Earthquake Engineering, Tenth World Conference © *1992 Balkema, Rotterdam. ISBN 90 5410 060 5*

Generation of simulated earthquake motions compatible with multi-damping response spectra

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ABSTRACT: An advanced method and application criteria are presented for generation of time history compatible with multi-damping response spectra. It can remove difficulty induced by existing methods and improve the accuracy of spectrum matching for two or three damping target spectra. The effectiveness of this method is shown by two application examples.

1 INTRODUCTION

Time history analyses are often required for seismic design of nuclear power plants, tall buildings and base isolated buildings. So if the input motion is given as design response spectra, generation of time history compatible with the design spectra is necessary. In this paper, an advanced method and application criteria for generation of time history compatible with multi-damping response spectra are presented that effectively remove difficulty induced by existing methods.

2 METHOD OF GENERATION

2.1 Basic theory

The method is an extension of the method developed by K.Lilhanand and W.S.Tseng(1987). It is based on the following assumption. That is, if small corrective time history is added to the original time history, then the occurence time of the maximum response to the resultant time history is close to it of the original time history and the resultant maximum response can be approximately evaluated by the sum of maximum responses to the original and corrective time histories.

From the assumptions, the maximum response : δS to the corrective time history is expressed as follows for M frequencies and N damping.

$$\{\delta S(\omega_i, h_k)\} = \int \{\xi_{ik}(t-\tau)\}\,\delta z\, d\tau \qquad (1)$$

where

ω_i:natural frequency, i=1,M; h_k:damping, k=1,N; ξ_{ik}:impulse response function;
δz:corrective time history;
t:occurrence time of maximum response and τ is the integration time parameter.

If δS are differences of the design spectra and the calculated spectra, the task of adjustment is to evaluate δz in Eq.(1) for given δS. So to match a set of design spectrum values for M frequencies and N damping values, we express δz as M×N linear combinations of time functions:f(t) and intensity coefficients:a as follows.

$$\delta z = \{f(t)\}^T\{a\} \qquad (2)$$

Substituting Eq.(2) into Eq.(1) the following linear algebraic equations are obtained.

$$[D]\{a\} = \{\delta S\} \qquad (3)$$

where

$$[D] = \int \{\xi_{ik}(t-\tau)\}\{f(\tau)\}^T d\tau \qquad (4)$$

Impulse response function for frequency: ω_j and damping: h_l is adopted as $f_{jl}(\tau)$.

$$f_{jl}(\tau) = \xi_{jl}(t-\tau) \qquad (5)$$

As evident from Eqs.(4) and (5), the element of [D] is the response of one mass system with ω_i and h_k to time function $f_{jl}(t)$. The integration of Eq.(4) can be solved analytically. So the unknown parameters:{a} can be obtained as solution of linear equations (3). Then the corrective time history: δz is computed by Eq.(2). The new time history at the i iterative step is as follows.

$$z_i(t)=z_{i-1}(t)+\delta z(t) \qquad (6)$$

The final time history is obtained by repeating the above scheme.

2.2 Points on application

The following application criteria are required from the assumption that δz is small.

a) δS should be small as compared to the design spectra: S_d. So δS_i at the i-th iterative step is set as follows.

$$\delta S_i=(S_d-S_{i-1})/(n-i+1) \qquad (7)$$

where S_{i-1}: response spectrum to i-1 step time history

n: total iterative number

Thus δS_i in the first step is one-nth of the initial error: (S_d-S_0) and small. The final δS_n becomes to the difference of the design and calculated response sapectra.

b) The spacing between two consecutive matching frequencies influences very much on the compatibility. That is, the wide spacing can match at the matching frequencies, but deviations at other frequencies increase. While the narrow spacing increases deviations all over by interference between frequencies or damping. To avoid this problem, the frequency spacing is selected such as the frequency response amplification factor at the central frequency of the two matching frequencies is equal to it at the matching frequencies. Applying the above criterion to the one mass system, the relation of two consecutive matching frequencies: ω_{m+1} and ω_m is as follows.

$$\omega_{m+1}=(1+2h\sqrt{1/\alpha^2-1})\omega_m \qquad (8)$$

where h : damping

α : ratio of the resonant amplitude at ω_m and the amplitude at the central frequency

The value of α is 0.5 ~1.0 from the definition and the following equation has been obtained from our experience.

$$\alpha=1.165h^{0.125} \qquad (9)$$

c) When the target design spectra are two or three multi-damping spectra, adequate results are not obtained in some cases even the above conditions because of interfering effects among each damping. In the case, using of weighting factors is effective to reduce the interfering effects. The values of weighting factors are 0.0~1.0 for the interfering terms among each damping in the coefficient matrix [D] and they are closed with 1.0 as the iterative step.

3 APPLICATION EXAMPLE

The presented procedure has been applied to two examples.

3.1 Two damping design spectra

In this example, the target spectra are a set of two damping: 1% and 5% design spectra for nuclear power plants and the target maximum acceleration is 230cm/s^2. In generating the time history matching the set of spectra, the number of matching frequencies are 200 for the 1% damping and 65 for the 5% damping from the criteria of Eqs.(8) and (9). The initial time history is generated by superposition of sinusoidal waves and multiplying shape function. Ten cycles of iteration were made for the spectrum matching. The weighting factor is 1.0.

The final results are shown Fig.1. As can be seen from the Fig.1a), The calculated maximum acceleration value converges to the target value. The Fig.1b) shows that the calculated time history spectra converge to the target spectra at the matching frequencies for both damping values with less than 4% of rms spectral deviation. In order to check up the accuracy of spectrum matching at a common set of frequencies other than the spectrum matching frequencies, the 1% and 5% spectra were recalculated at different 232 frequencies from the matching frequencies. The results are shown in Fig.1 c). As can be seen from this figure, the recalculated spectra correspond reasonably to the target spectra with less than 6% of rms spectral deviation.

3.2 Three damping design spectra

In the next example, the target spectra are a set of three damping: 2%, 5% and 10% design spectra for tall buildings and the target maximum acceleration is 360cm/s². In generating the time history matching the set of the spectra, the number of matching frequencies are 136 for the 2% damping, 74 for the 5% damping and 58 for the 10% damping. The initial time history is HACHINOHE NS record in TOKATIOKI earthquake.

Fifteen cycles of iteration were made for the spectrum matching and the weighting factor is 0.0 at the first ten cycles and 1.0 at the last five cycles. The final results are shown in Fig.2. As can be seen from the Fig.2a), the calculated maximum acceleration value converges to the target value. The integrated velocity and displacement time histories are also shown in Fig.2 a). They have non-stationarity such as natural earthquake records. Fig.2b) shows that the calculated time history spectra converge to the target spectra at the matching frequencies for three damping values with less than 5% of rms spectral deviation. To check up the spectrum matching at a common set of frequencies other than the spectrum matching frequencies, the 2%,5% and 10% spectra were recalculated at different 268 frequencies from the matching frequencies. The results are shown in Fig.2 c). As can be seen from this figure, the recalculated spectra correspond reasonably to the target spectra with less than 8% of rms for 2% damping and 4% of rms for 5% and 10% damping.

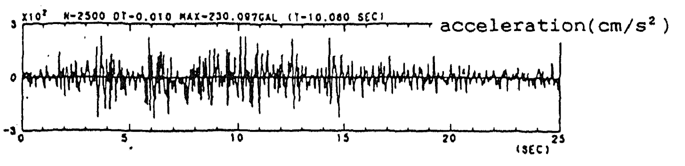
Fig.2d) shows the Fourier spectrum. It is not lineal spectrum but similar to it of natural earthquake records.

4 CONCLUSION

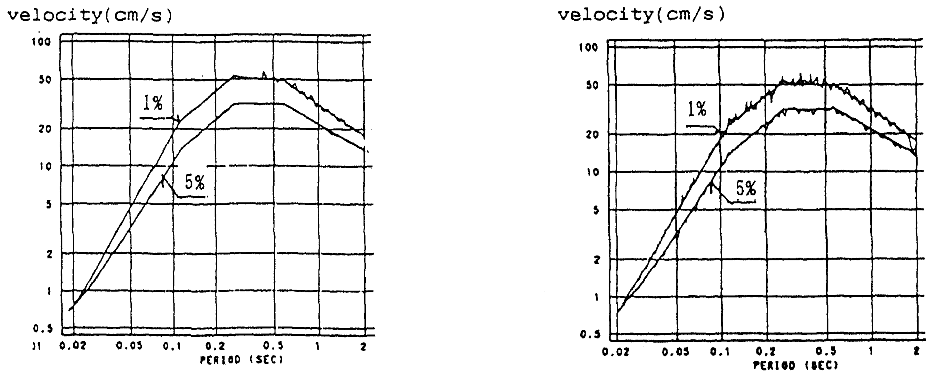
An advanced method and application criteria for generation of time history compatible with multi-damping response spectra has been presented. The application examples clearly show that this method is very effective for increasing of the accuracy of spectrum matching.

REFERENCES

K.Lilhanand & W.S.Tseng 1987. Generation of synthetic time histories compatible with multi-damping design response spectra. 9th SMiRT. k2



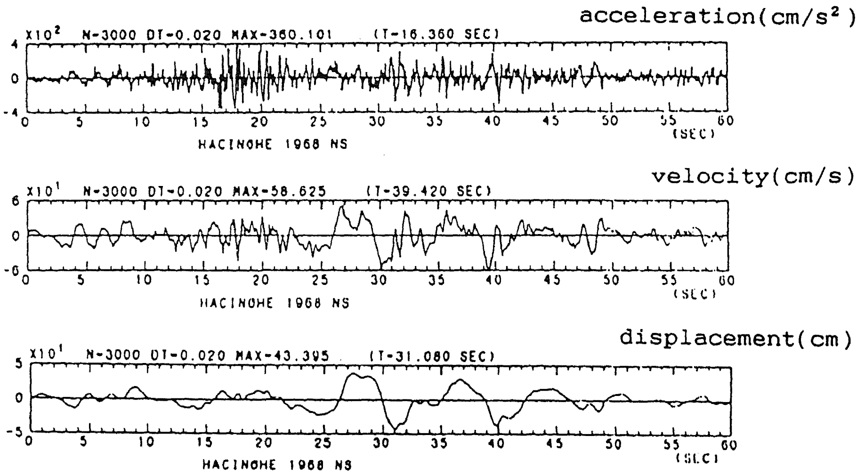
a) final time history



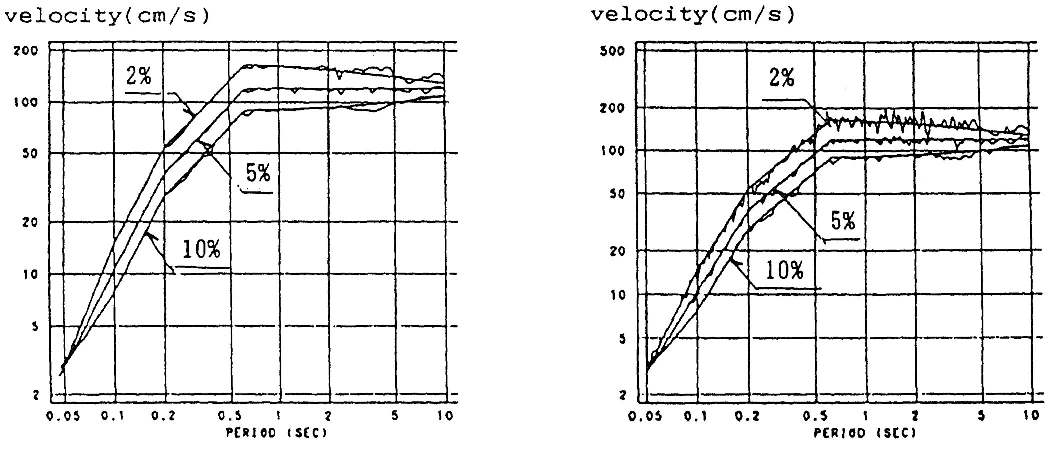
b) at matching frequencies

c) at other common frequencies

Fig.1 Comparison of spectra for nuclear power power plants calculated target

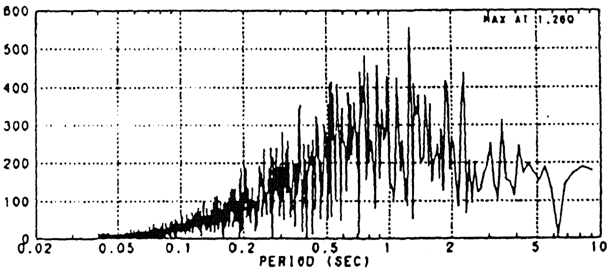


a) final time history



b) at matching frequencies

c) at other common frequencies



d) Fourier spectrum

Fig.2 Comparison of spectra for tall buildings calculated target