Chapter 35: Concept of Peak Acceleration

Introduction

In earthquake engineering, understanding how the ground shakes during a seismic event is crucial for designing safe and efficient structures. One of the most important parameters to characterize earthquake ground motion is **Peak Ground Acceleration (PGA)**, which represents the maximum acceleration experienced by the ground during an earthquake. PGA is a key input for seismic design, risk assessment, and performance-based engineering.

This chapter delves into the **concept of peak acceleration**, its **measurement**, **engineering significance**, **relationship with earthquake magnitude and intensity**, and how it is used in **design codes**. It also covers the **influence of soil conditions**, **site amplification**, and **instrumentation** used for recording ground acceleration.

35.1 Definition of Peak Ground Acceleration (PGA)

- **Peak Ground Acceleration (PGA)** is defined as the **maximum absolute value of horizontal acceleration** recorded at a particular location during an earthquake.
- Mathematically, if *a(t)* is the ground acceleration time history, then:

$$PGA = max \lor a(t) \lor \text{¿}$$

- It is typically measured in **g** (acceleration due to gravity) or **m/s²**.
- PGA does not provide information about duration or frequency content but gives a direct indication of the force exerted on structures at the base.

35.2 Engineering Importance of PGA

- **Structural Design Input**: PGA is the primary input parameter for many **seismic design codes** including IS 1893, which use it to define seismic zones and base shear.

- **Seismic Hazard Assessment**: It is a key parameter in **Probabilistic Seismic Hazard Analysis (PSHA)** and **Deterministic Seismic Hazard Analysis (DSHA)**.
- **Design of Lifelines and Infrastructure**: Bridges, dams, nuclear plants, and pipelines are designed to withstand forces based on expected PGA levels.

35.3 Measurement of Ground Acceleration

- Ground acceleration is recorded using **accelerographs** or **strong-motion seismographs**.
- These instruments capture the full acceleration time history during seismic shaking.
- Modern seismic stations record digital ground motion in three directions: two horizontal (X and Y) and one vertical (Z).

35.4 Response Spectra and PGA

- **Response spectra** represent the peak response (acceleration, velocity, displacement) of a set of single-degree-of-freedom (SDOF) systems to a ground motion.
- PGA is the **zero-period acceleration** of the acceleration response spectrum.
- PGA is thus a limiting value of the response spectrum at very high natural frequencies.

35.5 Factors Affecting Peak Acceleration

35.5.1 Earthquake Magnitude

- Larger magnitude earthquakes generally produce larger PGAs, but not linearly.
- The rate of increase of PGA with magnitude diminishes beyond a certain level.

35.5.2 Epicentral Distance

- PGA decreases with distance from the source (attenuation).
- Empirical attenuation relationships (Ground Motion Prediction Equations, GMPEs) are used to estimate PGA at various distances.

35.5.3 Site Conditions

- **Local soil and geology** play a significant role:
    - Soft soil amplifies ground motion → higher PGA.
    - Rock sites show lesser amplification → lower PGA.
- Site response analysis is needed to modify PGA for local conditions.

35.5.4 Fault Type and Depth

- Thrust faults and shallow-focus earthquakes tend to produce higher PGAs.
- The directionality of fault rupture can also cause **directivity effects** increasing PGA at certain locations.

35.6 PGA in Seismic Zoning and Building Codes

- In India, IS 1893 divides the country into seismic zones II to V, each associated with a **zone factor (Z)** representing expected PGA:
    - Zone II: Z = 0.10g
    - Zone III: Z = 0.16g
    - Zone IV: Z = 0.24g
    - Zone V: Z = 0.36g
- These values are used to calculate **design base shear** in structural analysis.
- PGA values in codes are **maximum credible values** with some level of conservatism.

35.7 Empirical Relationships and Attenuation Models

- PGA is commonly estimated using Ground Motion Prediction Equations (GMPEs) of the form:

$$\log_{10}(PGA) = a + bM - c\log_{10}(R + d)$$

where:

- M = magnitude
- R = hypocentral/epicentral distance
- a, b, c, d = empirical constants

- Different models exist for different tectonic settings (e.g., subduction zones, intraplate regions).

35.8 Peak Acceleration vs Peak Velocity and Displacement

Parameter	Unit	Captures	Significance
PGA	m/s^2 or g	Instantaneous ground force	Direct input to force-based design
PGV	cm/s	Velocity of ground movement	Correlates better with structural damage
PGD	cm	Ground displacement	Important for flexible structures

- **PGA** is more relevant for **stiff and short-period** structures.
- **PGV and PGD** are critical for **long-period** or flexible structures like bridges.

35.9 Limitations of Using PGA Alone

- PGA does not capture:
  - **Duration** of shaking
  - **Frequency content**
  - **Cumulative energy**
- For performance-based design, more detailed measures like **Spectral Acceleration (Sa)** and **Arias Intensity** are used.
- However, PGA remains the **most accessible and easily understood** seismic parameter.

35.10 Site-Specific Peak Acceleration Estimation

- Requires:
  a. Identification of seismic sources.

b. Selection of appropriate GMPEs.
c. Consideration of **local site class** (as per NEHRP/IS 1893).
d. Probabilistic or deterministic hazard modeling.

- **Microzonation studies** often present PGA maps with resolution down to city-block level.

35.11 Instrumentation for Recording PGA

- Instruments:
  - **Strong motion accelerometers**
  - **Digital recording systems** (24-bit or higher resolution)
- Networks in India:
  - **Indian Meteorological Department (IMD)**
  - **IITs and research institutions**
  - **Array installations in high-risk zones (e.g., Himalayan belt)**

35.12 Case Studies of Recorded PGA in Major Earthquakes

Earthquake	Year	Country	Recorded PGA
Bhuj Earthquake	2001	India	~0.35g
Northridge Earthquake	1994	USA (California)	~0.91g
Kobe Earthquake	1995	Japan	~0.84g
Nepal Gorkha Earthquake	2015	Nepal-India	~0.25g

- The high values highlight the need for **robust seismic design** in urban infrastructure.

35.13 Design Implications of High PGA

- High PGA leads to:
  - Increased base shear demand

- Higher lateral forces
- Greater detailing for ductility and energy dissipation

- Structures must be designed using **Response Reduction Factors (R)** and **Importance Factors (I)** to ensure safety.

35.14 Directionality and Peak Acceleration

- **Directional effects** occur when the rupture propagates toward a site, causing forward-directivity, which increases PGA in that direction.
- **Vector PGA**:
  - Engineers sometimes consider *Vector PGA* or *Resultant PGA* combining horizontal components:

$$PGA_{vector} = \sqrt{¿¿}$$

- Structures must be designed to resist **multi-directional shaking**, not just along a single axis.

35.15 Peak Acceleration on Structures vs Ground

- While **PGA** refers to free-field ground acceleration, structures experience **increased accelerations** at different levels (especially at the roof/top):
  - These are called **floor accelerations**.
  - Floor accelerations can be **2–3 times the PGA** due to resonance and mode shapes.
- Important for:
  - **Non-structural components** like suspended ceilings, piping, equipment, which often fail due to these higher accelerations.

35.16 Design Spectrum and its Relationship with PGA

- The **design acceleration spectrum** is anchored at PGA and varies with the period of vibration:
  - Short period: **Sa ≈ PGA × amplification factor**

- Long period: **Sa decreases with increasing period**

- IS 1893 provides standard response spectra scaled to PGA (Zone factor × Importance factor × Response Reduction factor).

35.17 Scaling Real Earthquake Records Using PGA

- In dynamic analysis, real ground motion records are used but scaled to match design PGA:
  - **Linear scaling**: Multiplies all accelerations to match target PGA.
  - **Spectral matching**: Adjusts the record to match response spectrum shape.

35.18 Use of PGA in Performance-Based Seismic Design (PBSD)

- PBSD requires defining **performance objectives** for different levels of ground shaking:
  - **Operational (PGA ≈ 0.1g)** – minor damage
  - **Life Safety (PGA ≈ 0.2g)** – moderate damage, no collapse
  - **Collapse Prevention (PGA ≈ 0.36g and above)** – severe damage, no total failure
- PGA is linked to **Annual Exceedance Probabilities** in performance criteria (e.g., 10% in 50 years).

35.19 Probabilistic Seismic Hazard Maps (PGA-Based)

- **PGA contour maps** represent expected maximum ground acceleration with certain return periods:
  - 475-year return period (10% chance in 50 years)
  - 2,475-year return period (2% in 50 years)
- Used in:
  - **Urban planning**
  - **Critical infrastructure design**

- **Insurance and risk modeling**

35.20 Limit State Design Approach Using PGA

- In Limit State Design, PGA governs the **Ultimate Limit State (ULS)** for seismic loading.
- Partial safety factors applied to seismic loads depend on PGA and structural importance.

35.21 Advances in PGA Prediction through AI and Machine Learning

- Recent research integrates **machine learning models** (e.g., Random Forests, Neural Networks) to predict PGA using:
  - Earthquake source data
  - Geotechnical site conditions
  - Historical records
- These models are more adaptable to regional conditions than traditional GMPEs.

35.22 Limitations of PGA in Modern Earthquake Engineering

- While PGA is simple and widely used, it is:
  - **Insensitive to duration** and frequency content
  - Not sufficient for **fragility analysis** or **soil liquefaction studies**
  - Less effective for **nonlinear dynamic response modeling**

35.23 Supplementary Ground Motion Parameters

- To overcome PGA's limitations, engineers often consider:
  - **Spectral Acceleration (Sa)** – period-dependent acceleration
  - **Arias Intensity** – total energy content
  - **Cumulative Absolute Velocity (CAV)**

- **Significant Duration** – time span of strong shaking
- These complement PGA in seismic hazard assessment.

35.24 IS Code Recommendations Related to PGA

- **IS 1893:2016 (Part 1)**:
  - Defines **Zone Factor (Z)** as effective PGA
  - Provides **design spectrum** anchored at PGA
  - Requires **site classification** and **amplification factors**
- **IS 456, IS 13920**: Use PGA indirectly through design base shear and ductility provisions.
