Chapter 7: High Performance Concrete Mixture Proportioning

Introduction

High Performance Concrete (HPC) represents a significant advancement in the field of concrete technology. Unlike conventional concrete, HPC offers superior properties such as high strength, enhanced durability, reduced permeability, and resistance to environmental aggressors. Its use is crucial in structures exposed to extreme loads or harsh environments, such as bridges, high-rise buildings, marine structures, and nuclear containment systems.

The performance of HPC is highly dependent on the careful selection of materials and precise mixture proportioning. Proportioning HPC is not simply a scaled-up version of normal concrete design; it involves a scientific understanding of the interaction between constituents and the targeted performance characteristics.

7.1 Characteristics of High Performance Concrete

High Performance Concrete is designed to meet specific performance requirements that are not achievable with conventional concrete. Key characteristics include:

- **Compressive Strength**: Typically exceeding 60 MPa, and in some cases going beyond 100 MPa.
- **Low Permeability**: Minimizes ingress of chlorides, sulfates, and other aggressive agents.
- **High Durability**: Resistance to freeze-thaw cycles, alkali-silica reaction, and chemical attacks.
- **Improved Workability**: Achieved with the use of superplasticizers and optimized aggregate grading.
- **Early Strength Gain**: Facilitates faster formwork removal and rapid construction.
- **Controlled Heat of Hydration**: Especially in mass concrete applications.

- **High Modulus of Elasticity** and **Low Creep**: Ensuring minimal long-term deformations.

7.2 Materials for HPC

1. Cement

- Use of Ordinary Portland Cement (OPC) Grade 43 or 53.
- Blended cements like Portland Pozzolana Cement (PPC) or Portland Slag Cement (PSC) are also used for durability.
- Compatibility with admixtures is crucial.

2. Supplementary Cementitious Materials (SCMs)

- **Silica Fume**: Enhances strength and durability, used in 5–10% replacement.
- **Fly Ash**: Improves workability and long-term strength.
- **Ground Granulated Blast Furnace Slag (GGBS)**: Enhances durability and reduces heat of hydration.
- **Metakaolin**, **Rice Husk Ash**, and **Alccofine** are also used for specific performance targets.

3. Aggregates

- High-quality, well-graded coarse and fine aggregates.
- Low water absorption and minimal deleterious materials.
- Maximum aggregate size typically 10–20 mm for HPC.

4. Chemical Admixtures

- **Superplasticizers** (High Range Water Reducers): Essential for achieving high workability without increasing water content.
- **Retarders**: To control setting time.
- **Accelerators**: For early strength.
- **Viscosity Modifying Agents (VMAs)**: For pumpability and stability in SCC (Self-Compacting Concrete).

5. Water

- Potable quality water with no harmful salts or organic impurities.
- Water-cement ratio as low as 0.25–0.35.

7.3 Principles of Mixture Proportioning for HPC

Designing HPC requires a performance-based approach. The major principles include:

1. Target Performance Specification

- Define the properties required in fresh and hardened states: strength, slump, setting time, durability, etc.

2. Selection of Appropriate Materials

- Choose compatible combinations of cement, SCMs, aggregates, and admixtures.

3. Optimization of Particle Packing

- Use of fine materials (silica fume, fly ash, etc.) to fill voids between cement grains.
- Improves density and reduces porosity.

4. Water-Binder Ratio

- Lower w/b ratio (typically 0.25–0.35) ensures low permeability and high strength.
- Must be balanced with the workability requirements.

5. Aggregate Grading

- Continuous grading to ensure minimum voids and maximum density.
- Avoid gap grading to prevent segregation.

6. Use of Admixtures

- Superplasticizers are used to reduce water demand without affecting workability.
- VMAs may be used where segregation is an issue.

7. Trial Mixes

- Essential for validating lab designs under real conditions.
- Adjustment based on setting time, slump, strength, and durability indicators.

7.4 Mix Design Procedure for HPC

Unlike standard IS:10262 methods for normal concrete, HPC design relies on empirical and experimental data. A general step-wise approach is:

Step 1: Define Requirements

- Characteristic compressive strength (fck)
- Workability (slump or flow)
- Exposure conditions
- Durability requirements

Step 2: Select w/b Ratio

- Based on target strength and durability.
- For HPC: generally 0.25 to 0.35.

Step 3: Estimate Binder Content

- Typically higher than conventional concrete.
- Total binder content = Cement + SCMs (Fly ash, Silica fume, etc.)
- Ranges between 400–600 kg/m^3.

Step 4: Select Proportions of SCMs

- Silica fume: 5–10%
- Fly ash: 15–30%
- GGBS: 25–50%

Step 5: Aggregate Proportions

- Coarse aggregates: 40–50% of total volume.
- Fine aggregates adjusted to maintain workability and packing density.

Step 6: Determine Admixture Dosage

- Based on manufacturer's recommendations.
- Adjust during trial mixes.

Step 7: Mixing and Testing

- Perform trial batches.
- Check for slump, air content, compressive strength, and durability indicators (RCPT, water absorption).

Step 8: Modify and Finalize

- Refine mix design based on test results.
- Ensure compliance with structural and durability requirements.

7.5 Durability Considerations in HPC Proportioning

Durability is a critical component in HPC mix design:

- **Permeability**: Controlled by lowering the w/b ratio and densifying the matrix.
- **Chloride Penetration Resistance**: Improved with silica fume and fly ash.
- **Sulfate Resistance**: Use of low C3A cement and pozzolanic materials.
- **Carbonation Resistance**: Dense matrix and cover depth are key.
- **Freeze-Thaw Resistance**: Use of air entrainment if necessary in cold climates.

7.6 Special Types of HPC

1. Self-Compacting High Performance Concrete (SCHPC)

- Flows under its own weight, requires no vibration.
- Needs precise control of viscosity and segregation resistance.

2. Reactive Powder Concrete (RPC)

- Extremely high strength (150–800 MPa).
- Uses very fine powders and no coarse aggregates.

3. Fiber Reinforced High Performance Concrete

- Incorporates steel, glass, or synthetic fibers.
- Improves ductility, impact resistance, and crack control.

7.7 Challenges in HPC Proportioning

- **Material Compatibility**: Especially between cement and admixtures.
- **Mixing Requirements**: HPC requires high energy mixing to disperse particles uniformly.
- **Workability Retention**: Slump loss is rapid, requiring modified admixtures or delayed casting.
- **Cost**: HPC is expensive due to special materials and quality control, hence optimized usage is critical.

7.8 Quality Control in High Performance Concrete

Ensuring consistency and meeting performance targets in HPC requires **stringent quality control** at all stages of concrete production:

A. Material Quality Checks

- **Cement**: Test for fineness, soundness, and consistency.
- **SCMs**: Ensure they meet IS codes (e.g., IS 3812 for fly ash).
- **Aggregates**: Check shape, surface texture, moisture content, and grading daily.
- **Water**: Test for pH, alkalinity, and impurities.
- **Admixtures**: Confirm compatibility with the selected cement.

B. Batching and Mixing

- Automated batching systems with accurate weigh scales are ideal.
- Sequence of adding materials is critical in HPC. Typically:
    a. Add 50% water with aggregates.
    b. Add cementitious materials.
    c. Add remaining water and admixtures.
- High shear mixers or pan mixers are preferred over drum mixers.

C. Fresh Concrete Testing

- **Slump Test** or **Slump Flow Test** (for SCC variants).
- **Air Content** by pressure meter (if air-entrainment is used).
- **Temperature** check at batching and pouring.
- **Setting Time** and **Workability Retention**.

D. Hardened Concrete Testing

- **Compressive Strength** (at 1, 3, 7, 28, and 56 days).
- **Modulus of Elasticity**.
- **Rapid Chloride Penetration Test (RCPT)**.
- **Water Absorption**, **Shrinkage**, and **Creep** tests.
- **Non-destructive Tests (NDT)** like rebound hammer or ultrasonic pulse velocity (UPV).

7.9 Field Applications and Placement of HPC

Proper placement and curing techniques are crucial for achieving desired performance in HPC structures.

A. Transportation and Handling

- Transport immediately after mixing to prevent slump loss.
- Use agitator trucks with controlled revolution speed.
- Minimize delay between mixing and placing (<60 minutes ideally).

B. Placement and Compaction

- For conventional HPC, use mechanical vibrators judiciously.
- For Self-Compacting HPC, avoid vibration altogether.
- Ensure formwork is leak-proof to prevent paste loss.

C. Curing Methods

- Start curing immediately after initial set.
- Use **membrane curing**, **wet burlap**, **ponding**, or **steam curing** (especially in precast plants).
- Steam curing accelerates strength gain but must be controlled to avoid thermal cracking.

D. Hot Weather and Cold Weather Concreting

- In hot climates: Use chilled water or ice flakes, and delay casting.
- In cold climates: Preheat materials or use set accelerators.

7.10 Case Studies of High Performance Concrete Usage

1. Bandra-Worli Sea Link, Mumbai

- Used HPC of grades M60 and above.
- Required high chloride resistance due to marine exposure.
- Silica fume and GGBS were extensively used.

2. Burj Khalifa, Dubai

- Used specially designed HPC for vertical pumping up to 600 meters.
- Mix included silica fume, fly ash, and high-range water reducers.
- Required early strength gain and very low permeability.

3. Delhi Metro Rail Corporation (DMRC)

- Precast segments made with HPC for high durability and rapid installation.
- Target strength of M60 with slump retention of 2 hours.
- Fly ash and GGBS were part of the mix.

7.11 Recent Advances and Innovations in HPC Mixture Design

A. Use of Nanomaterials

- **Nano-silica** and **Carbon nanotubes** are emerging additives.
- Improve microstructure and early-age strength.
- Still expensive and under research for widespread use.

B. AI and Machine Learning in Mix Design

- Machine learning models predict optimal mix proportions.
- Algorithms reduce trial mixes and improve cost-effectiveness.

C. Carbon-Neutral Concrete

- Blended binders reduce CO_2 emissions.
- Use of industrial waste like **fly ash**, **slag**, and **rice husk ash** helps achieve sustainability goals.

D. 3D Printing and HPC

- HPC is a candidate for 3D printed concrete structures.
- Requires tailor-made rheological properties and rapid setting control.

7.12 Limitations and Considerations in HPC Use

Despite its superior performance, HPC has some practical challenges:

- **Cost**: Materials like silica fume and high-grade admixtures are expensive.
- **Specialized Equipment**: May need high-energy mixers and automated batching plants.
- **Slump Loss**: Requires use of workability-retaining admixtures.
- **Skilled Workforce**: Improper handling may negate performance benefits.
- **Curing Sensitivity**: Any lapse in curing can severely affect durability.

7.13 Recommended Codes and Guidelines

Several Indian and international standards guide HPC design:

- **IS 456:2000** – General guidelines for concrete design.
- **IS 10262:2019** – Concrete mix proportioning (though limited for HPC).
- **IS 9103** – Chemical admixtures.
- **ASTM C494** – Water-reducing admixtures.
- **ACI 211.4R** – Guide for selecting proportions for HPC.
- **IRC SP:70** – Guidelines for HPC in bridges.