Koutavos test site located in the western part of the Kefalonia Island (Greece) was selected for this study (Fig. 1). This site was chosen to carry out geological reconnaissance and geophysical acquisition missions in the framework of SINAPS@ project and the NERA (Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation) project among others (Cultrera et al., [1]). The successive experimental missions that took place in the study site allowed the identification of the geological interfaces and to build a geological model of the region (Cushing, et al. [2]). Based on this model, a numerical model of the studied site has been proposed in this work. Refer to Cushing, et al. [2] and Touhami et al. [3] for further details about the proposed 3D geological model of Argostoli region.

The used numerical model has a dimension of about 27 x 30 x 53 km (Fig. 2). The mesh is unstructured in the vertical plane, allowing the number of elements to be optimized with respect to the propagated wavelengths (Touhami et al. [3]). The total number of degree of freedom is equal to 1.114×10^6 . A mesh grid resolution of 50 x 50 x 50 m defining the upper layers and the basin was used. Due to the complexity of the geometry of the Argostoli basin, a not-honouring meshing strategy, presented and verified in Touhami [4] for some simplest cases, has been adopted. Fig. 3 displays a view of the basin into the model.

The regional scale 3-D earthquake scenario, including the complex geology, is calibrated up to 10 Hz, using a 3-D spectral-element based software called SEM3D [5]. The spectral element method is a high-order version of the Finite Element Method. Those simulations were performed on Occigen supercomputer (a 3.5 pFlops Tier-1) and use 10x10x10 GLL (Gauss-Lobatto-Legendre) points.

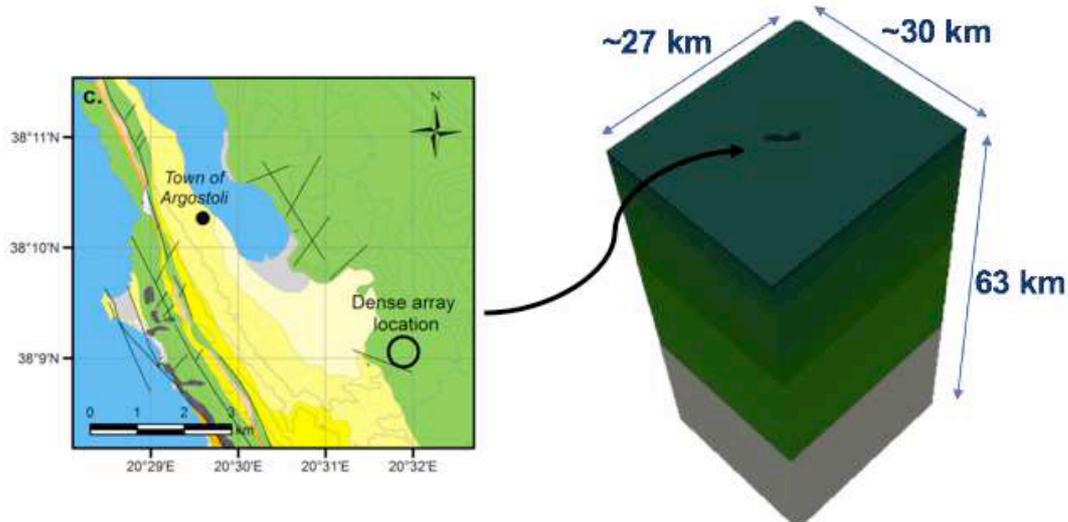


Fig. 1 – View of 3D model of the Argostoli area (Touhami et al. [3])

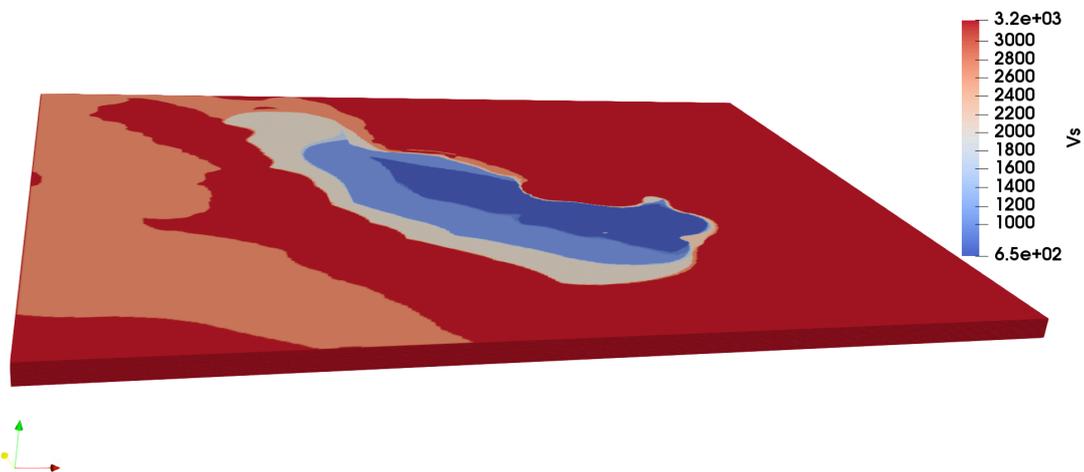


Fig. 2 – Section of the SEM3D mesh employed in this study, including the complex geology of the 3D basin model of the Argostoli area (Touhami et al. [3]).

Concerning the seismic sources, the fault discontinuities are modelled by means of a kinematic approach. In practice, the kinematic assumption of extended faults consists in considering a distribution of double couple point-wise sources along the fault plane, with different time-varying slip functions [6]. In this work, the kinematic source model RIK (Ruiz's Integral Kinematic) proposed by Ruiz et al. [6] was used. A Mw 6.0 earthquake was simulated. The fault segment has a 15 km x 10 km extension and its orientation is defined by the strike, dip, rake triplet (38° , 63° and 172° respectively). The hypocenter is placed at a depth of 10 km. The slip patch is discretized on a 150 x 100 grid points.



So as to assess the effect of the basin soil heterogeneities on the induced Rayleigh waves apparition, a second model with a fluctuation of the soil properties within the sedimentary basin is also performed. A spatially variable non-stationary random field for the unit mass density was used. The random field was generated using the randomField open toolbox [7] coupled with SEM3D. The random field follows an anisotropic Von Karman Correlation structure with a horizontal fluctuation length of 90 m and a vertical one of 40 m.

3. Results and discussion

In this section, the seismic response of the Argostoli basin is studied, by comparing two simulations with and without fluctuation of the soil properties within the sedimentary basin. The other properties, namely, the mesh grid, the extended source and the mean properties are the same in both models. Fig. 3 shows both the evolution of velocity contour plots nearby the basin and slip rate in the extended source for two time steps.

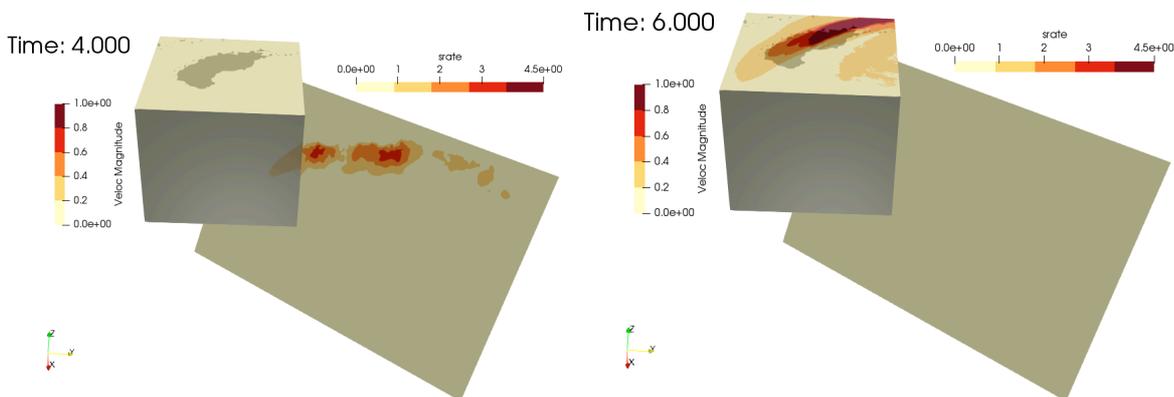


Fig. 3 – Velocity contour plots in the basin and slip rate contours on the fault plane at two-time step computation (Touhami [4])

The simulated accelerograms for the homogeneous numerical model obtained at several points at the surface of the basin are shown in Fig. 4. The results have been analyzed along a receiver profile crossing the basin longitudinally. The effect of the basin is highlighted by the creation of diffracted waves, particularly energetic inside the basin. Another aspect noted from the same figure is the elongation of signal duration at the surface of the basin. As example, Fig. 5 provides the three components of the obtained time-histories at the surface in a point inside the basin (point 1049). The signals are band-pass filtered between 0.1 and 10 Hz.

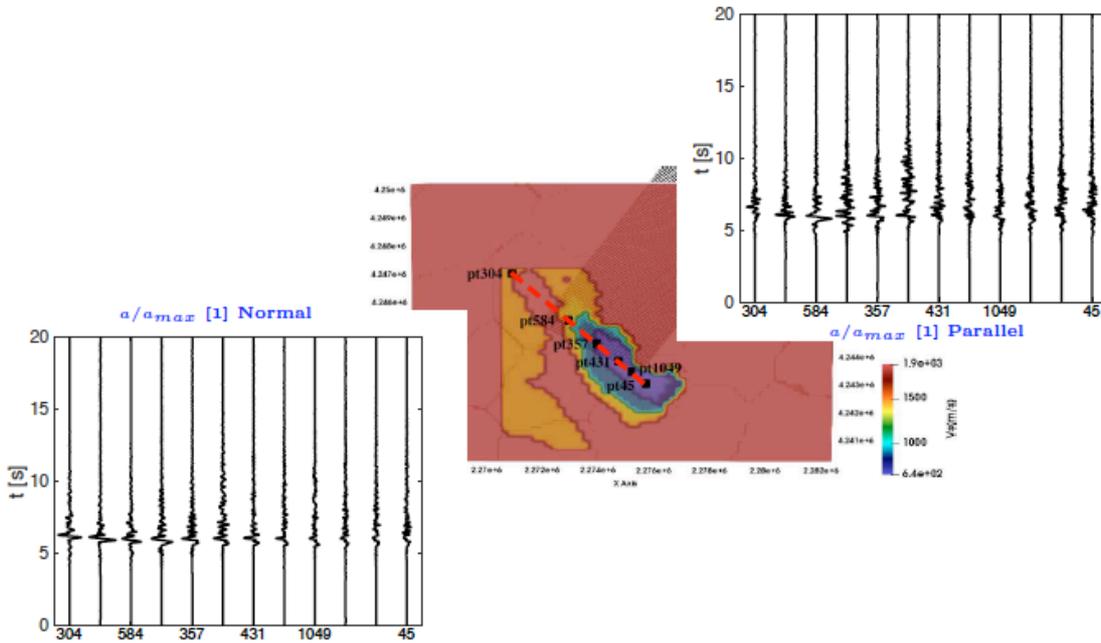


Fig. 4 – Normalized horizontal components (normal and parallel to the basin) of the time-history acceleration response along the longitudinal profile.

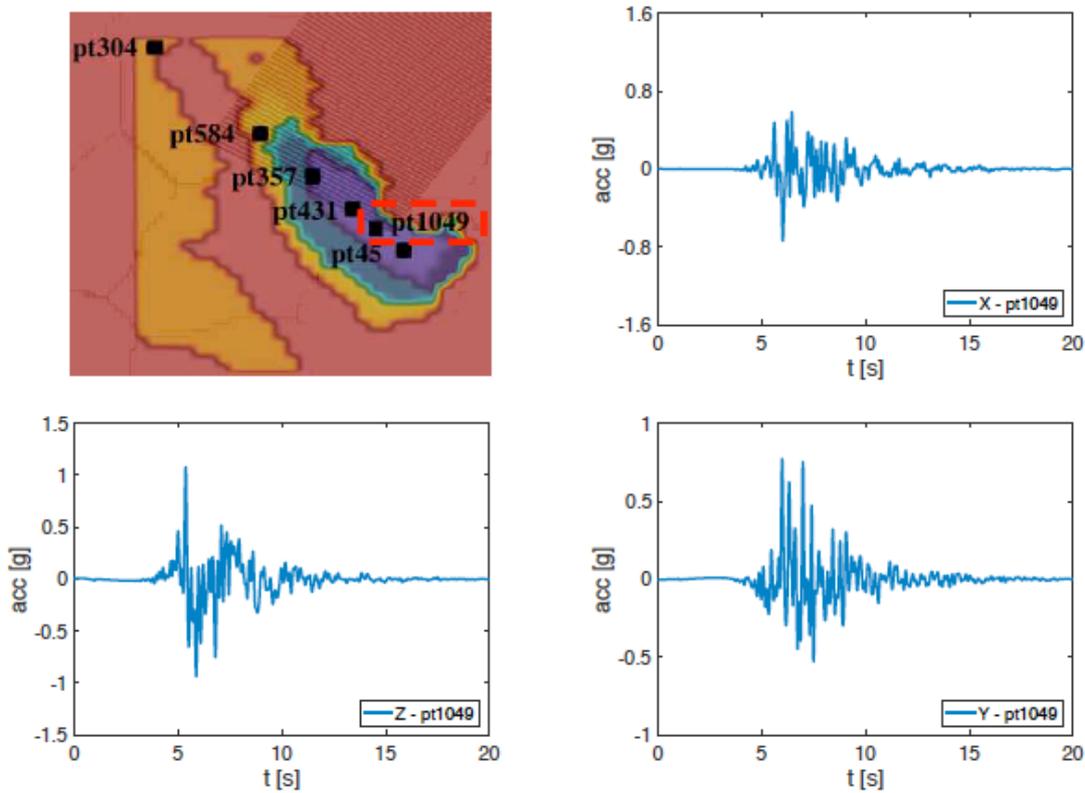


Fig. 5 – Acceleration time history obtained at the basin surface (point 1049) and filtered at 0.1 -10 Hz.



Fig. 6 shows the comparison of the normalized response's spectra of the obtained acceleration time-histories at P1049 (surface of the basin) from the models with homogeneous and heterogeneous basin properties. It is observed that a major difference between the two simulations is noticed at the high-period part of the propagated synthetic ground motion at the surface. Higher spectral values are found when the heterogeneous basin properties are taken into account, principally in the horizontal components of the signal.

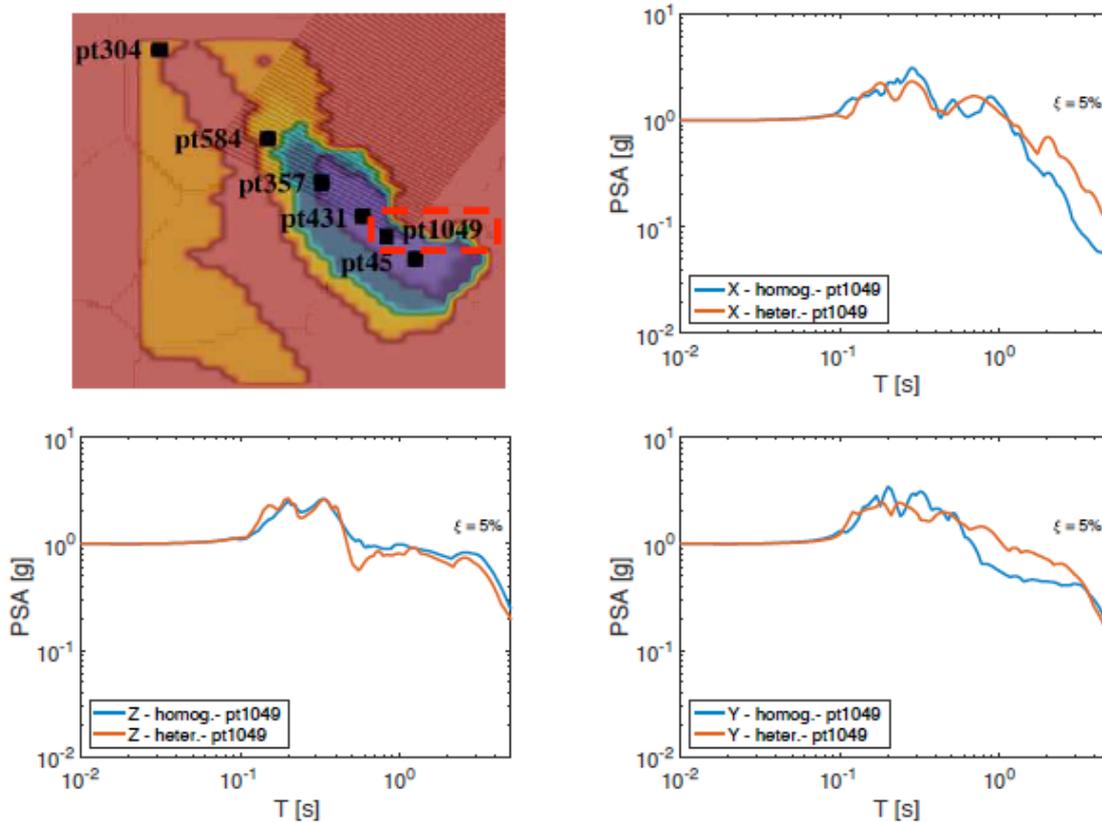


Fig. 6 – Normalized response's spectra of the obtained acceleration time-histories at P1049. Comparison between homogeneous (blue) and heterogeneous (red) models.

Concerning the estimation of rocking, according to Meza Fajardo and Papageorgiou [8] among others, angular displacement components of strong motion always accompany the translational displacement components induced by seismic waves. It is well known that rocking is associated with P, SV, and Rayleigh waves, while torsion is associated with SH and Love waves. In this work, the method proposed by Meza-Fajardo et al. [9] to identify and to separate body waves from surface waves is used. This method uses as criterion the representation of their polarization characteristics in a time-frequency correlation and taking into account their frequency-dependent phase velocities. Refer to Meza-Fajardo et al. [9] for further details about the used method.

So as to assess the effect of the basin soil heterogeneities on the induced Rayleigh waves apparition, a comparison between the size of the extracted Rayleigh wave components is performed. This comparison is done for the obtained surface signals at the point 1049 (Fig. 6) for the cases with and without fluctuation of the soil properties within the sedimentary basin. Fig. 7 shows the



original signal and the signal after extraction of the surface waves. It is noted that the rocking history with the largest amplitude was generated by the case when the soil heterogeneities are taking into account.

Finally, according to the obtained results, for the homogeneous case, at the point 1049, the Rayleigh waves were found between 0.2 and 0.4 Hz and between 0.2 and 1 Hz for the heterogeneous case.

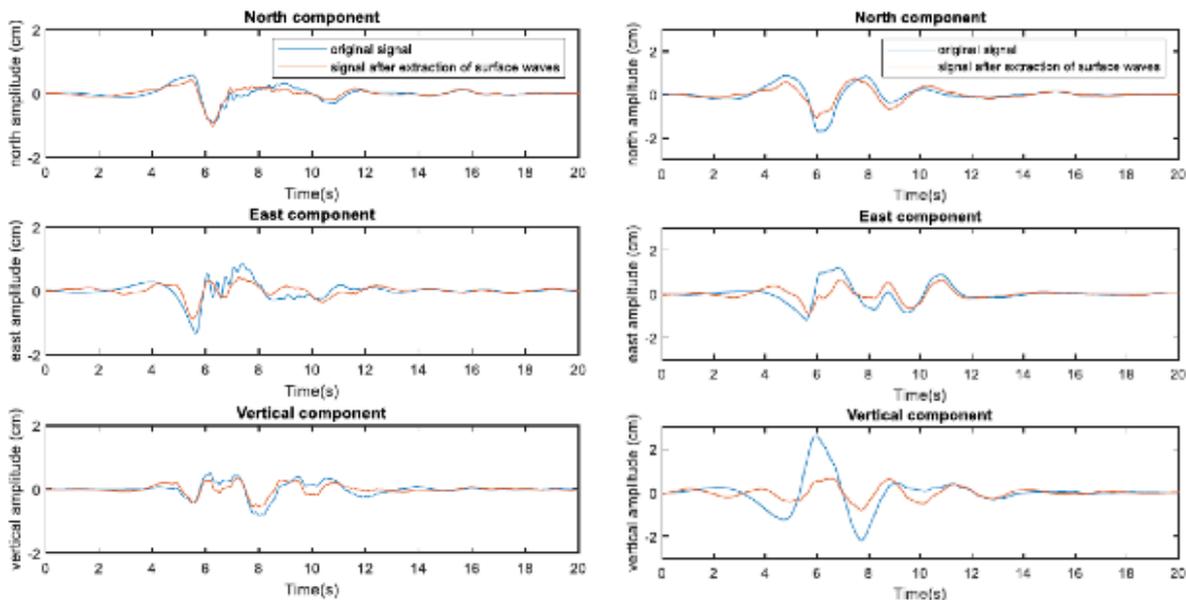


Fig. 7 – Comparison of the obtained original signal and the signal after extraction of the surface waves at the point 1049 for the cases without (left) and with (right) fluctuation of the soil properties within the sedimentary basin.

5. Conclusions

In this paper, the synthetic simulation of the seismic response of the experimental site of Argostoli (Greece) was presented. This work aims at showing the high-frequency prediction of a numerical model for future plausible earthquake scenarios and to assess the effect of the basin soil properties on the induced Rayleigh waves apparition. In addition, the introduction of heterogeneous fluctuations of the mean geological properties increase the apparition of Rayleigh waves at the surface of the basin.

Further works concern the use of the extracted signals as an input to study the response of long period structures (such as, high-rise buildings, fluid-storage tanks, suspension bridge tower-pier system) when subjected to surface waves.

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