# Lecture 8: Interpretation of Seismic Records – acceleration, velocity and displacement; Frequency and Time Domain parameters; Response Spectra and Spectral parameters; Epicenter and magnitude determination.

## Topics

- Base line correction of Strong Ground Motion
- Characteristics of Strong Ground Motion
- Time domain characteristics of Strong Ground Motion
- Frequency domain characteristics of Strong Ground Motion
- Response Spectra
- Spectral Parameters
- Corner and Cutoff frequency
- Fourier Amplitude Spectrum
- Fourier Spectrum Empirical Models
- Fourier Spectrum theoretical Models
- Other Amplitude Parameters
- Locating Earthquakes

***Keywords:*** *Ground motion, Acceleration, Velocity, Displacement, Frequency*

## Topic 1

### Base line correction of Strong Ground Motion

- Base line correction is processes of correct a recorded signal for the bias in zero-acceleration value, and any long period drift in zero level that may arise from instrumental and environmental effects. It is technique for removing long-period noise.

- Baseline correction is procedures to correct certain types of long period disturbances on accelerometric signals, both analog and digital.

- The simplest procedure is to subtract from the accelerogram its average value (which theoretically should be zero to ensure a zero velocity at the end of the seismic motion). Alternatively, in the case of digital accelerograms with pre-event, it is possible to remove from the entire signal the average value calculated only on the pre-event portion.

- In the case of more complex instrumental disturbances, more sophisticated baseline correction procedures can be used, for instance by first subdividing the velocity signal (obtained by integrating the initial accelerogram) into multiple ranges, by estimating subsequently the drifts relative to each range using least square regression, and finally by removing them.

- In processing the accelerometric data, the standard correction procedure has been used, i.e. the subtraction from the accelerograms of its average value.

- Figure 8.1a shows uncorrected raw strong ground motion and Figure 8.1b shows strong ground motion data after applying base line corrections

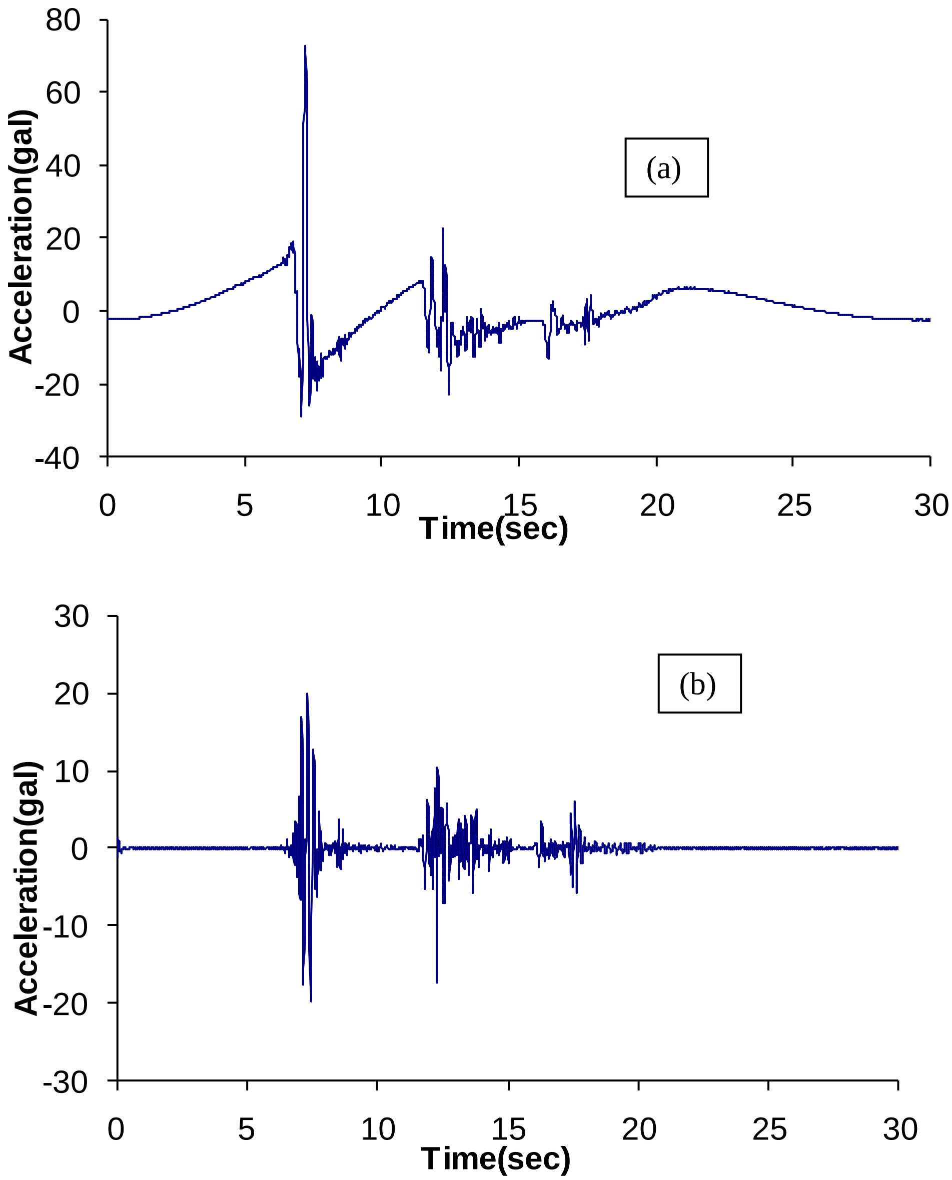



Figure 8.1: Typical Strong Ground Motion (a) Raw data and (b) base line corrected data

## Topic 2
### Characteristics of Strong Ground Motion

- On many occasions, ground motion parameters do not adequately describe the effects of ground shaking. For analysis of nonlinear problems such as the response of inelastic structures or the permanent deformation of an unstable slope, time histories of motion are required.

- Time histories can also be required in the development of site-specific design ground motions. In these cases, time histories that match target ground motion parameters such as peak accelerations, velocities, or spectral ordinates are required.

- In some cases, the local and regional geologic and tectonic conditions of the site of interest may be so similar to those of sites where actual strong motions have previously been measured that those strong motion records can be used directly.

- Usually, this is not the case, and artificial ground motions must be developed. Artificial ground motions can be developed in a number of different ways. The main challenges in their development are to ensure that they are consistent with the target parameters and that they are realistic.

- This is not easy as many motions that appear reasonable in the time domain may not when examined in the frequency domain, and vice versa. Many reasonable looking time histories of acceleration produce, after integration, unreasonable time histories of velocity and/or displacement. The quality of an artificial ground motion is very difficult to discern by eye.
- The most commonly used methods for generation of artificial ground motions fall into four main categories:
    1. Modification of actual ground motion records,
    2. Generation of artificial motions in the time domain,
    3. Generation of artificial motions in the frequency domain, and
    4. Generation of artificial motions using Green's function techniques.

## Topic3
### Time Domain Characteristics of Strong Ground Motion

- Peak Ground acceleration (PGA), velocity (PGV), and displacement (PGD) are the most common and easily recognizable time domain parameters of strong ground motion. For the sake of completeness, these parameters are indicated in figure below where time history traces of acceleration, velocity and displacement of the Sakarya record obtained in the August 17, 1999 Kocaeli (Mw-7.4) earthquake are illustrated in Figure 8.2.

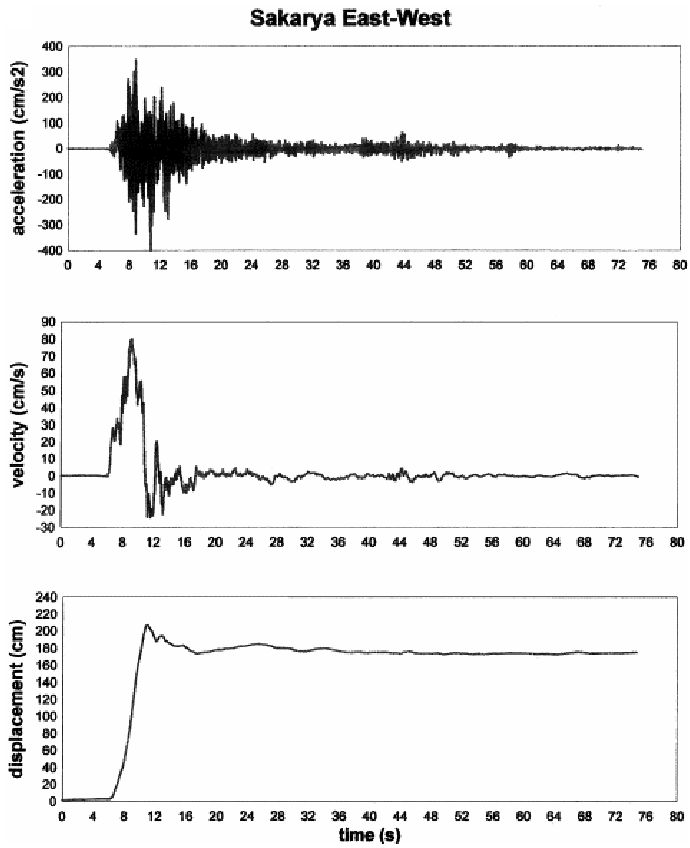



Fig 8.2: Acceleration, velocity and displacement time histories of the August 17, 1999 Kocaeli (Mw-7.4) earthquake

- This is a near-fault record from a major strike-slip earthquake, as evident by the pulse-like velocity and permanent displacement. This section addresses the modeling of root-mean–square (RMS) acceleration, the duration of the strong ground motion, and the time domain envelope functions.

- The resemblance of ground motion time histories to transient stochastic processes was noted years ago. Since then, a number of procedures that treat ground motions as stochastic processes have been developed. Many of these operate entirely in the time domain.

- A stationary stochastic process is one whose statistics remain constant with time. A stationary accelerogram, for example, would have a constant mean acceleration, constant standard deviation of acceleration, and constant frequency content-the accelerations would continue indefinitely.

- The fact that the acceleration amplitude of actual ground motions varies with time (ground motions have a beginning and an end, after all) renders their amplitudes non stationary. Studies have also shown that the frequency content of a typical ground motion is also nonstationary; it changes over the duration of shaking.

- Generation of an artificial ground motion time history in the time domain typically involves multiplying a stationary, filtered white noise signal by an envelope function that describes the buildup and subsequent decay of ground motion amplitude.

- Most recently, models that consider the nonstationarity of both amplitude and frequency content have been developed. The use of autoregressive moving average models has also increased in recent years.

## Topic 4

### Frequency-Domain Characteristics of Strong Ground Motion

- Ground motions can be generated quite conveniently in the frequency domain by combining a Fourier amplitude spectrum with a Fourier phase spectrum. The amplitude spectrum may be computed from an actual ground motion spectrum or may be represented by some theoretical means.

- The phase spectrum may be obtained from an actual ground motion or may be computed from a time history given by the product of white noise and an envelope function. Some investigators have used phase difference distributions as an indicator of phase structure to develop nonrandom, artificial phase spectra.

- Frequency-domain methods are particularly useful for generating motions that are consistent with target response spectra. Computer programs such as EQGEN assume initial Fourier amplitude and phase spectra, and then iteratively adjust the ordinates of the Fourier amplitude spectrum until a motion consistent with the target response spectrum is produced.

- The origin of the target response spectrum must be kept in mind when generating spectrum-compatible motions. Constant risk spectra, for example, represent the aggregate effect of potential earthquakes of many different magnitudes occurring at many different distances.

- Because a constant risk spectrum does not correspond to any particular seismic event, a motion generated from a constant risk target spectrum should not be expected to correspond to a particular seismic event.

## Topic 5

### Fourier Amplitude Spectrum

- One of the most important parameters describing strong ground motion during earthquakes is the Fourier-amplitude spectrum. Any periodic function can be expressed using Fourier analysis as the sum of a series of simple harmonic terms of different frequency, amplitude, and phase. Using the Fourier series, a periodic function, x(t), can be written as

$$x(t) = c_0 + \sum_{n=1}^{\infty} c_n \sin(\omega_n t + \varphi_n) \tag{8.1}$$

- A plot of Fourier amplitude versus frequency ($C_n$ versus $\omega_n$ from the above equation) is known as Fourier amplitude spectrum; a plot of Fourier phase angle ($\varphi_n$ versus $\omega_n$) gives the Fourier phase spectrum. The Fourier amplitude spectrum of a strong ground motion shows how the amplitude of the motion is distributed with respect to frequency. It expresses the frequency content of the motion very closely.

- The Fourier amplitude spectrum may be narrow or broad. A narrow spectrum implies that the motion has a dominant spectrum may be narrow or broad. A narrow spectrum implies that the motion has a dominant frequency, which can produce a smooth, almost sinusoidal time history. A broad spectrum corresponds to a motion that contains a variety of frequencies that produce a jagged, irregular time history.

- Since phase angles control the times at which the peaks of harmonic motions occur the Fourier phase spectrum influences the variation of ground motion with time. In contrast to Fourier amplitude spectra, Fourier phase spectra from actual earthquake records do not display characteristic shapes.

## Topic 6

### Response Spectra

- A response spectrum is used to provide the most descriptive representation of the influence of a given earthquake on a structure or machine.

- A response spectrum is a graphical relationship of maximum values of acceleration, velocity, and/or displacement response of an infinite series of elastic single degree of freedom (SDOF) systems subjected to a time dependent excitation.

- Response spectra are very useful tools of earthquake engineering for analyzing the performance of structures and equipment in earthquakes, since many behave principally as simple oscillators (also known as single degree of freedom systems). Thus, if you can find out the natural frequency of the structure, then the peak response of the building can be estimated by reading the value from the ground response spectrum for the appropriate frequency.

- Structures subject to earthquake is similar to a vehicle moving on the ground. In both cases there is relative movement between the vibrating system (structures or machines) and the ground.

- The system used for analysis consists of a mass, m, spring with constant k, and dashpot with viscous damping constant, c (with units of force x time per length) (Figure 8.3)

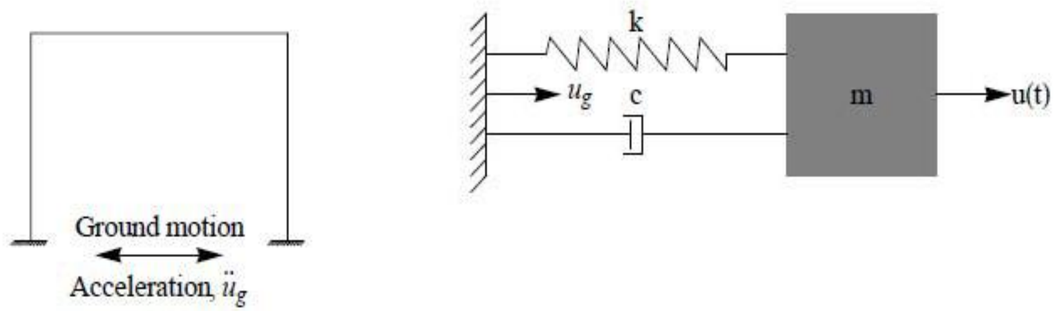



Figure 8.3: Simple damped mass -spring system with forcing function *u(t)*

$$m(\ddot{u}+\ddot{u}_g)+c\dot{u}+ku=0 \tag{8.2}$$

$$m\ddot{u}+c\dot{u}+ku=-m\ddot{u}_g \tag{8.3}$$

Where $u\,g$(t) is the ground motion, while $u$(t) is the motion of the mass relative to ground.

- If the ground acceleration from an earthquake is known, the response of the structure can be computed via using the Newmark's method.

- The response spectrum describes the maximum response of a single degree of freedom (SDOF) system to a particular input motion as a function of the natural frequency (or natural period) and damping ration of the SDOF system. Response spectra may be plotted individually to arithmetic scales, or may be combined, by virtue of the relationships of equation given below in tripartite plots.

- The tripartite plot displays spectral velocity on the vertical axis, natural frequency on the horizontal axis, and acceleration and displacement on inclined axis, and acceleration and displacement on inclined axes.

- The acceleration and displacement axes are reversed when the spectral values are plotted against natural period rather than natural frequency. The shapes of typical response spectra indicate that peak spectral acceleration, velocity, and displacement values are associated with different frequencies (or periods).

- At low frequencies the average spectral displacement is nearly constant; at high frequencies the average spectral acceleration is fairly constant. In between lies a range of nearly constant spectral velocity. Because of this behavior, response spectra are often divided into acceleration-controlled (high-frequency), velocity-controlled (immediate-freque3ncy), and displacement-controlled (low frequency) portions.

- Elastic response spectra assume linear structural force-displacement behavior. For many real structures, however, inelastic behavior may be induced by earthquake ground motions. An inelastic response spectrum can be used to account for the effects of inelastic behavior. A separate inelastic spectrum must be plotted to show total displacement. Spectral accelerations decrease with increasing ductility, but total displacements increase.

- Inelastic response spectra for acceleration and yield displacement for various values of the ductility factor is given below. Where $u_{\max}$ is the maximum allowable displacement and $u_y$ is the yield displacement.

$$\mu = u_{\max}/u_y \tag{8.4}$$

- Response spectra reflect strong ground motion characteristics indirectly, since they are "filtered" by the response of a SDOP structure. The amplitude, frequency content, and to a lesser extent, duration of the input motion all influence spectral values.

- It is important to remember that response spectra represent only the maximum Reponses of a number of different structures. However, the response of structures is of great importance in earthquake engineering, and the response spectrum has proven to an important and useful tool for characterization of strong ground motion.

## Topic 7

### Spectral Parameters

- **Predominant Period** - a single parameter that provides a useful, although somewhat crude representation of the frequency content of a ground motion is the predominant period, $T_p$. the predominant period is defined as the period of vibration corresponding to the maximum value of the Fourier amplitude spectrum.

To avoid undue influence of individual spikes of the Fourier amplitude spectrum, the predominant period is often obtained from a smoothed spectrum. While the predominant period provides some information regarding the frequency content, it is easy to see that motions with radically different frequency contents can have the same predominant period.

- **Bandwidth** – the predominant period can be used to locate the peak of the Fourier amplitude spectrum; however, it provides no information on the dispersion of spectral amplitudes about the predominant period. The bandwidth of the Fourier amplitude spectrum is the range of frequency over which some level of Fourier amplitude is exceeded. Bandwidth is usually measured at the level where the power of the spectrum is half its maximum value; this corresponds to a level of $1/\sqrt{2}$ times the maximum Fourier amplitude. The irregular shape of individual Fourier amplitude spectra often renders bandwidth difficult to evaluate. It is determined more easily for smoothed spectra.

- **Central Frequency** – the power spectral density function can be used to estimate statistical properties of the ground motion. Defining the nth spectral moment of a ground motion by

$$\lambda_n = \int_0^{\omega_N} \omega^N G(\omega) d\omega \tag{8.5}$$

- the central frequency $\Omega$ is given by

$$\Omega = \sqrt{\frac{\lambda_2}{\lambda_0}} \tag{8.6}$$

- The central frequency is a measure of the frequency where the power spectral density is concentrated. It can be used, along with the average intensity and duration, to calculate the theoretical median peak acceleration.

$$\ddot{u}_{\max} = \sqrt{2\lambda_0 \ln\left(2.8\frac{\Omega T_d}{2\Pi}\right)} \tag{8.7}$$

- **Shape factor** – the shape factor indicates the dispersion of the power spectral density function about the central frequency.

$$\delta = \sqrt{1 - \frac{\lambda_1^2}{\lambda_0 \lambda_2}} \tag{8.8}$$

- The shape factor always lies between 0 and 1, with higher values corresponding to larger bandwidths.

- **Kanai-Tajimi Parameters** – although individual power spectral density functions may have highly irregular shapes, averaging a number of normalized power spectral density functions for similar strong ground motions reveals a smooth characteristic shape. Kanai (1957) and Tajimi (1960) used a limited number of strong motion records to propose the following three-parameter model for power spectral density:

$$G(\omega) = G_0 \frac{1 + \left[ 2\xi_g \left( \omega / \omega_g \right) \right]^2}{\left[ 1 - \left( \omega / \omega_g \right)^2 \right]^2 + \left[ 2\xi_g \left( \omega / \omega_g \right) \right]^2} \tag{8.9}$$

- Where the parameters $G_0$, $\xi_g$ and $\omega_g$ determine the shape of the function.

## Topic 8

### Corner and Cutoff frequency

- When the Fourier amplitude spectra of actual earthquake motions are smoothed and plotted on logarithmic scales, their characteristic shapes can be seen more easily.

- Fourier acceleration amplitudes tend to be largest over an intermediate range of frequencies bounded by the corner frequency fc on the low side and the cutoff frequency fmax on the high side.

- The corner frequency can be shown theoretically to be inversely proportional to the cube root of the seismic moment. This result indicates that large earthquakes produce greater low-frequency motions than do smaller earthquakes.

- The cutoff frequency is not well understood; it has been characterized both as a near-site effect and as a source effect and is usually assumed to be constant for a given geographic region

## Topic 9

### Fourier Spectrum Empirical Models

- Trifunac and Lee [1989] provide empirical models for scaling Fourier amplitude spectra in terms of earthquake magnitude, source-to-site distance, site intensity, and recording site conditions. These models are based on the regression of the empirical amplitudes at specific frequencies.

- During the regression analyses of earthquake strong motion parameters in the 1970's Trifunac' suggested that the Fourier amplitude spectra (FS) of strong motion acceleration at a selected set of discrete periods, T, can be scaled in terms of the definition of the earthquake magnitude scale and a `correction' function in the following form:

$$\log_{10}\left[FS(T),_{p}\right] = M + \log_{10}A_0(R) - \log_{10}\{FS_0(T, M, p, s, v, R)\} \qquad (8.10)$$

- Where M is the local earthquake magnitude, ML; log10Ao (R) represents the amplitude attenuation functions versus distance. The term log10{FS0(T, M, p, s, v, R)} represents a `correction ' function which incorporates the effects of:

  1. Distribution of observations with respect to the assumed empirical model, as represented by the confidence level p selected for the approximate bound of spectral amplitudes FS(T),p
  2. Geologic site conditions, s, (s = 0 for alluvium, s = 2 for basement rock, s =1 for intermediate sites),
  3. Horizontal versus vertical ground motion differences, (v = 0 for horizontal and v =1 for vertical), and
  4. The frequency dependent attenuation effects of amplitudes versus distances, R. The term log10 FSO (T, M, p, s, v, R) was then determined by regression analysis.

## Topic 10

### Fourier Spectrum theoretical Models

- The Fourier Amplitude Spectrum (FAS) of free field horizontal acceleration at an epicentral distance (r) caused by the propagation of shear waves from an earthquake with a point source slip model is given by Boore [1983], Atkinson and Boore [1998], and Atkinson and Silva [2000]. Figure 8.4 shows components involved in Fourier Amplitude Spectrum (FAS) at site.

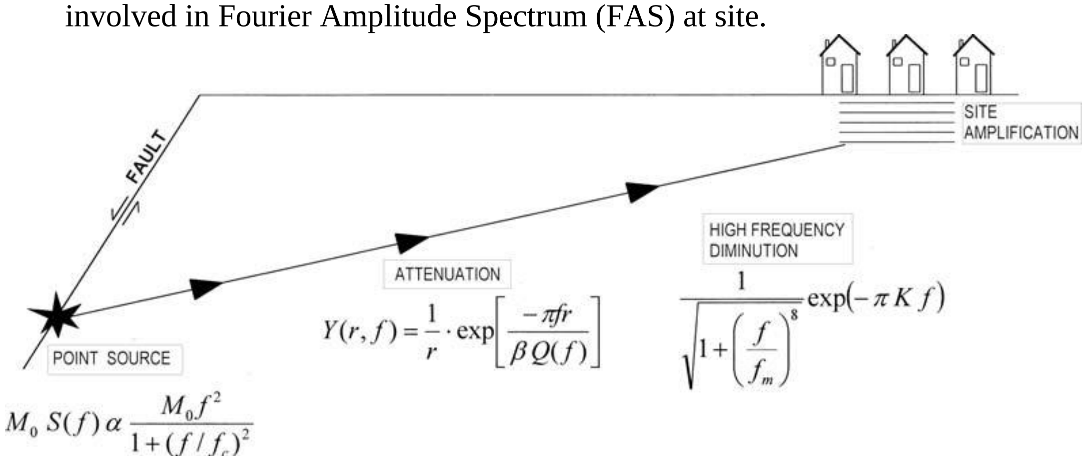



Fig 8.4: Elements of the Fourier amplitude spectrum of the earthquake ground motion modeling.

$$A(f,r) = C_0 M_0 S(f) Y(f,r) P(f) Z(f) \quad (8.11)$$

Where $C_0$ is the frequency independent scaling factor, $M_0$ is the seismic moment, S(f ) is the source spectrum, Y(f,r) is the attenuation factor, P(f ) is the high frequency decay factor, and Z(f ) is the scaling factor that accounts f or the site effects. For the ideal cases where Y(f,r), P(f ), and Z(f ) are not considered, A(f,r) is given by:

$$A(f,r) = C_0 M_0 S(f) \quad (8.12)$$

| | |
|---|---|
| $Y_G(r) = 1/r$ | for r<70km |
| $Y_G(r) = 1/70$ | for 70km<r<130km |
| $Y_G(r) = (1/70)\,(130/r)^{1/2}$ | for r>130km |

- The frequency independent scaling factor C0 is expressed as:

$$C_0 = (RPF) \big/ 4\pi\rho\beta^3 \quad (8.13)$$

- Where R = 0.55 is the scaling parameter to account for the average radiation parameter, P = 0.707 is the scaling parameter for partition into two horizontal parameters, and F = 2 is the scaling parameter to account for free surface amplification. Density and the shear wave propagation velocity of the medium in the vicinity of the source are indicated, respectively, by $\rho(g/cm^3)$ and $\beta$(km/sec).

- S(f ) is called the source spectrum, and accounts for the spectral model of the radiated waves from the source. It consists of two parts: the spectral shape and the scaling law (the relationship between the seismic moment and the corner frequency). One of the simplest and most commonly used source spectra with a single corner frequency, fc, is called the omega-squared spectrum.

$$S(f) = (2\pi f)^2 \big/ (1 + (f / f_c)^2) \quad (8.14)$$

- The corner frequency and the seismic moment are related by the so-called spectral scaling law:

$$fc = 4.9 \times 10^6 \beta (\Delta\sigma / M_0)^{1/3} \quad (8.15)$$

- Where $\Delta\sigma$ is in bars (1 bar = 105 Pa) and $M_0$ is the seismic moment in dyn–cm and $\beta$ is in km/sec. A number of studies have shown that choosing a constant value for $\Delta\sigma$, depending on the tectonic region, leads to predictions in good agreement with the empirical data. Thus, for constant $\Delta\sigma$, the source-spectral scaling is only a function of seismic moment. The most important parameter affecting the source is the stress drop, also called the stress parameter.

- For eastern North America, region-specific source models (the barrier model) have also been developed [Papageorgiou, 1988], where Y(f,r) is called the attenuation factor:

$$Y(f,r) = Y_G(r)Y_A(f,r) \tag{8.16}$$

- $Y_G(r)$ is the geometric attenuation factor due to geometric spreading of the seismic energy and $Y_A(r)$ is the anelastic attenuation. At epicentral distances (r) less than about 100 km, empirical evidence indicates a geometric attenuation by (1/r). Atkinson and Silva [2000] state that the geometric attenuation is proportional to (1/r) at epicentral distances less than 40 km but to (1/r)1/2 at epicentral distances greater than 40 km.

- The functional form of the geometric attenuation term developed by Atkinson and Boore [1995] is shown below:

- $Y_A(f,r)$ is the anelastic attenuation (or whole-path attenuation) factor given by the following expression:

$$Y_A(f,r) = \exp\left[-\pi f r / QB\right] \tag{8.17}$$

- where Q is the so-called quality factor and, in its simplest definition, can be taken as a constant ($Q = Q_0$).

- P(f ) serves as the high frequency diminution factor in Equation below, which accounts for the decay of spectral amplitudes at high frequencies, believed to be caused by the weathering in the upper layers of the medium. Boore [1983] assigns a fourth-order Butterworth filter for P(f ):

$$A(f,r) = C_0 M_0 S(f) Y(f,r) P(f) Z(f) \tag{8.18}$$

$$P_2(f) = \left[1 + (f/f_m)^8\right]^{-1/2} \tag{8.19}$$

- Anderson and Hough [1984] model P(f ) by the spectral decay factor κ as:

$$P_1(f) = \exp(-\pi k f) \tag{8.20}$$

- Boore [2000] combines P1(f ) and P2(f ) for the following definition for P(f ):

$$P(f) = P_1(f) P_2(f) \tag{8.21}$$

- The cut-off frequency filter (fm) may vary between 50 Hz [in the northeastern United States; Atkinson and Boore, 1998] and 100 Hz [in the western United States; Frankel, 1996].

- Z(f ) represents the scaling factor accounting for site effects. Geologic conditions in the upper crust and the general soil conditions in the site vicinity modify the FAS of the ground motion as a function of frequency by factors as high as 3.

- Although site response analysis methods are well developed, the necessity of obtaining detailed geotechnical information limits their general utilization. In the quarter wavelength approximation method [Joyner et al., 1981], the amplification at a specific frequency (or wavelength) (Aq (f )) is given by the square root of the ratio between the seismic impedance (ρ β) at the site averaged over a depth equal to one quarter of the wavelength and the seismic impedance at the source:

$$A_q(f) = \left(\rho_0\beta_0/\rho_s\beta_s\right)^{1/2} \tag{8.22}$$

- where the subscripts o and s indicate site and source media, respectively. The square-root impedance amplification is a first-order approach to complete amplification analysis using rigorous wave propagation theory.

- Boore and Joyner [1997] provide amplification values as a function of frequency for the assessment of Z(f ) in terms of typical soil profiles associated with NEHRP [1997] site classes. Amplifications for generic very hard rock ($v^{30}$ = 2900 m/sec), generic rock ($v^{30}$ = 620 m/sec), generic soil (v30 = 310 m/sec), NEHRP C class ($v^{30}$ = 520 m/sec), and NEHRP D class ($v^{30}$ = 255 m/sec) sites are provided in below Figure 8.5. The combined effect of site amplification Z(f ) and near-surface attenuation of high frequencies P1(f ), can be also seen in Figure 8.6 using κ = 0.003 sec for very hard rock sites and κ = 0.035 sec for other site types.

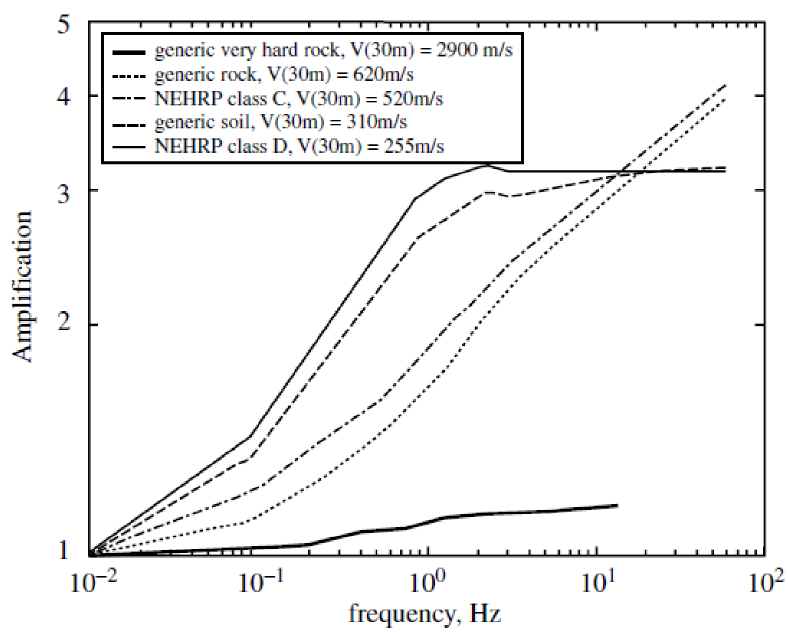



Fig 8.5: Site amplification factors for various site classes.

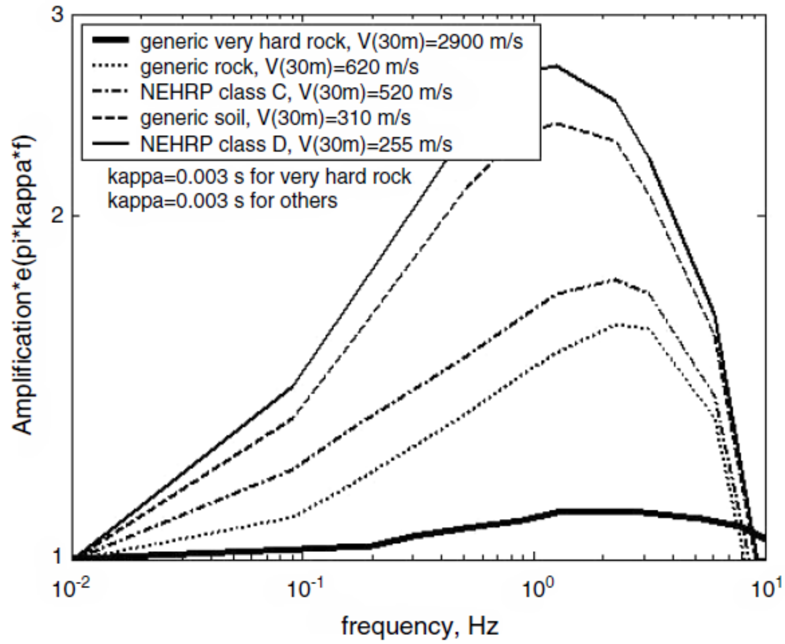



Fig 8.6: Combined effect of site amplification and diminution

## Topic 11

### Other Amplitude Parameters

- Although the parameters discussed previously are easily determined, they describe only the peak amplitudes of single cycles within the ground motion time history. In some cases, damage may be closely related to the peak amplitude, but in others it may require several repeated cycles of high amplitude to develop.

- The concept of effective acceleration can be describes as “that acceleration which is most closely related to structural response and to damage potential of an earthquake. It differs from and is less than the peak free-field ground acceleration. it is a function of the size of the loaded area, the frequency content of the excitation, which in turn depends on the closeness to the source of the earthquake, and to the weight, embedment, damping characteristic, and stiffness of the structure and its foundation.

- Some time histories are characterized by single-cycle peak amplitudes that are much greater than the amplitudes of other cycles. These single cycles often occur at high frequencies and consequently have little effect on structures with lower natural frequencies.

- In other time histories, such as the Koyna record, a number of peaks of similar amplitude are observed.

- Sustained Maximum acceleration and Velocity – Nuttli (1979) used lower peaks of the accelrogram to characterize strong motion by defining the sustained maximum acceleration for three (or five) cycles as the third (or fifth) highest (absolute) value of acceleration in the time history. The sustained maximum velocity was defined similarly.

- Although the PHA values for the 1972 Stone Canyon earthquake and 1967 Koyna earthquake records were nearly the same, a quick visual inspection indicates that their sustained maximum accelerations (three-or five cycle) were very different.

- For a structure that required several repeated cycles of strong motion to develp damage, the Koyna motion would be much more damaging than the Stone Canyon motion, even though they had nearly the same PHA. For these motions, the sustained maximum acceleration would be a better indicator of damage potential than the PHA.

- Effective Design Acceleration – the notion of an effective design acceleration, with different definitions, has been proposed by at least two researchers. Since pulses of high accelerationat high frequencies induce little response in most structures, Benjamin and Associates (1988) proposed that an effective design acceleration be takne as the peak acceleration that remains after filtering out accelerations above 8 to 9 Hz. Kennedy (1980) proposed that the effective design acceleration be 25% greater than the third highest (absolute) peak acceleraton obtained from a filtered time history.

## Topic 12

### Locating Earthquakes

- We can locate earthquakes using a simple fact: an earthquake creates different seismic waves (P waves, S waves, etc.) The different waves each travel at different speeds and therefore arrive at a seismic station at different times. P waves travel the fastest, so they arrive first. S waves, which travel at about half the speed of P waves, arrive later.

- A seismic station close to the earthquake records P waves and S waves in quick succession. With increasing distance from the earthquake the time difference between the arrival of the P waves and the arrival of the S waves increases.

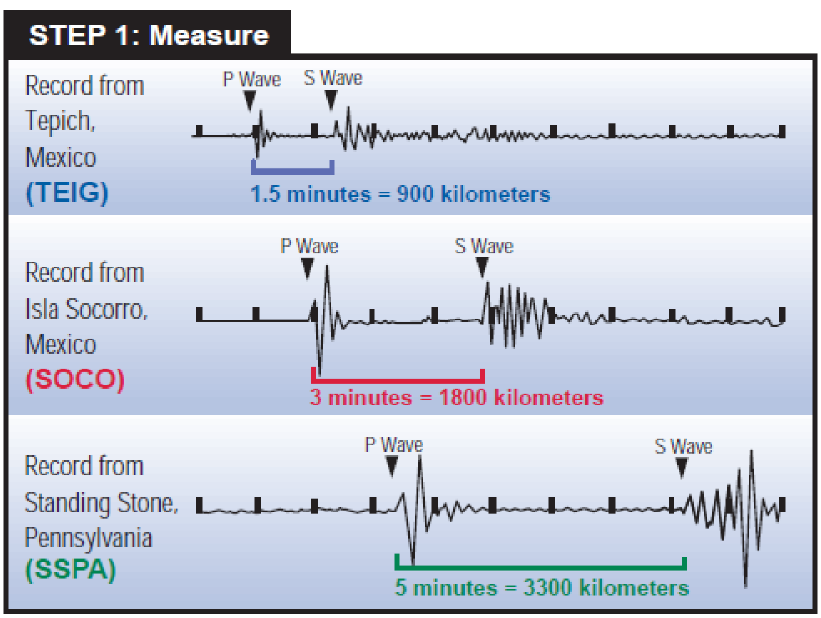
- Although modern techniques are more complex, we have illustrated the basic concept using an example of an earthquake near Mexico and seismic stations in North America. The following two steps show how we determine distance from the seismograms and estimate the location using three stations.

- Step 1: The time between the arrival of the P wave and the arrival of the S wave (S-P time) is measured at each station (Figure 8.7a). The S-P time indicates the distance to the earthquake similar to how the time interval between the flash of light and the sound of thunder indicates the distance to a thunderstorm.

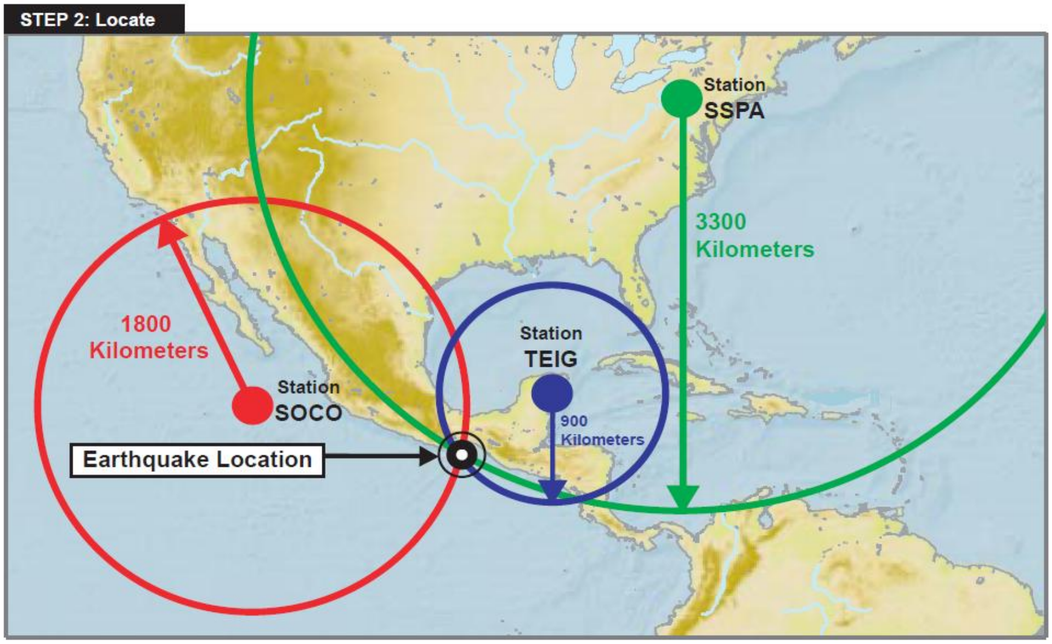
- In our example, station TEIG (with an S-P time of 1.5 minutes) is closest to the earthquake, and station SSPA (with an S-P time of 5 minutes) is farthest away. From observing and analyzing many earthquakes, we know the relationship between the S-P time and the distance between the station and the earthquake.

- We can therefore convert each measured S-P time to distance. A time interval of 1.5 minutes corresponds to a distance of 900 kilometers, 3 minutes to 1800 kilometers, and 5 minutes to 3300 kilometers.

- Step 2: Once we know the distance to the earthquake for three stations, we can determine the location of the earthquake. For each station we draw a circle around the station with a radius equal to its distance from the earthquake (Figure 8.7b). The earthquake occurred at the point where all three circles intersect.




(a)




(b)

Fig 8.7(a, b): Location of epicenter

Lecture 8 in Interpretation of Seismic Records – acceleration, velocity and displacement; Frequency and Time Domain parameters; Response Spectra and Spectral parameters; Epicenter and magnitude determination.