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SYNOPSIS Site response analyses were conducted at the Treasure Island site where surface motions were recorded during the Loma Prieta earthquake. The analyses were conducted using a nonlinear dynamic effective stress method which took into account the effects of the liquefaction that occurred at the site. The rock motions recorded at nearby Yerba Buena Island were used as input motions. Computed and recorded ground motions transverse to the direction of wave propagation and associated response spectra were in good agreement. Agreement was also good in the radial direction, except in certain frequency bands higher than 1.25 Hz. Coherence studies showed that some of these discrepancies may be due to low coherence between the Treasure Island and Yerba Buena motions in these same frequency bands.

INTRODUCTION

During the Loma Prieta earthquake of 1989, ground accelerations were recorded on rock at Yerba Buena Island and on dredged sandfill on nearby Treasure Island (Figure 1). Three-dimensional views of these accelerations are shown in Figure 2. Many site response studies of the Treasure Island site have been conducted using the one-dimensional (1-D) equivalent linear analysis incorporated in the SHAKE computer program (Schnabel et al., 1972). Typical results have been presented by Hryciw et al. (1991) and Idriss (1990) shown in Figures 3 and 4, respectively. Somewhat different site models were used in both of the cited studies, but the response spectra for the E-W direction are in general agreement. The computed spectra underestimate the recorded spectra substantially, especially in the N-S direction.

Liquefaction was noted at the Treasure Island site during the Loma Prieta earthquake. Therefore, the total stress equivalent linear method would be expected to underestimate the longer periods as the reduction in small strain soil stiffness due to high porewater pressures cannot be taken into account. This effect has also been noted by Hryciw et al. (1975). Another factor that can contribute to the discrepancy between recorded and computed motions arises from the nature of the ground motions and the assumptions used in 1-D analyses.

Site motions are comprised of both body waves and surface waves. However, the 1-D response analyses are based on the assumption that the surface waves are derived entirely from body waves, from shear waves propagating vertically. Therefore, the accuracy of site response simulations depends in part on the degree to which surface waves are present in the site motions. The presence of surface waves in the overlying soil deposit will lead to a lack of coherence between the recorded ground motions at the surface and the input rock motions. This problem has been discussed previously by Finn (1979) and illustrated using Japanese site data from Ohta et al. (1977).

The effects of high porewater pressure and the coherence of the Treasure Island and Yerba Buena Island recorded motions on site response simulations of the Treasure Island motions will be examined in detail.

SITE CONDITIONS

The site conditions assumed for analysis were those established by Gibbs et al. (1992) for the Treasure Island site (Figure 5). The selection of soil properties were also influenced by Idriss (1990), Hryciw et al. (1991) and Silva (1993).

Liquefaction was reported to have occurred at the Treasure Island site. Resistance data for the Treasure Island fill was inferred from blow counts reported by Hryciw et al. (1991) and from the time to liquefaction as evident from the recorded acceleration records. Porewater pressure model parameters for DESRA-2 were selected consistent with these data.

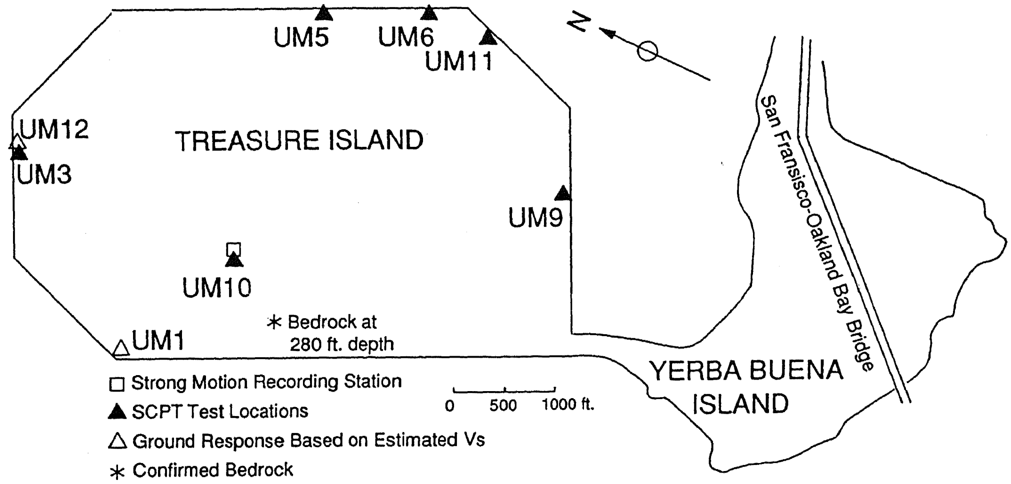

Figure 1. Site plan of Treasure Island and Yerba Buena Island (after Hryciw et al., 1991).

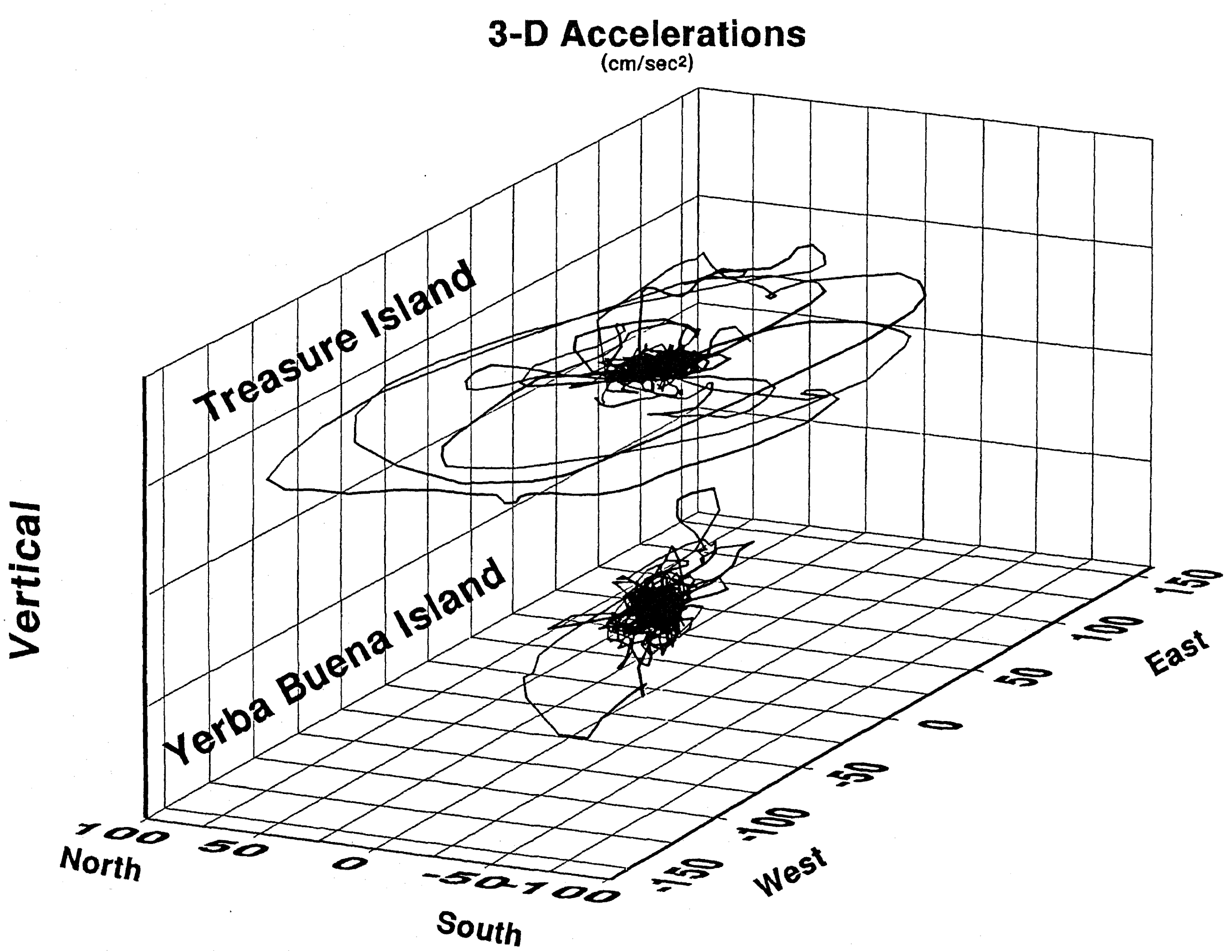

Figure 2. Three-dimensional view of accelerations recorded at Treasure Island and Yerba Buena Island.

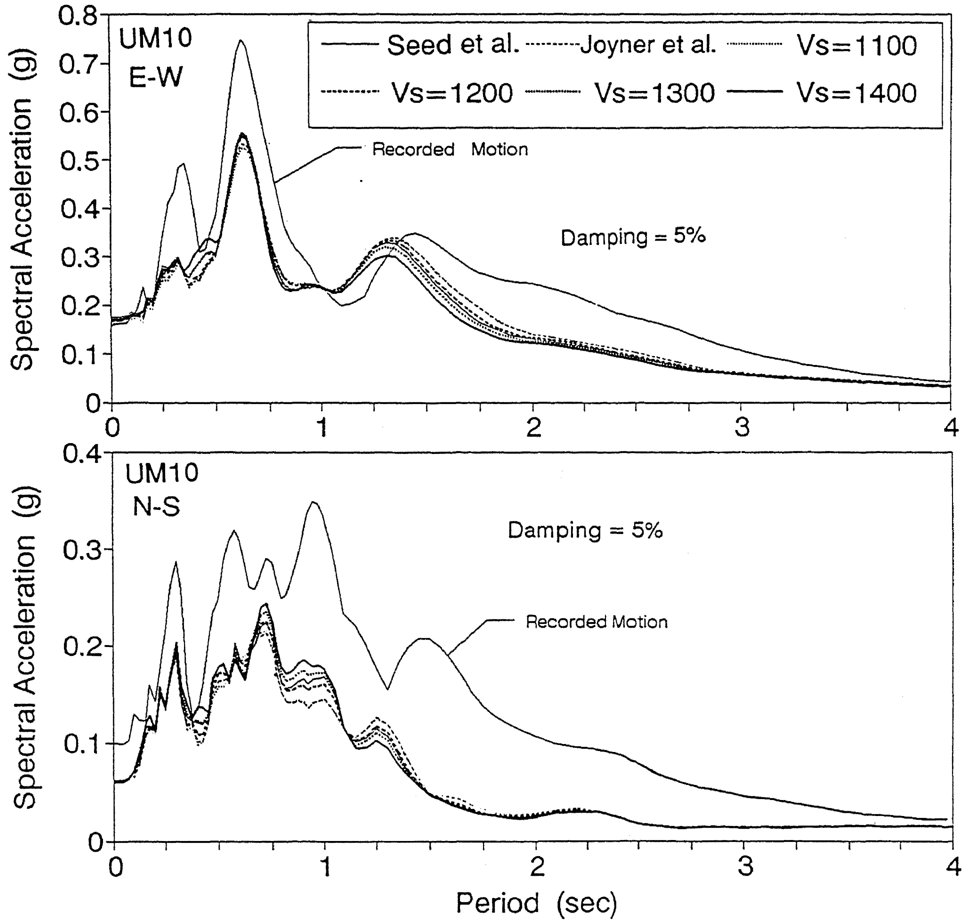

Figure 3. Spectral accelerations at Treasure Island (UM10) using various assumptions for propagation velocity of Old Bay sediments (after Hryciw et al., 1991).

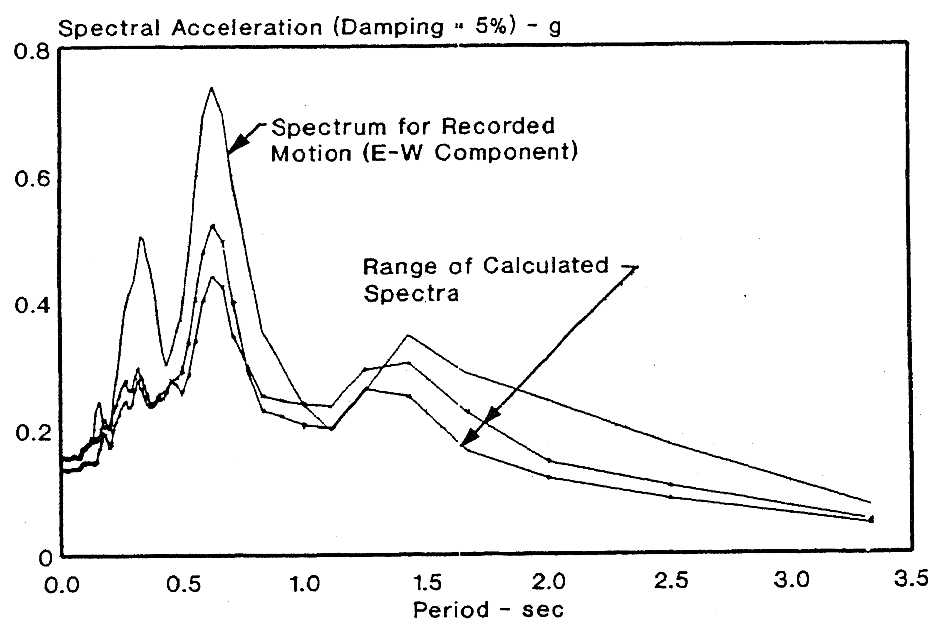

Figure 4. Spectra for recorded and calculated motions at Treasure Island (after Idriss, 1990).

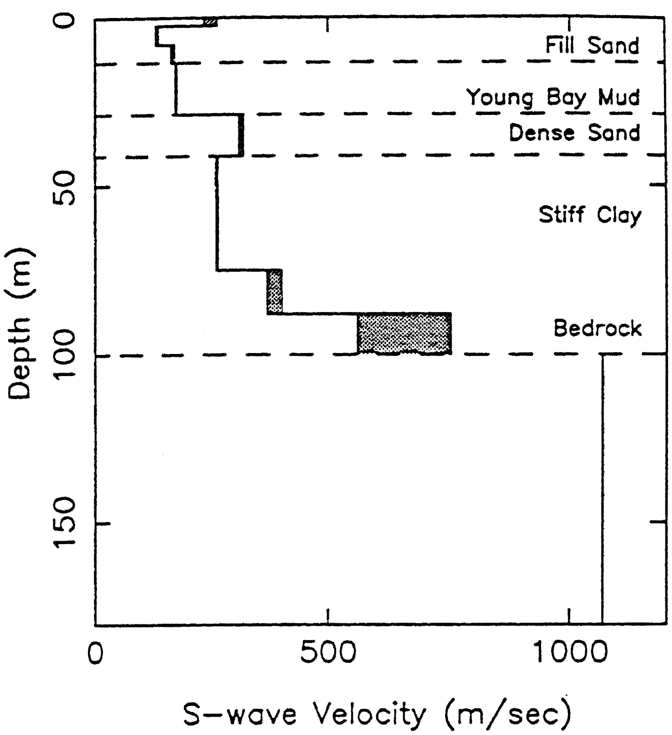

Figure 5. Soil profile and shear wave velocities at Treasure Island determined by Gibbs et al. (1992).

SITE RESPONSE ANALYSES

Analyses in E-W and N-S Directions

The site response analyses of the Treasure Island site were conducted using the 1-D nonlinear effective stress program DESRA-2 (Finn et al., 1977; Lee and Finn, 1978).

The analyses were conducted first using the recorded N-S and E-W components of the Yerba Buena rock motions as input. The computed and recorded surface accelerations are plotted for the E-W direction in Figure 6 and for the N-S direction in Figure 7. The agreement in the E-W direction is very good in the region of strong shaking. The computed post-liquefaction response represented by the quasi-harmonic accelerations after 15s are somewhat stronger than the recorded motions. This could be due to two factors: the residual strength assumed for the post-liquefied sand is too high, and/or the viscous damping incorporated for numerical control during integration is to high. At this preliminary stage, these possible refinements were not pursued.

The strong motions in the N-S direction are adequately simulated for engineering purposes but the agreement is not as good as in the E-W direction (Figure 7).

The computed spectrum for the E-W direction is compared with the spectrum of the recorded motions in Figure 8. The two spectra agree very well. The inclusion of porewater pressures and true nonlinear response has resulted in major improvements over the total stress spectra in Figures 3 and 4.

The computed and recorded spectra in the N-S direction are shown in Figure 9. The agreement here is not as good as in the E-W direction, but it is greatly improved over the total stress spectra in Figure 4

It is clear from Figure 9 that in the N-S direction the simulation is very good for periods less than 0.8s. There are significant differences in the period range 0.8s - 1.2s where the computed spectrum underestimates the response. For periods greater than 1.5s, the computed spectrum also underestimates the response.

Analysis in Radial and Transverse Directions

The recorded acceleration components at Treasure Island and at Yerba Buena Island were resolved into transverse and radial components normal and parallel to the direction of wave propagation. Site response studies were conducted to obtain transverse and radial accelerations and corresponding acceleration response spectra for Treasure Island. The computed and recorded ground accelerations in the transverse and radial directions agreed rather well.

The computed acceleration spectrum in the transverse direction (Figure 10) shows better agreement with the spectrum of recorded motions at periods above 0.5s than was the case for the E-W direction (Figure 8), but the agreement has deteriorated in the period range 0.3s - 0.5s. The computed spectrum in the radial direction (Figure 11) shows the same good agreement in the period range 0.8s with the spectrum of the recorded motions noted previously in the N-S direction. There is some improvement in the computed spectrum at periods longer than 0.8s, but there are still significant differences in the period range 0.8s - 1.2s and 1.4s - 2.2s.

It is interesting to note the changes in peak spectral response at various periods resulting from rotation of the recorded ground accelerations from N-S and E-W directions to radial and transverse components.

COHERENCE STUDIES

The coherence of the N-S components of the recorded accelerations at the Treasure Island and Yerba Buena sites is shown in Figure 12. The coherence is generally very good for frequencies above 1.25 Hz. This range corresponds to periods less than 0.8s over which good agreement between the computed spectrum and the

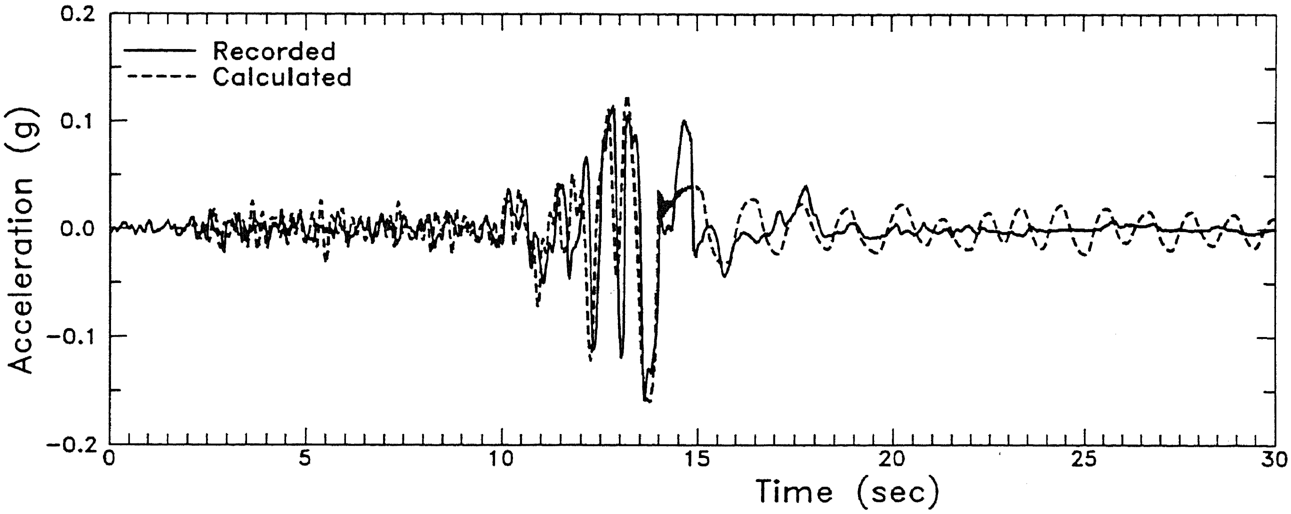

Figure 6. Time histories of recorded and calculated E-W accelerations at Treasure Island.

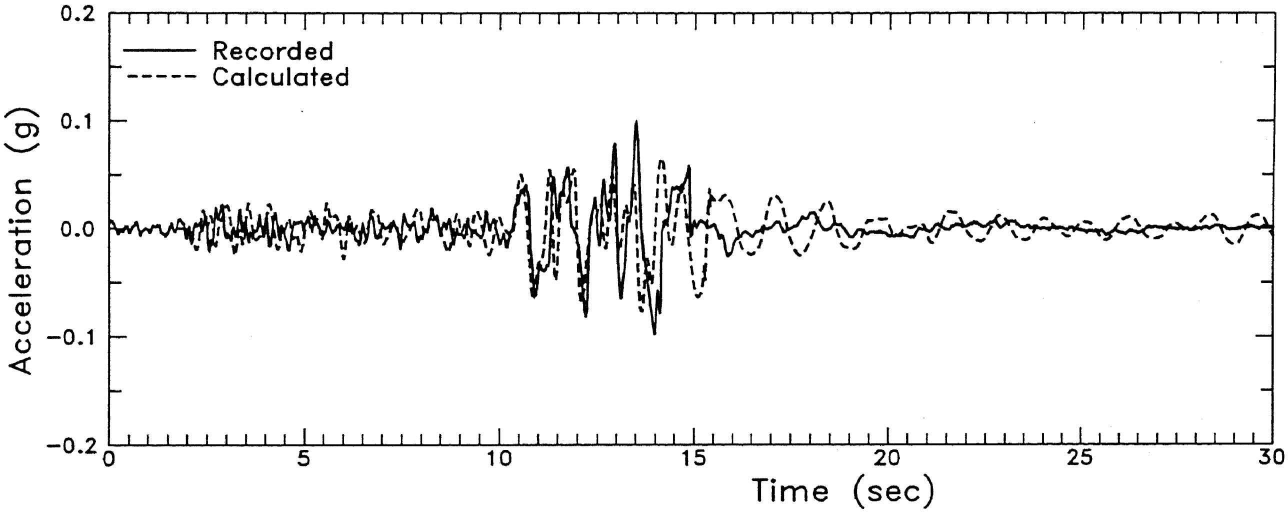

Figure 7. Time histories of recorded and calculated N-S accelerations at Treasure Island.

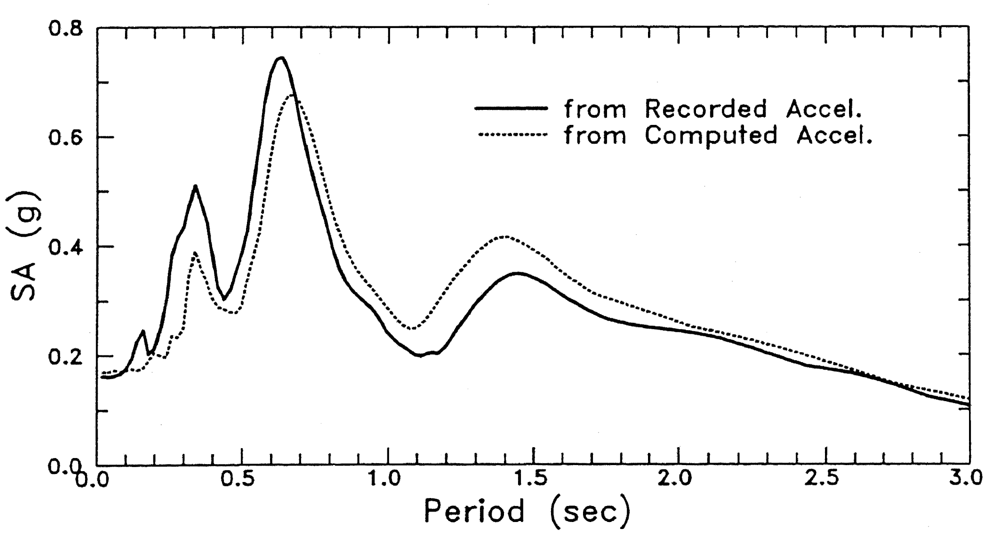

Figure 8. Response spectra for recorded and calculated E-W accelerations at Treasure Island (5% damping).

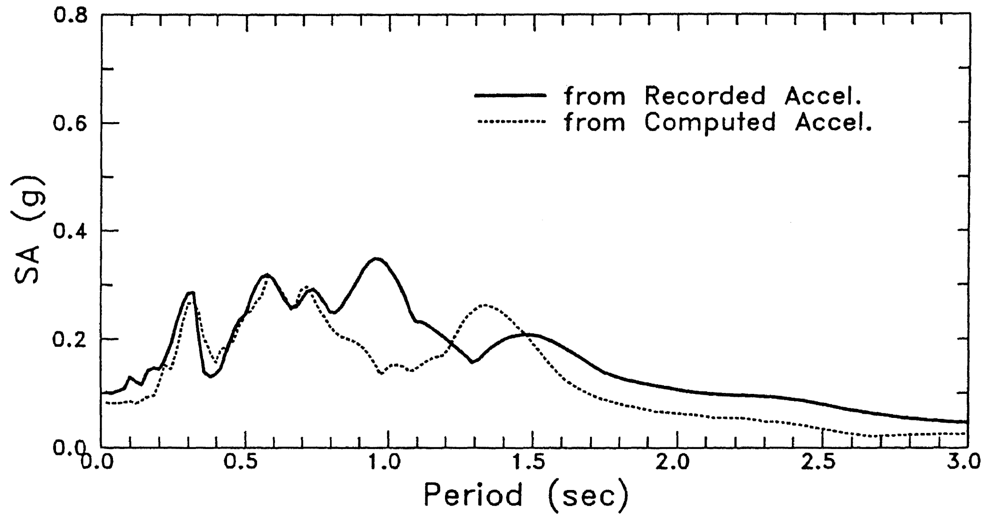

Figure 9. Response spectra for recorded and calculated N-S accelerations at Treasure Island (5% damping).

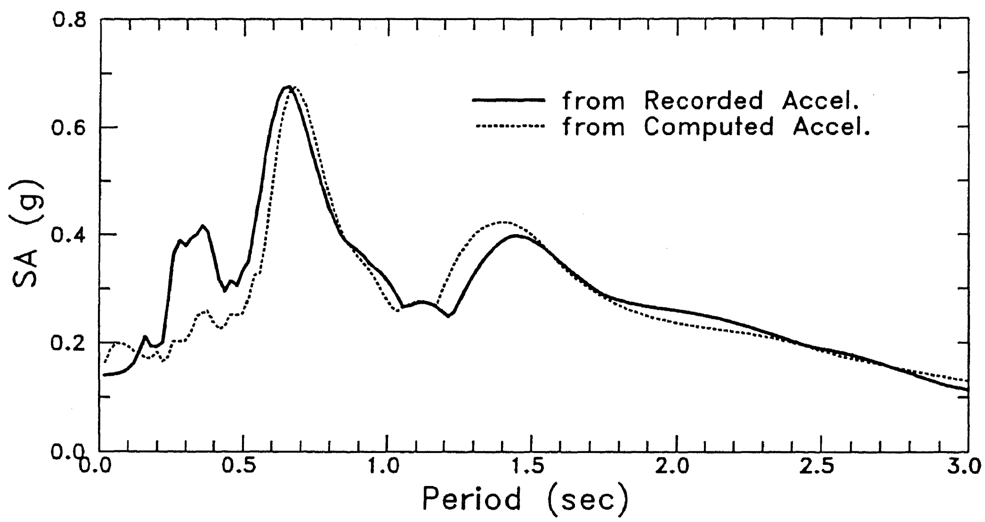

Figure 10. Response spectra for transverse accelerations at Treasure Island (5% damping).

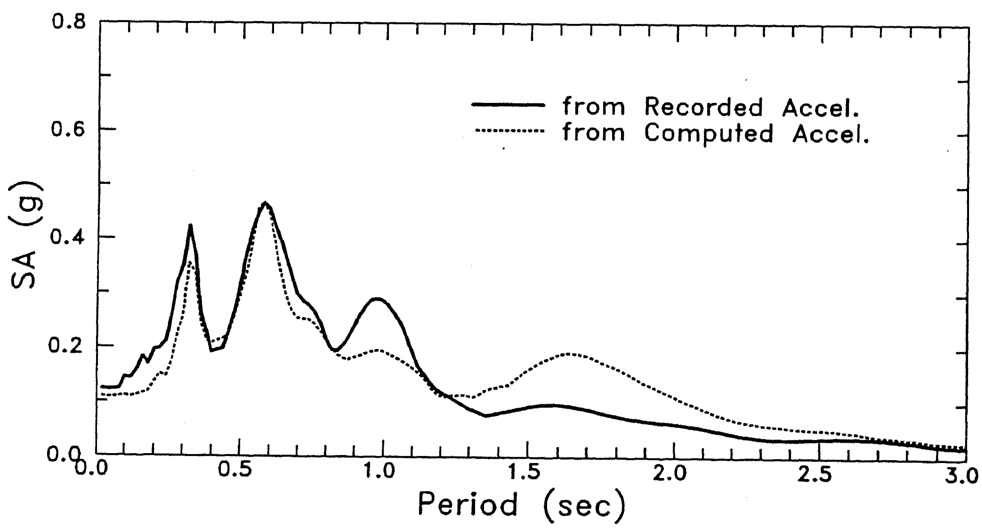

Figure 11. Response spectra for radial accelerations at Treasure Island (5% damping).

spectrum of the recorded motions was observed. The coherence is much less in the lower frequencies below 1.25 Hz. This range corresponds to periods greater than 0.8s where less satisfactory agreement with the spectrum of recorded motions was noted.

The coherence of the E-W components of recorded motion is shown in Figure 13. The coherence in the long period range (low frequency range) is much higher than in the N-S direction and this is reflected in better simulation of the acceleration response spectrum at these periods. The lowest coherence is in the high frequency range greater than 4 Hz, corresponding to periods shorter than 0.25s. The effects of this lack of short period coherence is reflected in the comparison between the computed spectrum and the spectrum of recorded motions in Figure 8.

CONCLUSIONS

Nonlinear dynamic effective stress analysis resulted in a much better simulation of the seismic response of the Treasure Island site than previous total stress analysis. This is to be expected as the site liquefied during the earthquake. The high porewater pressures generated by earthquake shaking softened the site and led to longer period motions.

In certain period ranges, there are still significant differences between recorded and computed response in the N-S direction. Coherence studies show that there are several frequency ranges of low coherence between the motions recorded at Yerba Buena and Treasure Island. Therefore, no matter how good a constitutive model may be, it will not be possible to obtain a good simulation of recorded response over period ranges of low coherence between recorded input and output motions.

ACKNOWLEDGEMENTS

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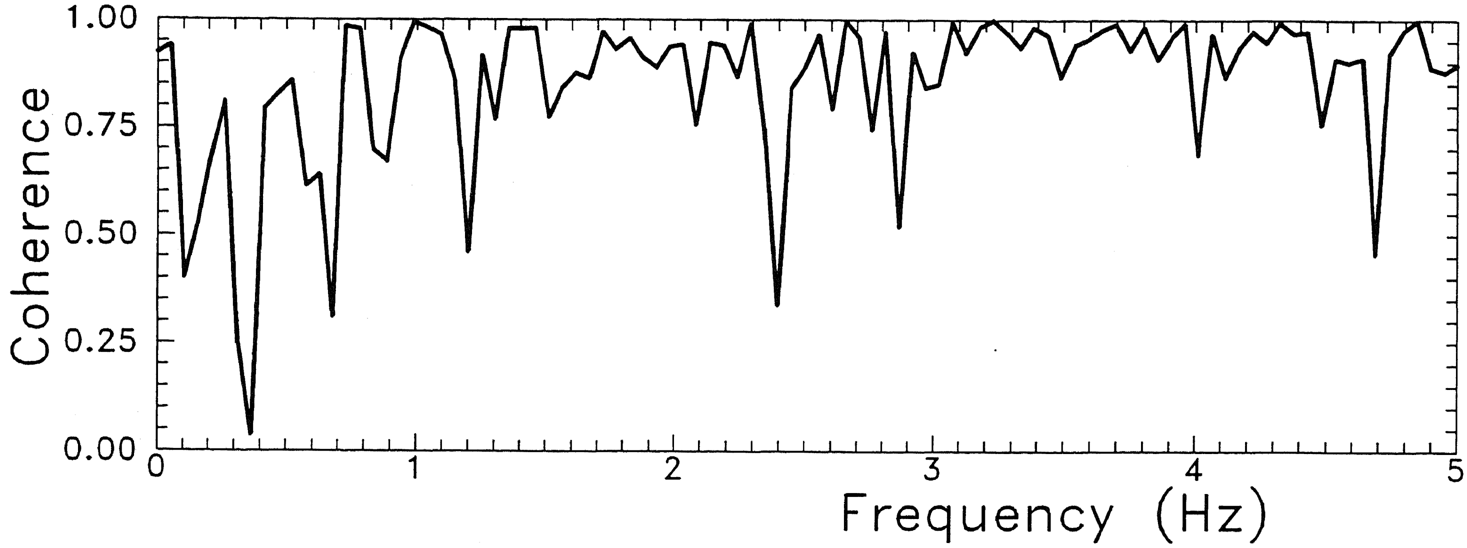

Figure 12. Coherence of the N-S recorded accelerations at Treasure Island and Yerba Buena Island.

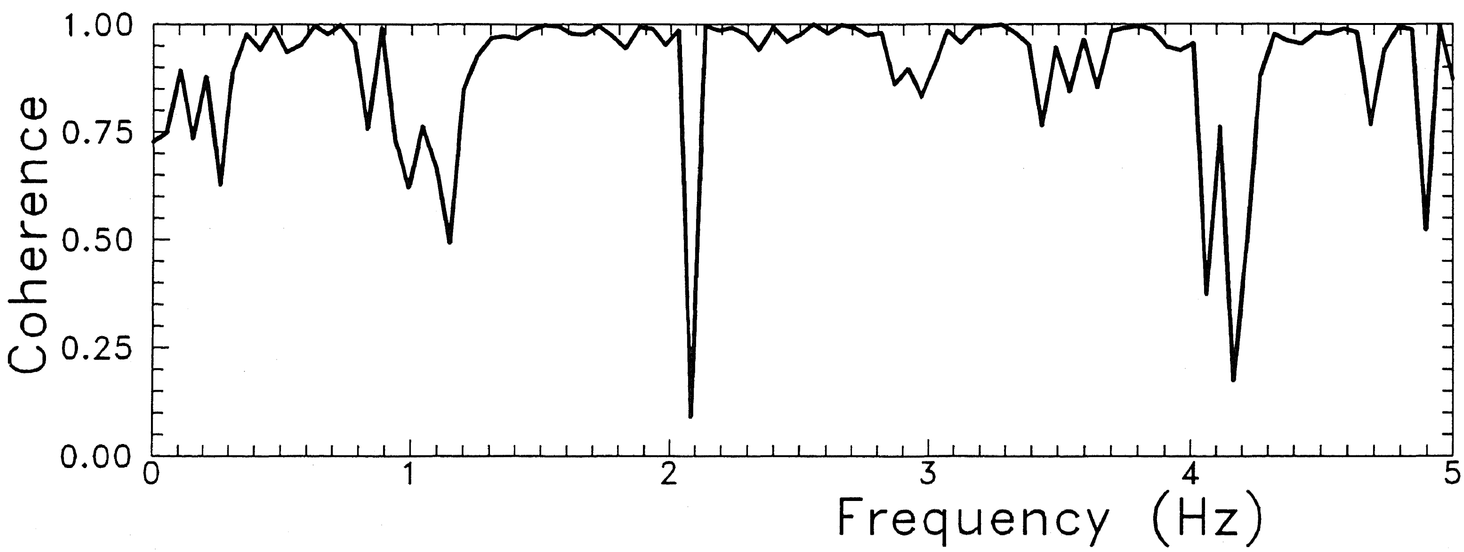

Figure 13. Coherence of the E-W recorded accelerations at Treasure Island and Yerba Buena Island.