Chapter 10: Creep and Shrinkage

Introduction

Concrete, though considered a rigid and durable material, exhibits time-dependent deformations under sustained load and environmental conditions. Two of the most critical long-term deformations that must be considered in structural design are **creep** and **shrinkage**. These phenomena affect the dimensional stability, serviceability, and durability of reinforced and prestressed concrete structures.

Understanding the mechanisms, influencing factors, and mitigation strategies for creep and shrinkage is essential for civil engineers, especially in the design of high-rise buildings, long-span bridges, pavements, dams, and other critical infrastructures.

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1. Creep of Concrete

1.1 Definition

Creep is the **gradual increase in strain or deformation** in concrete when it is subjected to a constant stress over a long period. Unlike elastic deformation, creep is time-dependent and continues as long as the stress is applied, even if the load remains unchanged.

Mathematically:

$$\text{Total Strain} = \text{Elastic Strain} + \text{Creep Strain}$$

1.2 Mechanism of Creep

Creep primarily occurs due to the **viscoelastic nature** of the cement paste. The mechanism includes:

- **Moisture movement** in the gel pores
- **Viscous flow** of the hydrated cement paste
- **Microcracking** within the transition zones

- **Internal structural rearrangements** in the calcium silicate hydrate (C-S-H) gel

1.3 Types of Creep

1. **Basic Creep**: Occurs when concrete is loaded in a sealed environment without moisture exchange.
2. **Drying Creep (Pickett Effect)**: Occurs when concrete loses moisture under load. Drying enhances creep significantly.
3. **Autogenous Creep**: Happens even in the absence of external moisture movement, especially significant in high-strength concrete due to internal chemical shrinkage.

1.4 Factors Affecting Creep

- **Stress Level**: Creep is approximately proportional to the applied stress (below 30-40% of compressive strength).
- **Water-Cement Ratio (w/c)**: Higher w/c increases creep due to higher porosity.
- **Age at Loading**: Concrete loaded at an early age shows more creep.
- **Moisture Conditions**: High ambient humidity reduces creep; drying conditions accelerate it.
- **Aggregate Content**: Richer mixes with less aggregate show more creep.
- **Type of Cement**: Slow-hydrating cements (e.g., Type IV) show less creep.
- **Temperature**: Higher temperatures accelerate creep rate.

1.5 Measurement of Creep

A **creep test** is conducted using:

- A **creep frame** with dead load.
- **Dial gauges** or LVDTs to record strain.
- **Companion specimens** without load to isolate shrinkage from total deformation.

The **Creep Coefficient** is a commonly used parameter:

$$\phi = \frac{\text{Creep Strain}}{\text{Elastic Strain at loading}}$$

Typical values:

- Normal concrete: ϕ = 1.5 to 2.5

- High-strength concrete: ϕ = 0.8 to 1.5

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2. Shrinkage of Concrete

2.1 Definition

Shrinkage is the **time-dependent volume reduction** of concrete occurring **without the application of external load**. It mainly results from **loss of moisture** or **chemical reactions** in the paste.

Shrinkage is an **unrestrained contraction**, but in real structures, **restraints lead to tensile stresses**, which may cause **cracking**.

2.2 Types of Shrinkage

1. **Plastic Shrinkage**
   - Occurs **within few hours after placing concrete**.
   - Caused by **rapid evaporation of surface water**.
   - Results in **cracking** due to differential shrinkage.
   - Preventable by **curing, windbreaks, fogging**.
2. **Drying Shrinkage**
   - Occurs when hardened concrete loses water from capillary pores to the environment.
   - Most significant type.
   - Can continue for **months to years**.
   - Heavily influenced by **humidity, aggregate type, and curing**.
3. **Autogenous Shrinkage**
   - Volume reduction due to **chemical reactions** (hydration) in low water-cement ratio concretes.
   - Prominent in **high-strength concrete** ($w/c < 0.4$).
   - Can cause early-age cracking.
4. **Carbonation Shrinkage**
   - Caused by **reaction of CO_2 with calcium hydroxide** in concrete to form calcium carbonate.
   - Leads to minor long-term shrinkage.
   - Prominent in **exposed concrete surfaces**.

2.3 Factors Affecting Shrinkage

- **Water-Cement Ratio**: Higher w/c leads to more drying shrinkage.
- **Aggregate Volume**: More aggregates reduce shrinkage by restraining the paste.
- **Curing Duration**: Inadequate curing leads to higher shrinkage.
- **Humidity**: Low relative humidity (below 50%) significantly increases drying shrinkage.
- **Size and Shape**: Slabs and thin sections have more surface area, hence higher shrinkage.
- **Type of Cement**: Rapid-hardening cements can increase early-age shrinkage.

2.4 Measurement of Shrinkage

Standard test specimens (e.g., 75mm × 75mm × 285mm prisms) are used. Shrinkage strain is measured using:

- **Length comparator**
- **Mechanical or digital dial gauges**

The shrinkage is expressed as **microstrain (με)**:

$$\text{Shrinkage Strain} = \frac{\Delta L}{L} \times 10^{6} (\mu\varepsilon)$$

Typical drying shrinkage for ordinary concrete:

- 400 to 800 με at 1 year

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3. Effects on Concrete Structures

- **Deflections**: Creep and shrinkage contribute to excessive long-term deflections.
- **Cracking**: Shrinkage can induce tensile stresses that exceed tensile strength.
- **Prestressed Concrete**: Loss of prestress force due to creep and shrinkage is critical.
- **Structural Stability**: In indeterminate structures, redistribution of internal forces can occur.

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4. Control and Mitigation Measures

4.1 For Creep

- Use **low w/c ratio** and **high-strength concrete**.
- Increase **aggregate content** (preferably with low creep aggregates like basalt).
- Use **supplementary cementitious materials** (like fly ash, silica fume).
- Provide adequate **curing** before loading.
- Design with **creep coefficients** in mind using IS:456 or ACI guidelines.

4.2 For Shrinkage

- Ensure **adequate curing** (minimum 7–14 days).
- Use **shrinkage-reducing admixtures** (SRA).
- Incorporate **proper joint spacing** in slabs and pavements.
- Use **low heat cements** for massive structures.
- Optimize **aggregate size and gradation**.
- Provide **steel reinforcement** to resist shrinkage cracks.

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5. Relevant IS Codes and Standards

- **IS 456:2000** – Code of Practice for Plain and Reinforced Concrete
- **IS 1199:2018** – Methods of Sampling and Analysis of Concrete
- **IS 516:2018** – Methods of Tests for Strength of Concrete
- **IS 1343:2012** – Code of Practice for Prestressed Concrete
- **ACI 209R** – Prediction of Creep, Shrinkage, and Temperature Effects

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6. Mathematical Modeling of Creep and Shrinkage

6.1 Creep Modeling Approaches

Several mathematical models are used to predict the long-term creep behavior of concrete. These are especially important in structural design software and finite element analysis. Key models include:

a) Linear Viscoelastic Model

- Assumes that concrete behaves like a **combination of springs (elastic elements)** and **dashpots (viscous elements)**.

- Common analogs:
  - **Maxwell Model** (series combination of spring and dashpot)
  - **Kelvin-Voigt Model** (parallel combination)
  - **Burger's Model** (Maxwell + Kelvin-Voigt)

b) Creep Compliance Function ($J(t, t_0)$)

$$\varepsilon(t) = J(t, t_0) \cdot \sigma$$

Where:

- $\varepsilon(t)$: total strain at time t
- σ: applied constant stress
- $J(t, t_0)$: compliance function, depending on loading time t_0

c) Creep Coefficient Method ($\varphi(t, t_0)$)

$$\phi(t, t_0) = \frac{\text{Creep strain}}{\text{Instantaneous elastic strain at } t_0}$$

Used widely in design standards like **IS 456**, **ACI 209**, and **Eurocode 2**.

6.2 Shrinkage Prediction Models

Models account for drying, environmental conditions, and material properties.

a) Empirical Equations (IS and ACI models)

IS 456:2000 provides:

$$\varepsilon_{sh} = k_3 \cdot \varepsilon_{sh0}$$

Where:

- ε_{sh0}: basic shrinkage strain (dependent on concrete grade)
- k_3: function of section size and curing

ACI 209R-92 gives time-dependent shrinkage strain based on:

- Relative humidity
- Volume-to-surface ratio
- Cement content and type

b) B3 Model (Bazant's Model)

A comprehensive and semi-empirical model developed at Northwestern University, USA, widely used in advanced research and software applications.

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7. Practical Examples and Case Studies

7.1 Example – High-Rise Building

A 30-storey tower uses **post-tensioned slabs**. Improper accounting of creep led to:

- **Excessive downward deflection** at mid-spans
- **Misalignment of cladding panels**
- Post-construction retrofitting required

7.2 Example – Bridge Segmental Construction

Creep and shrinkage caused:

- **Longitudinal shortening of segments**
- **Displacement of bearings and expansion joints**
- Need for **creep compensation measures** during erection

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8. Experimental Investigation Techniques

8.1 Creep Test Setup

- Cylindrical or prismatic specimens (100 × 200 mm typical)
- Applied stress ~30% of cube strength
- Measurements taken with:
  - **Mechanical dial gauges**
  - **Strain gauges**
  - **Digital extensometers**

8.2 Shrinkage Test Setup

- Sealed and unsealed specimens for autogenous vs drying shrinkage

- Environmental chamber used to simulate controlled humidity and temperature
- Standard reference: **ASTM C157**, **IS 1199**

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9. Importance in Modern Construction Practices

9.1 Precast and Prestressed Concrete

- **Pre-tensioned beams** are especially vulnerable to prestress loss due to creep and shrinkage
- **Shrinkage-induced cracking** is common in thin precast panels

9.2 High-Performance Concrete (HPC)

- Lower w/c ratio → lower permeability but higher autogenous shrinkage
- Need for **shrinkage-compensating admixtures**

9.3 Mass Concrete Structures

- Thermal shrinkage becomes significant
- **Differential volume changes** between core and surface can cause internal cracking

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10. Current Research Trends and Innovations

- **Nano-silica** and **graphene additives** to reduce creep and shrinkage
- Use of **self-healing concrete** to counteract shrinkage-induced cracks
- **AI-based prediction models** for long-term deformations
- Development of **3D printed concrete**, where early-age shrinkage is critical

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