Simulation of Seismic Waves

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ABSTRACT

This paper analyzes the existing methods for simulating seismic waves. The wavelet method, which has good localized characteristics, is used to simulate seismic waves which are non-stationary random processes. The simulation is improved by considering other contributing factors such as the duration, the phase, the earthquake magnitude and the distance. Then the simulated seismic history is obtained for the given response spectrum and earthquake correlation parameters.

1. INTRODUCTION

Many engineering projects require a seismic analysis. The design and analysis of antiseismic structures are necessary in large-scale engineering facilities, especially nuclear power plants. Because of the plant hazards and complexity, nuclear power plant designers are required to analyze the structural response to seismic events to assure public safety, so proper structural analysis for seismic loads is crucial. However, for safety reasons, nuclear sites are usually located in areas where earthquakes do not frequently occur, so sufficient site earthquake data and seismic characteristics are difficult to obtain. Furthermore increasing numbers of buildings and improved dynamic analysis require accurate simulations of seismic history. Accurate simulated histories will affect the safety and validity of the nuclear plant design. However, most existing engineering simulations are based on Fourier analyses, which is for stationary random processes, while seismic waves are non-stationary random processes so Fourier analysis is not appropriate. This paper describes improved simulation method for seismic events.

2. ANALYSIS OF SIMULATION METHODS

2.1 Current Method

Simulated seismic histories used for engineering design must represent the frequency spectrum, the duration and other earthquake properties. However, simulating seismic waves is complex and difficult. Most methods need further development although they have been widely applied. There are three typical methods have been used to simulate seismic waves, including the synthesis method based on mathematical series, the modification method based on natural history curves and a method based on the earthquake and wave theories. The synthesis method based on the response spectrum is the most common and most advanced method in engineering practice. The earthquake history is simulated by constructing a stationary process using trigonometric series and then multiplying by an envelope curve. The usual model is:

$$X(t)=f(t)\sum_{k=0}^{n}C_k\cos(\omega_k t+\varphi_k)\ ,$$

where φ_k are the random phase angles which are uniformly distributed in（0，2π）and $f(t)$ is the intensity envelope function. Then $a(t)$ is defined as:

$$a(t)=\sum_{k=0}^{n} C_k \cos(\omega_k t+\varphi_k),$$

where $a(t)$ is a stationary Gaussian process and C_k is the amplitude spectrum of the seismic time course. C_k can be calculated from the power spectrum density function as:

$$C_k=[4S(\omega_k)\cdot\Delta\omega]^{1/2},$$

where $S(\omega)$ is the power spectrum density function which can be obtained from the given response spectrum. Then the initial wave is modified iteratively to meet the engineering requirements. But the method has some defects which are serious and unavoidable.

2.2 Defects

Most methods are based on the random theory of a stationary process. Fourier analysis, which is widely applied to simulations, is the best method for stationary random processes. But seismic waves are non-stationary, so Fourier analysis is not very applicable. Figures 1-4 show the defects in simulating. Signal f1 (t) (Fig.1) and f2 (t) (Fig. 2) are both constructed from the functions sin(10t) and sin(20t). f1 (t) is the sum of sin(10t) and sin(20t) in the whole duration. The first half of f2 (t) is sin(10t) while the second half is sin(20t). But the frequency spectrums of both signals after Fourier analysis transformation are the same (Fig. 3). There the signal in f(t) are uniformly distributed across the whole time field $(-\infty\ +\infty)$ in $\hat{f}(\omega)$, so $\hat{f}(\omega)$ can not describe the local character of the time field. Therefore, the Fourier analysis is not very suitable for seismic waves as a non-stationary process.

The phase spectrum also has an impact on the simulation. Usually, the phase spectrums in the various methods are assumed to be uniformity distribution in the$(0, 2\pi)$and the frequency spectrums are stationary instead of non-stationary. The curves in Fig. 5 and Fig. 6 show that the phase spectrum remarkably affects the simulated waves. Fig. 5 shows the simulated seismic waves based on the actual phases while Fig. 6 shows the wave based on the assumed phases. The obvious differences can significantly influence the inelasticity structural response. Thus, better representations of the phase spectrum can improve the simulation.

In addition, because the structural damage increases with duration, the different event durations result in very different damage, especially when the structural damage is in the inelasticity response stage. The earthquake magnitude and distance also affect the simulation since they influence the distribution of the long and short cycles in the seismic waves. Although some simulation methods are based on earthquake properties and mechanisms, they are not fit for many engineering analyses.

All these defects affect the accuracy of the simulated waves which affects the engineering analysis. Therefore, improved methods are needed.

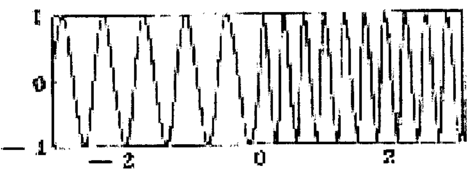
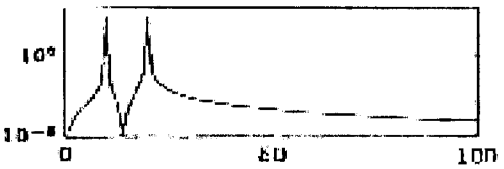


Figure 1 f1(t)

Figure 2 f2(t)



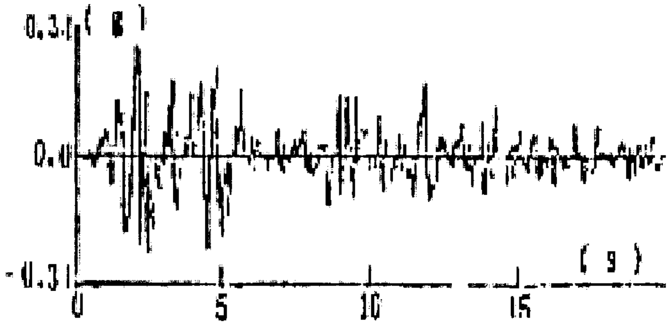


Figure 3 $\hat{f}(\omega)$

Figure 4 EI Centro Time History

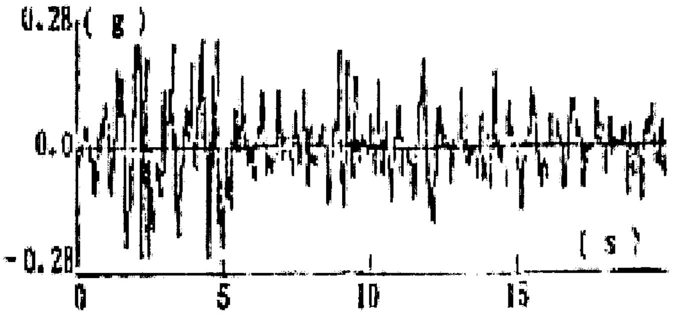


Figure 5 EI Centro Simulated Wave with Real Phases

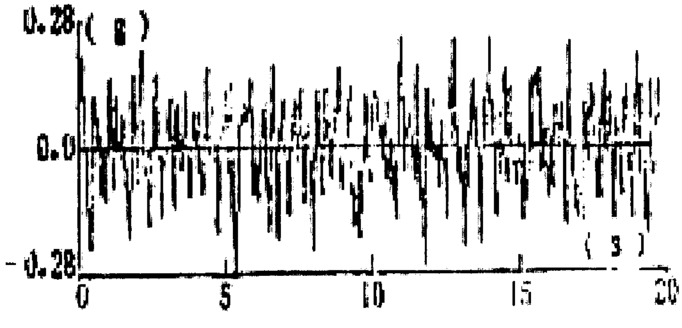


Figure 6 EI Centro Simulated Wave with Assumed Phases

3. WAVELET SIMULATION METHOD

The importance of improved simulation technology requires more advanced engineering methods. Wavelet technology applied to seismic events provides a promising avenue to improved methods. Wavelet technology, which has good localized characteristics, is more suitable for simulating seismic waves with non-stationary attributes than Fourier analysis.

The present analysis uses the binary discrete wavelet transform, which is easily implemented numerically, for the simulation with multi-resolution analysis as the main simulation tool where:

$$f(t)=\sum_{n}\left(\sum_{k}a_k^1 h_{n-2k}+\sum_{k}b_k^1 g_{n-2k}\right)\varphi(t-n)$$

a_k^1 and b_k^1 are the wavelet coefficients, h_{n-2k} are the scale coefficients and g_{n-2k} are the derived coefficients based on the scale coefficients. The vital scale function $\varphi(t-n)$, which has good localized character and is suitable for the properties of seismic waves, is defined by the following equations:

$$\phi(\omega)=H\left(\frac{\omega}{2}\right)\phi\left(\frac{\omega}{2}\right)$$

$$|H(\omega)|^2+|H(\omega+\pi)|^2=1,$$

where $\phi(\omega)$ and $H(\omega)$ are the Fourier transforms of $\varphi(t)$ and h respectively.

The calculation of a_k^1 and b_k^1 is based on the energy conversation. The energy can be obtained from the power spectrum based on the response spectrum. The expression $|w_f(a,b)|^2\Delta a\Delta b/C_\psi a^2$, where C_ψ is determined by the wavelet function $\psi(t)$, shows the energy of the scale space Δa and the interval Δb at scale a and time center b. The wavelet values at the a scale can then be calculated with the initial simulation values calculated from the Mallat transform. The phase difference determines the area and degree of concentration. The phase difference can be adjusted so that the simulated values satisfy the original requirements and the relevant laws such as the Code for Seismic Design of Nuclear Power Plants.

Finally, the effect of the duration is considered by multiplying by a normalization function which reflects the duration and the total time of an earthquake. To some extent, the effect of earthquake magnitude and distance can be reflected in the value of the duration. The frequency distribution may also be modified for various earthquake magnitudes.

4. CONCLUSIONS

The simulated seismic wave can be obtained for the given response spectrum using the wavelet method. The seismology knowledge, the duration, the phase, the earthquake magnitude and the earthquake distance are considered comprehensively in the improved method. The wavelet method corrects some of the defects of existing methods.

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