Chapter 28: Magnitude and Intensity of Earthquakes

Introduction

In the domain of Earthquake Engineering, understanding the strength and impact of earthquakes is crucial for designing earthquake-resistant structures. Two fundamental parameters used to describe an earthquake are **magnitude** and **intensity**. While these terms are often used interchangeably by the public, they have distinct scientific meanings. **Magnitude** measures the energy released at the source of the earthquake, whereas **intensity** refers to the effects or shaking produced at specific locations. This chapter explores various scales used to quantify these parameters, their relevance in structural engineering, and how these measurements influence seismic design.

28.1 Difference Between Magnitude and Intensity

Aspect	Magnitude	Intensity
Definition	Measure of energy released at the earthquake's source	Measure of shaking felt at a location
Measured by	Seismographs	Human observation and instrumental data
Units/Scales	Richter Scale, Moment Magnitude Scale	Modified Mercalli Intensity (MMI) Scale
Value uniqueness	Single value per earthquake	Varies from place to place

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28.2 Earthquake Magnitude

28.2.1 Richter Magnitude Scale (ML)

- Developed in 1935 by Charles F. Richter.
- Based on the amplitude of seismic waves recorded on a Wood-Anderson seismograph.
- Logarithmic scale: each unit increase corresponds to 10 times more amplitude and ~32 times more energy release.
- Formula:

$$M_L = \log_{10}(A) - \log_{10}(A_0)$$

- Where:
  - A = maximum amplitude of seismic waves
  - A_0 = amplitude for a standard earthquake at 100 km
- Suitable for small to medium earthquakes (typically < 6.8).

28.2.2 Moment Magnitude Scale (Mw)

- Currently the most widely used magnitude scale.
- Based on **seismic moment (Mo)**:

$$M_w = \frac{2}{3}\log_{10}(M_0) - 10.7$$

- Where:
  - $M_0 = \mu \cdot A \cdot D$
  - μ = shear modulus of rocks (~30 GPa)
  - A = rupture area
  - D = average displacement
- Provides consistent values across a wide range of earthquake sizes.
- Does not saturate like the Richter scale for large earthquakes.

28.2.3 Other Magnitude Scales

- **Body Wave Magnitude (Mb):** Based on P-wave amplitude.
- **Surface Wave Magnitude (Ms):** Based on Rayleigh surface waves.
- **Duration Magnitude:** Based on the duration of shaking.

Each scale serves different purposes and may be used based on the nature of the seismic event and available data.

28.3 Earthquake Intensity

28.3.1 Modified Mercalli Intensity Scale (MMI)

- Developed by Giuseppe Mercalli, modified by Harry Wood and Frank Neumann.
- Qualitative scale ranging from **I (not felt)** to **XII (total destruction)**.
- Based on observed effects on people, buildings, and natural objects.

MMI Level	Description
I	Not felt
III	Felt indoors
V	Felt by nearly everyone
VII	Damage to poorly built structures
IX	Heavy damage, ground cracks
XII	Total destruction

- Not based on instrumental readings, but helpful for assessing local impact.

28.3.2 MSK Intensity Scale (Medvedev–Sponheuer–Karnik)

- Used in India and Europe.
- Similar to MMI but with more emphasis on building response.
- Intensity values range from I to XII.
- Accounts for structural vulnerability in describing effects.

28.4 Correlation Between Magnitude and Intensity

- No direct formula connects magnitude and intensity due to dependence on local geology, building design, and distance from the epicenter.
- However, empirical relationships exist:

$$I = aM + b\log_{10}(r) + c$$

- Where:
  - I = intensity at a site
  - M = magnitude
  - r = distance from epicenter
  - a, b, c = empirically derived constants
- Typically, a magnitude 6.0 earthquake could produce intensity VI–VIII near the epicenter.

28.5 Seismic Energy Release

- Energy released (in Joules) by an earthquake can be approximated from magnitude:

$$\log_{10} E = 1.5M + 4.8$$

- Where:

- E = energy in ergs
- M = magnitude

- A magnitude 7.0 earthquake releases about **32 times** more energy than a magnitude 6.0.

28.6 Significance in Earthquake Engineering

- **Magnitude** is used to define seismic hazard zones and earthquake-resistant design codes (e.g., IS 1893).
- **Intensity** is crucial for post-event assessments and emergency planning.
- Understanding both helps in:
  - Estimating **Peak Ground Acceleration (PGA)**
  - Seismic zoning
  - Structural retrofitting strategies

28.7 Instrumentation and Data Collection

Seismometers and Accelerographs

- **Seismometer:** Measures ground displacement and records waveforms.
- **Accelerograph:** Records acceleration, essential for structural engineering analysis.
- Both help estimate:
  - Epicentral distance
  - Ground motion parameters
  - Site response

28.8 Factors Affecting Intensity at a Location

- **Distance from epicenter**
- **Local soil and geology**
- **Topography**
- **Depth of focus**
- **Building construction quality**

Soft soils can amplify shaking, increasing the local intensity even for a moderate earthquake.

28.9 Applications in Indian Seismic Design

- **Bureau of Indian Standards (BIS)** uses magnitude and intensity data to define seismic zones (Zone II to V).
- Design basis earthquake (DBE) and maximum considered earthquake (MCE) are evaluated using magnitude and past intensity records.
- Seismic microzonation efforts also use intensity distributions for hazard mapping.

28.10 Attenuation Relationships (Ground Motion Prediction Equations)

28.10.1 Introduction to Attenuation

- Attenuation refers to the decrease in earthquake ground motion (amplitude and energy) with increasing distance from the source.
- Used to estimate seismic parameters like Peak Ground Acceleration (PGA), velocity, and displacement at a site.
- Essential for seismic hazard analysis and structural response studies.

28.10.2 General Form of Attenuation Equation

$$Y = f(M, R, S) = C_1 + C_2 M - C_3 \log(R + C_4) + C_5 S$$

Where:

- Y: Ground motion parameter (e.g., PGA)
- M: Moment magnitude
- R: Distance from source (epicentral or hypocentral)
- S: Site conditions (rock or soil)
- $C_1, C_2, \ldots$: Empirical constants

28.10.3 Commonly Used Attenuation Models

- Boore–Joyner–Fumal model
- Campbell model
- Abrahamson–Silva model

These models are region-specific and developed based on seismic recordings and local geology.

28.11 Isoseismal Maps and Their Interpretation

28.11.1 Isoseismal Lines

- Contour lines joining locations of equal seismic intensity.

- Used to visualize the distribution of shaking across a region after an earthquake.

28.11.2 Uses of Isoseismal Maps

- Help in identifying:
  - Epicenter location
  - Areas with anomalous ground response
- Useful in:
  - Seismic microzonation
  - Insurance and loss estimation
  - Validation of attenuation models

28.12 Factors Causing Variation in Observed Intensity

While magnitude is a fixed value, intensity can vary across locations due to multiple influencing factors:

28.12.1 Local Soil Conditions

- Soft soils may amplify ground motion (e.g., basin effects).
- Hard rock sites generally exhibit lower shaking.

28.12.2 Topography

- Ridge and hill effects may increase shaking on slopes and crests.
- Valleys may trap and amplify seismic waves.

28.12.3 Depth of Focus

- Shallow-focus earthquakes (depth < 70 km) produce more surface shaking than deep-focus events.

28.12.4 Distance from Epicenter

- Intensity decreases with increasing distance, but not uniformly.
- Attenuation rate depends on crustal structure and wave path.

28.12.5 Building Type and Density

- Poorly constructed or unreinforced masonry buildings suffer greater damage.
- Densely built-up areas may show more intense effects.

28.13 Importance of Magnitude and Intensity in Seismic Design Codes

28.13.1 Indian Seismic Codes (IS 1893)

- **Magnitude** is used for defining **design basis earthquake (DBE)** and **maximum considered earthquake (MCE)**.
- **Intensity** guides **structural performance objectives**, damage criteria, and acceptable limits.

28.13.2 Zonation and Design Spectra

- Seismic zones (Zone II to Zone V in India) correlate with expected ground shaking intensity.
- Design spectra in IS 1893 are derived from ground motion prediction (attenuation) models.

28.14 Role of Intensity in Post-Earthquake Damage Assessment

- Rapid assessment of affected areas is conducted using **felt reports**, **field surveys**, and **instrumental recordings**.
- Intensity mapping helps:
  - Estimate probable structural damage
  - Guide relief operations and urban planning
  - Improve building codes by learning from past failures

28.15 Recent Advancements and Digital Tools

28.15.1 ShakeMaps

- Produced by agencies like USGS.
- Digital maps showing ground shaking distribution (PGA, PGV, MMI).
- Useful for emergency response and communication.

28.15.2 Seismic Intensity Apps and AI Tools

- Mobile apps (e.g., MyShake, LastQuake) collect real-time intensity data from users.
- AI tools are being used to estimate intensities and damage probabilities using satellite imagery and real-time data.
