Chapter 19: Elements of Seismology

Introduction

Seismology is the scientific study of earthquakes and the propagation of elastic waves through the Earth. It forms the foundational basis of Earthquake Engineering, helping engineers understand the origin, nature, and behavior of ground motion. With increasing urban development in seismic-prone areas, the knowledge of seismological principles is vital for designing earthquake-resistant structures. This chapter delves into the elements of seismology relevant for civil engineers, such as causes of earthquakes, seismic waves, magnitude and intensity scales, and the characteristics of ground motion.

19.1 Causes of Earthquakes

19.1.1 Tectonic Movements

- Caused due to relative motion between tectonic plates.
- Most earthquakes are generated by the sudden release of energy accumulated due to plate movements.
- Boundaries: divergent, convergent, and transform faults.

19.1.2 Volcanic Activity

- Earthquakes that occur due to volcanic eruptions.
- Less frequent but can be highly destructive locally.

19.1.3 Induced Seismicity

- Result of human activities such as:
  - Reservoir-induced seismicity.
  - Mining explosions.
  - Deep well injections and hydraulic fracturing (fracking).

19.1.4 Collapse Earthquakes

- Caused by underground cave-ins or mine collapses.
- Usually of minor magnitude.

19.2 Elastic Rebound Theory

- Proposed by Reid in 1910.

- Describes how energy is stored in rocks along a fault line.
- Sudden slip occurs when stress exceeds rock strength, releasing stored elastic strain energy as seismic waves.

19.3 Seismic Waves

19.3.1 Body Waves

- Travel through the Earth's interior.

(a) Primary (P) Waves

- Compressional, fastest seismic waves.
- Can travel through solids, liquids, and gases.

(b) Secondary (S) Waves

- Shear waves, slower than P-waves.
- Travel only through solids.

19.3.2 Surface Waves

- Travel along Earth’s surface; responsible for most damage.

(a) Love Waves

- Horizontal shear motion, side-to-side.

(b) Rayleigh Waves

- Rolling motion, both vertical and horizontal.
- Typically cause more destruction than body waves.

19.4 Seismographs and Seismometers

- Instruments used to detect and record ground motion.

19.4.1 Components

- A mass-spring system with a damping device.
- Records ground acceleration, velocity, or displacement.

19.4.2 Strong-Motion Seismographs

- Designed to record high-amplitude motions during intense earthquakes.
- Used for engineering purposes.

19.5 Earthquake Magnitude and Intensity

19.5.1 Magnitude

- Quantifies the energy released at the source.
- **Richter Scale (ML):** Logarithmic; not effective for very large earthquakes.
- **Moment Magnitude Scale (Mw):** Based on seismic moment; more accurate and widely used.

19.5.2 Intensity

- Qualitative measure of effects on people, structures, and the Earth's surface.
- **Modified Mercalli Intensity (MMI) Scale:** Ranges from I (not felt) to XII (total destruction).
- Varies with distance from epicenter and local site conditions.

19.6 Earthquake Zoning and Seismic Hazard Maps

19.6.1 Seismic Zoning

- Divides regions based on seismic hazard levels.
- In India, zones are classified as Zone II, III, IV, and V (Zone V being most severe).

19.6.2 Parameters Considered

- Past seismicity.
- Tectonic features.
- Fault zones.
- Soil conditions.

19.6.3 Indian Seismic Zoning Map (IS:1893)

- Provides design acceleration values (Z) for each zone.
- Updated periodically based on new data.

19.7 Ground Motion Characteristics

19.7.1 Peak Ground Acceleration (PGA)

- Maximum acceleration recorded at a site during an earthquake.

19.7.2 Duration

- Time interval over which significant shaking occurs.
- Longer durations can cause fatigue in structures.

19.7.3 Frequency Content

- Ground motion contains a mix of frequencies.
- Tall buildings resonate with low frequencies; short buildings with high frequencies.

19.7.4 Response Spectrum

- A plot showing peak response (acceleration, velocity, displacement) of single-degree-of-freedom systems to ground motion.
- Essential for seismic design of structures.

19.8 Earthquake Recording Networks

19.8.1 Global Seismographic Network (GSN)

- Worldwide network for monitoring seismic activity.

19.8.2 Indian National Seismological Network (INSN)

- Operated by IMD (India Meteorological Department).
- Collects data for research and earthquake early warning systems.

19.9 Plate Tectonics and Indian Context

19.9.1 Plate Boundaries Near India

- Indo-Australian Plate colliding with Eurasian Plate.
- Himalayan region is seismically very active due to this interaction.

19.9.2 Indian Earthquake-Prone Regions

- Himalayan belt (Zone V)
- Northeastern states
- Kutch region in Gujarat

- Indo-Gangetic plains

19.10 Faults and Focal Mechanisms

19.10.1 Fault Types

- **Normal Fault:** Due to extension.
- **Reverse/Thrust Fault:** Due to compression.
- **Strike-slip Fault:** Horizontal movement (e.g., San Andreas Fault).

19.10.2 Focal Mechanism

- Describes the orientation of the fault and direction of slip during an earthquake.
- Often visualized using “beach ball” diagrams.

19.11 Site Effects and Local Soil Conditions

19.11.1 Site Amplification

- Soft soils amplify seismic waves more than hard rock.
- Can result in increased shaking and damage.

19.11.2 Liquefaction

- Saturated soils lose strength during intense shaking.
- Causes ground failure and building collapse.

19.12 Earthquake Early Warning Systems (EEWS)

19.12.1 Principle

- Based on detecting P-waves to give advance notice before destructive S- and surface waves arrive.

19.12.2 Application

- Can provide seconds to minutes of warning.
- Useful in halting trains, shutting down gas lines, and alerting public.

19.13 Engineering Applications of Seismology

- Ground motion parameters are used in structural design codes.
- Input for dynamic analysis of buildings and infrastructure.
- Development of time history records and response spectra.
- Site selection for critical infrastructure.

19.14 Seismotectonics

19.14.1 Definition and Scope

- Study of the relationship between earthquakes, active tectonics, and geological structures.
- Combines geological, geophysical, and seismological data.

19.14.2 Fault Mapping

- Identifies active faults and their movement history.
- Important for seismic microzonation.

19.14.3 Regional Seismotectonics in India

- Himalayan collision zone.
- Indo-Burmese arc.
- Kachchh rift zone.
- Peninsular shield (intraplate earthquakes).

19.15 Seismic Microzonation

19.15.1 Concept

- Subdividing a region into zones with similar seismic hazard characteristics.
- Done at a much finer scale than seismic zoning maps.

19.15.2 Parameters Considered

- Geology, soil profile, topography, groundwater level, fault proximity.
- Historical seismicity and ground motion amplification.

19.15.3 Application

- Urban planning and infrastructure siting.
- Delhi, Guwahati, Bengaluru, Chennai are already microzoned.

19.16 Seismic Hazard Assessment

19.16.1 Types

- **Deterministic Seismic Hazard Assessment (DSHA):** Based on the largest credible earthquake on nearby faults.
- **Probabilistic Seismic Hazard Assessment (PSHA):** Takes into account uncertainties in size, location, and recurrence of earthquakes.

19.16.2 Output

- Hazard curves.
- Uniform hazard spectra.
- Risk contours for design purposes.

19.17 Earthquake Recurrence and Return Period

19.17.1 Recurrence Interval

- The average time between two large earthquakes on the same fault segment.
- Based on paleoseismology, historical records, and fault slip rate.

19.17.2 Gutenberg-Richter Relationship

- Log(N) = a – bM Where:
  - N = number of earthquakes greater than or equal to magnitude M
  - a, b = region-specific constants.

19.18 Recent Major Earthquakes in India and Their Seismological Analysis

19.18.1 Bhuj Earthquake (2001)

- Mw 7.7, high casualties due to ground shaking and liquefaction.

19.18.2 Sikkim Earthquake (2011)

- Mw 6.9, highlighted vulnerability of northeastern regions.

19.18.3 Nepal-Gorkha Earthquake (2015)

- Affected northern India; Mw 7.8.
- Triggered re-evaluation of seismic risk in Himalayan states.

19.19 Future Trends in Seismology and Earthquake Prediction

19.19.1 Earthquake Forecasting

- Long-term prediction based on stress accumulation and tectonic movements.
- Statistical models using historical data.

19.19.2 Real-Time Seismology

- Use of GPS and InSAR (Interferometric Synthetic Aperture Radar) for crustal deformation.
- Internet-based sensor networks and AI-based analysis.

19.19.3 Global Collaborations

- IRIS, GSN, USGS, and Indian agencies (IMD, IITs, NGRI).
- Data sharing for improved understanding and hazard mitigation.