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Generation of Earthquake Signals

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Abstract

Seismic verification can be performed either as a full scale test on a shaker table or as numerical calculations. In both cases it is necessary to have an earthquake acceleration time history. This report describes generation of such time histories by filtering white noise.

Analogue and digital filtering methods are compared. Different methods of predicting the response spectrum of a white noise signal filtered by a band-pass filter are discussed. Prediction of both the average response level and the statistical variation around this level are considered. Examples with both the IEEE 301 standard response spectrum and a ground spectrum suggested for Swedish nuclear power stations are included in the report.

Key words: Seismic verification, response spectrum prediction, extreme value distribution

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Introduction

In order to verify the resistance of buildings, structures and components to seismic events simulations are necessary. Simulations can either be performed as testing on a vibrator or as numerical calculations. In both cases time histories consisting of earthquake events are required. Since at least 20 years there exist well working iterative methods for generating time histories with a prescribed frequency content (response spectrum).

Although there are many similarities between generating time histories for calculations and for vibrator table tests, there is a big difference. An earthquake test performed on a vibrator can very seldom be repeated. Even if the test object survives the test without visible damage its strength can have been decreased. The results of several repeated test runs can therefore underestimate the seismic strength of an object. Before performing a new earthquake test it is often necessary to mount a new test object on the vibrator. This is not always possible, for example if the test object is a prototype, if the test object is very expensive, or if the time for mounting and preparing the object for a test is long. A calculation on the other hand can be repeated as many times as necessary.

Seismic events are stochastic with respect to the magnitude, the duration and the frequency content. The strength of a construction varies from one individual to another. Therefore a statistical approach must be used during seismic verification. If the verification is performed by testing the only way to do this is by using safety factors, the acceleration time history used at a seismic test must have a much higher level and broader frequency range than the expected "mean earthquake". The safety factor is used for uncertainties both in the earthquake magnitude and in the strength of the tested object.

To avoid overtesting, the response spectrum of an earthquake signal generated for vibrator table testing should override the required response spectrum as little as possible. A time history for calculation simulations on the other hand should have a statistical variation both above and below the expected response spectrum. If the distribution in the magnitudes of an expected earthquake is known, a family of time-histories can be generated and used for multiple calculations. The mean value and the variance of the calculated stress responses are used to decide if the object is qualified to be used in areas where seismic events can occur.

It is well known that numerical calculations, performed by time-step integration, of complicated structures take long time. It is therefore desired that the statistical variation in the responses of buildings and structures subjected to earthquakes with given statistical properties could be calculated by other methods than Monte Carlo simulations. If the model of the building or structure is linear and if the expected earthquake has a known statistical distribution, the statistical distribution of the responses can be calculated analytically.

This report models the earthquake as a normal distributed stochastic process filtered by a linear band pass filter. The filter is designed so that the expectation values of the response spectrum of the filtered signal is as close as possible to the prescribed ground response spectrum of the earthquake. Behind this model lies the assumption that the earthquake at its source is a white noise process and that the limited frequency band of the earthquake at the location of the building is due to frequency dependent damping of the earthquake shock wave during its transmission in the rock. Another filter simulating the soil and the building can of course be included in the model as long as they are assumed to be linear. From given filters, expected response spectra are calculated and compared with results from Monte Carlo simulations.

Earthquake analysis with response spectrum

In earthquake engineering the response spectrum method is very central. By this method it is possible to compare different time histories with respect to the damage they will cause on buildings and structures. As earthquakes have short duration the damage is not due to fatigue, but will occur if the maximum response of the building or the structure exceeds a critical level. The physical mechanisms depend on the object subjected to the earthquake and can be quite different. For a building it can be buckling of columns and for a relay it can be contact bounces.

The simplest model of a dynamic system is the Single Degree of Freedom System (SDOF) model. All mass of the system is assumed to be concentrated in a rigid block, all stiffness in a spring and all damping in a viscous damper. Figure 1 shows such a system.

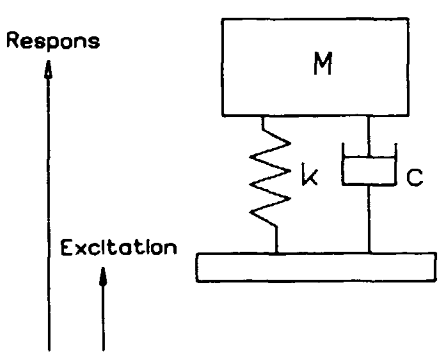

Figure 1: A schematic sketch of a Single Degree of Freedom System

The response of the system when excited by the accelerating ground is given by a second order differential equation

$$\ddot{y} + 2\rho\omega_n(\dot{y} - \dot{x}) + \omega_n^2(y - x) = 0 \qquad (1)$$

where

x:	Excitation
y:	Response
ζ:	Relative damping
ω_n:	Natural frequency

The natural frequency and the relative damping are given by

$$\omega_n = \sqrt{\frac{k}{m}} \tag{2}$$

$$\rho = \frac{c}{2 \cdot \sqrt{km}} \tag{3}$$

As the natural frequency, i.e. the stiffness and mass, of the object is not known, the maximum response due to the earthquake will have to be calculated for a lot of frequencies in the interesting frequency range. The damping in the analysis should be similar to that of the object, typically 5%.

The advantages by the response spectrum method is

- The analysis is related to damage real products will suffer during earthquakes
- The analysis gives a large data reduction, a time-history is sampled by several kbytes, but the response spectrum contains only 40-50 response points
- The probabilistic behaviour of an earthquake is taken into account as no detailed specification of the time-history is given.

Of course there are also some disadvantages by the method, the most important are:

- It is possible to construct a response spectrum that has no corresponding time-history
- Infinitely many different time-histories can have the same response spectrum

As response spectrum methods are used at nearly all stages of an earthquake analysis, different types of response spectrum are defined. The ground response spectrum specifies the ground motion during an earthquake. This spectrum varies with the geographic locations. The floor response spectrum specifies the motion at a specific floor in a specific building. It is calculated by civil engineers from a given ground response spectrum. The secondary response spectrum specifies the responses of large structures and equipment mounted at a specific location in the building. They are used when qualifying components mounted at secondary structures.

When qualifying equipment for an earthquake, the severity is given by the Required Response Spectrum (RRS). If the verification is performed by testing, the response spectrum of the acceleration signal recorded on the vibrator table is called the Test Response Spectrum (TRS). Of course the TRS should envelop the RRS.

Differences between discrete and continuous models

The real earthquake event is of course a continuous process, but as computers are used for the simulations the used model will be discrete. Formulas in continuous time and in discrete time differ, take for example the Fourier transforms or up-crossing intensity of a stochastic process. Therefore a bit different intermediate results will be obtained with a continuous model than with a discrete model. Mixing between formulas for continuous and discrete time models should be avoided.

Comparison between a continuous and discrete low-pass filter

The simplest low-pass filter (LP-filter) in continuous time is the RC-link, see Figure 2.

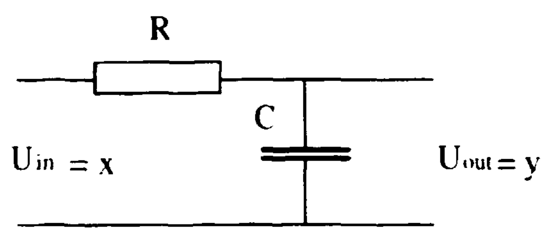

Figure 2: An electrical network that can be used as a low-pass filter

The differential equation relating the output voltage with the input voltage is

$$RC \cdot \frac{dy}{dt} + y = x \tag{4}$$

Laplace transformation gives the transfer function for the filter

$$H(s) = \frac{Y(s)}{X(s)} = \frac{1}{1 + RC \cdot s} \tag{5}$$

Let

$$s = i\omega \text{ and } \omega_c = 2\pi \cdot f_c = \frac{1}{RC}$$

where f_c is the cut-off frequency and w_c is its corresponding angular frequency.

The transfer function can now be written as

$$H(i\omega) = \frac{1}{1 + i\dfrac{\omega}{\omega_c}} \tag{6}$$

To find the corresponding filter in discrete time, the simplest approach is to write the differential equation for the RC-link as a difference equation

$$RC \cdot \frac{y_t - y_{t-1}}{T} + y_t = x_t \tag{7}$$

where T is the sampling interval.

By using the back-step operator B, defined by

$$y_{t-1} = By_t$$

the equation can be written as

$$RC \cdot \frac{(1-B)y_t}{T} + y_t = x_t \tag{8}$$

Z-transformation gives

$$\frac{Y(z)}{X(z)} = G(z) = \frac{1}{1 + \frac{RC}{T}(1 - z^{-1})} \tag{9}$$

the frequency characteristics of the filter is obtained by letting

$$z = \exp(i\omega T) \qquad -\pi \leq \omega T \leq \pi$$

The transfer function can be written as

$$G(e^{i\omega T}) = \frac{1}{1 + \frac{RC}{T}(1 - e^{-i\omega T})} \tag{10}$$

As an example, let the cut-off frequency of the filter be a quarter of the sampling frequency, i.e.

$$\frac{1}{RC} = 2\pi \frac{1}{4} \cdot \frac{1}{T} \quad \Rightarrow \quad \frac{RC}{T} = \frac{2}{\pi}$$

and let the sampling frequency be 100 Hz, i.e.

$$T = 0.01$$

According to Nyquist's sampling theorem the sampling frequency must be at least twice the highest frequency in the signal. In this example we can have frequency components up to 50 Hz and want to filter them at 25 Hz. In many earthquake application the cut-off frequency will be a bit lower than 25 Hz. In the Standard Response Spectrum, SRS, suggested by international standards, 16 Hz is the upper break frequency of the strong part of the earthquake spectrum. But the spectrum describing the ground motion on a hard rock site in Sweden is suggested to have a strong part up to 20-30 Hz, so the example is not unrealistic.

Figure 3 shows the amplitude of the transfer function for the analogue filter and the digital filter obtained from the simple difference equation (7).

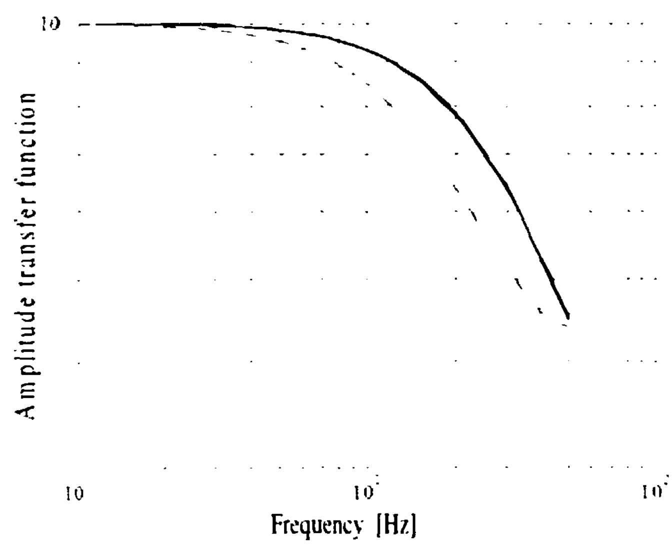

Figure 3 The amplitude transfer functions of an analogue 1st order low pass filter (solid curve) and of a digital filter obtained from the simple difference equation (7) (dashed curve).

It should be noted that Figure 3 is drawn in logarithmic scales. The digital filter approximates the analogue filter rather well up to 3 Hz, but for higher frequencies the correspondence is not very good. Take for example 25 Hz, at this frequency the analogue filter damps a signal 30 % and the digital filter 45 %.

A much better approach for the difference equation is

$$RC \cdot \frac{y_t - y_{t-1}}{T} + \frac{y_{t-1} + y_t}{2} = \frac{x_{t-1} + x_t}{2} \tag{11}$$

Z-transformation gives

$$\frac{Y(z)}{X(z)} = G(z) = \frac{1}{1 + RC \frac{2}{T} \cdot \frac{z-1}{z+1}} \tag{12}$$

The transfer function is then

$$G(e^{i\omega T}) = \frac{1}{1 + RC\frac{2}{T}\cdot\frac{e^{i\omega T}-1}{e^{i\omega T}+1}} \tag{13}$$

The same numerical example as above i.e.

$$\frac{RC}{T} = \frac{2}{\pi}, \qquad T = 0.01$$

gives amplitude transfer functions according to Figure 4

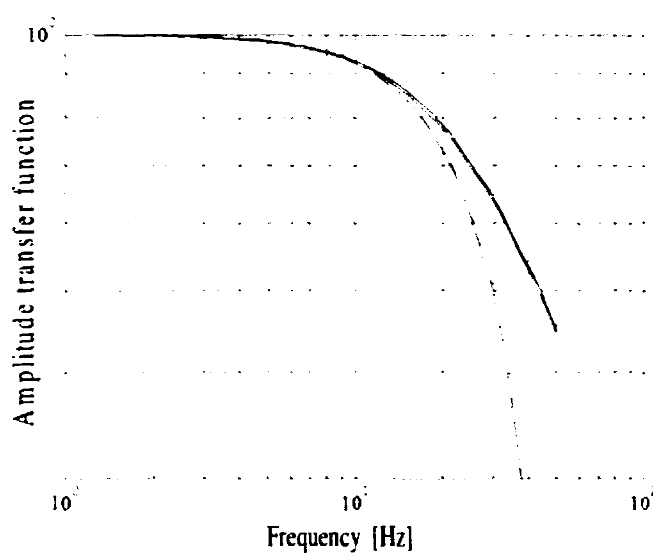

Figure 4 The amplitude transfer functions of an analogue 1st order low pass filter (solid curve) and of a digital filter obtained from the improved difference equation (11) (dashed curve).

As can be seen from Figure 4 the correspondence between the filters is now better. The digital filter approximates the analogue filter rather well up to 12 Hz, while for the filter obtained from the simple difference equation this figure was 3 Hz. In the stop-band, i.e. frequencies around 25 Hz there is no improvement and at frequencies near half the sampling frequency, i.e. 50 Hz, the new approach gives a worse correspondence with the analogue filter.

To improve the correspondence between the digital and the analogue filter in the stop-band it is possible to "translate" the digital filter curve along the frequency axis. This method is frequently used in signal analysis and the method is called prewarping. To do this we should use the same difference equation, but with another time constant. The new time constant should be selected in such a way that the damping of the digital and the analogue filter at the cut-off frequency are the same.

With the new time constant, rc, the transfer function of the digital filter can be written as

$$G(e^{i\omega T}) = \frac{1}{1 + rc\frac{2}{T} \cdot \frac{e^{i\omega T} - 1}{e^{i\omega T} + 1}} \tag{14}$$

As

$$\frac{e^{i\omega T} - 1}{e^{i\omega T} + 1} = i \cdot \tan(\frac{\omega T}{2}) \tag{15}$$

we get

$$\left|G(e^{i\omega T})\right|^2 = \frac{1}{1 + \left(rc\frac{2}{T} \cdot \tan(\frac{\omega T}{2})\right)^2} \tag{16}$$

If we use the same sampling frequency and cut-off frequency (a quarter of the sampling frequency) as in the earlier examples we have

$$\omega_c T = \frac{\pi}{2}$$

According to equation (5), the right hand side of equation (16) should be equal to ½. This gives the following equation to be used for determining the time constant rc:

$$\frac{1}{2} = \frac{1}{1 + \left(rc\frac{2}{T} \cdot \tan(\frac{\pi}{4})\right)^2}$$

From which we get

$$rc\frac{2}{T} = 1$$

The amplitude transfer function for the filter is plotted in Figure 5.

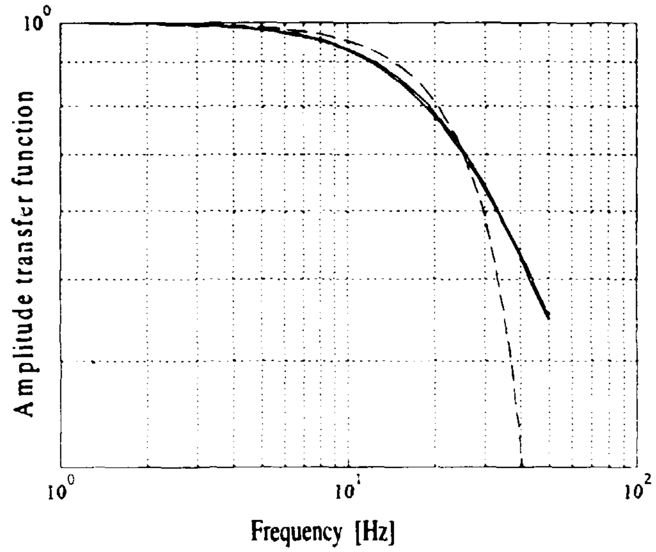

Figure 5 The amplitude transfer functions of an analogue 1st order low pass filter (solid curve) and of a digital filter obtained from the improved difference equation (11) and prewarping (dashed curve).

The stop band of the digital filter shown in Figure 5 is more close to the stop band of the analogue filter than the stop band of the digital filter shown in Figure 4. However this improvement in the stop band is achieved by a larger deviation from the analogue filter in the frequency range 6-12 Hz.

The digital filters used in these examples have been derived from difference equations approximating the differential equation for the analogue filter. It's also possible to get the digital filter by a transformation from the s-plane to the z-plane. Comparing equations (5) and (12) it shows that the digital filter is obtained from the analogue one by the transformation

$$G(z) = H(s)\big|_{s=c\frac{z-1}{z+1}} \tag{17}$$

The value of the constant c is determined from the condition that both the analogue and the digital filter should damp 3 dB at the filter cut-off frequency.

The relation

$$s = c\frac{z-1}{z+1} \tag{18}$$

is a mapping between the s- and z-plane. The imaginary axis in the s-plane is mapped to the unit circle in the z-plane. As the transfer function in the s-plane is obtained by evaluating H(s) along the imaginary axis and in the z-plane by evaluating G(z) along the unit circle, this transformation is in some sense the correct one.

On the other hanu the sin-~lest approach based on the difference equation (7) gives

$$G(z) = H(s)\big|_{s=\frac{1-z^{-1}}{T}} \tag{19}$$

By this transformation the imaginary axis in the s-plane is mapped on a circle in the right hand part z-plane (the circle has its origo in z=0.5 and its radius is equal to 0.5).

The examples show that it is not possible to get exact agreement by a first order digital low-pass filter with a first order analogue filter for all frequencies. In a traditional filtering problem the prewarped filter (shown in Figure 5) is often good enough. But when using the filter to shape a prescribed earthquake spectrum the situation is quite different. If the spectrum is realistic it originates from a physical reality, i.e. filtering in the soil or in a building. As this filtering takes place in continuous time the discrete frequency warped filter gives too low levels in the high frequency part of the spectrum. The problem is even more severe, to predict maximum values of a process of filtered white noise, the second moment, λ_2, of the spectrum must be calculated. This is done by the following formula

$$\lambda_2 = \int \omega^2 S(\omega)\cdot d\omega = \int \omega^2 |H(\omega)|^2 \cdot d\omega \tag{20}$$

where $S(\omega)$ is the power spectral density and $H(\omega)$ is the transfer function. Figure 6 shows $\omega^2 \,|\, H(\omega) \,|^2$ as a function of the frequency for a first order filter.

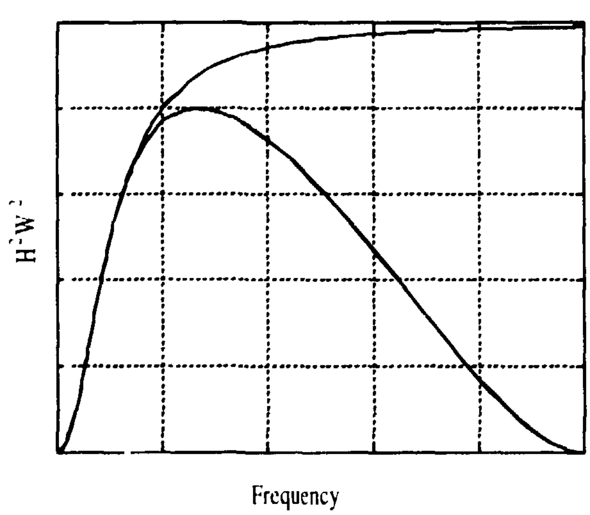

Figure 6 The square of the amplitude transfer function times the square of the frequency as a function of the frequency for an analogue 1st order low pass filter (upper curve) and its corresponding frequency warped digital filter (lower curve)

One solution to this is to use a much higher sampling frequency. The difference between the filters is small in the beginning of the stop-band. However this will lead to many data points in the sequences and also to numerical problems when using the filters. Another solution to this problem is to use a higher order of the digital filter, it is then possible to get a lower slope in the middle of the stop band.

Probability for up-crossing of a given level

Exact formulas for the up-crossing frequency of a normal process exist both for the continuous case and the discrete case. In the continuous case the up-crossing frequency is given by Rice's formula

$$f(u) = \frac{1}{2\pi}\sqrt{\frac{\lambda_2}{\lambda_0}}\exp\left[\frac{-u^2}{2\lambda_0}\right] \tag{21}$$

where

u:	level
f(u):	probability for up-crossing of level u
λ_2:	second moment of the process
λ_0:	variance of the process

In the discrete case the corresponding formula is

$$f(u) = \frac{1}{2\pi\sqrt{1-\rho^2}}\int_{-\infty}^{u}\int_{u}^{\infty}\exp\left[-\frac{x^2+y^2+2\rho xy}{2(1-\rho^2)}\right]dxdy \tag{22}$$

where

u:	level
f(u):	probability for up-crossing of level u
ρ	correlation between two adjacent sampling points

The difference in the up-crossing frequencies calculated by these two formulas is of course due to the fact that a maximum between two sampling points will not be detected in the discrete case. To get accuracy in determining the maximum value it is therefore sometimes necessary to interpolate the original signal before searching for maxima.

Prediction of the maximum response

Elementary approach

The simplest approach for predicting the maximum response level is to say that the expected number of up-crossings of that level during a time corresponding to the duration of the earthquake should be equal to one i.e.

$$f(u)\cdot 2\cdot T = 1 \tag{23}$$

The factor 2 in front of T is due to the fact that both positive and negative peaks are used in the response spectrum, whereas f(u), the up-crossing frequency, only gives the positive peaks. If the signal is symmetric with respect to zero the distributions of negative and positive peaks are equal.

From this equation the level u can be determined. This approach is used in many other applications for determining an extreme value, for example high sea waves in offshore engineering. In that case the determined level is called the hundred year wave if T = 100 years. If many earthquakes are realised some of them will have maximum responses above u and other below. One disadvantage of this approach is that the variance in the maximum response can not be determined.

Prediction of the maximum response by Poisson approximation

If the extreme values in a stochastic process can be assumed to be independent, the distribution of the extreme values is determined by the Poisson distribution. For a long sequence this approximation is found to work well, but an earthquake has such a short duration that there can be problems. Let

$N_u(T)$	Number of up-crossings of level u during the time T
f(u)	Up-crossing frequency
k	number of up-crossings
M_T	The maximum value during the time T
G(u)	Distribution function of the extreme value
g(u)	Density function of the extreme value

The expectation of the number of up-crossings is given by the up-crossing frequency and the duration of the earthquake:

$$E[N_u(T)] = f(u)\cdot 2\cdot T \tag{24}$$

As in the simple approach the fact that both positive and negative peaks are used in the response spectrum is taken into account by the factor 2 at the duration T.

The probability for k up-crossings, if a Poisson approximation is used, is:

$$P\{N_u(T)=k\} = \exp\{-E[N_u(T)]\} \cdot \frac{\{E[N_u(T)]\}^k}{k!} \tag{25}$$

The probability that the maximum value is less than u is

$$P\{M_T < u\} = P\{N_u(T)=0\} = \exp\{-E[N_u(T)]\} = \exp[-2T \cdot f(u)] = G(u) \tag{26}$$

The probability density function is then

$$g(u) = \frac{dG(u)}{du} \tag{27}$$

The mean value of the maximum response is given by

$$E[u] = \int_{-\infty}^{\infty} u \cdot g(u) \cdot du \tag{28}$$

This integral is possible to evaluate numerically.

An advantage with this approach is that it is possible to use the distribution function for calculating prediction limits.

Example: IEEE 344 Standard Response Spectrum

Figure 7 shows the Standard Response Spectrum (SRS) according to the IEEE 344 standard. This spectrum is suggested to be used for seismic testing of electromechanical equipment. The spectrum is broad-banded and could therefore be used for testing where a general seismic classification is wanted. Only the shape of the spectrum is specified, the absolute level will have to be specified for each test.

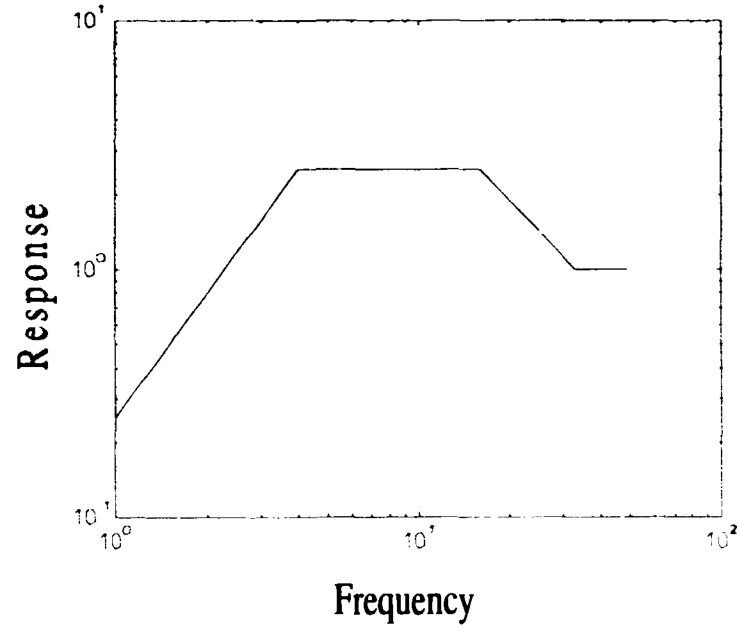

Figure 7 The Standard Response Spectrum according to IEEE 344

A band pass filter according to Figure 8 was designed. The predicted response spectrum of white noise filtered by this filter is shown in Figure 9.

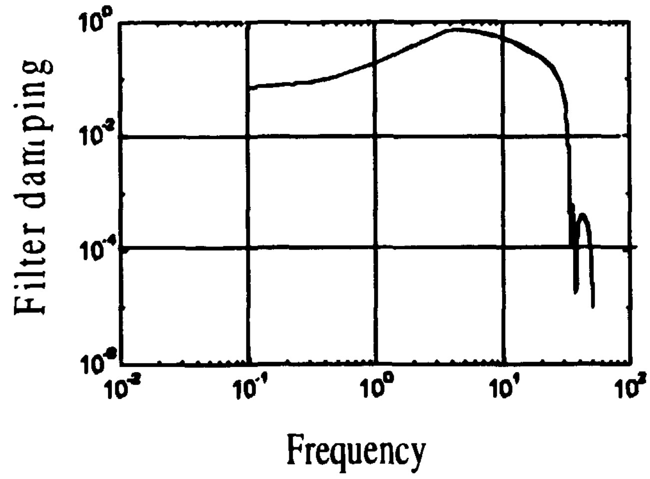

Figure 8 The digital band pass filter used for generating time histories with response spectrum according to IEEE 344

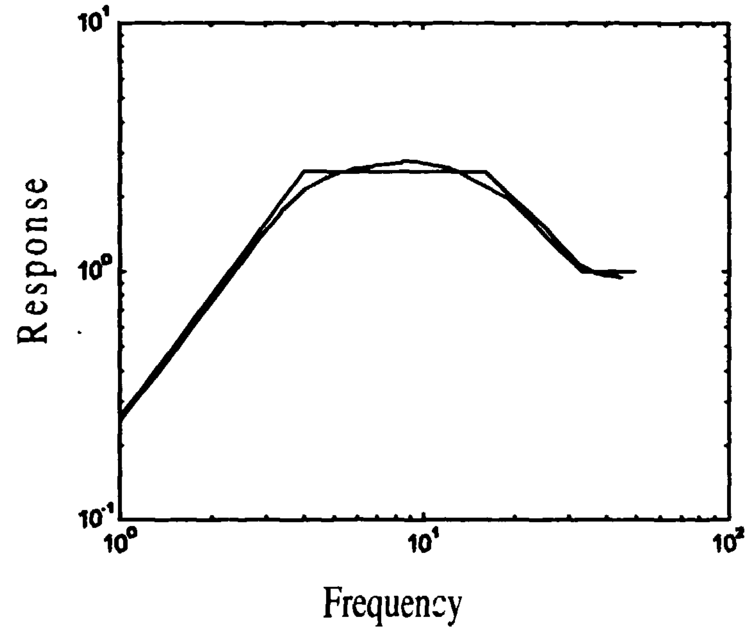

Figure 9 The predicted response spectrum after filtering white noise with the filter shown in Figure 8. The prediction was performed by the simple approach. The straight lines show the target spectrum (SRS according to IEEE 344).

From Figure 8 it can be seen that the filter starts to damp at about 4 Hz, while the response spectrum has a flat slope up to 16 Hz. As the response at a certain frequency of a response spectrum is built up of both the amplified signal with frequency contents around the actual response frequency and rigid body motion from lower frequencies this is the expected behaviour. From Figure 9 it is seen that the sharp corners of the IEEE standard response spectrum at 4 Hz and 16 Hz are not obtained in the simulated spectra. The corners could be made sharper by using higher order low-pass filters, but the physics behind a response spectrum, i. e. filtering of the shock wave in the rock will be modelled by a rather simple filter. The reason for the sharp corners in the IEEE-standard response spectrum is that this spectrum is obtained as an envelope of a lot of possible spectra. The envelope is "drawn by a ruler" and this results in unphysical sharp corners. No further work on getting sharper corners in the predicted spectrum was therefore done, even if it probably should be possible to obtain a predicted spectrum closer to the IEEE spectrum.

The predicted response spectrum can be calculated either by the simple approach given by equation (23) or by using the model based on the Poisson approximation. Figure 10 shows the predicted spectra from these two methods.

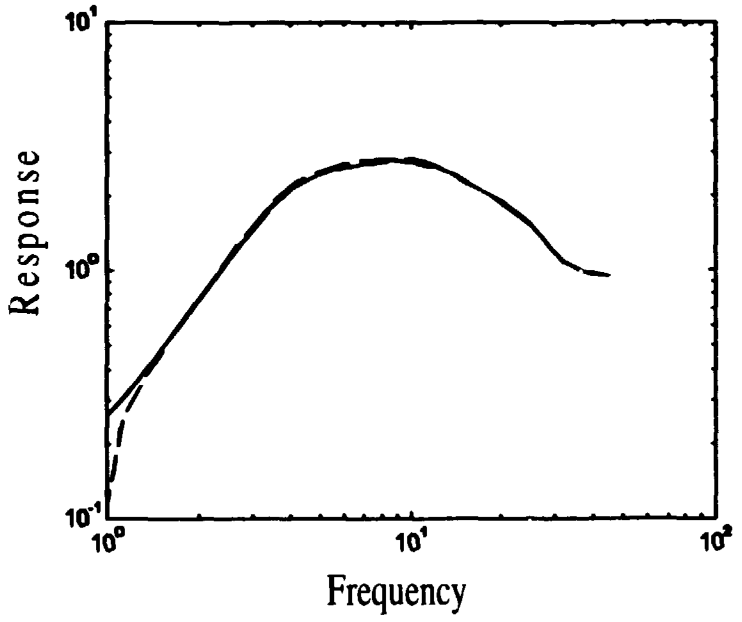

Figure 10 A comparison between predicting the response spectrum by the simple approach (dashed line) and by using the Poisson approximation (solid line).

The differences between the two spectra is rather small. The main advantages by using the more complicated model is that the variance of the simulated spectra can be calculated. Figure 11 shows the predicted response spectra, the 5% and 95% prediction limits and a spectrum obtained from one simulation.

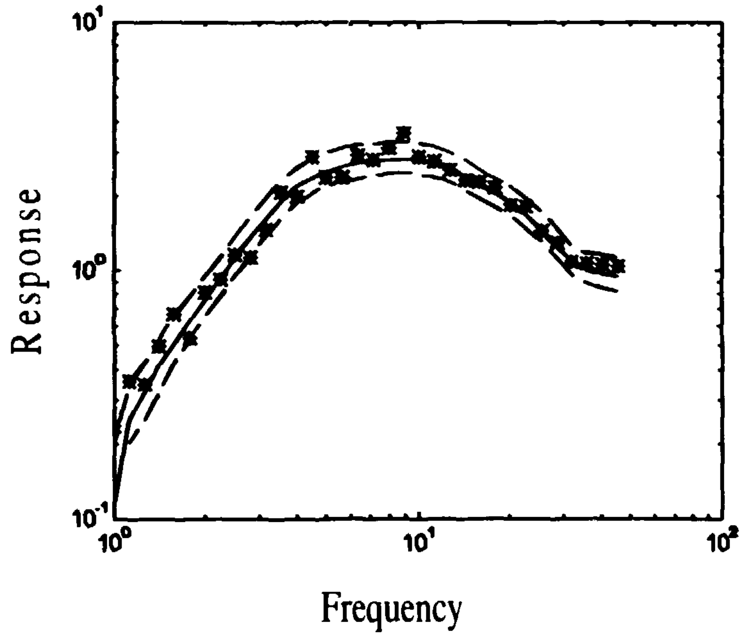

Figure 11 A response spectrum obtained after one simulation (asterisks) together with the predicted spectrum (solid line) and the 5% and 95 % prediction limits (dashed lines).

If the average spectrum of 20 simulations is calculated a close agreement between the predicted response spectrum and the simulated mean response spectrum is obtained, see Figure 12.

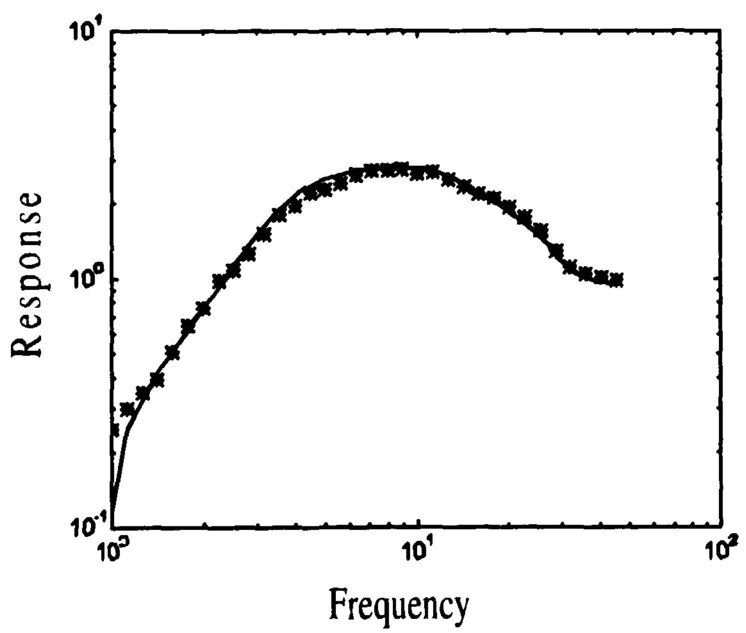

Figure 12 A mean response spectrum obtained after 20 simulations (asterisks) together with the predicted spectrum (solid line).

By using the Poisson approximation it is also possible to predict the probability density function (pdf) and the cumulative distribution function (cdf) of the maximum responses. Figure 13 shows the predicted pdf and the achieved histogram for the response at 4.5 Hz after 1000 simulations. Figure 14 shows the predicted cdf and the achieved distribution for the same simulation. It is clear that the skew pdf function is predicted but that the response levels are somewhat too low.

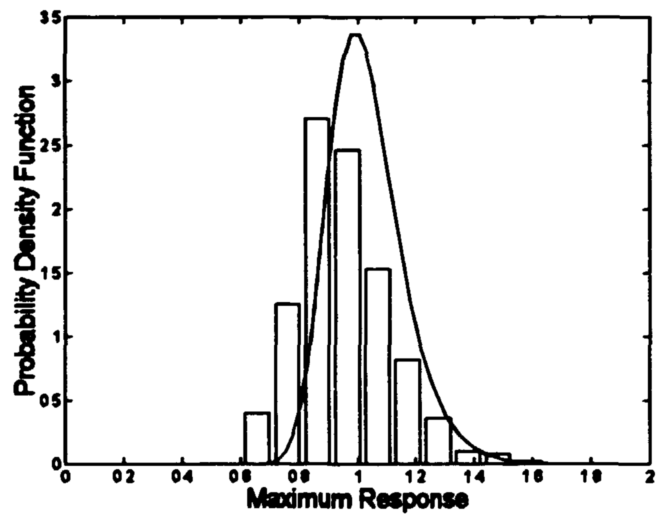

Figure 13 The maximum responses obtained at 1000 simulations (the histogram) together with the predicted probability density function of maximum responses.

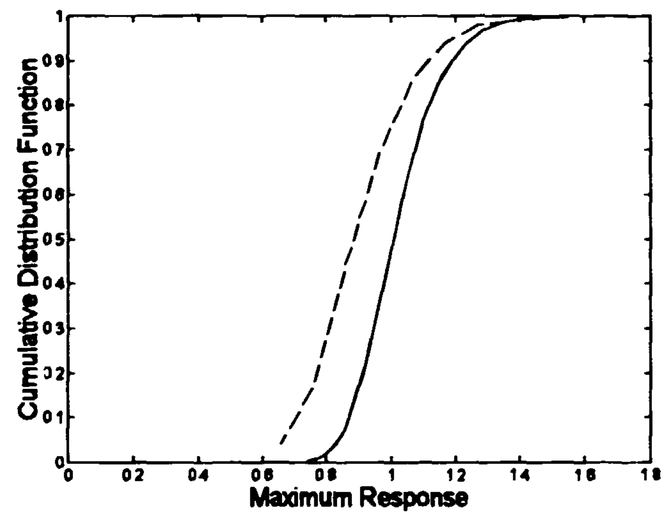

Figure 14 The predicted cumulative distribution function (cdf) (solid line) and the achieved cumulative distribution (dashed line) for the maximum responses obtained at 1000 simulations.

Example: Response spectrum suggested for a typical hard rock site in Sweden

For the nuclear power facilities in Sweden the seismic risks must be taken into account. Geologic investigations have shown that an expected Swedish earthquake has higher frequency contents than the earthquakes in the USA. Figure 15 shows a suggested response spectrum for a Swedish earthquake.

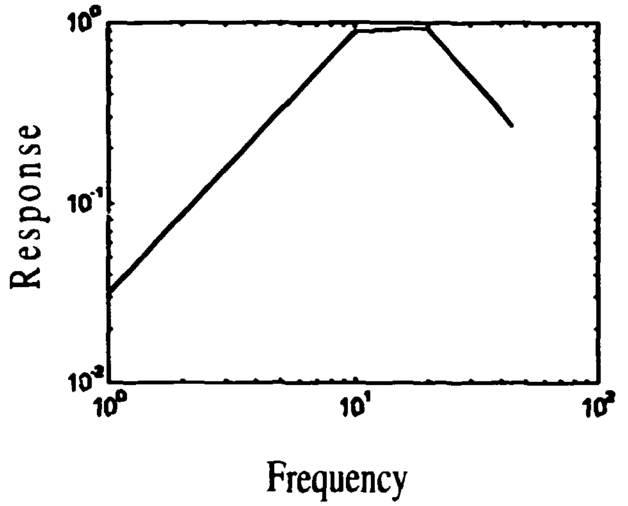

Figure 15 A response spectrum suggested for a typical hard rock site in Sweden.

A suitable band-pass filter was designed and the predicted response spectrum, when white noise is filtered by this filter, is shown in Figure 16 .

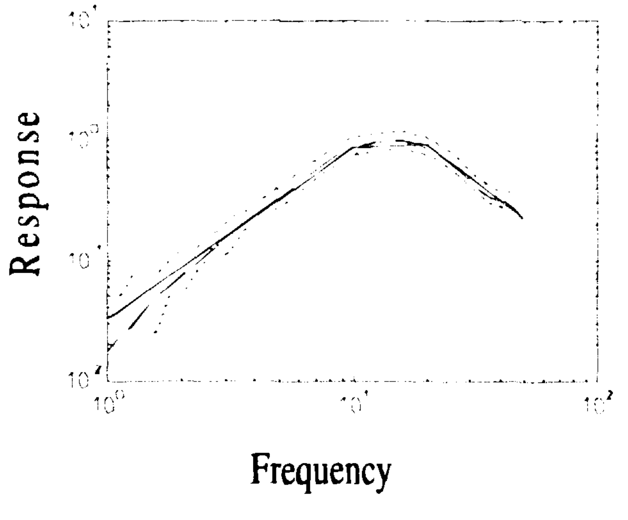

Figure 16 The target spectrum (solid line), the predicted spectrum (dashed line) and the 5% and 95% prediction limits (dotted lines).

Figure 17 shows the mean spectrum obtained after 20 simulations. As can be seen from this figure the agreement between the prescribed and obtained response spectra is close. This is also expected as the suggested response spectrum is not the result of enveloping a lot of possible spectra.

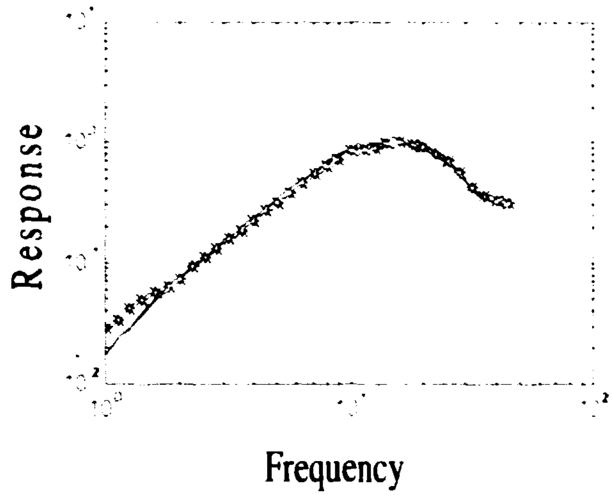

Figure 17 A mean response spectrum obtained after 20 simulations (asterisks) together with the predicted spectrum (solid line).

Of course it is also possible to calculate pdf and variances of the simulated response spectra. The results are very close to those obtained for the IEEE 344 standard response spectrum.

Discussions

From the two examples it is clear that the models for predicting response spectra works rather well, but that the predicted response levels are a bit too low. The pdf obtained by the Poisson approximation are asymptotic distributions, i. e. fully correct for infinitely long sequences. To use a model based on this assumption on a 30 seconds long earthquake (the IEEE 344 standard response spectrum) or a 10 seconds long earthquake (the response spectrum suggested for a typical hard rock site in Sweden) is of course an approximation.

Another problem is that local maxima in the signals in the Poisson approximation are assumed to be independent. This is surely not the case for such short sequences. A nearlying problem is how to handle that the maximum responses in the response spectrum are absolute maxima, i. e. both positive and negative peaks should be used. The calculations in this report are performed as if all local maxima and minima are independent. This can be one reason why the predicted spectra and pdf are a bit to high. Looking at the time histories recals that large minima often follow after large maxima, i. e. there is a dependence.

Suggestions for further work

In this work only given response spectra are simulated. In a real application the situations is often that a ground response spectrum is given and a building or a secondary structure will be excited by the corresponding earthquake. The problem is to predict if earthquakes will cause such large responses in the building or secondary structure that damage occurs. This problem is often solved by Monte Carlo simulations. This means that a lot of different time-histories, with the same statistical parameters, are generated and the responses of the building from each of them calculated. If the model of the building is complicated these calculations take a long time.

If the response of the building is linear, the building can be modelled by a linear filter. The expected maximum responses can then be estimated in the same manner as the response spectrum. The mean value and variance of the response of the building can then be calculated without simulations. Even secondary structures inside the building can be modelled by a linear filter and their responses calculated.

Another task is how to choose the filter from which the time-history is obtained by filtering white noise. In this work the filter is designed by a "manual iterative" procedure. It should be possible to solve the filter design problem as an optimization problem.

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