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# EFFECT OF INPUT MOTION CHARACTERISTICS ON SEISMIC GROUND RESPONSES

FARHANG OSTADAN[1], SAIF MAMOON[2], and IGNACIO ARANGO[1]

[1]Bechtel Corporation, 50 Beale Street, P. O. Box 193965
San Francisco, California, 94119-3965, U.S.A.

[2]Formerly With Bechtel

## ABSTRACT

Seismic design motions are often determined in terms of a design ground acceleration spectrum. The design spectrum is subsequently used in an iterative process to develop spectrum-compatible acceleration time history. In current practice, mainly the frequency amplitudes of the time history are adjusted to match the response spectrum. For each response spectrum, several compatible acceleration time histories can be developed. In this paper, the characteristics of the motion such as phase angles and strong motion duration are examined and their effects on the ground responses are evaluated. General guidelines are presented to select the most appropriate spectrum-compatible time history.

## KEYWORDS

Acceleration time history; ground response; spectrum-compatible; phase angle; design motion; strong motion duration.

## INTRODUCTION

The generation of the spectrum-compatible time history involves an iterative process in which the Fourier components of a selected time history are adjusted until the spectral amplitudes of the motion closely match those of the design spectrum. This problem is an "ill posed" problem in which more than one time history may be developed to match/envelope the design spectrum. As a result, several time histories may be generated which may have entirely different characteristics and yet match the same design (target) spectrum and thus, comply with the requirements.

In this paper, the effects of several input time histories on seismic ground responses are examined while maintaining the spectrum-matching characteristics of these time histories. Seismic ground responses in terms of spectral acceleration responses, maximum shear stresses, and strain-compatible soil properties are presented and compared.

## SCOPE OF THE STUDY

### Target Spectra

Four target spectra groups were used in this study. These groups are specified on Table 1. The first group represents the design motion for a site in Eastern United States (US) close to a fault capable of generating a magnitude 5 earthquake. The second group also represents the design motion for a site in Eastern US representative of a distant large magnitude (Magnitude 7) event. The target spectrum for the third group is the Applied Technology Council (ATC) rock spectrum (S1 Spectrum) scaled to a maximum acceleration of .19g. Finally, the fourth group is based on the US Regulatory Guide 1.60 response spectrum scaled to 0.20g.

Table 1. Summary of spectrum-compatible time histories

| Target Spectrum Group No. | Target Spectrum | Time History ID Number | Total Duration (Sec) | Strong Motion Duration (Sec) | Max. Accel. | Original Time History |
|---|---|---|---|---|---|---|
| 1 | Eastern US Local E.Q. | 1 | 10 | 6.3 | 0.19 | Synthetic Motion |
| | | 2 | 15 | 3.7 | 0.19 | Saquenay E.Q., Canada, 1968 |
| | | 3 | 10 | 1.4 | 0.19 | Saquenay E.Q., Canada, 1968 |
| 2 | Eastern US Distant E.Q. | 4 | 15 | 8.6 | 0.10 | Saquenay E.Q., Canada, 1968 |
| | | 5 | 15 | 6.0 | 0.10 | Saquenay E.Q., Canada, 1968 |
| 3 | ATC S1 Motion | 6 | 40 | 6.3 | 0.19 | Loma Prieta E.Q., CA 1989 |
| | | 7 | 40 | 15.8 | 0.19 | Loma Prieta E.Q., CA 1989 |
| 4 | NRC RG 1.60 Motion | 8 | 22 | 13.7 | 0.20 | Synthetic Motion |
| | | 9 | 24 | 2.3 | 0.20 | Helena E.Q., Montana, 1935 |

Typical spectrum matching for time histories in Group 1 is shown in Fig. 1.

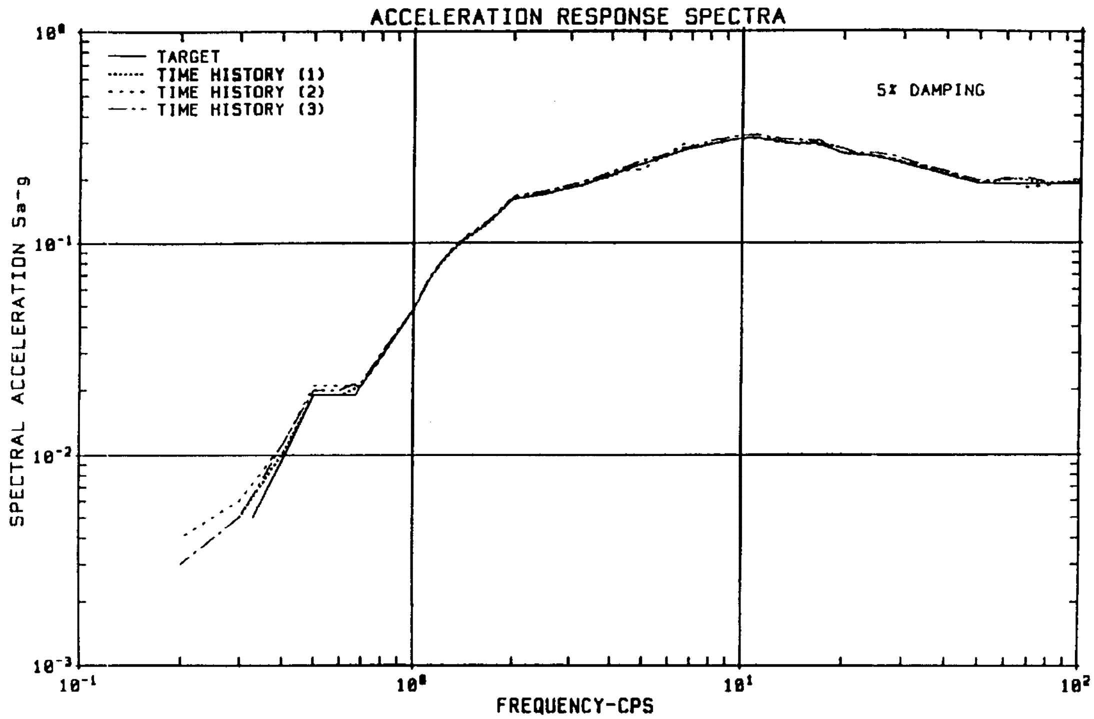


Fig. 1. Comparison of spectra for time histories in group 1

Soil Profiles

In the study performed (Bechtel, 1993) several soil profiles consisting of a 200 ft. deep uniform sand profile with a relative density of 75 percent and a layered soil profile with intercalated layers of sand and clay were considered. Both profiles were analyzed using the standard modulus reduction and damping soil properties (Seed *et al.*, 1972). Both the equivalent linear program SHAKE (Schnabel *et al.*, 1972) and the nonlinear program DESRA (Lee and Finn, 1978, modified by Bechtel, 1991) were used for ground response analyses. Due to limitation in space, only the selected SHAKE results for the uniform sand layer subjected to the time histories of the selected groups of target spectrum are presented.

## SITE RESPONSE ANALYSIS RESULTS

Cyclic Shear Stress Ratios

Cyclic shear stress ratios (induced cyclic shear stress at any one depth normalized with respect to the vertical effective stress) are used in the evaluation of the potential to liquefaction and settlement of a soil deposit. Typical computed stress ratios are plotted versus depth in Fig. 2. As shown in the fig., differences in excess of 50 percent in the results can be observed depending on the input motion time history. These differences are more pronounced near the ground surface where their impact on liquefaction is more significant.

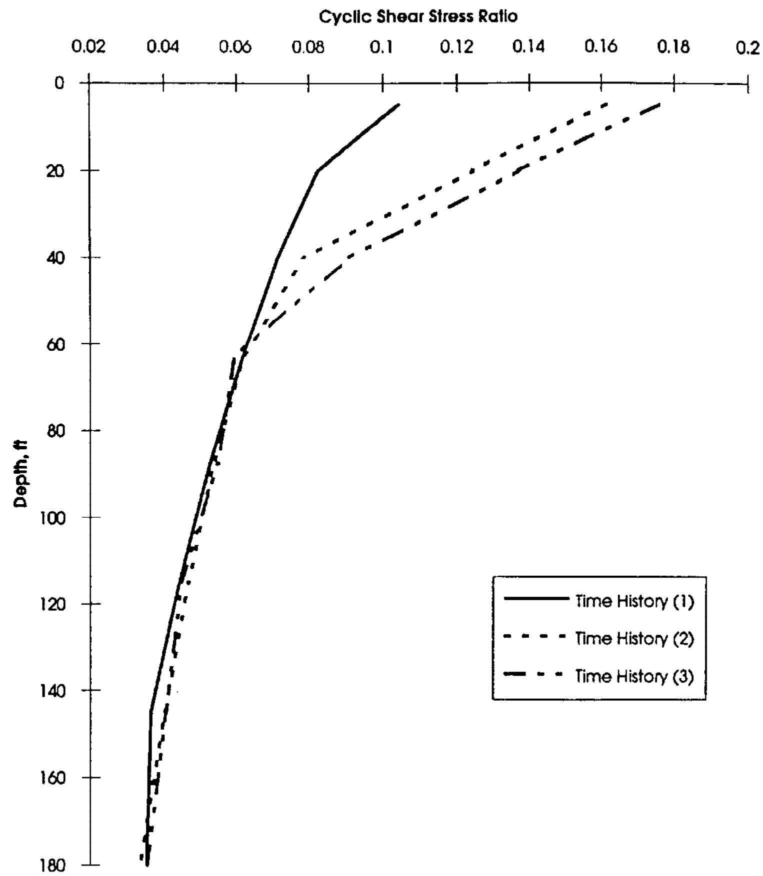


Fig. 2. Depth vs. cyclic shear stress ratios

## Strain-Compatible Soil Properties

Strain-compatible soil properties (shear modulus and damping ratios) are used in Soil-Structure Interaction Analyses. Typical computed strain-compatible properties using time histories in Group 4 are shown in Figs. 3 and 4. As depicted in these figs., the effect of input motion on the degraded soil properties are minor with the larger effects shown on the damping values.

## Ground Surface Motion

The motions at the ground surface (or at the foundation level) are used as input for seismic structural analysis and in determining seismic responses of the structure. Typical response motions at the ground surface in terms of 5 percent damped acceleration response spectra are shown in Fig. 5. As depicted in this fig., the effect of the input motion characteristics on the surface spectral amplitudes especially the peak ground acceleration (PGA) are significant.

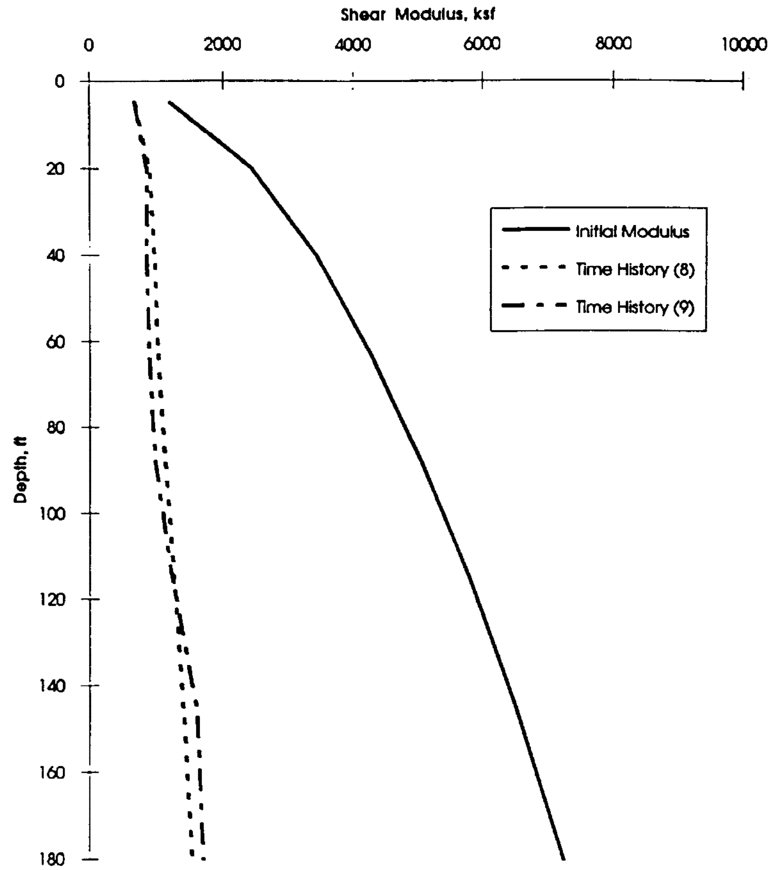


Fig. 3. Depth vs. shear modulus

Other Characteristics of Input Time Histories

In an attempt to explore the reasons for the differences in the responses presented above, the characteristics of the input time histories in each group (after modification to match the respective target spectra) were examined. The energy and the normalized energy time histories (the Husid energy) for each acceleration time history were computed using

Energy Time History $$E(t) = \int_0^t a^2(t).\ dt \quad (1)$$

Maximum Energy $$E_{max} = \int_0^{Td} a^2(t).\ dt \quad (2)$$

Normalized Energy Time History $$ER(t) = E(t) / E_{max} \quad (3)$$

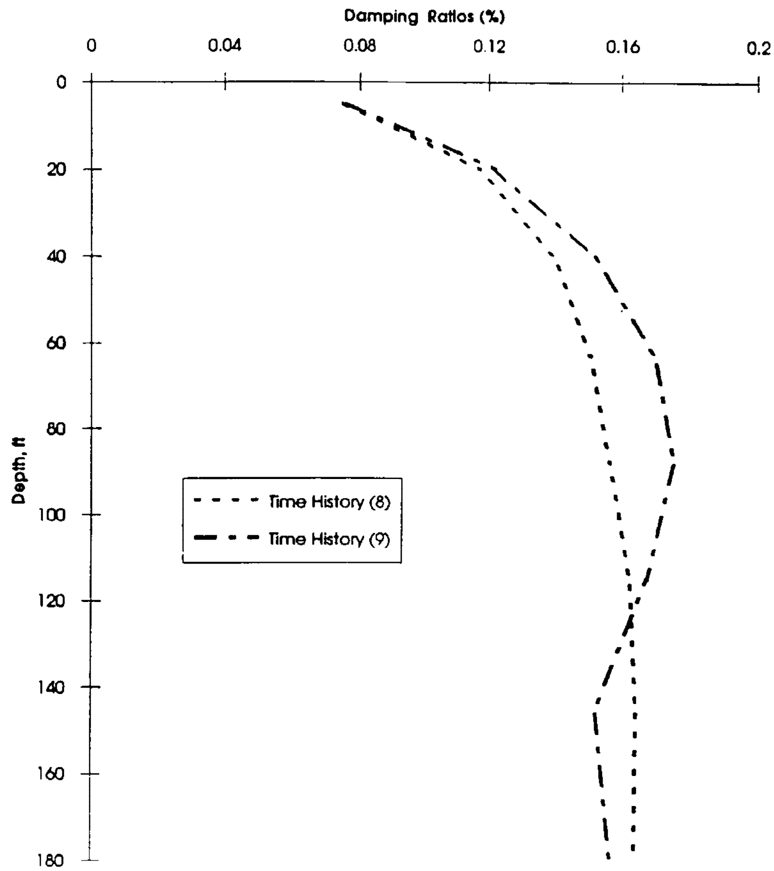


Fig. 4. Depth vs. damping ratios

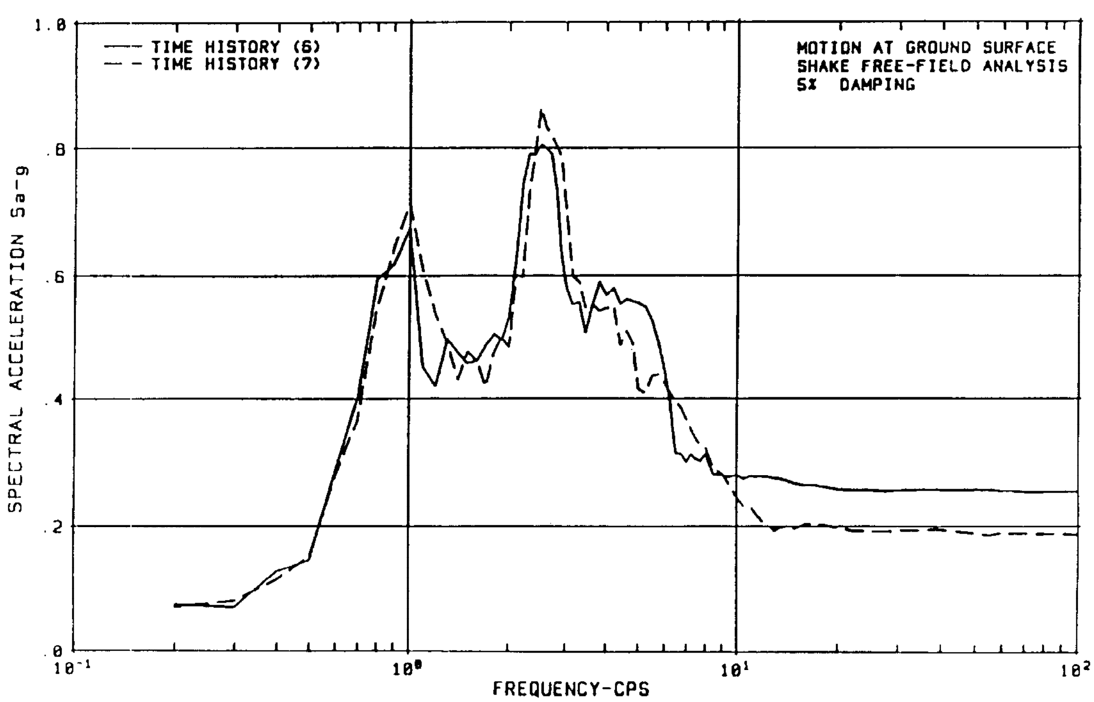


Fig. 5. Acceleration response spectra

where a(t) is the acceleration at time t and $T_d$ is the total duration of the motion. The time histories of the normalized energy for all 9 input time histories shown on Table 1 were computed. Figure 6 shows typical results for the time histories in Group 1. As shown in this fig., the rate of energy build-up (the slope of the normalized energy curve) is larger for time histories 2 and 3 as compared to that of time history 1. The sudden increase in the normalized energy time history is due to the presence of large amplitude cycles with short duration in the time history record. The rate of energy build-up can also be observed by comparing the strong motion duration for each time history. The strong motion duration is defined as the duration between the times reaching 75 percent and 5 percent ($T_{75}$-$T_5$) of the normalized energy for each time history. This duration is also shown on Table 1. The shortest duration corresponds to the largest rate of energy build-up in each group. An examination of the cyclic stress ratios shows that the input time histories with larger rate of energy build-up in general result in larger stress ratios. Similar trend can be observed when the response motions at the ground surface are examined.

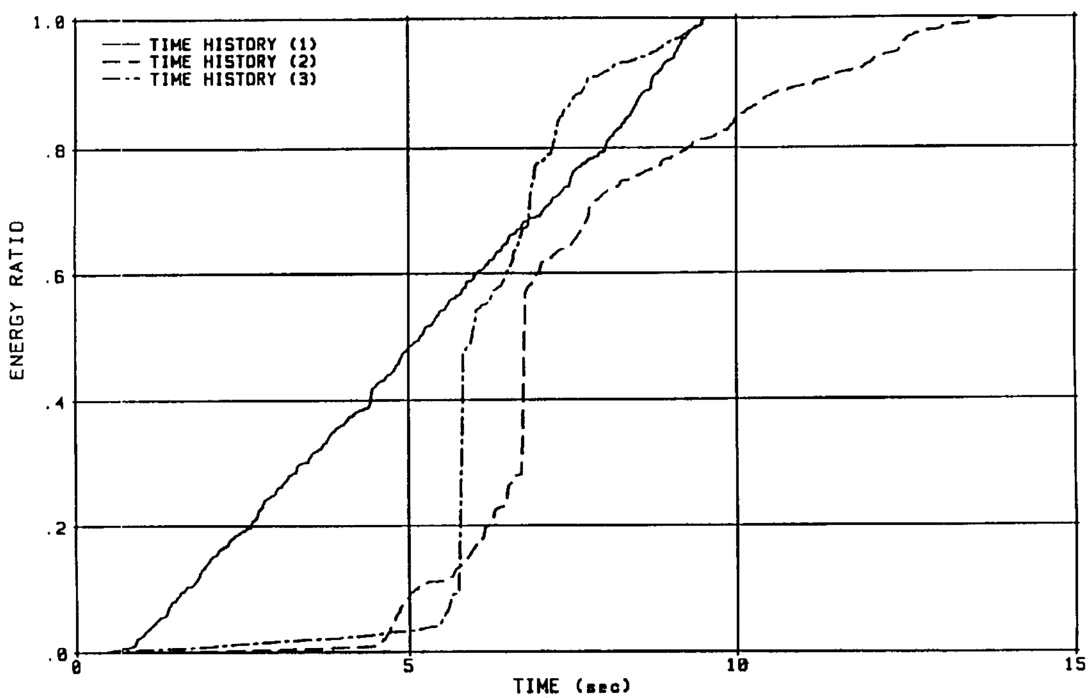


Fig. 6. Normalized energy time history

## SUMMARY AND CONCLUSIONS

Seismic analyses were performed to examine the effect of the characteristics of several spectra-compatible input time histories on the ground responses. The results reported above are based on the analysis of a uniform sand soil profile using the computer program SHAKE. The following conclusions are, however, based on the full scope of the study in which the layered sites as well as the nonlinear analyses using the modified version of the program DESRA were considered.

- For a given design ground response spectrum, significant differences in the ground responses may be obtained from the use of different spectrum-compatible input time histories depending on the other characteristics of the input motion such as the phase angles and strong motion duration. The effects on the degraded soil shear modulus is less pronounced.

- The normalized energy and the rate of energy build-up (or strong motion duration) of a time history provide a reasonable basis for assessing the effect of different time histories on site responses.

- Recognizing the significance of the input time history characteristics on the seismic ground responses, such characteristics should be carefully examined prior and subsequent to matching the target spectrum.

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