Chapter 29: Magnitude and Intensity Scales

Introduction

Earthquakes are complex natural phenomena whose effects on the built environment must be understood quantitatively for proper design and mitigation. The assessment of an earthquake's strength is a fundamental step in seismic analysis and engineering design. To evaluate and communicate the impact and energy released during an earthquake, two distinct but complementary concepts are used: **Magnitude** and **Intensity**.

Magnitude measures the energy released at the source of the earthquake, while **Intensity** measures the effects of the earthquake at specific locations. These two scales serve different purposes but are often confused. Understanding their definitions, measurement methods, variations, and engineering implications is critical in earthquake engineering.

29.1 Seismic Magnitude Scales

Magnitude scales are logarithmic measures of the total energy released by an earthquake. The magnitude is independent of the observer's location and is a fundamental parameter in seismology and earthquake-resistant design.

29.1.1 Richter Magnitude Scale (Local Magnitude, ML)

- Developed by Charles F. Richter in 1935 for Southern California.
- Based on the amplitude of seismic waves recorded by a Wood-Anderson seismograph.
- Formula:

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

- where:
  - A is the maximum amplitude of ground motion.
  - $A_0(\delta)$ is a standard amplitude for a given distance.
- **Limitations:**
  - Not suitable for large earthquakes ($>$ M 6.5) due to saturation.
  - Applicable only to local events (up to ~600 km).

29.1.2 Body-Wave Magnitude (Mb)

- Calculated using amplitude of P-waves (primary waves).
- Useful for detecting deep-focus and distant earthquakes.
- Saturates for magnitudes above 6.5.

29.1.3 Surface-Wave Magnitude (Ms)

- Based on the amplitude of surface waves (Rayleigh or Love waves).
- Calculated over a period of ~20 seconds.
- Better suited for shallow and distant earthquakes.

29.1.4 Moment Magnitude (Mw)

- Developed to overcome saturation issues of other scales.
- Related to **seismic moment**:

$$M_0 = \mu A D$$

- where:
  - μ: shear modulus of the rock (~30 GPa),
  - A: fault area,
  - D: average displacement.

  Moment Magnitude:

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

- **Advantages:**
  - Does not saturate.
  - Reliable for all sizes and types of earthquakes.
  - Adopted by most international agencies (e.g., USGS).

29.2 Seismic Intensity Scales

Intensity refers to the perceived shaking and damage observed at a specific location due to an earthquake. It varies with distance from the epicenter, geology, and structural characteristics.

29.2.1 Modified Mercalli Intensity (MMI) Scale

- Qualitative scale ranging from I (not felt) to XII (total destruction).
- Based on:

- Human perception of shaking.
- Damage to structures.
- Ground deformation.

MMI Level	Description
I	Not felt except by a few.
V	Felt indoors; unstable objects disturbed.
VII	Difficult to stand; slight structural damage.
IX	General panic; considerable damage.
XII	Total destruction; ground surface waves seen.

- Widely used in seismic hazard zonation and vulnerability mapping.

29.2.2 European Macroseismic Scale (EMS-98)

- Designed for European structures and conditions.
- Provides detailed damage descriptions per building type.
- Used for post-earthquake surveys.

29.2.3 Medvedev–Sponheuer–Karnik (MSK) Scale

- Previously used in India and USSR.
- Similar in structure to MMI.
- Focuses on human reactions, damage to buildings, and ground effects.

29.3 Differences Between Magnitude and Intensity

Aspect	Magnitude	Intensity
Definition	Energy released at source	Effects at specific location
Measurement tool	Seismograph	Field surveys, questionnaires
Units	Logarithmic scale (e.g., Mw, ML)	Roman numerals (I–XII)
Distance effect	Constant for all locations	Varies with location
Usage	Engineering calculations, comparison	Impact assessment, insurance, public response

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29.4 Isoseismal Maps

- **Isoseismal lines** connect points of equal intensity.
- Help in visualizing spatial distribution of shaking.
- Useful in identifying local amplification effects due to soil and terrain.

29.5 Correlation Between Magnitude and Intensity

Though distinct, empirical relationships exist:

$$I = aM + b - c \log_{10} R$$

Where:

- I: Intensity at a distance R,
- M: Magnitude,
- a, b, c: Empirical constants,
- R: Distance from epicenter.

These correlations are used in attenuation models and regional seismic hazard assessment.

29.6 Engineering Implications of Magnitude and Intensity

- **Magnitude** is essential for:
  - Defining design basis earthquake (DBE) and maximum considered earthquake (MCE).
  - Estimating seismic loads using response spectra.
- **Intensity** is important for:
  - Assessing local damage patterns.
  - Post-earthquake reconnaissance.
  - Insurance loss estimation.

Understanding both scales allows engineers to better predict potential damage, evaluate building code requirements, and design safer infrastructure.

29.7 Seismological Basis for Magnitude-Intensity Relationships

Magnitude and intensity are fundamentally different in measurement and use, but seismologists and engineers often require a **functional relationship** between them for practical applications like:

- Ground motion prediction equations (GMPEs)
- Seismic hazard microzonation
- Early warning systems

29.7.1 Empirical Relationships

Numerous region-specific empirical formulas have been developed. A generic form is:

$$I = aM - b\log(R) + c$$

Where:

- I: intensity at a site,
- M: earthquake magnitude,
- R: hypocentral or epicentral distance (km),
- a, b, c: constants calibrated to local geological settings.

These models are validated by historical earthquake data.

29.8 Limitations and Sources of Uncertainty

29.8.1 Magnitude Scale Limitations

- **Saturation** in older scales like ML and Ms for large earthquakes.
- **Regional Calibration**: Not all magnitude scales are universally applicable.
- **Instrumentation Dependency**: Affected by sensor sensitivity and type.

29.8.2 Intensity Scale Limitations

- **Subjectivity**: Intensity depends on human perception and building type.
- **Data Sparsity**: Limited field reports in remote regions.
- **Non-uniform Construction Practices**: Affect perceived intensity.

29.9 Intensity Prediction Equations (IPEs)

IPEs estimate expected intensity at a given location due to an earthquake of known magnitude and location.

General form:

$$I = f(M, R, Site)$$

Where:

- M: magnitude,
- R: distance from source,
- **Site**: accounts for soil type and local amplification.

Used in:

- Scenario shake maps,
- Loss estimation models (e.g., HAZUS),
- Insurance sector for disaster risk models.

29.10 Use of Intensity in Seismic Hazard Assessment

- **Microzonation Maps**: Combine observed intensities with geological data.
- **Risk Zonation**: Modified Mercalli or MSK intensities help classify areas into seismic zones (e.g., Zone II–V in India).
- **Design Ground Motion Parameters**: Intensity indirectly used to derive design spectrum parameters.

29.11 Contemporary Developments in Seismic Scaling

29.11.1 ShakeMap Systems

- Developed by USGS and adopted worldwide.
- Combine instrumental data (magnitude, ground motion) and IPEs to produce real-time intensity maps.
- Used for disaster response, resource allocation, and communication.

29.11.2 Internet-Based Macroseismic Data Collection

- **Did You Feel It? (DYFI)** program gathers public input.
- Converts subjective observations into intensity values.
- Enhances data granularity in low-instrumentation areas.

29.12 Case Studies on Magnitude and Intensity Application

29.12.1 2001 Bhuj Earthquake, India (Mw 7.7)

- Severe ground shaking caused by a high-magnitude intraplate event.
- MMI reached IX–X in epicentral areas.
- Extensive damage highlighted the need for better zoning based on both magnitude and observed intensities.

29.12.2 2015 Nepal Earthquake (Mw 7.8)

- High Mw but moderate intensity in urban zones due to depth and fault type.
- Demonstrated importance of structural vulnerability in determining intensity impact.

29.13 Summary Tables and Charts (Optional for Textbooks)

Although not requested in your format, textbooks often include:

- **Comparison tables** of magnitude scales,
- **Charts showing Mw vs. energy release**,
- **Maps with overlaid isoseismals and intensity data points**.

These visual aids reinforce the conceptual differences and real-world use of magnitude and intensity measures.
