1.5 Concrete (Part I)

This section covers the following topics.

- Constituents of Concrete
- Properties of Hardened Concrete (Part I)

1.5.1 Constituents of Concrete

Introduction

Concrete is a composite material composed of gravels or crushed stones (coarse aggregate), sand (fine aggregate) and hydrated cement (binder). It is expected that the student of this course is familiar with the basics of concrete technology. Only the information pertinent to prestressed concrete design is presented here.

The following figure shows a petrographic section of concrete. Note the scattered coarse aggregates and the matrix surrounding them. The matrix consists of sand, hydrated cement and tiny voids.

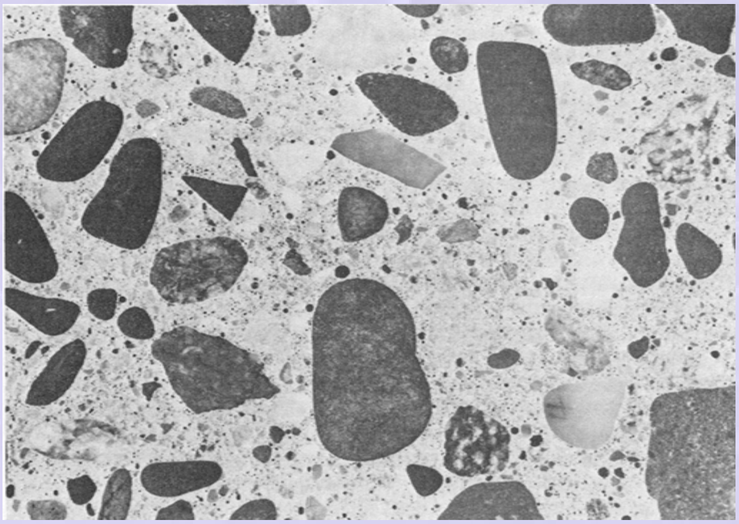

Figure 1-5.1 Petrographic section of hardened concrete

(Reference: Portland Cement Association, *Design and Control of Concrete Mixtures*)

Aggregate

The coarse aggregate are granular materials obtained from rocks and crushed stones. They may be also obtained from synthetic material like slag, shale, fly ash and clay for use in light-weight concrete.

The sand obtained from river beds or quarries is used as fine aggregate. The fine aggregate along with the hydrated cement paste fill the space between the coarse aggregate.

The important properties of aggregate are as follows.

1) Shape and texture
2) Size gradation
3) Moisture content
4) Specific gravity
5) Unit weight
6) Durability and absence of deleterious materials.

The requirements of aggregate is covered in **Section 4.2** of **IS:1343 - 1980**.

The nominal maximum coarse aggregate size is limited by the lowest of the following quantities.

1) 1/4 times the minimum thickness of the member
2) Spacing between the tendons/strands minus 5 mm
3) 40 mm.

The deleterious substances that should be limited in aggregate are clay lumps, wood, coal, chert, silt, rock dust (material finer than 75 microns), organic material, unsound and friable particles.

Cement

In present day concrete, cement is a mixture of lime stone and clay heated in a kiln to 1400 - 1600ºC. The types of cement permitted by **IS:1343 - 1980** (**Clause 4.1**) for prestressed applications are the following. The information is revised as per **IS:456 - 2000**, *Plain and Reinforced – Concrete Code of Practice*.

1) Ordinary Portland cement confirming to **IS:269 - 1989**, *Ordinary Portland Cement, 33 Grade – Specification*.
2) Portland slag cement confirming to **IS:455 - 1989**, *Portland Slag Cement – Specification*, but with not more than 50% slag content.
3) Rapid-hardening Portland cement confirming to **IS:8041 - 1990**, *Rapid Hardening Portland Cement – Specification*.

Water

The water should satisfy the requirements of **Section 5.4** of **IS:456 - 2000**.

"Water used for mixing and curing shall be clean and free from injurious amounts of oils, acids, alkalis, salts, sugar, organic materials or other substances that may be deleterious to concrete and steel".

Admixtures

IS:1343 - 1980 allows to use admixtures that conform to **IS:9103 - 1999**, *Concrete Admixtures – Specification*. The admixtures can be broadly divided into two types: chemical admixtures and mineral admixtures. The common chemical admixtures are as follows.

1) Air-entraining admixtures
2) Water reducing admixtures
3) Set retarding admixtures
4) Set accelerating admixtures
5) Water reducing and set retarding admixtures
6) Water reducing and set accelerating admixtures.

The common mineral admixtures are as follows.

1) Fly ash
2) Ground granulated blast-furnace slag
3) Silica fumes
4) Rice husk ash
5) Metakoline

These are cementitious and pozzolanic materials.

1.5.2 Properties of Hardened Concrete (Part I)

The concrete in prestressed applications has to be of good quality. It requires the following attributes.

1) **High strength** with low water-to-cement ratio
2) **Durability** with low permeability, minimum cement content and proper mixing, compaction and curing

3) **Minimum shrinkage** and **creep** by limiting the cement content.

The following topics are discussed.

1) Strength of concrete
2) Stiffness of concrete
3) Durability of concrete
4) High performance concrete
5) Allowable stresses in concrete.

Strength of Concrete

The following sections describe the properties with reference to **IS:1343 - 1980**. The strength of concrete is required to calculate the strength of the members. For prestressed concrete applications, high strength concrete is required for the following reasons.

1) To sustain the high stresses at anchorage regions.
2) To have higher resistance in compression, tension, shear and bond.
3) To have higher stiffness for reduced deflection.
4) To have reduced shrinkage cracks.

Compressive Strength

The compressive strength of concrete is given in terms of the **characteristic compressive strength** of 150 mm size cubes tested at 28 days (f_{ck}). The characteristic strength is defined as the strength of the concrete below which not more than 5% of the test results are expected to fall. This concept assumes a normal distribution of the strengths of the samples of concrete.

The following sketch shows an idealised distribution of the values of compressive strength for a sizeable number of test cubes. The horizontal axis represents the values of compressive strength. The vertical axis represents the number of test samples for a particular compressive strength. This is also termed as frequency. The average of the values of compressive strength (mean strength) is represented as f_{cm}. The characteristic strength (f_{ck}) is the value in the x-axis below which 5% of the total area under the curve falls. The value of f_{ck} is lower than f_{cm} by 1.65σ, where σ is the standard deviation of the normal distribution.

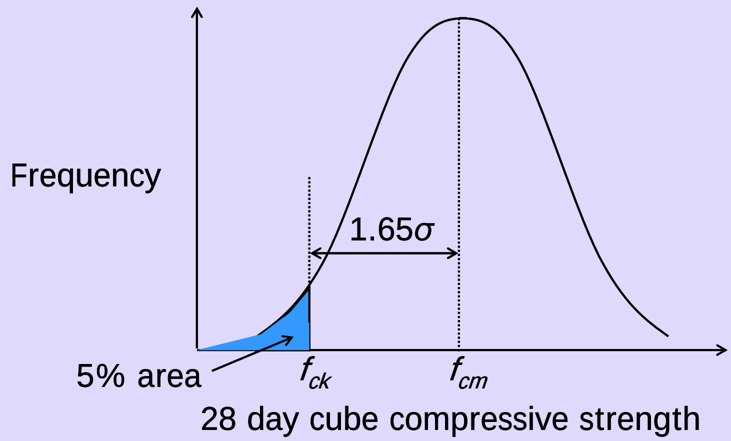

Figure 1-5.2 Idealised normal distribution of concrete strength
(Reference: Pillai, S. U., and Menon, D., *Reinforced Concrete Design*)

The sampling and strength test of concrete are as per **Section 15** of **IS:1343 - 1980**. The grades of concrete are explained in **Table 1** of the Code.

The minimum grades of concrete for prestressed applications are as follows.

- 30 MPa for post-tensioned members
- 40 MPa for pre-tensioned members.

The maximum grade of concrete is 60 MPa.

Since at the time of publication of **IS:1343** in 1980, the properties of higher strength concrete were not adequately documented, a limit was imposed on the maximum strength. It is expected that higher strength concrete may be used after proper testing.

The increase in strength with age as given in **IS:1343 - 1980**, is not observed in present day concrete that gains substantial strength in 28 days. Hence, the age factor given in **Clause 5.2.1** should not be used. It has been removed from **IS:456 - 2000**.

Tensile Strength

The tensile strength of concrete can be expressed as follows.

1) **Flexural tensile strength**: It is measured by testing beams under 2 point loading (also called 4 point loading including the reactions).
2) **Splitting tensile strength**: It is measured by testing cylinders under diametral compression.

3) **Direct tensile strength**: It is measured by testing rectangular specimens under direct tension.

In absence of test results, the Code recommends to use an estimate of the flexural tensile strength from the compressive strength by the following equation.

$$f_{cr} = 0.7\sqrt{f_{ck}} \quad \textbf{(1-5.1)}$$

Here,

f_{cr} = flexural tensile strength in N/mm^2

f_{ck} = characteristic compressive strength of cubes in N/mm^2.

Stiffness of Concrete

The stiffness of concrete is required to estimate the deflection of members. The stiffness is given by the modulus of elasticity. For a non-linear stress (f_c) versus strain (ε_c) behaviour of concrete the modulus can be initial, tangential or secant modulus.

IS:1343 - 1980 recommends a **secant modulus** at a stress level of about 0.3f_{ck}. The modulus is expressed in terms of the characteristic compressive strength and not the design compressive strength. The following figure shows the secant modulus in the compressive stress-strain curve for concrete.

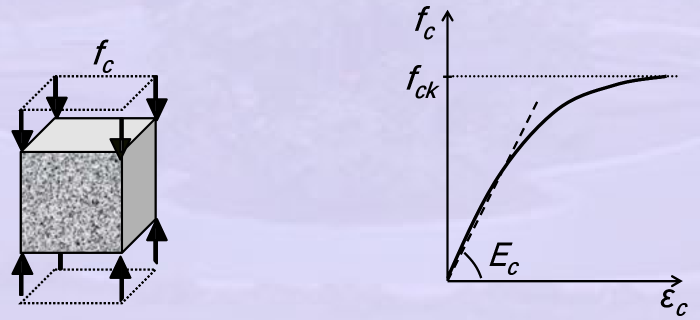

Figure 1-5.3 a) Concrete cube under compression, b) Compressive stress-strain curve for concrete

The modulus of elasticity for short term loading (neglecting the effect of creep) is given by the following equation.

$$E_c = 5000\sqrt{f_{ck}} \quad \textbf{(1-5.2)}$$

Here,

E_c = short-term static modulus of elasticity in N/mm^2

f_{ck} = characteristic compressive strength of cubes in N/mm^2.

The above expression is updated as per **IS:456 - 2000**.

Durability of Concrete

The durability of concrete is of vital importance regarding the life cycle cost of a structure. The life cycle cost includes not only the initial cost of the materials and labour, but also the cost of maintenance and repair.

In recent years emphasis has been laid on the durability issues of concrete. This is reflected in the enhanced section on durability (**Section 8**) in **IS:456 - 2000**. It is expected that the revised version of **IS:1343** will also have similar importance on durability.

The durability of concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. The common durability problems in concrete are as follows.

1) Sulphate and other chemical attacks of concrete.
2) Alkali-aggregate reaction.
3) Freezing and thawing damage in cold regions.
4) Corrosion of steel bars or tendons.

The durability of concrete is intrinsically related to its water tightness or permeability. Hence, the concrete should have low permeability and there should be adequate cover to reinforcing bars. The selection of proper materials and good quality control are essential for durability of concrete.

The durability is addressed in **IS:1343 - 1980** in **Section 7**. In Appendix A there are guidelines on durability. **Table 9** specifies the maximum water-to-cement (w-c) ratio and the minimum cement content for different exposure conditions. The values for moderate exposure condition are reproduced below.

Table 1-5.1 Maximum water-to-cement (w-c) ratio and the minimum cement content for moderate exposure conditions (**IS:1343 - 1980**).

Min. cement content	: 300 kg per m^3 of concrete
Max w-c ratio*	: 0.50

(*The value is updated as per **Table 5** of **IS:456 - 2000**.)

Table 10 provides the values for the above quantities for concrete exposed to sulphate attack.

To limit the creep and shrinkage, **IS:1343 - 1980** specifies a maximum cement content of 530 kg per m^3 of concrete (**Clause 8.1.1**).

High Performance Concrete

With the advancement of concrete technology, high performance concrete is getting popular in prestressed applications. The attributes of high performance concrete are as follows.

1) High strength
2) Minimum shrinkage and creep
3) High durability
4) Easy to cast
5) Cost effective.

Traditionally high performance concrete implied high strength concrete with higher cement content and low water-to-cement ratio. But higher cement content leads to autogenous and plastic shrinkage cracking and thermal cracking. At present durability is also given importance along with strength.

Some special types of high performance concrete are as follows.

1) High strength concrete
2) High workability concrete
3) Self-compacting concrete
4) Reactive powder concrete
5) High volume fly ash concrete
6) Fibre reinforced concrete

In a post-tensioned member, the concrete next to the anchorage blocks (referred to as end block) is subjected to high stress concentration. The type of concrete at the end blocks may be different from that at the rest of the member. Fibre reinforced concrete is used to check the cracking due to the bursting forces.

The following photo shows that the end blocks were cast separately with high strength concrete.

Figure 1-5.4 End-blocks in a bridge deck

(Courtesy: Cochin Port Trust, Kerala)

Allowable Stresses in Concrete

The allowable stresses are used to analyse and design members under service loads. **IS:1343 - 1980** specifies the maximum allowable compressive stresses for different grades of concrete under different loading conditions in **Section 22.8**.

Allowable Compressive Stresses under Flexure

The following sketch shows the variation of allowable compressive stresses for different grades of concrete **at transfer**. The cube strength at transfer is denoted as f_{ci}.

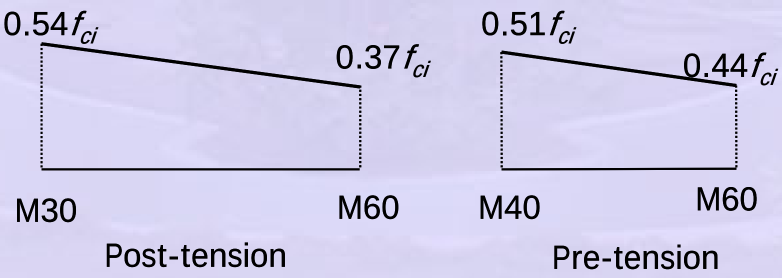

Figure 1-5.5 Variation of allowable compressive stresses at transfer

The following sketch shows the variation of allowable compressive stresses for different grades of concrete **at service loads**.

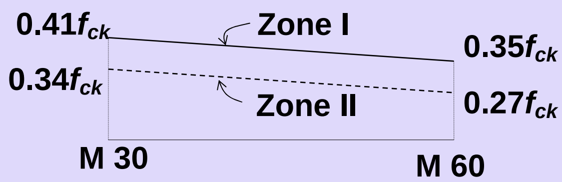

Figure 1-5.6 Variation of allowable compressive stresses at service loads

Here, Zone I represents the locations where the compressive stresses are not likely to increase. Zone II represents the locations where the compressive stresses are likely to increase, such as due to transient loads from vehicles in bridge decks.

Allowable Compressive Stresses under Direct Compression

For direct compression, except in the parts immediately behind the anchorage, the maximum stress is equal to 0.8 times the maximum compressive stress under flexure.

Allowable Tensile Stresses under Flexure

The prestressed members are classified into three different types based on the allowable tensile stresses. The amount of prestressing varies in the three types. The allowable tensile stresses for the three types of members are specified in **Section 22.7**. The values are reproduced below.

Table 1-5.2 Allowable tensile stresses (**IS:1343 - 1980**)

Type 1	No tensile stress
Type 2	3 N/mm^2. This value can be increased to 4.5 N/mm^2 for temporary loads.
Type 3	Table 8 provides hypothetical values of allowable tensile stresses.

The purpose of providing hypothetical values is to use the elastic analysis method for Type 3 members even after cracking of concrete.