CE G615- Earthquake Engineering

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Earthquake Ground Motion Parameters and Seimic Zoning Map of India

BITS Pilani
Hyderabad Campus

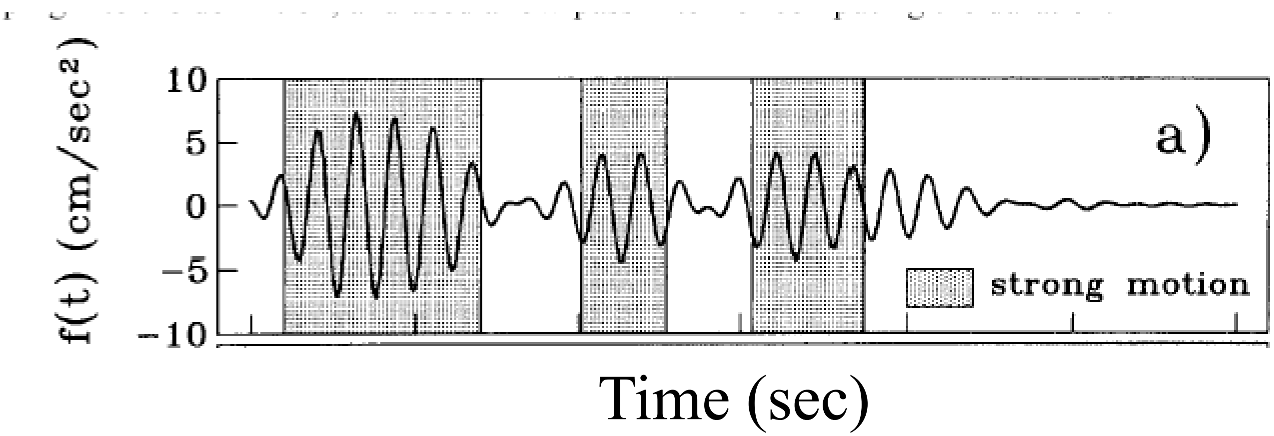
Topics to be covered

- Ground Motion Recording
- Ground Motion Parameters
- Seismic Hazard Analysis
- Seismic Microzonation
- Seismic Maps

Strong Ground Motion

Evaluation of the effects of earthquakes requires the study of ground motion

Engineering Seismology deals with vibrations related to earthquakes, which are strong enough to cause damage to people and environment

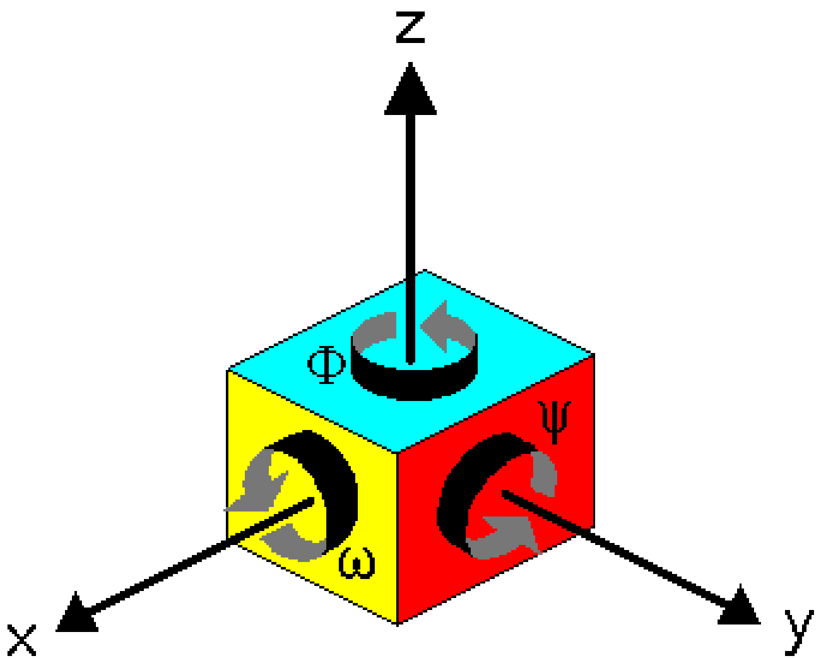


Components of Ground Motion

The ground motions produced by earthquakes at any particular point have

3 translational components.

3 rotational components.



In practice,

- translational components of ground motion are measured
- rotational components are ignored.

Measuring ground motion

- Seismographs are used to measure the ground motion.
- Seismogram:

  Output from the seismograph. Ground motion at a measuring station as a function of time.

- Seismograms typically record motions in three cartesian axes (x, y, and z), with the z axis perpendicular to the Earth's surface and the x- and y- axes parallel to the surface.
- Three inertial seismometers are commonly used in one instrument housing to measure up-down, east-west, north-south motions simultaneously.

Strong motion seismographs

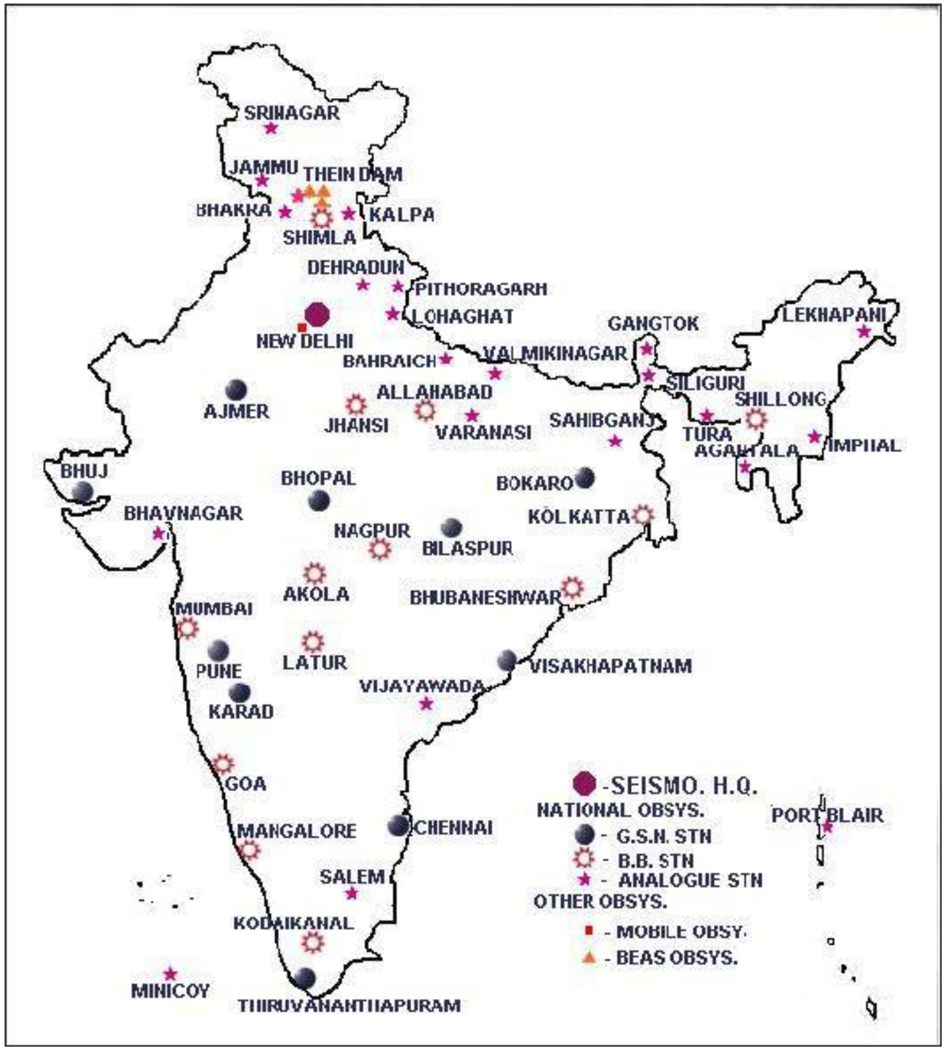
Designed to pickup strong, high-amplitude shaking close to quake source

•Most common type is the accelerometer

•Directly records ground acceleration

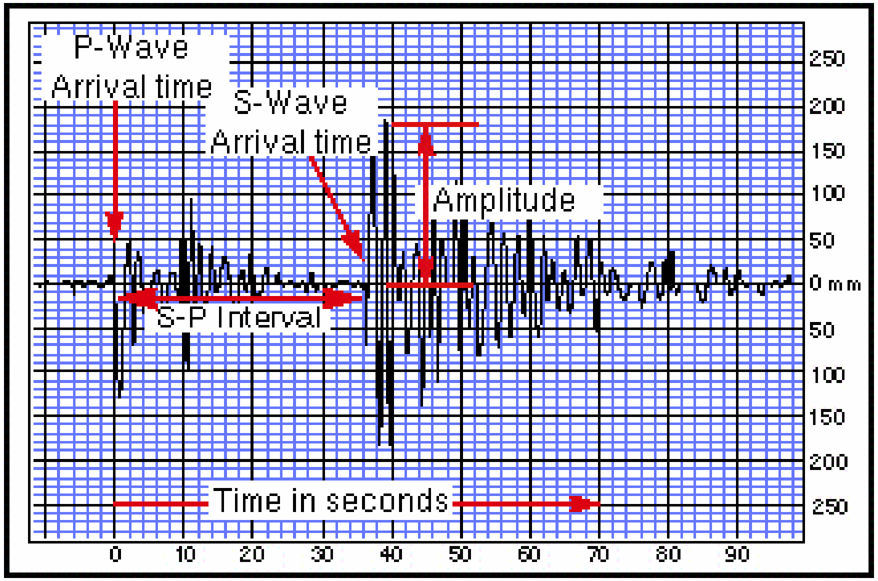
•Recording is triggered by first waves

•Difficult to differentiate S and surface waves



Seismogram interpretation

- Seismograms can provide information on
  - location of epicenter
  - magnitude of earthquake
  - source properties
- Most seismograms record P, S & surface waves
- First arrival is P wave
- After a pause of several seconds the higher amplitude S wave arrives



- surface waves follow and may continue for tens of seconds
- surface waves are slower but persist to greater distances than P & S waves

Wave terminology

Wave amplitude

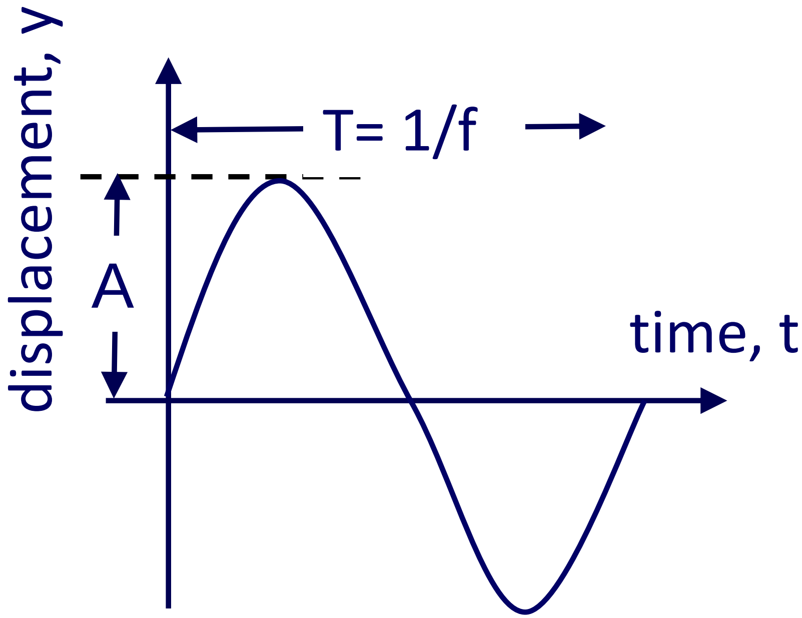
– height of a wave above its zero position

Wave period

– time taken to complete one cycle of motion

Frequency

– number of cycles per second (Hertz)
  - human ear can detect frequencies in range 15-20000 Hz
  - felt shaking during quake has frequencies 1-20 Hz



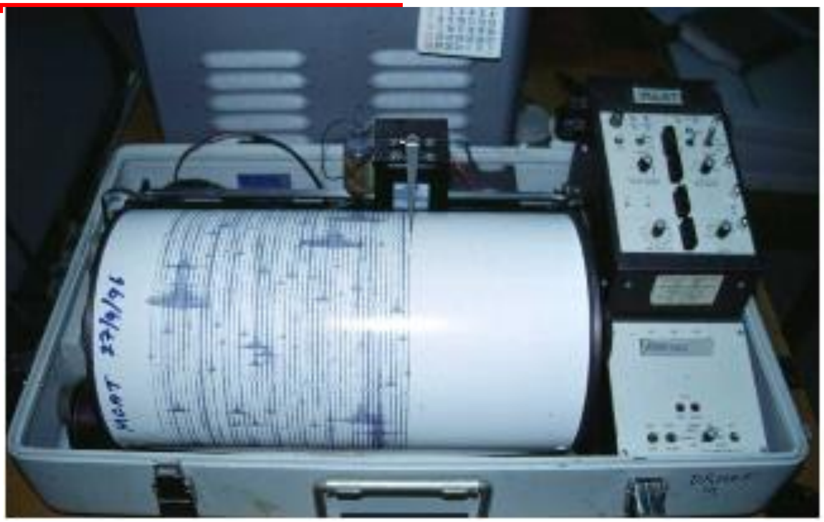
A= amplitude

T= Period

f = frequency

Ground Motion Recording

- The actual ground motion at a given location is derived from instrumentally recorded motions.
- The most commonly used instruments for engineering purposes are strong motion accelerographs/ accelerometers.
- These instruments record the acceleration time history of ground motion at a site, called an accelerogram.
- Correction to recorded accelerogram required
  - to account for instrument distortion and base line correction
- The resulting corrected acceleration record can be used by engineers to obtain
  - ground velocity and ground displacement by appropriate integration.



Digital strong motion accelerograph

Ground Motion Recording

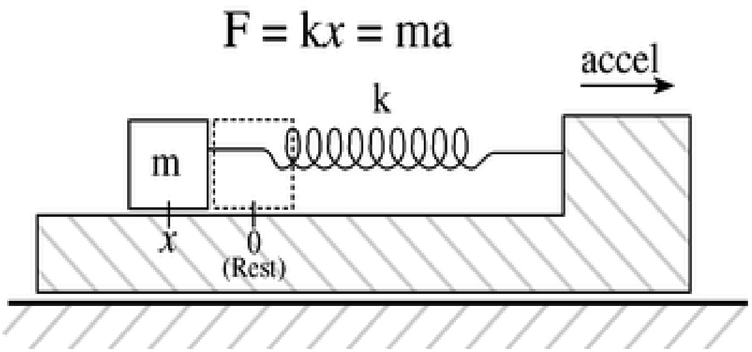
Types of Accelerometers:

1. ***Electronic*** : transducers produce voltage output
2. ***Servo controlled***: use suspended mass with displacement transducer
3. ***Piezoelectric:*** Mass attached to a piezoelectric material, which develops electric charge on surface.

- Generally accelerometers are placed in ***three orthogonal directions*** to measure accelerations in three directions at any time.
- Sometimes ***geophones*** (velocity transducers) are attached to accelerometers to measure the seismic wave velocities.

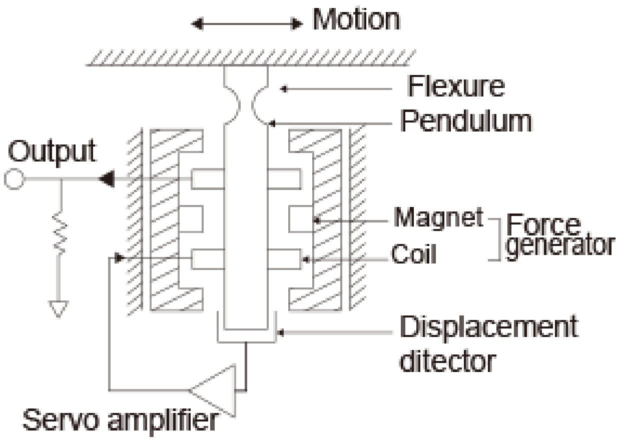
Ground Motion Recording

Servo Accelerometer (Force-balance)



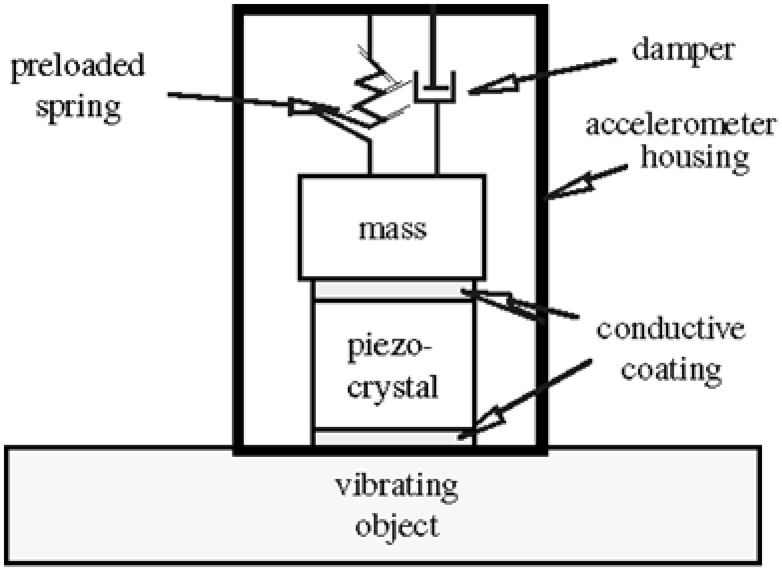
Principle: An acceleration *a* will cause the mass to be displaced by ***ma/k***

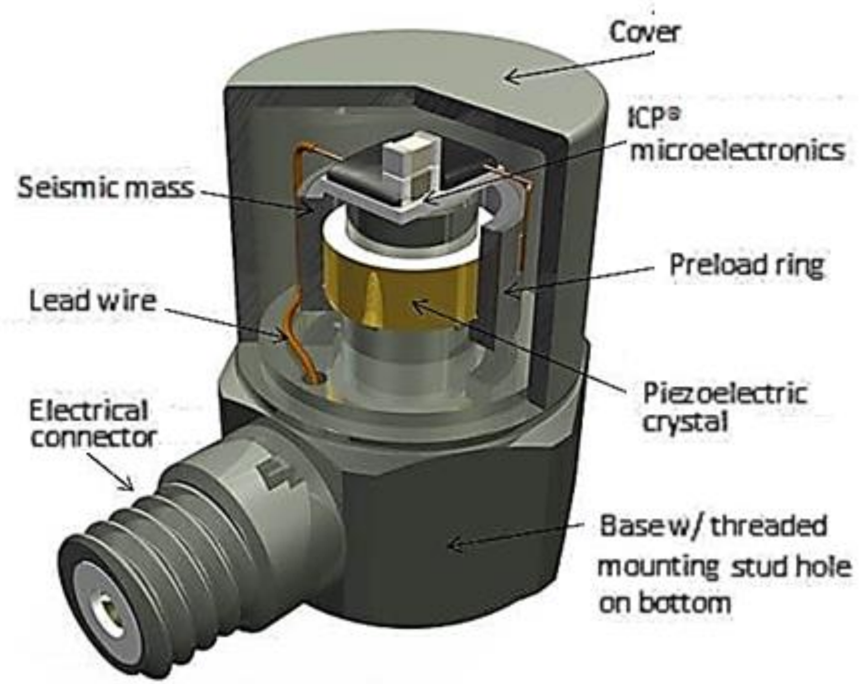
- If acceleration is applied to this assembly, a force is exerted on the mass and it will attempt to move from the Rest position.
- When the displacement detector detects motion, the counterbalancing force is provided by a magnetic coil by increasing current by means of a servo amplifier to maintain the null position.
- The coil current provides the restoring force required to maintain the null position and this current will be in direct proportion to the applied acceleration.



Ground Motion Recording

Piezoelectric Accelerometer



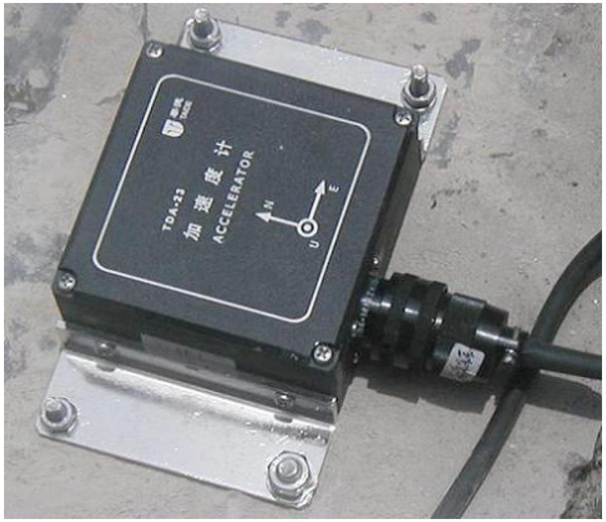


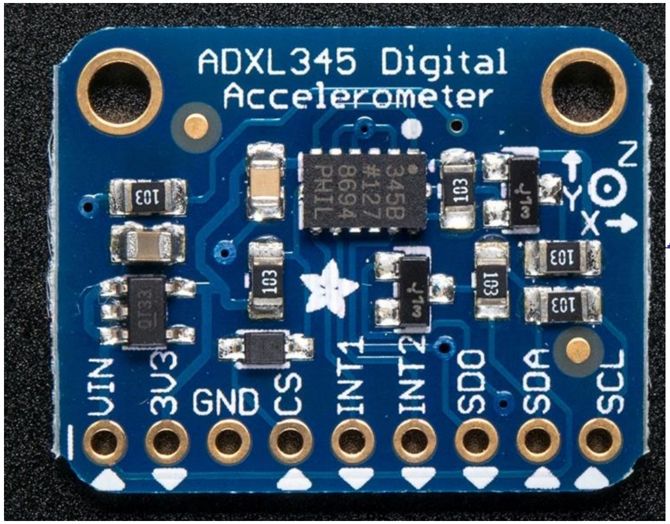
Principle: piezoelectric accelerometers convert one form of energy into another and provide an electrical signal in response to a quantity that is being measured. Acceleration acts upon a seismic mass that is restrained by a spring or suspended on a cantilever beam, and converts a physical force into an electrical signal. Before the acceleration can be converted into an electrical quantity it must first be converted into either a force or displacement. This conversion is done via the mass spring system shown in the figure.

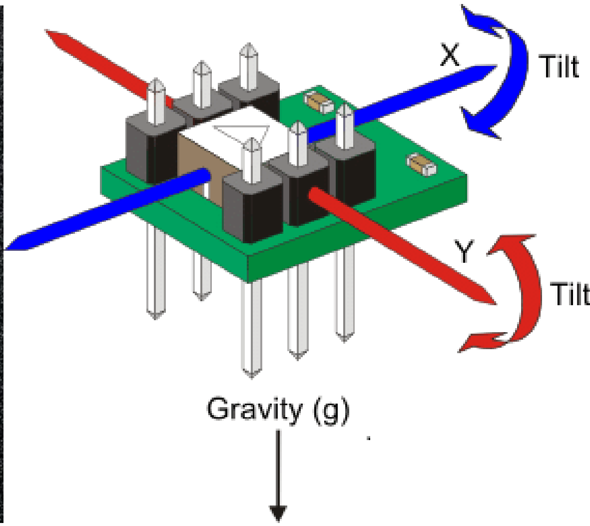
Ground Motion Recording

Electronic Accelerometer

Three-direction electronic accelerometer uses the latest integrated accelerometer chip. It features small volume, low power consumption, zero fine tuning, continuous, stable and reliable operation



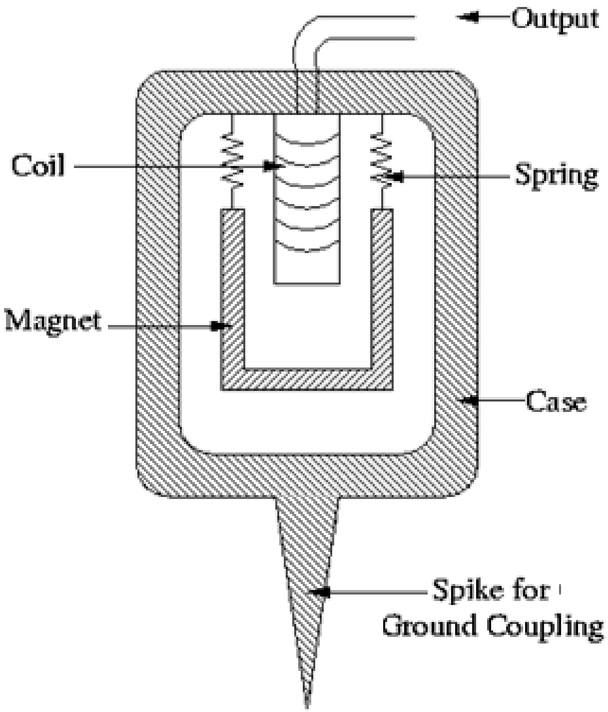




Ground Motion Recording

Geophone

Geophones (**velocity transducers**) are used to measure the seismic wave velocities. They transform the mechanical wave energy to electrical voltage and the response is captured with time to obtain the velocity of seismic waves



Ground Motion Recording

Geophone

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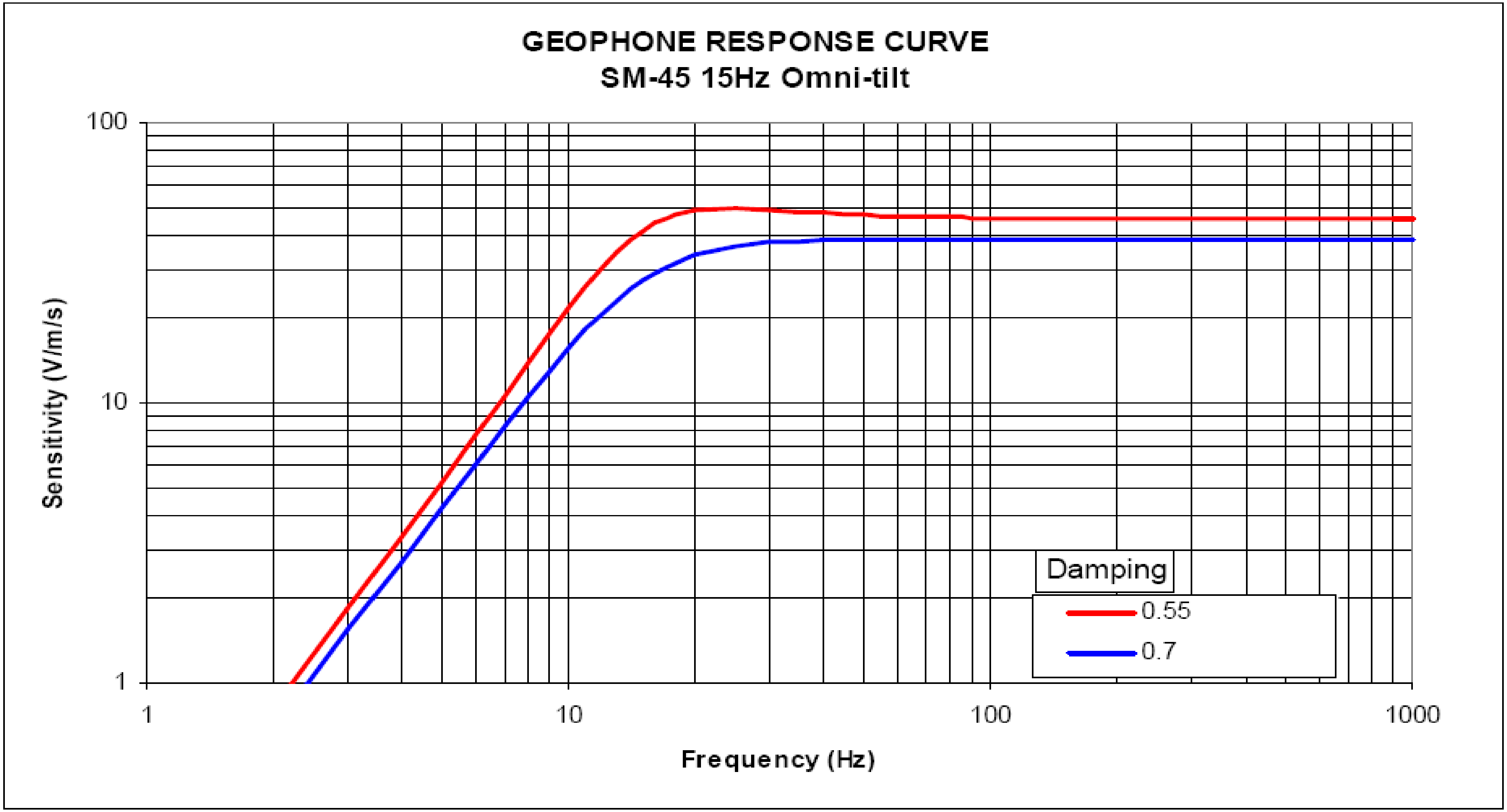
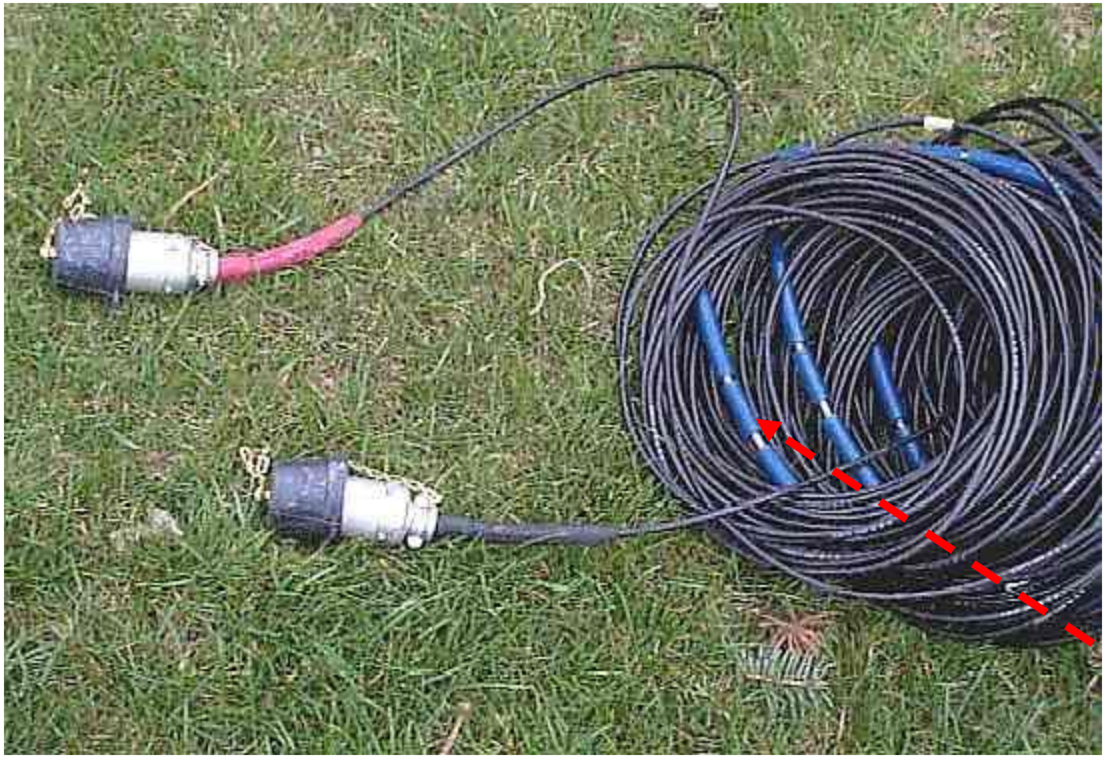


Ground Motion Recording

Array of Geophones



Vertical component geophones

Take-out points where a geophone can be connected to the pair of conductors

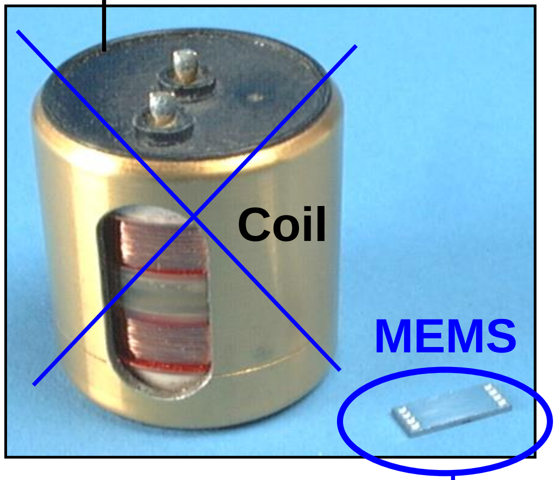
An array of geophones connected to conductors are used for seismic surveying

Ground Motion Recording

Micro Electronic Mechanical Systems (MEMS)

Micro Electronic Mechanical Systems (MEMS) are a recently developed device providing Broad-Band Sensing. MEMS are micro fabricated non-laser passive components. These are about 1 to 10 microns in size, which is smaller than the width of a human hair. Most of the traditional moving coil type geophones are now being replaced by MEMS.

Velocity Sensitive



Acceleration sensitive

Ground Motion Recording

Hydrophones: for ocean floor seismic sensing

Instead of recording displacement, hydrophones record changes in pressure. A piezo-electric crystal senses the pressure change and creates a voltage. This sensor is used for ocean floor seismic sensing.

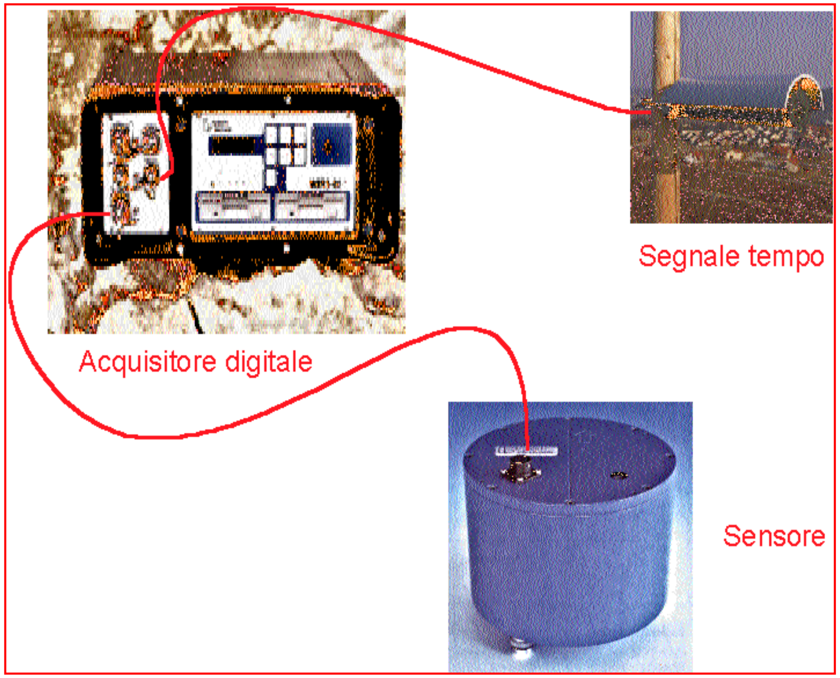
Ground Motion Recording

Broadband Seismometer

Broadband seismometers can detect motion over a range (or band) of frequencies (0.01 Hz to 50 Hz)

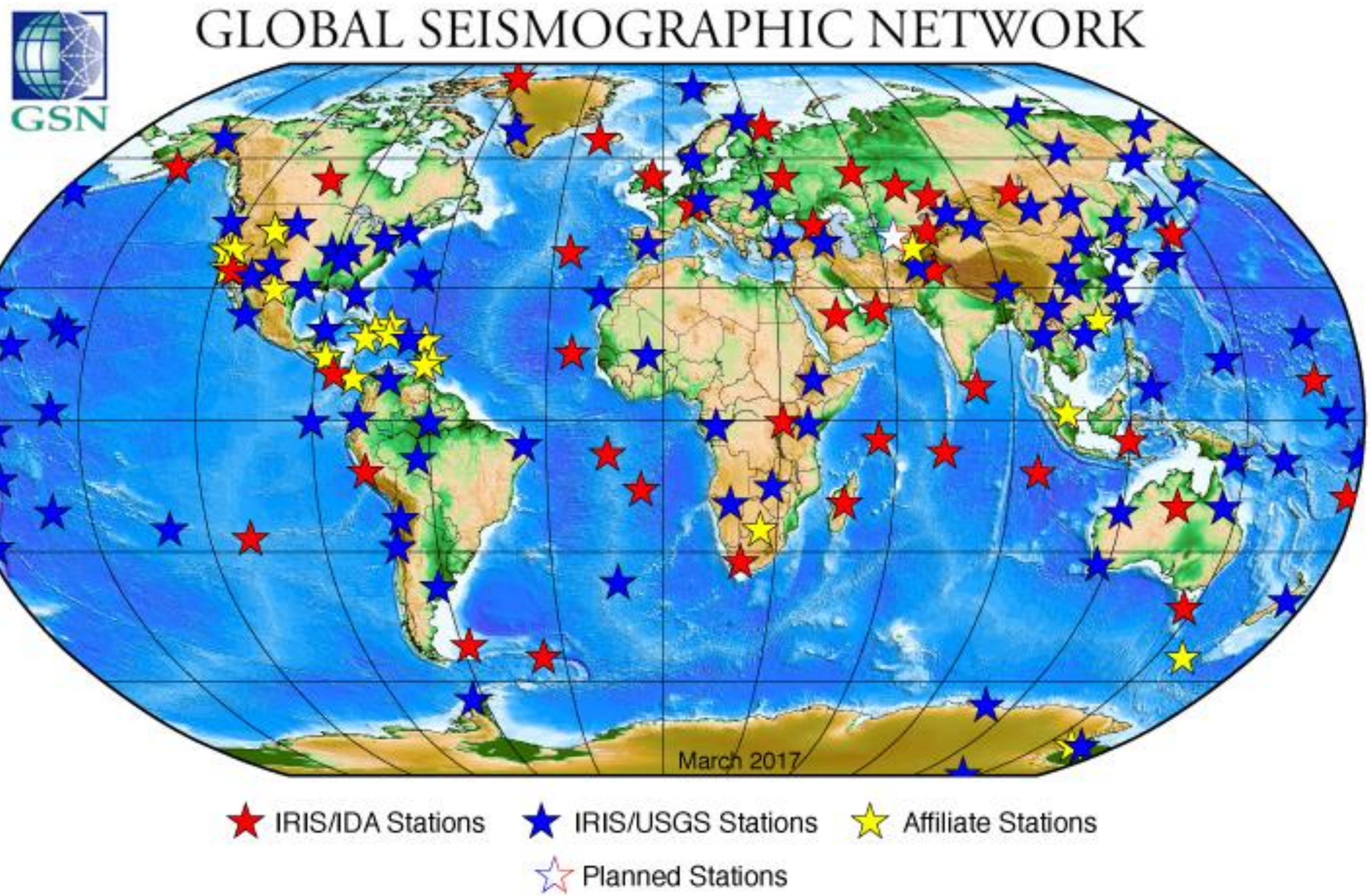
For regional seismology, the frequency range of interest is from 0.05 to 20 Hz therefore; broadband sensors are most useful for recording regional earthquakes

Ground Motion Recording



Modern seismic monitoring

Strong motion seismographs



The Global Seismographic Network (GSN) is a 150+ station, globally distributed, state-of-the-art digital seismic network providing free, realtime, open access.

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Ground Motion Parameters

Amplitude *Frequency content* *Duration*

Ground Motion Parameters

An earthquake history can be described using ***Amplitude*, *Frequency content***, and ***Duration***.

Amplitude: The most common measures of amplitude are

PGA: Peak ground acceleration (Horizontal- PHA & Vertical- PVA)
EPA: Effective peak acceleration
PGV: Peak ground velocity (PHV & PVV)
EPV: Effective peak velocity
PGD: Peak ground displacement

Frequency Content: The frequency content of an earthquake history is often described using Fourier Spectra, Power spectra and response spectra.

Duration: The duration of an earthquake history is somewhat dependent on the magnitude of the earthquake.

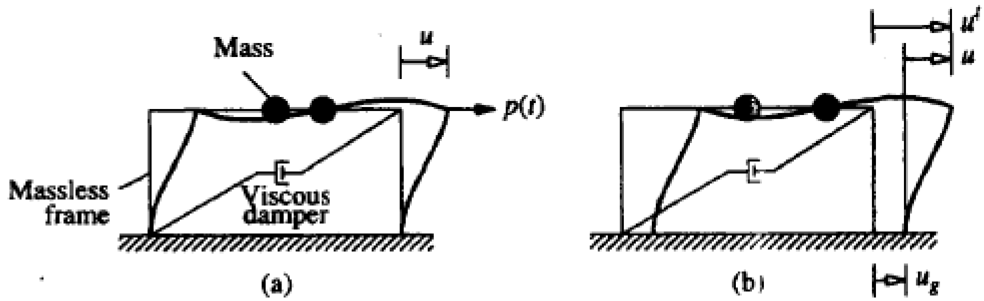
Ground Motion Parameters

PGA: The absolute value of the largest horizontal acceleration at a location.

It is the most important strong motion parameter. In a stiff structure, the maximum value of the induced force is equal to PGA $\times$ Mass

Measurement of ground acceleration

A seismograph can be illustrated by a mass-spring-dashpot single degree of freedom system.



The response of such system for shaking is given by

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

Where *u* is the trace displacement (relative displacement between seismograph and ground), $\ddot{u}_g$ is the ground displacemeacceleration, c is the damping coefficient, k is the stiffness coefficient.

Measurement of ground acceleration

If the ground displacement is simple harmonic at a circular frequency ω_g , the ground acceleration amplitude is calculated from the trace displacement amplitude using the equation:

$$\frac{|u|}{|\ddot{u}_g|} = \frac{1}{\omega^2} R_d$$

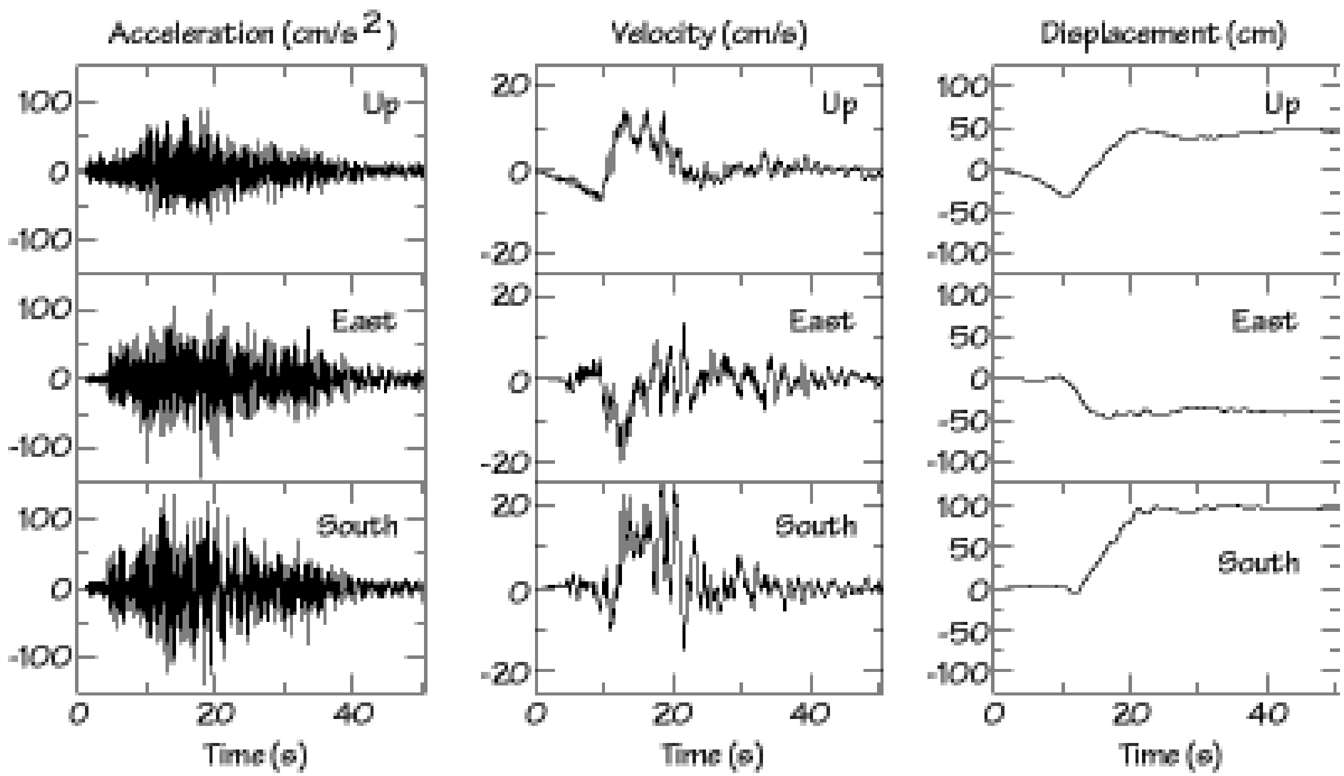
$$R_d = \frac{1}{\sqrt{\left(1 - \beta^2\right)^2 + (2\xi\beta)^2}}.$$

Where ω is the undamped natural circular frequency

β is tuning ratio, given by ω_g / ω

ξ Is damping ratio, given by $\dfrac{c}{2\sqrt{km}}$

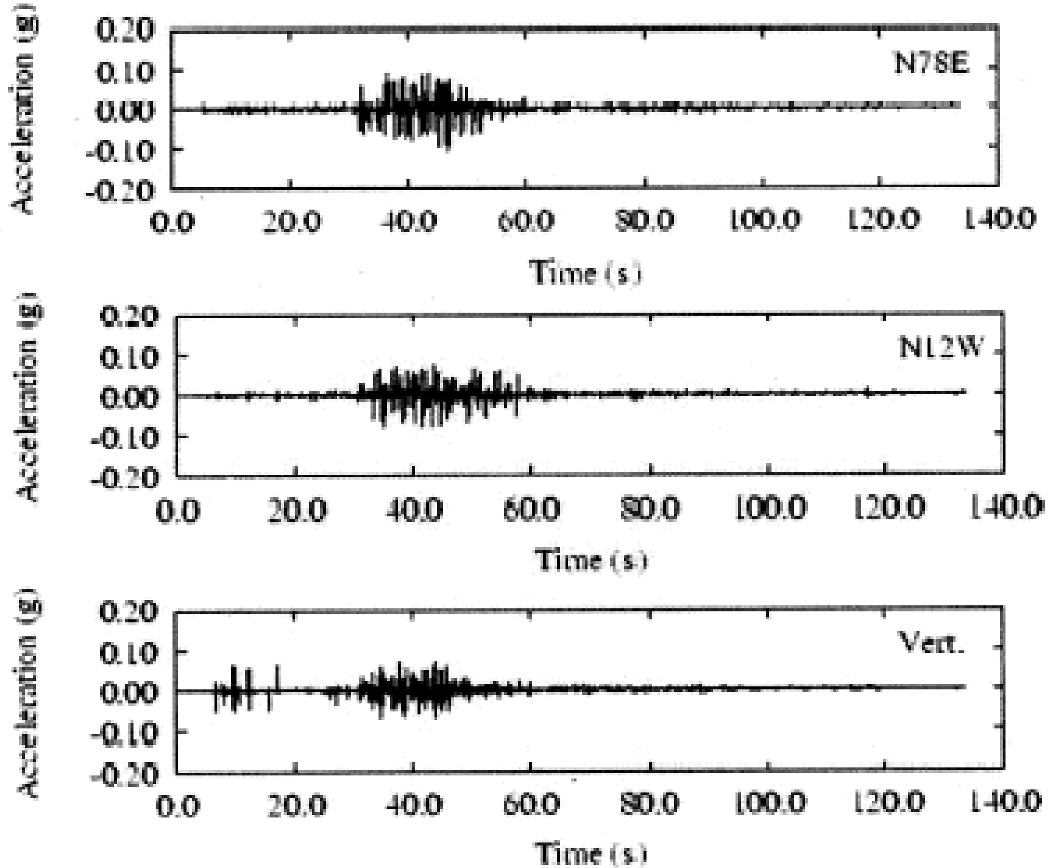
Amplitude Parameters



Source: Kramer (1996)

From the time histories of acceleration, velocity and displacement are obtained by integrating the acceleration records. All other amplitude parameters are calculated from these time histories.

Strong ground motion record of Bhuj earthquake



PGA = 0.106 g

PGA = 0.08 g

PGA = 0.07 g

Strong motion accelerograms recorded on the ground floor of the Passport Office Building at Ahmedabad during 2001 Bhuj earthquake.

Peak Acceleration

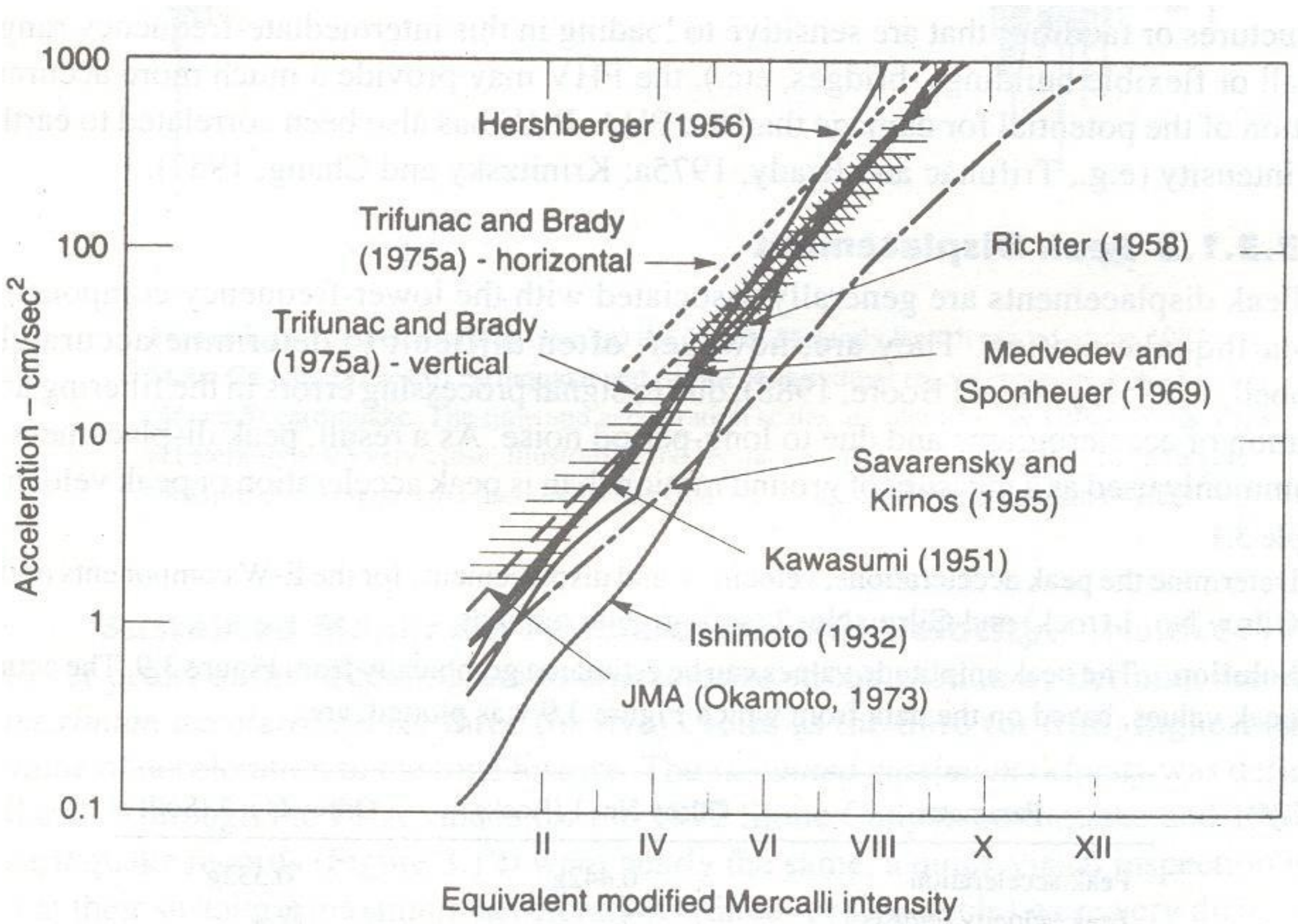
- Most commonly used measure of amplitude of a ground motion is the Peak horizontal acceleration (PHA). It is the absolute maximum value obtained from accelerogram.

- Maximum resultant PHA is the vector sum of two orthogonal components. Estimation of PHA is most important for any design. PHA and MMI relationship (Trifunac and Brady, 1975) are often used.

- PVA is not that important and PVA = (2/3)PHA is commonly assumed for design (Newmark and Hall, 1982).

- Peak acceleration data with frequency content/duration of earthquake is important. Because for e.g. 0.5g PHA may not cause significant damage to structures if earthquake duration is very small.

Peak Acceleration



Proposed relationships between PHA & MMI (Trifunac & Brady, 1975).

Peak Acceleration

Why vertical accelerations are not very important?

Structures have gravity acting against vertical accelerations due to earthquake. Static forced induced due to gravity provide adequate resistance to dynamic forces induced due to vertical accelerations during earthquake.

PVA ≈ 2/3 PHA

PVA > 2/3 PHA near epicenter

PVA < 2/3 PHA at distances far from epicenter

Peak Velocity and Displacement

- Peak horizontal velocity (PHV) is also used to characterize ground motion. PHV is better than PHA for intermediate frequencies as velocity is less sensitive to higher frequency.

- For above reason, many times PHV may provide better indication for damage than PHA. PHV and MMI relationship (Trifunac and Brady, 1975) are also used.

- Peak displacements are associated with low frequency components of earthquake motion. Hence signaling and filtering error of data is common and hence not recommended for practical uses over PHA or PHV.

Amplitude Parameters

Effective Peak Acceleration: The acceleration which is effective in causing structural damage. This depends on size of loaded area, weight, damping and stiffness properties of structure and its location with respect to epicenter.

Note: EPA, the maximum ground acceleration to which a building responds, which tends to be ⅔ – ¾ the PGA

Sustained Maximum Acceleration:

The absolute values of highest accelerations that sustained for 3 and 5 cycles in acceleration time history are defined as 3-cycle sustained and 5-cycle sustained accelerations respectively.

Design ground motion parameters

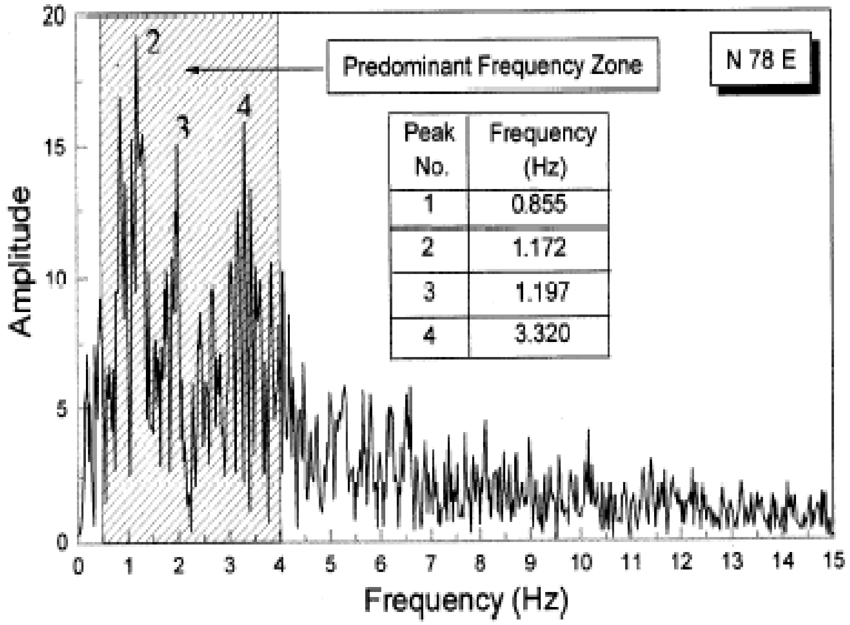
Why not use peak ground acceleration form earthquake time history?

- Complete reliance on peak ground acceleration for design proved to give wrong results.
- This is because, more often the peak acceleration corresponds to very high frequencies which are out of the range of the natural frequencies of most structures.
- Therefore, large values of peak ground acceleration alone can seldom initiate either resonance in the elastic range or be responsible for large scale damage in the inelastic range.

Therefore, different parameters are required to characterize the severity and the damage potential of the earthquake ground motion. In general, these parameters are frequency and duration of strong ground motion

Frequency Content Parameters

The frequency content describes clearly how the amplitude of ground motion is distributed among different frequencies. The frequency content of a ground motion can be obtained by transforming the ground motion from time domain to a frequency domain through a Fourier transform.



Peak No.	Frequency (Hz)
1	0.855
2	1.172
3	1.197
4	3.320

Source: Kramer (1996)

Frequency Content Parameters

The frequency content of an earthquake history is often described using Fourier Spectra, Power spectra and response spectra.

Fourier Spectra

A periodic function (for which an earthquake history is an approximation) can be written as

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

where c_n and ϕ_n are the *amplitude* and *phase angle* respectively of the n^{th} harmonic in the Fourier series.

Fourier Spectra

- A spectrum is, first of all, a function of frequency.
- For our purposes, it is determined from a single time series, such as a record of the ground motion.
- The spectrum in general shows some frequency-dependent characteristic of the ground motion.

Fourier Spectra

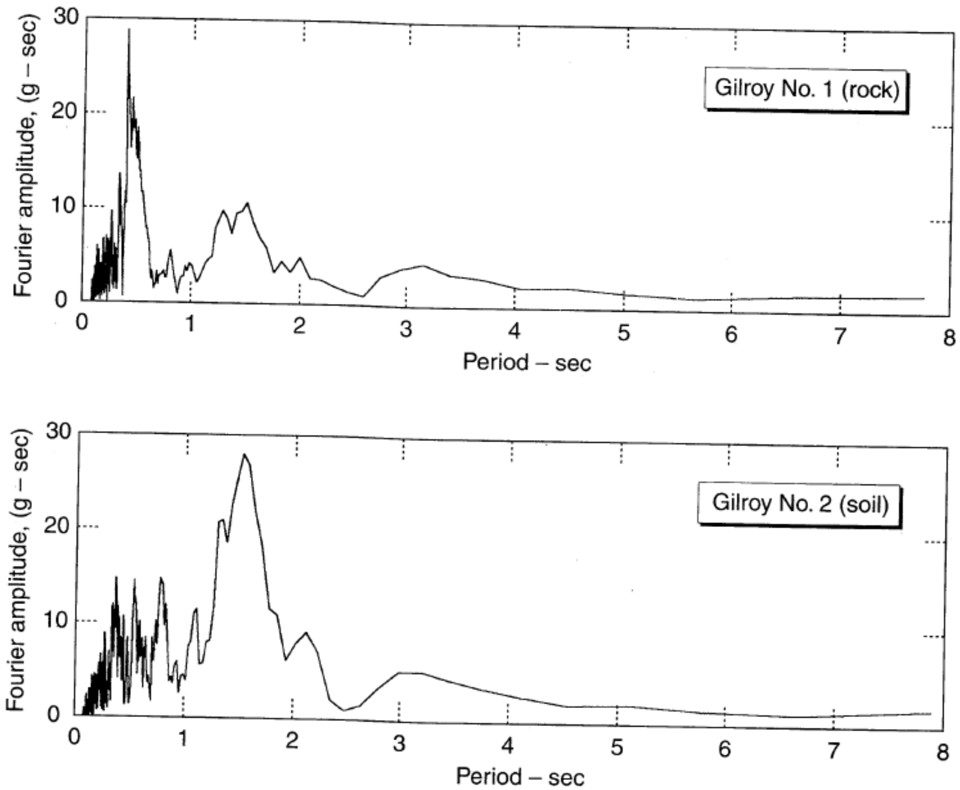
The *Fourier amplitude spectrum* is a plot of c_n versus ω_n

- Shows how the amplitude of the motion varies with frequency.
- Expresses the frequency content of a motion

The *Fourier phase spectrum* is a plot of ϕ_n versus ω_n

- Phase angles control the times at which the peaks of harmonic motion occur.
- Fourier phase spectrum is influenced by the variation of ground motion with time.

Fourier Amplitude Spectrum



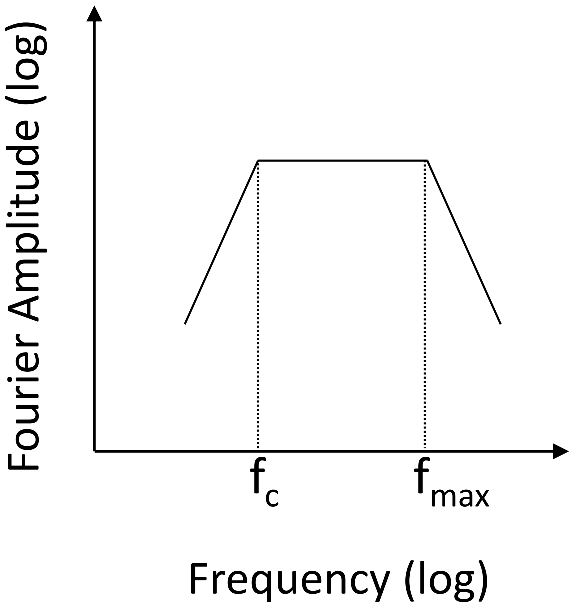
Source: Kramer (1996)

Fourier amplitude spectra for Gilroy No. 1 and Gilroy No. 2 strong motion records in Gilroy, California during 1989 Loma Preita Earthquake

Fourier Amplitude Spectrum

The Fourier amplitude spectra of actual earthquakes are often plotted on logarithmic scales, so that their characteristic shapes can be clearly distinguished from the smoothed curves.

Two frequencies that mark the range of frequencies for largest Fourier acceleration amplitude are corner frequency (f_c) and cutoff frequency (f_{max})

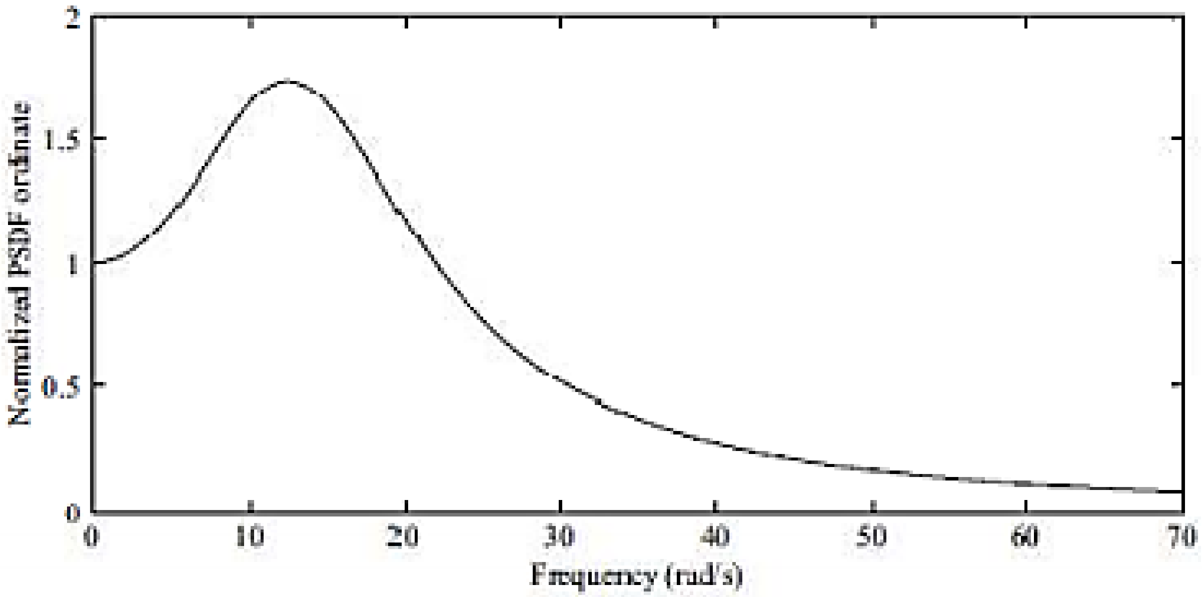


f_c is a very important parameter because it is inversely proportional to the cube root of seismic moment, thus indicating that large earthquakes produce greater low-frequency motions.

Frequency Content Parameters

Power Spectrum: is a plot of power spectrum density *G(ω)* versus natural circular frequency ω_n .

The power spectrum density (PSD) function is closely related to the Fourier amplitude spectrum:



$$G(\omega) = \frac{1}{\pi T_d} c_n^2$$

where G(ω) is the PSD, T_d is the duration of the ground motion, and c_n is the *amplitude* of the n^{th} harmonic in the Fourier series.

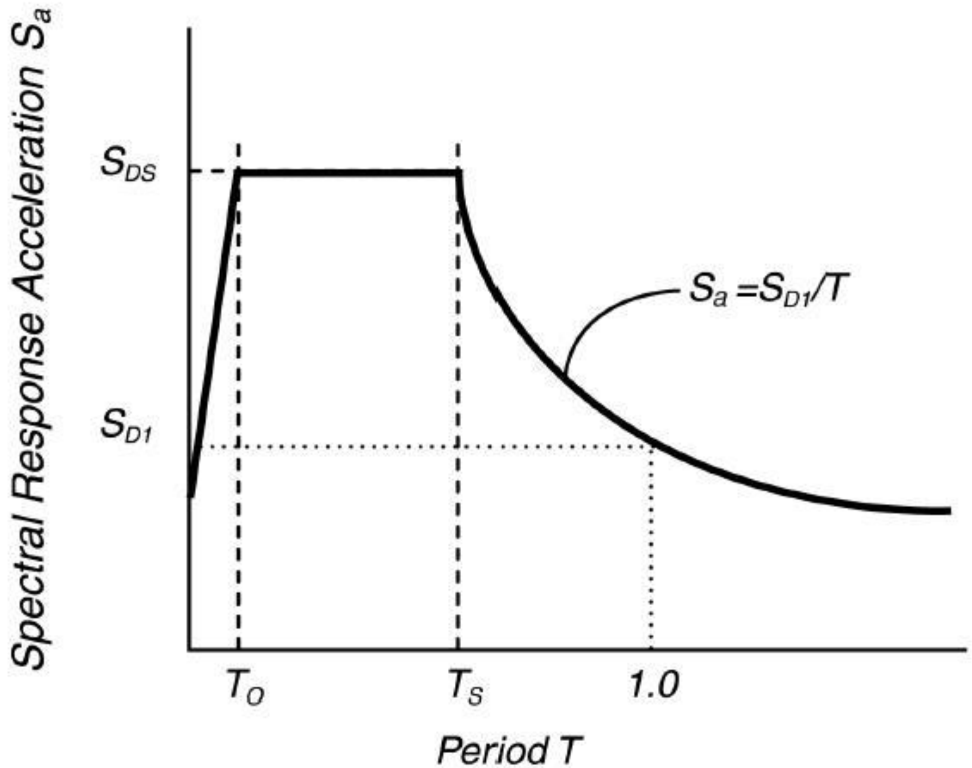
PSD function is used to characterize an earthquake history as a random process.

Response Spectra

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

- Response spectra are widely used in earthquake engineering.

- A response spectrum is a plot of the maximum response amplitude (displacement, velocity or acceleration) versus time period of a system to a given component of ground motion.



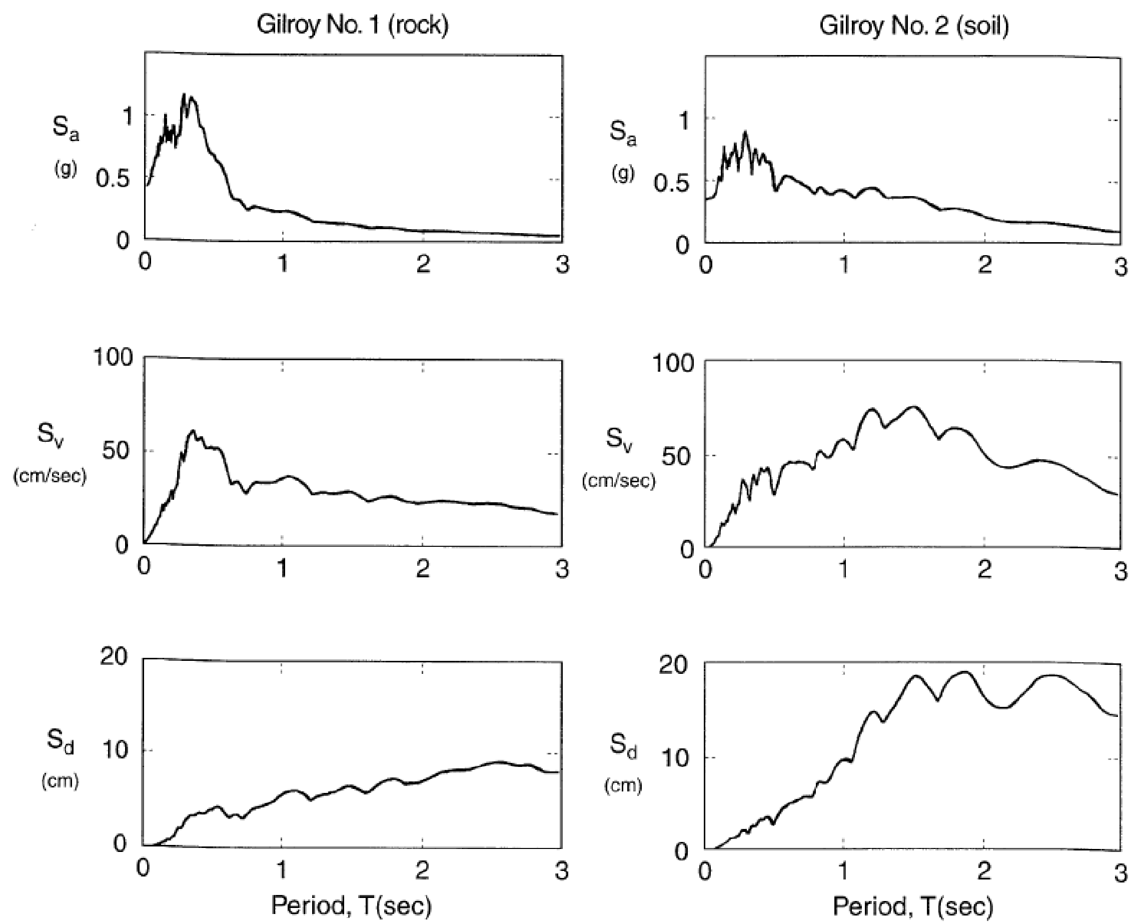
- Using the response spectrum, peak response of buildings to earthquakes can be assessed

Response Spectra

The response spectrum describes the maximum response of a structure to a particular input motion as a function of frequency and damping ratio.

The seismic response spectra from two sites (one rock and the other soil) for the same earthquake motion are shown

The response of soil and rock is quite different for the same vibration.

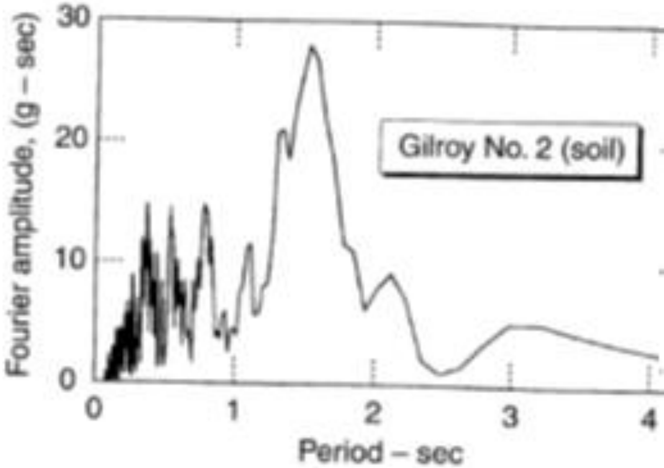


Source: Kramer (1996)

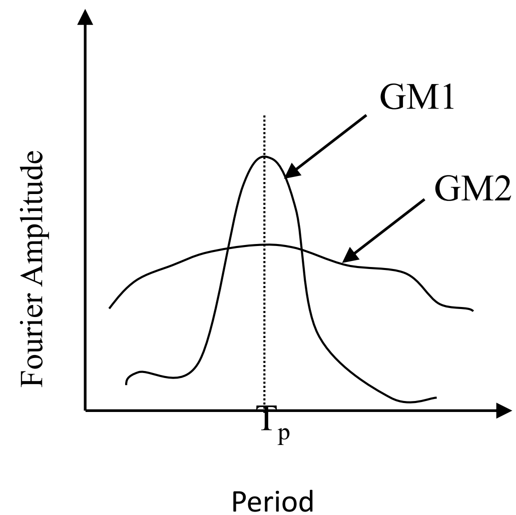
Fig: Response spectra with 5% damping for Gilroy, California during 1989 Loma Preita Earthquake

Predominant Period

Predominant Period **(T_p)**: Period of vibration corresponding to the maximum value of the Fourier amplitude spectrum. This parameter represents the frequency content of the motion.

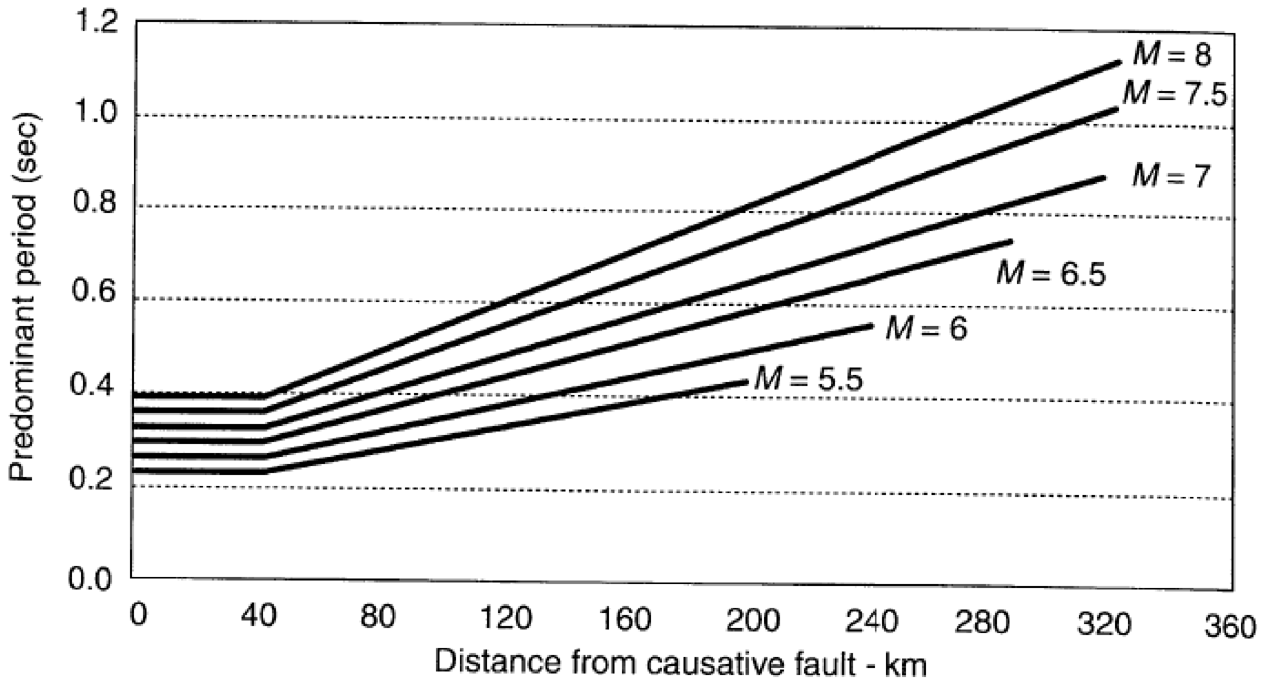


The predominant period for two different ground motions (GM1 & GM2) with different frequency contents can be same, making the estimation of frequency content crude.



T_p is same for the two ground motions, though the frequency content is different

Predominant Period



Source: Kramer (1996)

Variation Of Predominant Period At Rock Outcrops With Magnitude And Distance

Duration

Duration of an earthquake is very important parameter that influences the amount of damage due to earthquake.

A strong motion of very high amplitude of short duration may not cause as much damage to a structure as a motion with moderate amplitude with long duration can cause.

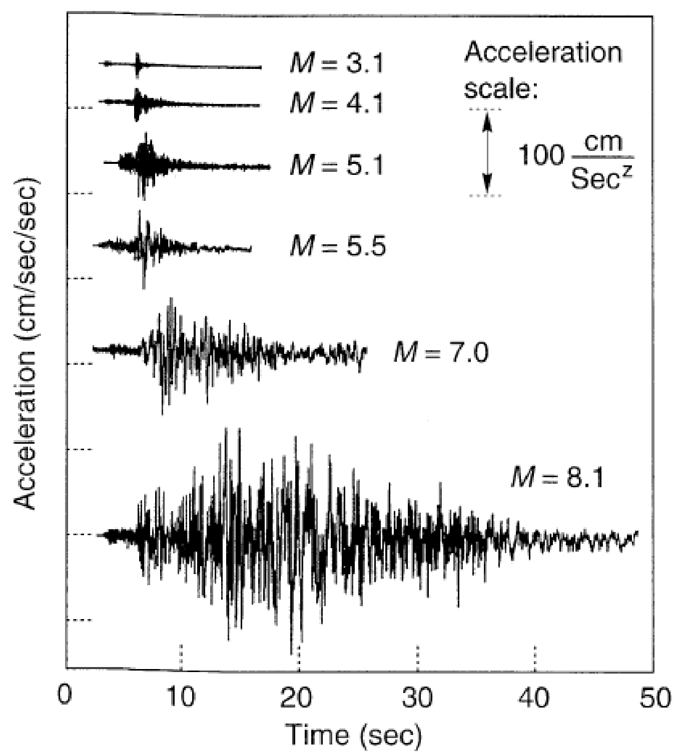
This is because the ground motion with long duration causes more load reversals, which is important in the degradation of stiffness of the structures and in building up pore pressures in loose saturated soils.

Duration represents the time required for the release of accumulated strain energy along a fault, thus increases with increase in magnitude of earthquake.

Relative duration does not depend on the peak values. It is the time interval between the points at which 5% and 95% of the total energy has been recorded.

Duration

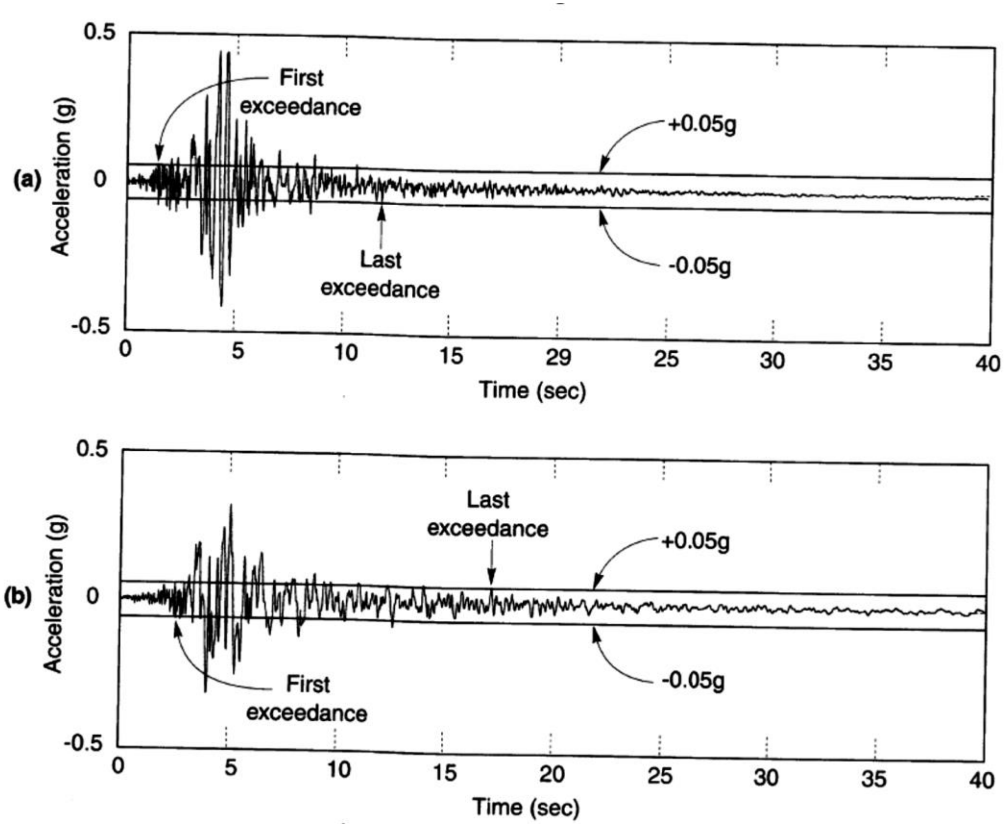
The duration of an earthquake history is somewhat dependent on the magnitude of the earthquake. Figure below shows accelerograms from six earthquakes off the Pacific coast of Mexico. The epicentral distance was the same for all six earthquakes.



Source: Kramer (1996)

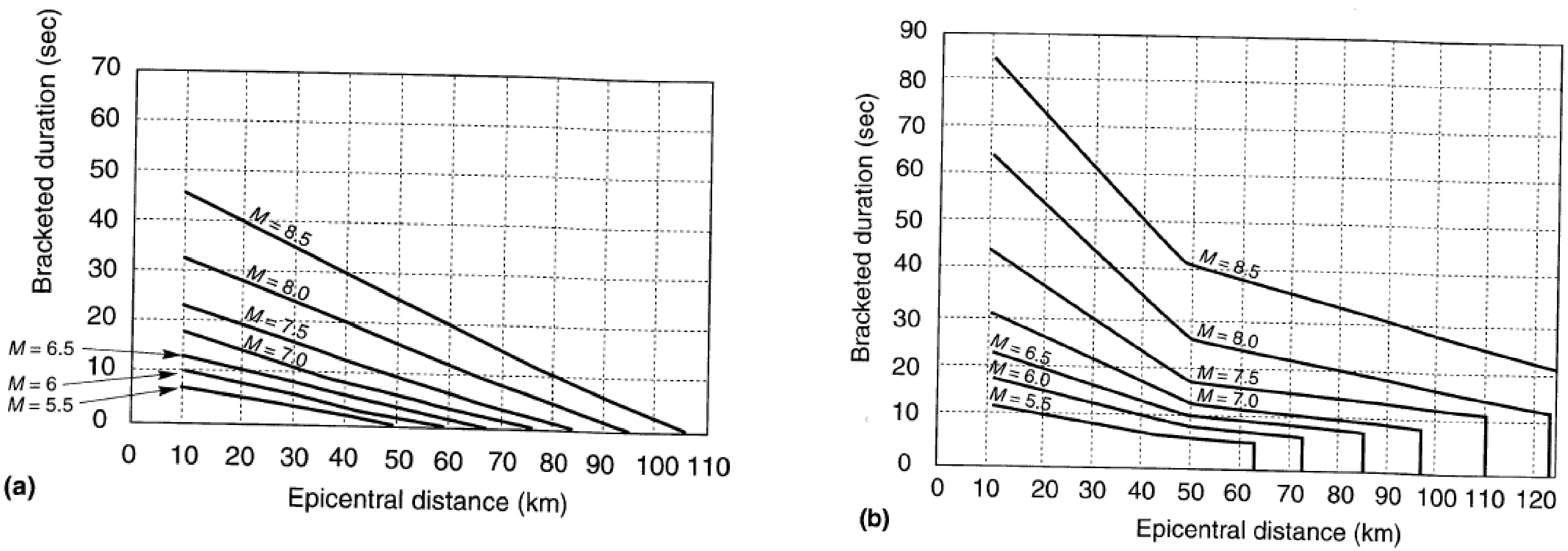
Bracketed Duration

Bracketed duration is the measure of time between the first and last exceedence of a threshold acceleration 0.05 g.



Source: Kramer (1996)

Bracketed Duration



Source: Kramer (1996)

Variation of Bracketed Duration (0.05 G Threshold) With Magnitude And Epicentral Distance: (A) Rock Sites; (B) Soil Sites

Estimation of PGA by Regression Analysis

- Ground motion parameters are usually estimated through predictive relationships. These relationships express ground motion parameter in terms of the quantities that affect it strongly.
- Predictive relationships play important role in seismic hazard analysis.
- The functional form of the predictive relationship is usually selected to reflect the mechanism of the ground motion process as closely as possible
- This minimizes the number of empirical coefficients and allows to apply the relationship with greater confidence to ground conditions that are poorly represented in the database.
- Predictive relationships are often arrived at by the regression analysis of the available strong motion data
- These relationships have to be updated time to time after major earthquakes in the region.

Estimation of PGA by Regression Analysis

Common forms of predictive relations are based on the following observations:

1. Peak values of strong motion parameters are usually lognormally distributed.
2. Earthquake magnitude *M* is typically defined as the logarithm of some peak ground motion parameter *Y*. Thus *M* proportional to ln *Y*
3. The spreading of stress waves as they travel away from the earthquake source attenuates the body wave and surface wave amplitudes
4. The area over which the fault rupture occurs, increases with increase in the earthquake magnitude. Thus the effective distance *R* increases with the earthquake magnitude
5. The material damping decreases the ground motion amplitudes with distance exponentially
6. Ground motion parameters may be influenced by source characteristics like type of fault or the site characteristics like the type of soil and topography of the region.

Estimation of PGA by Regression Analysis

Typical Predictive relationship

Campbell (1981) used worldwide data to obtain a relationship for the mean PHA for sites within 50 km of fault rupture in magnitude 5.0 to 7.7 earthquakes as:

$$\ln \text{PHA (gals)} = -4.141 + 0.868\,M - 1.09 \ln [R + 0.0606 \exp (0.7\,M)]$$

Note 1 gal = 981 cm/sec^2

Where M is the local magnitude for magnitude less than 6 or surface wave magnitude for magnitude less than 7 and R is the closest distance to the fault rupture in kilometers.

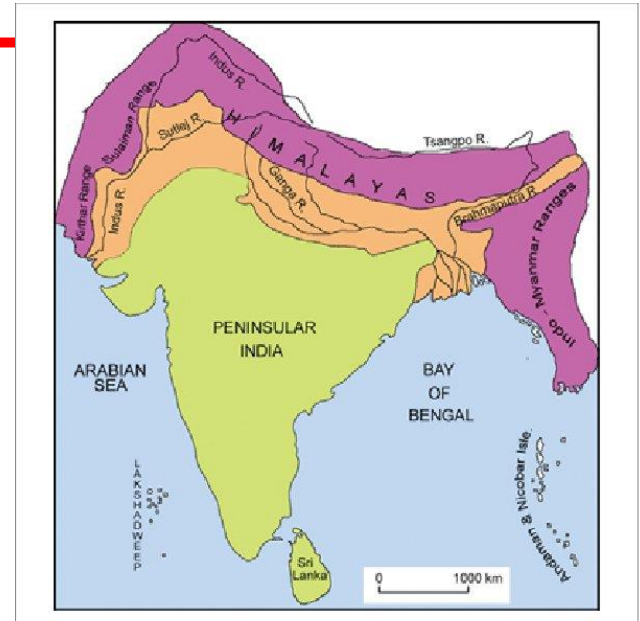
Several other predictive relationships are available in literature, which are developed for different regions

Predictive relationships for India

The following generalized predictive relationship has been proposed for peninsular India by Iyengar and Raghukanth (2004)

$\ln Y = C_1 + C_2\,(M\text{-}6) + C_3\,(M\text{-}6)^2 - \ln R - C_4\,R + \ln \varepsilon$

where Y, M, and R refer to PGA(g), moment magnitude, and hypocentral distance, respectively



Koyna-Warna Region:

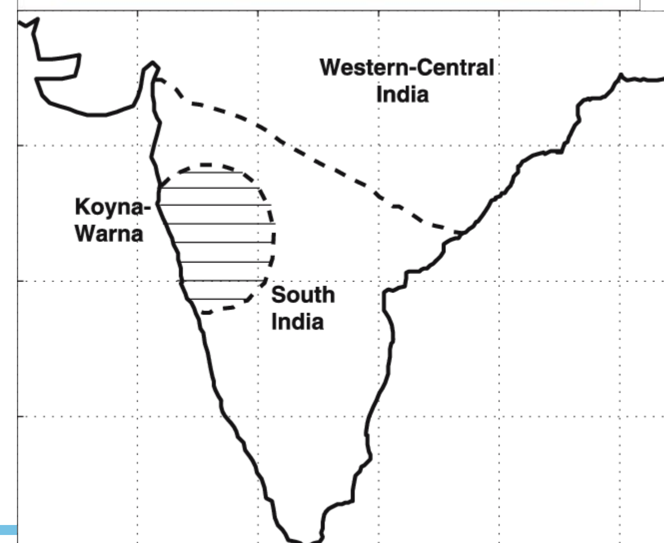
$C_1 = 1.7615$; $C_2 = 0.9325$; $C_3 = -0.0706$; $C_4 = 0.0086$; $\sigma(\ln \varepsilon) = 0.3292$

Western-central Region:

$C_1 = 1.7236$; $C_2 = 0.9453$; $C_3 = -0.0740$; $C_4 = 0.0064$; $\sigma(\ln \varepsilon) = 0.3439$

Southern Region:

$C_1 = 1.7816$; $C_2 = 0.9205$; $C_3 = -0.0673$; $C_4 = 0.0035$; $\sigma(\ln \varepsilon) = 0.3136$



Predictive relationships for India

The following predictive relationship has been proposed for Himalayan Region of India by Sharma (2000).

$\log(A) = -2.87 + 0.634\,M - 1.16\log(X + e^{0.62M})$

where A, M, and X refer to PGA(g), moment magnitude, and hypocentral distance, respectively

The database consisting of 66 peak ground vertical accelerations from five earthquakes recorded by Strong Motion Arrays in India have been used to develop the relationship.

Seismic Hazard Analysis

Deterministic *Probabilistic*

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Seismic Hazard Analysis … INTRODUCTION

Seismic hazard analysis involves the quantitative estimation of ground shaking hazards at a particular area.

Seismic hazard s can be analyzed deterministically or probabilistically

A critical part of seismic hazard analysis is the determination of Peak Ground Acceleration (PGA) and response acceleration (Spectral acceleration) for an area/site.

Spectral acceleration (S_a) is preferred for the design of civil engineering structures. It is an accepted trend in engineering practice to develop design response spectrum for different types of foundation materials such as rock, hard soil and weak soils.

Seismic Hazard Analysis (SHA)

Deterministic Seismic Hazard Analysis (DSHA):

In the deterministic approach, the strong-motion parameters are estimated for the maximum credible earthquake, assumed to occur at the closest possible distance from the site of interest, without considering the likelihood of its occurrence during a specified exposure period.

Probabilistic Seismic Hazard Analysis (PSHA):

Probabilistic approach integrates the effects of all the earthquakes expected to occur at different locations during a specified life period, with the associated uncertainties and randomness taken into account.

Difference b/w DSHA and PSHA

DSHA	PSHA
Assumes single scenario	Assumes many scenarios
Selects single magnitude for each seismic source	Considers all magnitudes associated with all seismic sources
Selects the closest distance between the source and site	Considers all possible distances between source and site
Assumes effects due to magnitude and distance	Considers all effects

……See Reference slides for more details on DSHA and PSHA

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Seismic Microzonation

Meaning Definition Explanation

Seismic Microzonation

- Definition: mapping of seismic hazard at local scales to incorporate the effects of local soil conditions.
- Seismic Microzonation is the process for estimating the response of soil layers under earthquake excitations and thus the variation of earthquake characteristics on the ground surface.
- Seismic microzonation is the initial phase of earthquake risk mitigation and requires multidisciplinary approach with major contributions from geology, seismology, geotechnical and structural engineering.
- Microzonation falls into the category of "applied research".
- Microzonation works are carried out in important cities like Delhi, Dehradun, Gujarat, Guwahati, Haldia, Jabalpur, Sikkim and Talchir.

Source: Introduction to Engineering Seismology, Dr. P. Anbazhagan

Use of Seismic Microzonation

The microzonation map can serve many purposes:

1. It can offer valuable information to the engineers for the seismic designs of buildings and structures

2. Assessment of seismic risk to the existing structures and constructions, land use management and also for the future construction of defense installation, heavy industry, and important structures like dams, nuclear power stations and other public utility services.

3. Estimation of the potential for liquefaction and landslides. It also provides the basis for estimating and mapping the potential damage to buildings.

4. Mapping the losses expected from a particular level of seismic shaking is called microzonation for risk.

5. The main purpose of microzonation is to provide the local authorities with tools for assessing the seismic risk associated with the use of lands as well as to estimate the seismic motion to be used in the design of new structures and/or retrofitting existing ones.

Source: Introduction to Engineering Seismology, Dr. P. Anbazhagan

Seismic Microzonation

A Seismic microzonation study consists of three stages:

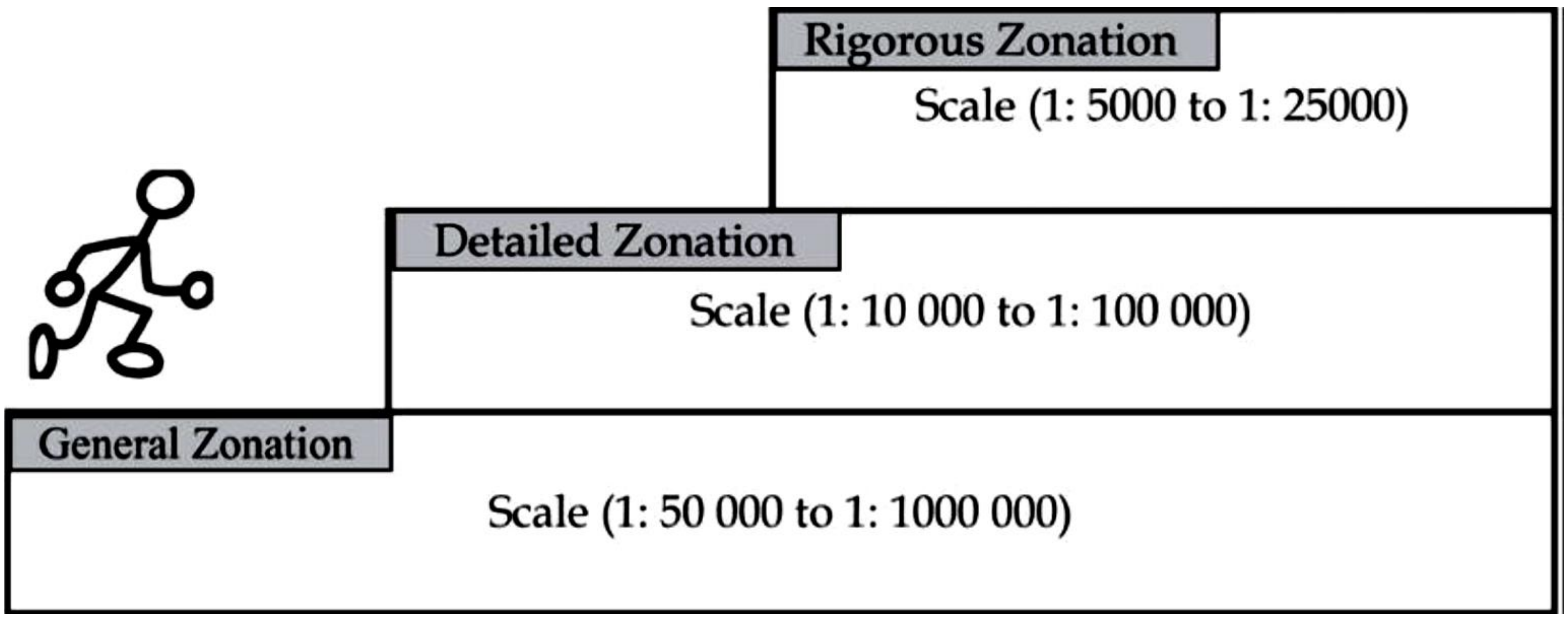
(1) Estimation of the regional seismic hazard,

(2) Determination of the local geological and local geotechnical site conditions

(3) Assessment of the probable ground response and ground motion parameters on the ground surface

Seismic Microzonation

Levels of Seismic Microzonation



Three Grades of Seismic Microzonation recommended by the Technical Committee of the International Society of Soil Mechanics and Foundation Engineering (ISSMFE)

Source: https://nidm.gov.in/easindia2014/err/pdf/earthquake/seismic_microzonation.pdf

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Steps in Seismic Microzonation

The first step illustrates the assessment of the expected ground motion using the deterministic and probabilistic seismic hazard analysis.

The Second Step involves the site characterized for the study area at local scale of 1:20,000 using geotechnical and shallow subsurface geophysical data.

Third step is the study of local site effects using first and second part output data and producing the ground level hazard parameter.

Forth step is the assessment of liquefaction potential considering the site amplification and soil properties.

Fifth step is the landslide hazard assessment valid only for hilly terrains.

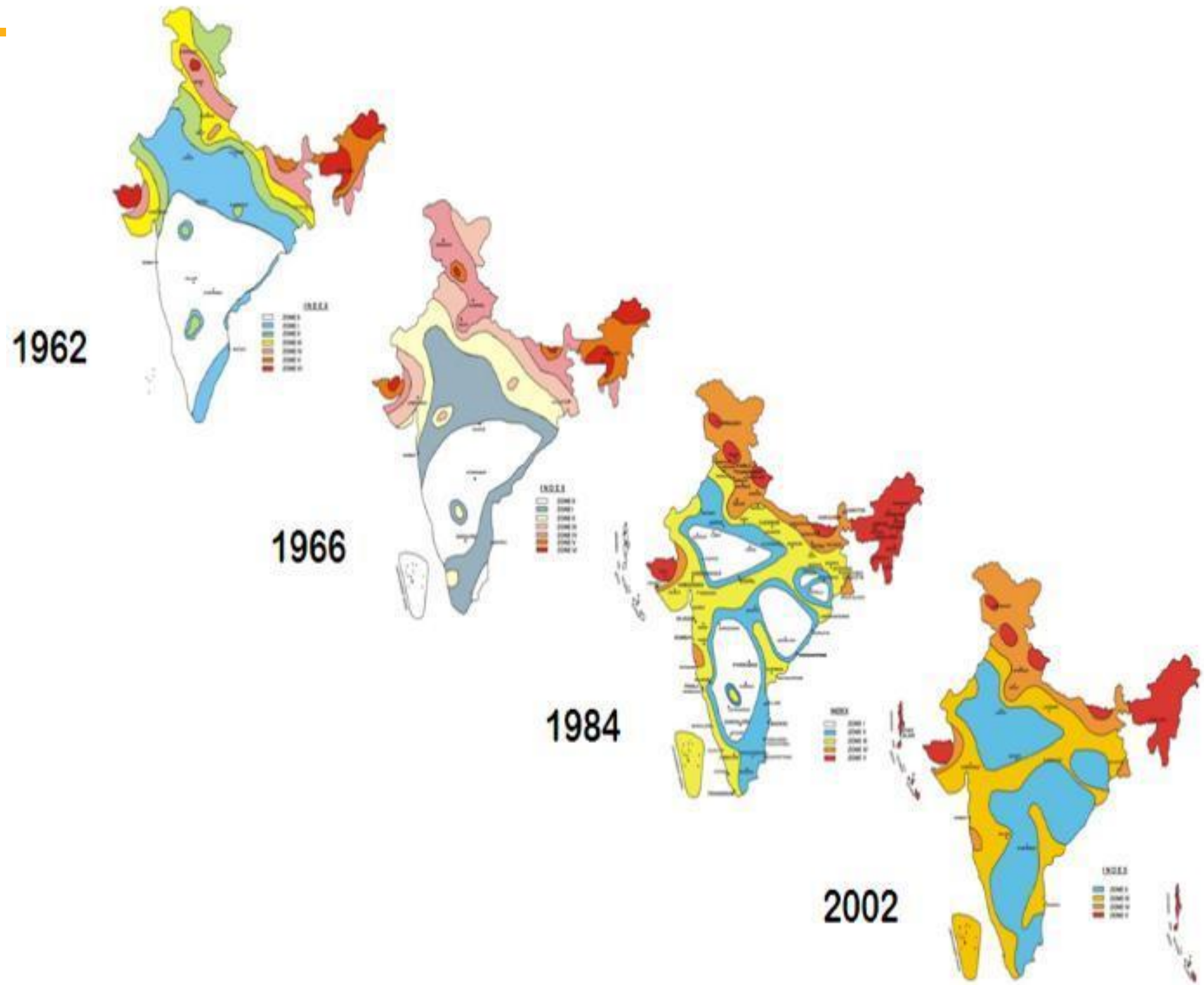
The sixth step is the tsunami hazard mapping which is valid only for coastal regions.

The final step is integration of all the above maps by assigning proper ranks and weights based on importance to prepare the final zonation map of region.

Finally microzonation maps are prepared in terms of ground motion parameters and factor safety against liquefaction

Source: Introduction to Engineering Seismology, Dr. P. Anbazhagan

Seismic Zoning In India



Zone	Magnitude
Zone V	Very High Risk Quakes of Magnitude *8* and greater
Zone IV	High Risk Quakes upto Magnitude *7.9*
Zone III	Moderate Risk Quakes upto Magnitude *6.9*
Zone II	Seismic Disturbances upto Magnitude *4.9*

Seismic Zoning In India

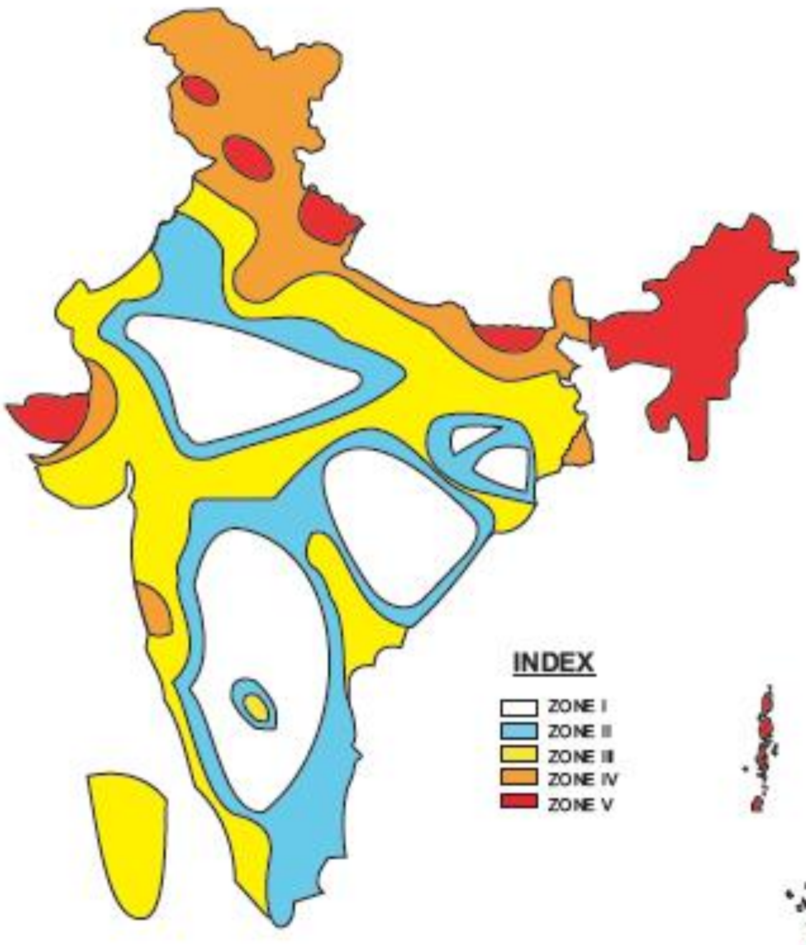


Figure 3: Indian Seismic Zone Map of 1970

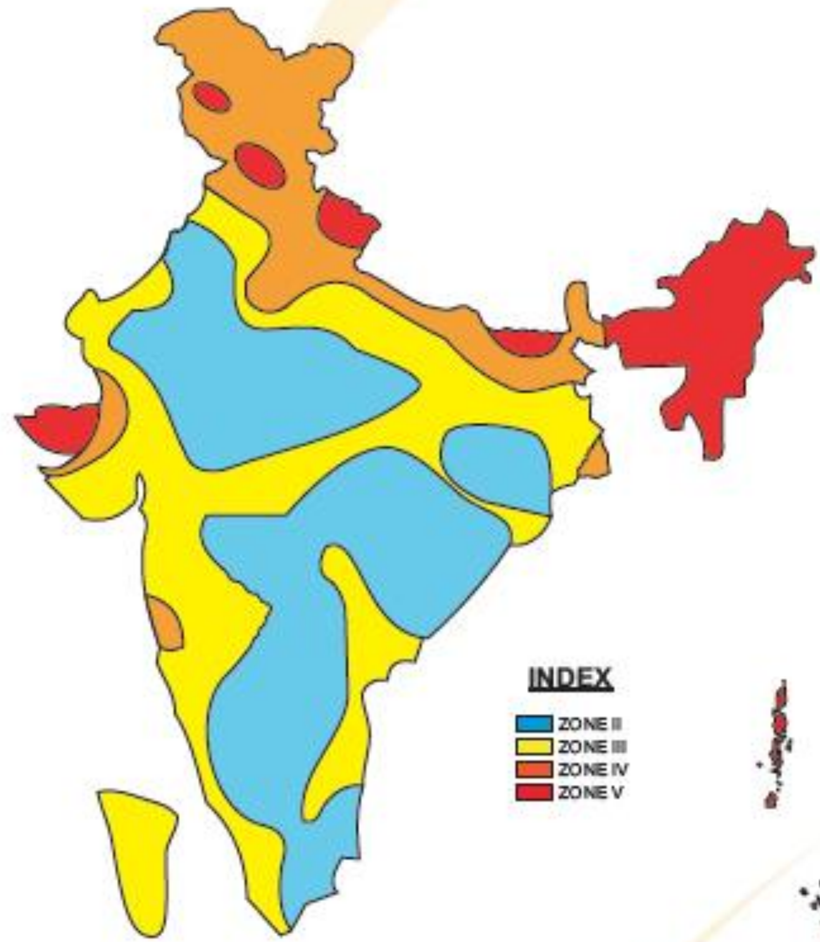
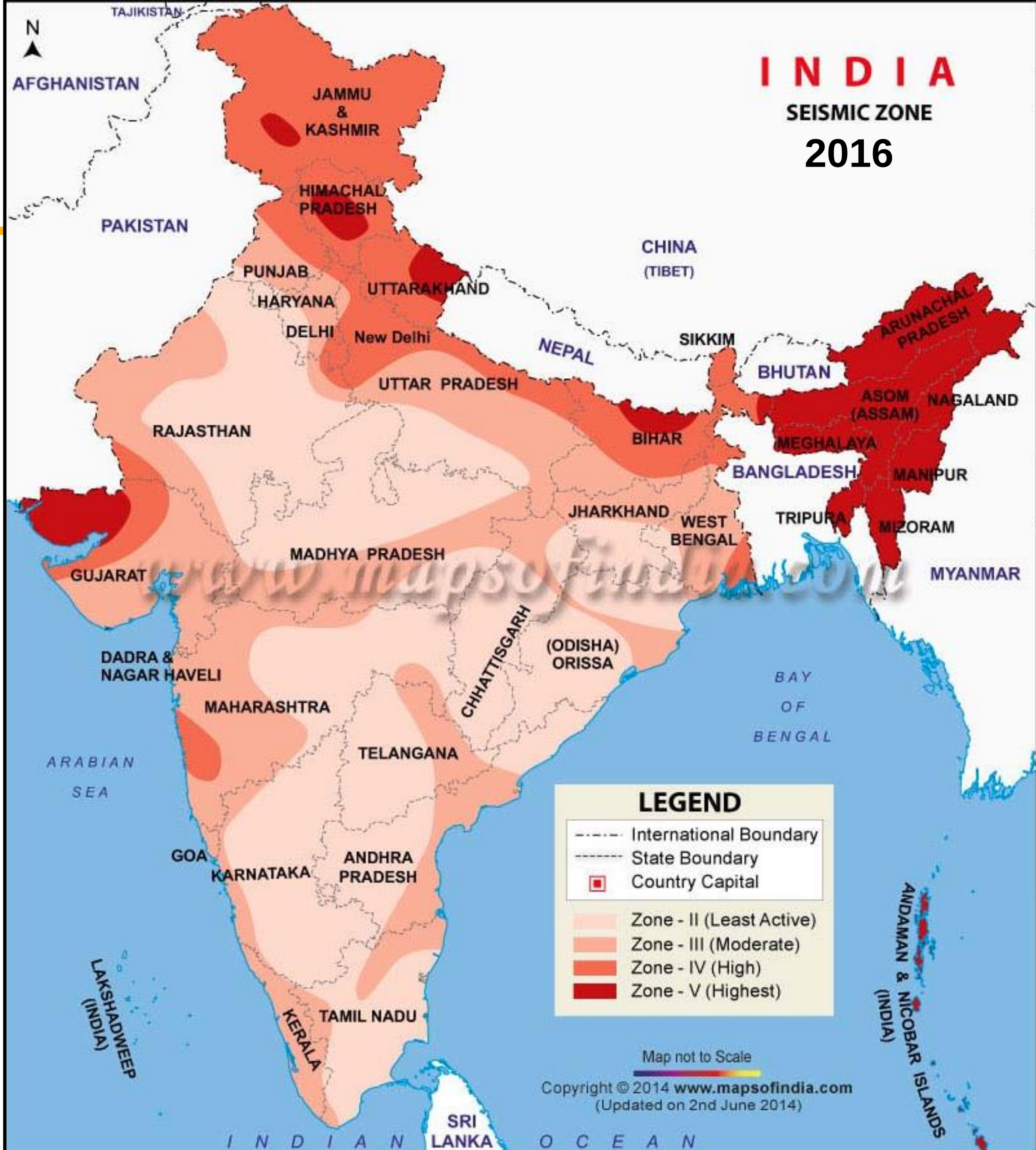


Figure 4: Indian Seismic Zone Map as per IS :1893 (Part 1)-2002



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Seismic Zoning in India

2016 –till date

Source: https://www.mapsofindia.com/maps/india/seismiczone.htm

Seismic Zoning In India

Zone	**Damage risk and Intensity**	**Region**
Zone V	(**Earthquake** Very high damage risk zone - areas may expect intensity maximum of ***MSK IX or more***)	The entire North-east, including all the seven sister states, the Kutch district, parts of Himachal and Jammu & Kashmir, and the Andaman and Nicobar islands. These areas may experience
Zone IV	(**Earthquake** High damage risk zone - areas may expect intensity maximum of ***MSK VIII***)	Parts of the Northern belt starting from Jammu and Kashmir to Himachal Pradesh. Also including Delhi and parts of Haryana. The Koyna region of Maharashtra is also in this zone.
Zone III	(**Earthquake** Moderate damage risk zone - areas may expect intensity maximum of ***MSK VII***)	A large part of the country stretching from the North including some parts of Rajasthan to the South through the Konkan coast, and also the Eastern parts of the country.
Zone II	(**Earthquake** Low damage risk zone - areas may experience intensity ***MSK VI***)	These two zones are contiguous, covering parts of Karnataka, Andhra Pradesh, Orissa, Madhya Pradesh, and Rajasthan, known as low risk earthquake zones.

Seismic Zoning In India

Date	Event	Time	Magnitude	Max. Intensity	Deaths
16 June 1819	Cutch	11:00	8.3	VIII	1,500
12 June 1897	Assam	17:11	8.7	XII	1,500
8 Feb. 1900	Coimbatore	03:11	6.0	X	Nil
4 Apr. 1905	Kangra	06:20	8.6	X	19,000
15 Jan. 1934	Bihar-Nepal	14:13	8.4	X	11,000
31 May 1935	Quetta	03:03	7.6	X	30,000
15 Aug. 1950	Assam	19:31	8.5	X	1,530
21 Jul. 1956	Anjar	21:02	7.0	IX	115
10 Dec. 1967	Koyna	04:30	6.5	VIII	200
23 Mar. 1970	Bharuch	20:56	5.4	VII	30
21 Aug. 1988	Bihar-Nepal	04:39	6.6	IX	1,004
20 Oct. 1991	Uttarkashi	02:53	6.6	IX	768
30 Sep. 1993	Killari (Latur)	03:53	6.4	IX	7,928
22 May 1997	Jabalpur	04:22	6.0	VIII	38
29 Mar. 1999	Chamoli	12:35	6.6	VIII	63
26 Jan. 2001	Bhuj	08:46	7.7	X	13,805

Some Past Earthquakes in India

References

- University of Buffalo
- University College London
- Binghamton University
- Kettering University
- Earthquake Tips-C V R Murthy
- U S Geological Survey
- NICEEE
- IITB,IITK, IISC-Slides from NPTEL
- EERI
- IIT Kanpur Manuals
- Earthquake Resistant design of structures by Pankaj Agarwal

Acknowledgment

- Dr. Kaylana Rama J for his teaching slides and materials

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Reference Slides …if any

More explanations on DSHA and PSHA

Deterministic seismic hazard analysis

- The DSHA approach uses the **known** seismic sources **sufficiently near the site** and **available** historical seismic and geological data to generate discrete, single-valued events or models of ground motion at the site.
- Typically one or more earthquakes are specified by magnitude and location with respect to the site.
- Usually the earthquakes are assumed to occur on the portion of the site closest to the site.
- The site ground motions are estimated deterministically, given the magnitude, source-to-site distance, and site condition.

Deterministic seismic hazard analysis

DSHA consists of four primary steps:

1. Identification and characterization of all sources
2. Selection of source-site distance parameter
3. Selection of "controlling earthquake"
4. Definition of hazard using controlling earthquake

Deterministic seismic hazard analysis

Identification and characterization of all sources

Identification

All sources capable of producing significant ground motion at the site

Large sources at long distances

Small sources at short distances

Characterization

Definition of source geometry

Establishment of earthquake potential

Deterministic seismic hazard analysis

Identification and characterization of all sources

Characterize geometry

Point source

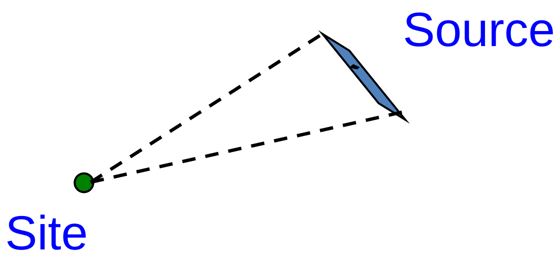
Constant source-site distance

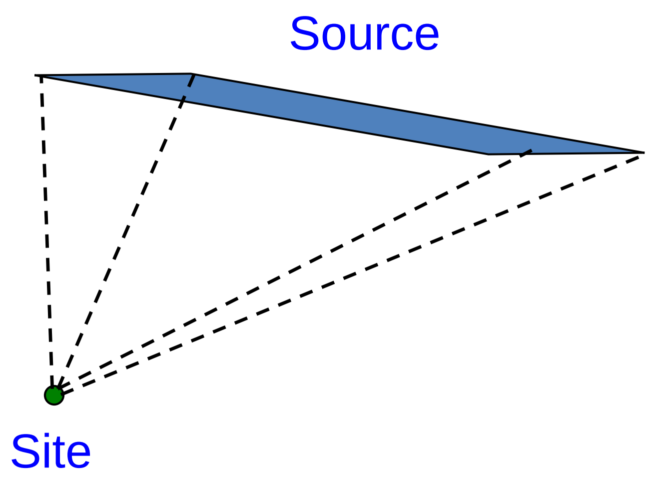
Volcanoes, distant short faults

Linear source

One parameter controls distance

Shallow, distant fault





Deterministic seismic hazard analysis

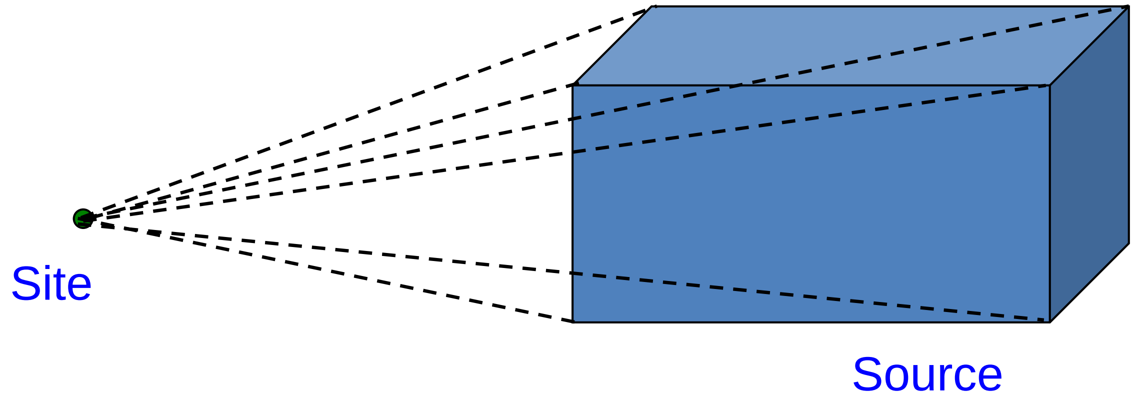
Identification and characterization of all sources

Characterize geometry

Three-dimensional Source

Three parameters control distance

- Close sources of large dimensions
- Insufficient data for accurately determining the source geometry



Deterministic seismic hazard analysis

Identification and characterization of all sources

Which sources are capable of producing significant motion at the site of interest?

What is significant motion?

Parametric definition

Peak acceleration - usually ~0.05g

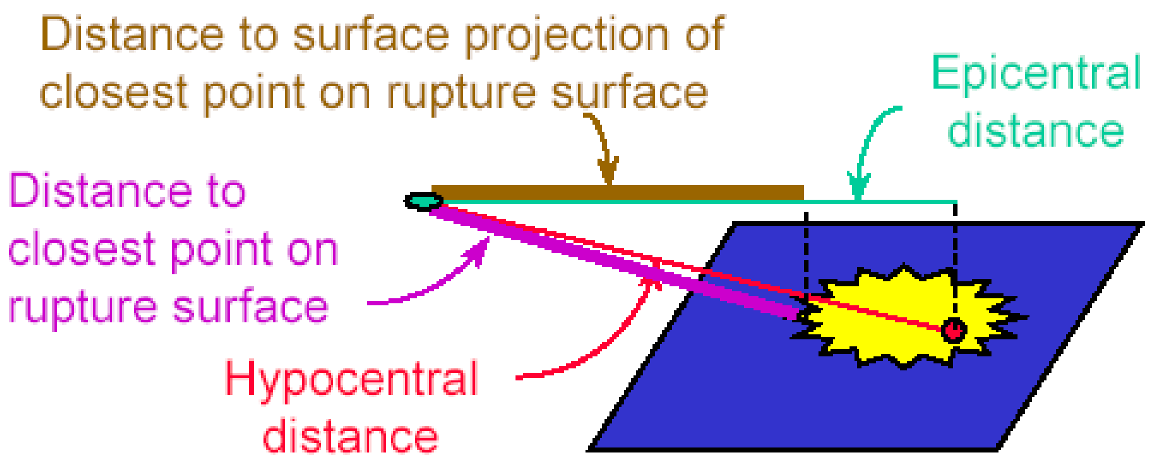
Spectral acceleration - at fundamental period, if known

Other parameters

Use predictive (attenuation) relationship to determine distance of interest

Deterministic seismic hazard analysis

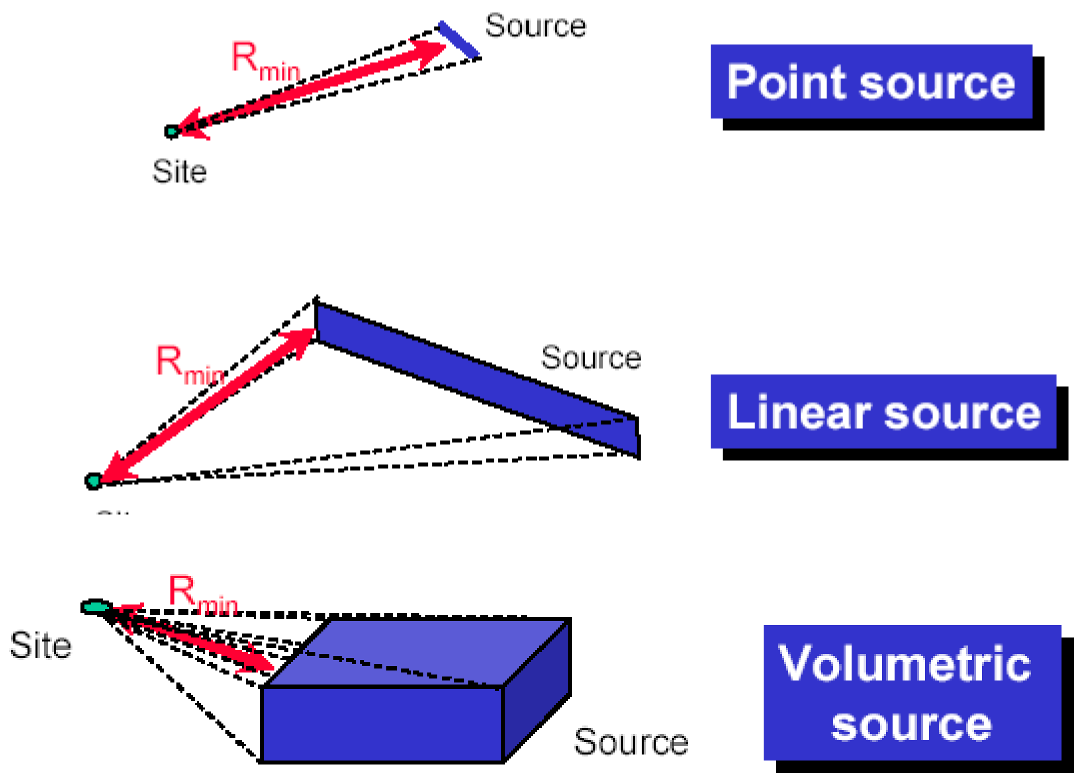
Determination of source-site distance



Deterministic seismic hazard analysis

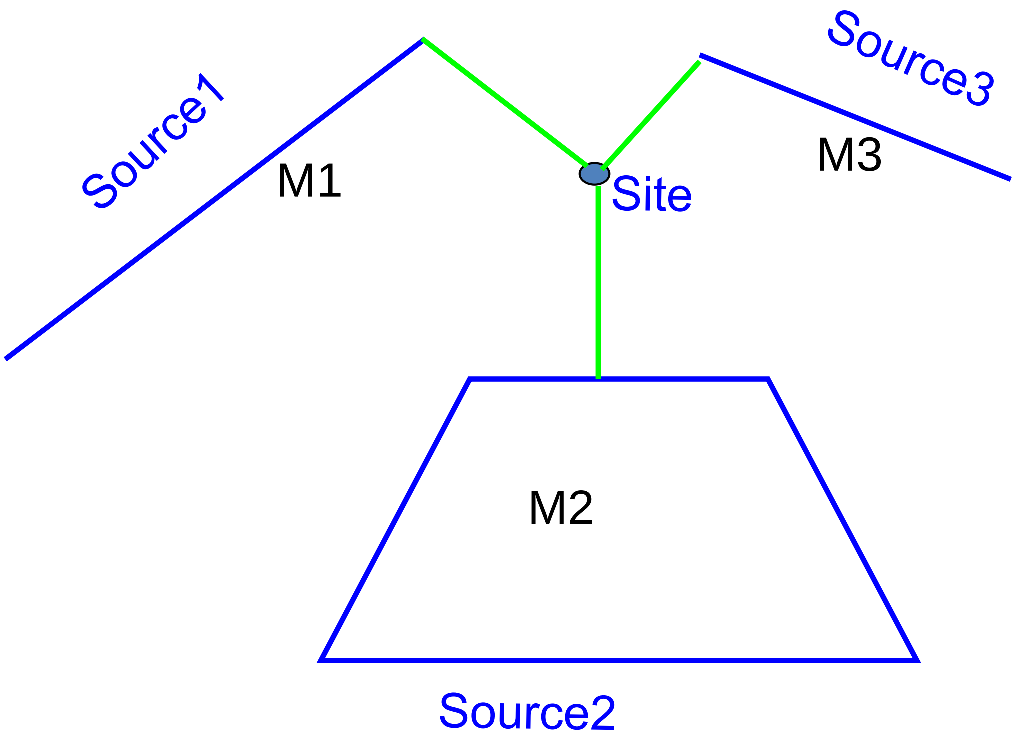
Determination of source-site distance

Typically assume shortest source-site distance (“worst case” scenario)



Deterministic seismic hazard analysis

Determination of source-site distance



Deterministic seismic hazard analysis

Selection of controlling earthquake

Establish earthquake potential - typically M_{max}

Empirical correlations

- Rupture length correlations
- Rupture area correlations
- Maximum surface displacement correlations

"Theoretical" determination

- Slip rate correlations

Deterministic seismic hazard analysis

Empirical relationships between M_w, Surface rupture length L (km), rupture area A (km^2) and maximum surface displacement D (m)

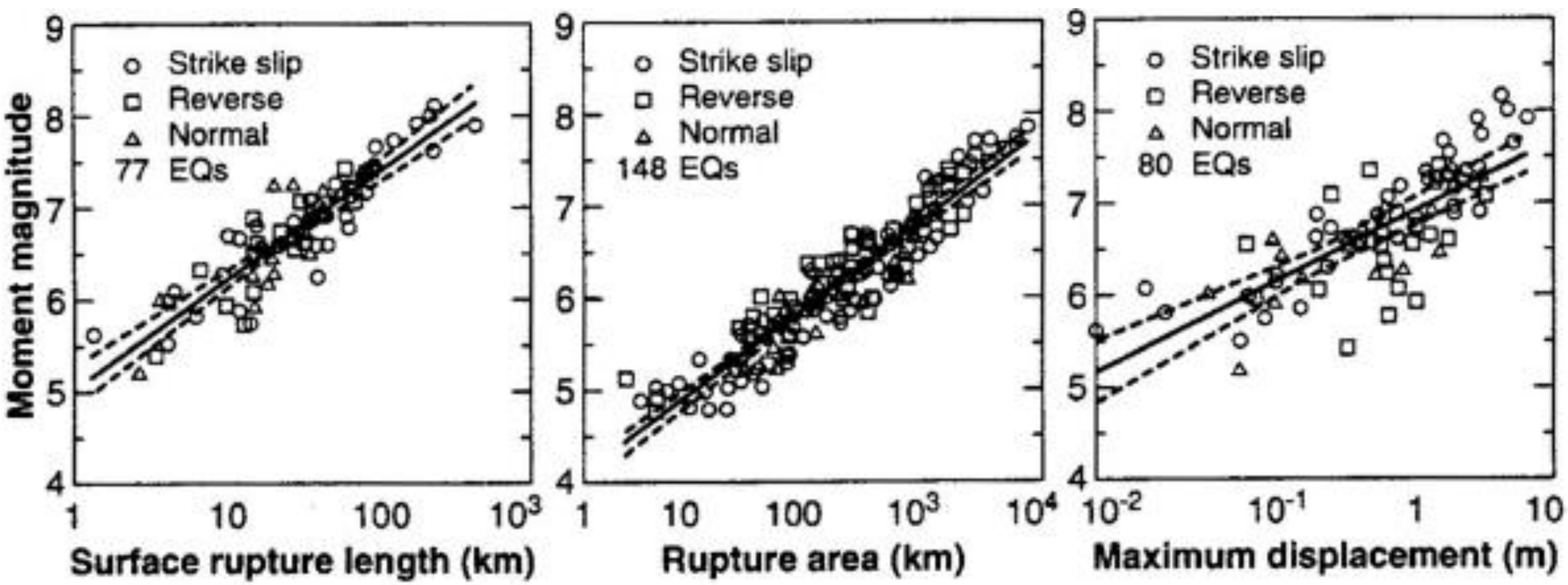
Fault Movement	Number of Events	Relationship	σ_{M_w}	Relationship	$\sigma_{\log L, A, D}$
Strike slip	43	$M_w = 5.16 + 1.12 \log L$	0.28	$\log L = 0.74M_w - 3.55$	0.23
Reverse	19	$M_w = 5.00 + 1.22 \log L$	0.28	$\log L = 0.63M_w - 2.86$	0.20
Normal	15	$M_w = 4.86 + 1.32 \log L$	0.34	$\log L = 0.50M_w - 2.01$	0.21
All	77	$M_w = 5.08 + 1.16 \log L$	0.28	$\log L = 0.69M_w - 3.22$	0.22
Strike Slip	83	$M_w = 3.98 + 1.02 \log A$	0.23	$\log A = 0.90M_w - 3.42$	0.22
Reverse	43	$M_w = 4.33 + 0.90 \log A$	0.25	$\log A = 0.98M_w - 3.99$	0.26
Normal	22	$M_w = 3.93 + 1.02 \log A$	0.25	$\log A = 0.82M_w - 2.87$	0.22
All	148	$M_w = 4.07 + 0.98 \log A$	0.24	$\log A = 0.91M_w - 3.49$	0.24
Strike slip	43	$M_w = 6.81 + 0.78 \log D$	0.29	$\log D = 1.03M_w - 7.03$	0.34
Reverse[a]	21	$M_w = 6.52 + 0.44 \log D$	0.52	$\log D = 0.29M_w - 1.84$	0.42
Normal	16	$M_w = 6.61 + 0.71 \log D$	0.34	$\log D = 0.89M_w - 5.90$	0.38
All	80	$M_w = 6.69 + 0.74 \log D$	0.40	$\log D = 0.82M_w - 5.46$	0.42

Source: Wells and Coppersmith (1994).

[a] Regression relationships are not statistically significant at a 95% probability level (note inconsistency of regression coefficients and standard deviations).

Deterministic seismic hazard analysis

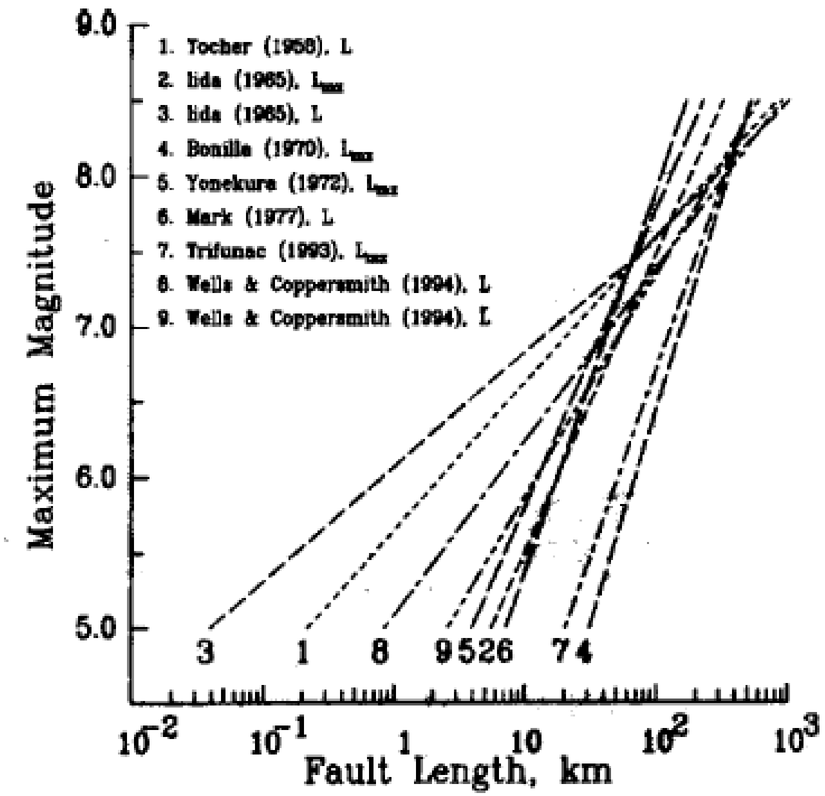
Scatter inherent in databases used by Wells and Coppersmith (1994) in developing the correlations.



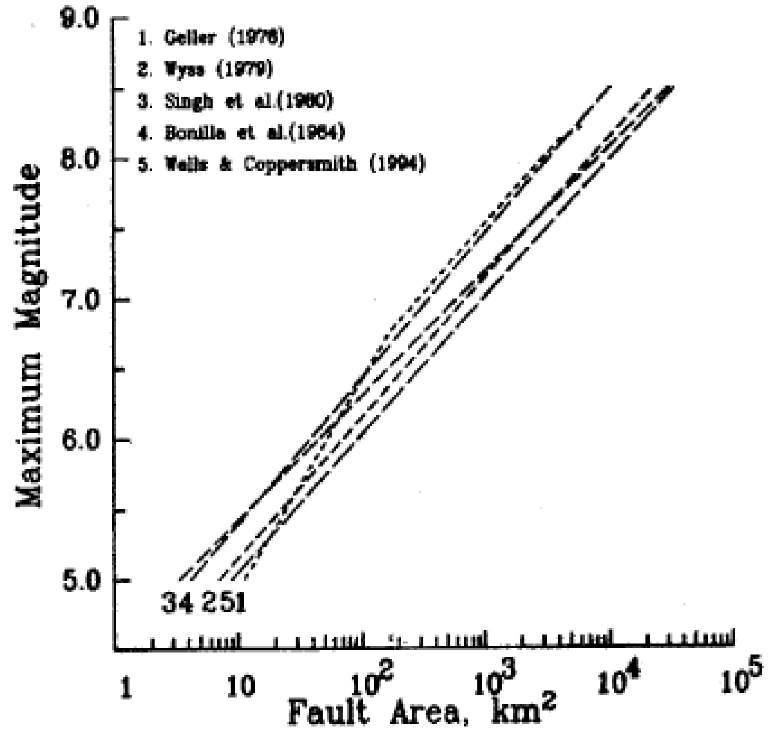
Deterministic seismic hazard analysis

Comparison of several empirical relationships used to find the maximum magnitude from

(a) the fault rupture length and (b) the fault rupture area



(a)



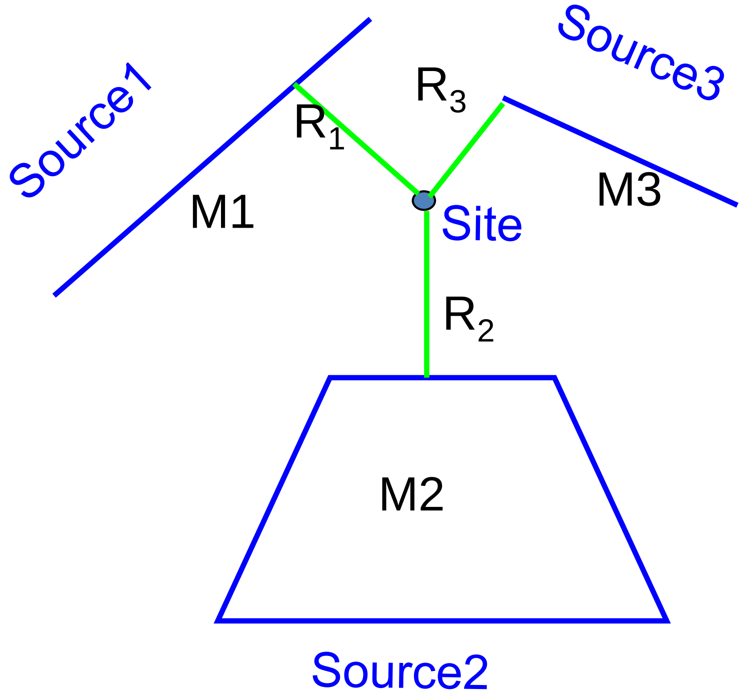
(b)

Deterministic seismic hazard analysis

Selection of controlling earthquake

Decision should be based on ground motion parameters of greatest interest

- Consider all sources
- Assume M_{max} occurs at R_{min} for each source
- Compute ground motion parameter(s) based on M_{max} and R_{min}
- Determine critical value(s) of ground motion parameter(s)

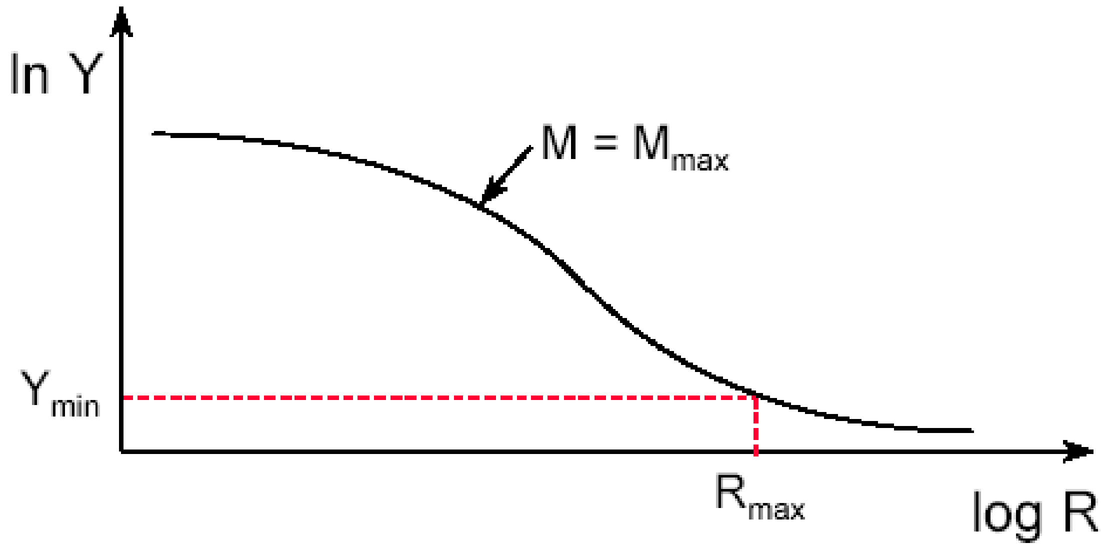


Deterministic seismic hazard analysis

Selection of controlling earthquake

Estimate maximum magnitude that could be produced by any source in vicinity of site.

Find value of R_{max} - corresponds to M_{max} at threshold value of parameter of interest, Y_{min}. (Y is ground motion parameter)



Deterministic seismic hazard analysis

Selection of controlling earthquake

Predictive relationships are used to estimate the ground motion parameter (Y).

Most commonly used ground motion parameter is PHA

Typical predictive relationship for PHA

$\ln PHA\ (gals) = 6.74 + 0.859\ M - 1.80 \ln (R+25)$ (R in km)

Cornell at al (1979)

Plot the variation of Y with R for known magnitude M

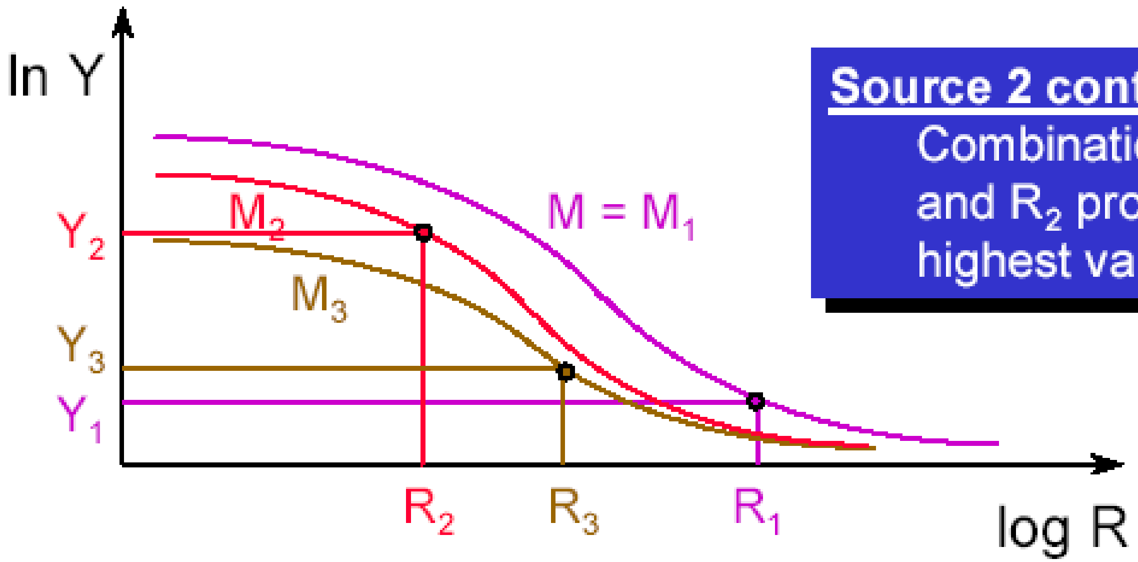
Plot these variations for all the sources

Mark the distances from the sources

Measure Y for the distance for different sources from the plots

Deterministic seismic hazard analysis

Select the controlling source for which the combination of magnitude and distance produces highest value of Y.



Source 2 controls
Combination of M_2 and R_2 produces highest value of Y

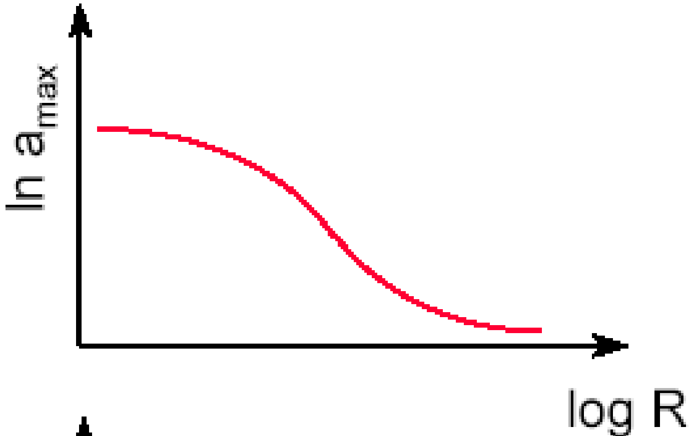
Deterministic seismic hazard analysis

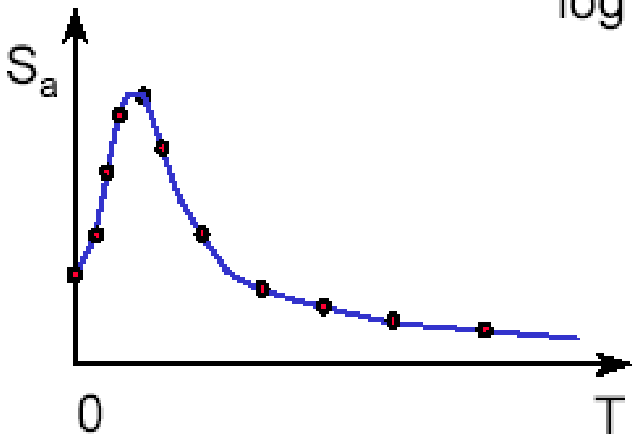
Use M and R to determine such parameters as:

Peak acceleration

Spectral accelerations

Duration





Deterministic seismic hazard analysis

Theoretical Determination of M_{max} for Himalayas

- From west to east, the entire Himalaya has a length of about 2500 km, and the width of the associated seismic source is about 100 km.
- The source of major earthquakes along the Himalaya has been postulated as a gently dipping detachment plane, north of the main boundary fault (MBF), at a depth of about 20 to 30 km.
- Thus, the total rupture plane of the Himalaya has an area *A* of about 2.5×10^5 km^2.
- The shear modulus, μ for the Himalayan rocks can be taken as 3.4×10^{11} dyne/cm^2.
- After accounting for the trans-Himalayan deformations, the long-term average of the slip rate, *s* , along the Himalayan detachment plane is corroborated to be about 15 mm/year.
- This gives the moment rate
- $M_r = \mu A s = 1.275 \times 10^{27}$dyne-cm/year.
- Assuming that the recurrence period (T)for largest earthquakes with magnitude 8(+) anywhere in the Himalaya is about 40 years,
- $M_0 = M_r T = 5.1 \times 10^{28}$ dyne-cm
- **$M_{max} = \log M_0/1.5 - 10.7 = 8.4$**

Probabilistic seismic hazard analysis

1. Goal: to quantify the rate (or probability) of exceeding various ground-motion levels at a site, given all possible earthquakes
2. Traditionally: Peak Ground Acceleration (PGA) used to quantify ground motion
3. Today: Response Spectral Acceleration (SA) preferred – expected SA in accordance to the natural frequency of the building.
4. PSHA characterizes uncertainty in location, size, frequency and effects of earthquakes and combines all of them to compute probabilities of different levels of ground shaking.

Probabilistic seismic hazard analysis

<u>METHODOLOGY</u>

1. Identification and characterization of all sources
2. Characterization of seismicity of each source
3. Determination of motions from each source
4. Probabilistic calculations

<u>UNCERTAINITIES</u>

- Uncertainty in source-site distance
- Distribution of earthquake magnitudes
  - Gutenberg-Richter Recurrence law
- Predictive relationships
- Temporal uncertainty
- Combining uncertainties – probability computations

Probabilistic seismic hazard analysis

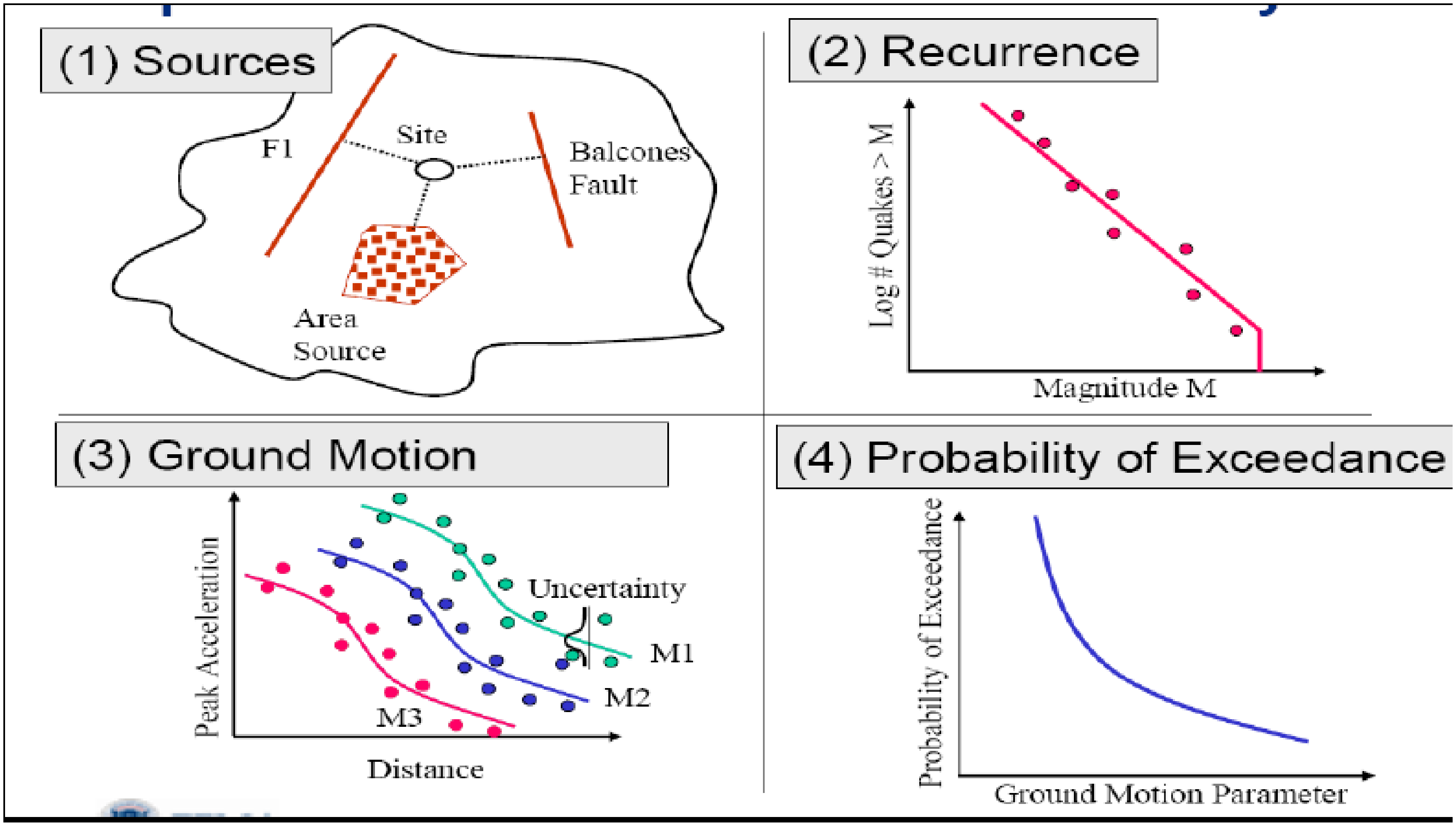
A PSHA calculates the probability of exceeding all levels of ground shaking at a certain location (all different earthquake scenarios)

This is useful for reinsurance/insurance purposes (annual premiums), design code exceedance and government hazard.

It consists of the following steps:

1) Collect data on tectonics & geology
2) Compile an earthquake catalogue for the region
3) Define seismic sources zones
4)Determine magnitude-frequency relationships
5) Select an appropriate set of GMPEs
6) Calculate probability of each level of acceleration
7) Construct hazard curves and maps

Probabilistic seismic hazard analysis



THANK YOU!