CONCRETE TECHNOLOGY

Second Edition

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Preface

Concrete is the most widely used building material. It is versatile, has desirable engineering properties, can be moulded into any shape, and, more importantly, is produced with cost-effective materials. Although recent developments in plastics and other lighter materials have resulted in the replacement of concrete in some applications, the use of concrete worldwide has increased phenomenally, especially in infrastructure projects. In fact, these developments have complimented and improved the performance and use of concrete in structures.

The knowledge of concrete's controlled production, maintenance, testing, and repair is vital for a discerning designer to ensure its optimal use. The large number of failures of structures has underlined the need for a better understanding of the behaviour of concrete, especially in challenging environmental conditions. This, in turn, warrants the need to have a sound knowledge of the selection of materials, mix proportioning, and quality control methods.

About the Book

The book is intended to help students and professional engineers gain a broader understanding of concrete as a construction material. It discusses the subject in its historical perspective together with a chronology of the developments relating to concrete as a material and its applications and technologies. It explains the fundamental concepts of concrete construction in simple language and covers the aspects of material science, mix proportioning, and construction. This book combines sound theory with adequate practical examples based on empirical observations both from the laboratory and the field.

New to the Second Edition

The first edition of the book was published more than 10 years ago and since then there have been revisions of codes of practices both in India and abroad as well as advances in concrete technology practices. This edition, in addition to revision of standard codes, includes recent developments in the field of concrete technology. Some of the prominent changes in this edition are as follows:

- A new chapter on rheological models of concrete (chapter 6) focuses on the flow characteristics of fresh concrete
- Exclusive chapters on the properties of fresh and hardened concrete (chapters 4 and 7)
- A new chapter provides improved treatment of the different stages of manufacture of concrete (chapter 5)
- Updated and revised content with new sections on reactive powder concrete, pervious concrete, geopolymer concrete, and manufactured (M) sand
- Improved pedagogy with numerous additional illustrations and multiple choice questions at the end of each chapter

Content and Coverage

The text explains the theoretical and practical aspects of the subject exhaustively. Incorporating the provisions of the code, IS: 456-2000, it includes the latest developments in the field of concrete construction.

The book begins with a historical account of concrete and developments in this field in Chapter 1. Chapters 2 and 3 discuss the properties of constituent materials and chemical and mineral admixtures. Chapters 4 to 9 discuss the properties of fresh and hardened concrete, different stages of manufacture of concrete, rheological models of concrete, and mix proportioning to produce concrete to suit specific requirements. Chapter 10 is devoted to a discussion on the various types of steel reinforcement used in concrete structures. The effect of corrosion and durability of concrete are discussed in Chapters 11 and 12, respectively.

Research in material technology has led to the development of lightweight concrete for reducing foundation loads, high and ultrahigh-strength concrete for applications in tall buildings and bridges, high-performance concrete for special performance requirements, special concretes such as polymer concrete for high durability, and steel-fibre-reinforced concrete for preventing cracks in concrete. These have been discussed in detail in Chapters 13 to 17. Various aspects of the production of ready mix concrete and its use are covered in Chapter 18. The construction of structures such as dams and large bridge piers, where the dimensions of the volume of concrete necessitate taking extra care of excessive amounts of heat of hydration, needs special mass concrete. The issues involved in mass concreting are discussed in Chapter 19.

Reinforcement detailing and formwork erection are an essential part of concrete construction at the site. The ultimate goal of achieving excellent infrastructure depends on the people on the job, who need to know the intricacies of such detailing aspects as tolerances and accuracy of fabrication. It is well known that the best of designs using the most sophisticated computer programs will not make the structure behave well unless the concrete construction and the reinforcement detailing practice conform to the prescribed specification. This important aspect has been discussed in Chapter 20. Chapter 21 discusses structural concrete block masonry, and Chapter 22 deals with the quality control issues involved in the production of concrete and construction of concrete structures. Recognizing the importance of the rehabilitation of ailing structures, Chapters 23 and 24 discuss repair materials and technologies. Concrete structures exposed to aggressive environmental conditions are discussed in Chapter 25, and Chapter 26 deals with underwater concrete structures.

Concrete testing is gaining importance from the point of view of the need to monitor and evaluate the existing concrete structures for their safety and upkeep. Important testing techniques and procedures are discussed in Chapter 27. Chapters 28 to 31 focus on special materials in construction, concreting machinery and equipment, performance and maintenance of concrete structures, and future trends in concrete technology, respectively.

Acknowledgements

While writing the book, references have been made to many previous works on the subject. As an acknowledgement, these works have been included in *Bibliography*. I acknowledge with reverence my professors, P. Purushothaman, S.R. Srinivasan at the College of Engineering, Guindy, Chennai, and Thomas Paulay and R. Park at the University of Canterbury, Christchurch, New Zealand. I owe my learning of the subject to them. I thank my colleagues at the Indian Institute of Technology Madras for their constructive suggestions.

I am indebted to my parents, R. Pushpavathi and A.M. Ramalingam, who have been an abiding source of inspiration for me. I owe heartfelt thanks to my wife Vanaja for her unwavering love and support, without which this book would not have been possible.

Finally, I acknowledge the support and guidance provided by the editorial team at the Oxford University Press India and thank the Press for giving me an opportunity to author this book for the benefit of both students and professionals.

This book presents the latest scientific advances in concrete technology and addresses all the variability of concrete to enable a comprehensive treatment of interrelated issues. I hope that this work will be welcomed by the profession as an authoritative resource on concrete construction. Comments and suggestions for the improvement of the book are welcome and can be sent at santhaar@gmail.com.

A.R. SANTHAKUMAR

Contents

CHAPTER 1

Concrete: Past, Present, and Future

Concrete is weak compared to steel. It is also brittle. Yet, it is the most widely used building material. This is because of its versatility, and because it has desirable engineering properties. It can be made on-site using easily available materials and can be moulded into any shape and the surface can be textured and coloured for aesthetic purposes. Most importantly, it can be produced with cost-effective materials.

Can we use wood to build a dam or a furnace? Can we use steel to lay a pavement? Or, can we use asphalt to construct a building frame? The answer is obviously ‘No’. However, we can use concrete to build all these structures elegantly. In the words of J.W. Kelly, ‘*It is used to support, to enclose, to surface and to fill*.’

Concrete possesses very good water-resistant properties and, hence, can be used in intake towers for drawing water, dams and water tanks for storing, and canal linings for transporting water. Structural elements are often built with reinforced concrete. Examples are pile foundations, footings, beams, floors, walls, columns, and roofs.

Concrete is a strong and tough material. Reinforced concrete resists cyclones, earthquakes, blasts, and fires much better than timber and steel if designed properly. Flying fragments pose a great hazard to people during cyclones and tornadoes. Walls built with concrete have sufficient strength and mass to resist wind-driven debris compared to wood or sheet steel walls.

When compared to wood or steel, concrete has an inherent fire-resistant property. It regains its properties on cooling when the temperatures reached and the duration of the fire are not abnormally high.

Compared to many other engineering materials, such as steel and rubber, concrete requires less energy input for its manufacture. Currently, a large number of mineral admixtures, which are waste products of other industries, are being beneficially used in making quality concrete. Thus, from the consideration of energy and resource conservation and sustainability of the environment, concrete is the most preferred material.

In India, reinforced concrete has been used extensively for the construction of houses, buildings, roads, bridges, and dams. The advantages of concrete are well known to engineers and architects. However, the use of concrete for low-cost housing and rural housing has not been extensive. There are many areas where there could be a considerable increase in the use of cement-based products. As compared to burnt clay bricks, which use the fertile topsoil depriving it for agricultural purpose, precast products such as concrete lintels, joists, and concrete framework for doors and windows provide better and cost-effective solutions for building affordable houses. Such houses require less maintenance compared to those made from other materials, making concrete competitive when lifecycle cost is considered.

1.1 Historical Background

Though concrete is an extensively used material today, there was a time when it was still unknown. In those days, structures were built using burnt clay bricks, stone, or steel. The Pyramids of Giza, Egypt (West 1985), were built around 2540 BC, that is, nearly 45 centuries ago. The Great Wall of China (Calder 1983), completed in about 230 BC, is 20 centuries old. However, the Romans made a number of structures with concrete. The Pantheon in Rome, Italy (Gunnar 1997), was constructed nearly 19 centuries ago. It is a 6-m-thick mass concrete covered by a 43.3 m diameter concrete dome roof. The fall of the Roman Empire led to the loss of information about concrete technology. The Egyptians, Romans, Chinese, Mayans, and Indians (National Geographic Society 1986) were using various kinds of natural cements at the beginning of 1700 AD. These cements contained some form of lime-sand mortar.

Around 1756, John Smeaton, trying to build the Eddystone Lighthouse (Gunnar 1997), conducted a series of experiments to find a substance that will set underwater. He used pozzolana for his construction and published the results of his experiments in a paper in 1791. Until the mid-19th century, concrete was made using lime. It is actually the invention of the steam locomotive that created a need for concrete for building rail bridges in Europe. In 1824, Joseph Aspdin (Mehta 1986) patented the material that he called *Portland cement*. The name was chosen because the concrete produced out of this cement resembled a well-known quality of stone mined on the isle of Portland in Dorset, England. However, it was I.C. Johnson (Evans 1998) who in 1845 noticed that sintered material produced superior cement. He produced this superior cement for the first time in his factory. However, lime still continued to be used in combination with Portland cement to provide better workability to the fresh mixture. Thus, the cement we use today has been in production for the last 150 years (Table 1.1).

Table 1.1 History of development of concrete structures

Year	Structures/Techniques
2540 BC	The Pyramid of Khufu (Cheops) is built in Giza, Egypt.
100 AD	The Pantheon is built in Rome, Italy.
1757	Leonhard Euler publishes the equations for elastic buckling of columns.
1773	Coulomb becomes the first to understand the theory of beams ($\sigma = My/I$), but his results were not widely known.
1816	A concrete bridge is constructed over the Dordogne River in Souillac, France.
1824	Joseph Aspdin patents a material that he calls Portland cement.
1850	The invention of reinforced concrete is credited to Joseph-Louis Lambot of France who built a rowboat, which was exhibited in the Paris exposition of 1854.
1853	Francois Coignet of France builds a 6-m-long roof using reinforced concrete.
1889	The Eiffel tower is completed, supported on massive concrete foundations.
1908	Concrete stress distribution is proposed.
1924	The world's production of Portland cement goes up to 50 million tonnes/year. An increasing number of bridges are being made of concrete to provide roads for the cars that were being mass produced on assembly lines.
1928	Patent by Eugène Freyssinet for prestressed concrete.
1950	Fly ash, a waste material extracted from the flue gas of coal-fired power plants, begins to be widely used to reduce the amount of cement required in concrete.
1976	It is discovered that the strength of concrete can be increased by adding micro-silica. Silica fume is obtained as a result of the environmental treatment of fumes from silicon furnaces.
1994	Reactive powder concretes with strength of 700 MPa and more are developed by Pierre Richard in France.
1997	The Confederation bridge in Canada is completed, with span of 250 m and a total length of 12.9 km. Concrete of strength up to 90 MPa is manufactured.

Since then, the developments related to concrete across the world have manifested themselves in the different concrete technologies used at construction sites today. Changes in material technology have led to new ways of manufacturing and delivering concrete. On-site mixing is slowly giving way to ready-mixed concrete. The ongoing developments in concrete-pumping techniques have presented new ways of transporting and placing concrete. From the humble beginning of Portland cement, today researchers are working on improving the strength of concrete to 700 MPa (reactive powder concrete), which was first developed by Pierre Richard in France.

India has been building noteworthy structures for thousands of years. There is enough evidence of the use of bricks in India nearly 3000 years back during the Indus Valley Civilization. The excavations of Mohenjo Daro and Harappa indicate this. Just as in Europe, the railway network in India too used bridges made of steel and concrete for crossing rivers. Prestressed concrete was used for the first time to build garages for military tanks in 1940. The first prestressed concrete bridge was constructed in 1949 on the Assam rail link, followed by the Palar road bridge near Chennai in 1952 with 23 spans of 28.4 m each. Concrete has been the main material for building high dams (Bhakra Dam, Bilaspur, 226 m high), long bridges (Ganga Bridge, Patna, 5575 m long; second Thane creek bridge, Mumbai, 1.837 km long; six-lane second Hooghly cable-stayed bridge, Kolkata, 837 m long), and monumental structures (Bahai Temple, New Delhi).

1.2 Components of Concrete

Hardened concrete can be considered to have three distinct phases: (a) the hardened cement paste (HCP) or matrix, (b) the aggregate, and (c) the interfacial or transition zone (TZ) between the HCP and the aggregate. For optimum performance, all the three phases should be considered explicitly. Figure 1.1 shows the cut and polished surface of concrete. In this figure, the first two phases can be identified easily.

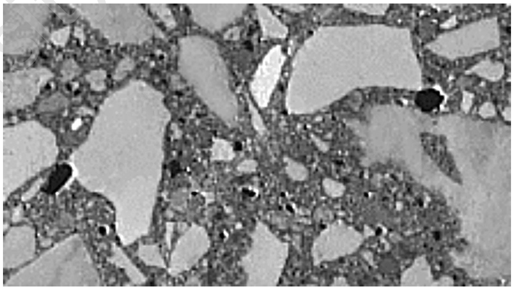

Fig. 1.1 Cut and polished surface of concrete

When examined under a powerful electron microscope, the structure of HCP in the vicinity of large aggregates is observed to be very different from the structure of bulk paste. The zone of 10–50 mm around the large aggregate is seen to be a weak porous transition zone. The aforementioned three phases can also have sub-phases. For instance, the aggregate phase consists of several minerals and voids. In addition, the structure of concrete undergoes changes with time and location (space). It is affected by temperature, humidity, and time. A brief description of the individual components of concrete is essential to understand the behaviour of these phases.

The HCP is about 30–40% of the volume of concrete. It is a product of Portland cement and water. The quantity of water is about 7–15% and cement about 14–21% of the volume. Their relative quantities affect the strength, and the strength is mainly controlled by the water–cement ratio.

The aggregates constitute 60–70% of the volume and comprise both fine and coarse aggregates. The aggregates are inert fillers. They contribute to concrete's weight and deformation characteristics. Figure 1.2 shows the constituents of concrete. Concrete also contains air, which is a part of the paste phase. It comes from two sources. Nearly 2% of the volume of concrete is entrapped air, out of which about 1–2% is sometimes deliberately introduced as entrained air using an air-entraining admixture. The entrained air in concrete makes it resist freeze–thaw cycles better, making it durable. However, it certainly causes a reduction in strength and density.

The important properties of concrete are (a) air content, (b) fluidity, (c) strength, (d) setting time, and (e) durability. Admixtures are added to modify one or more of these properties in the fresh or hardened state of concrete.

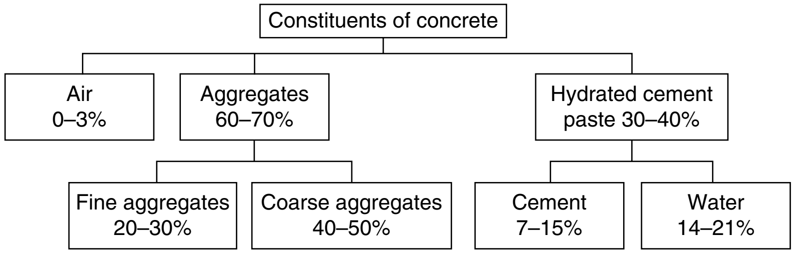

Fig. 1.2 Constituents of concrete

1.3 Strength Development

The transformation of fresh concrete to hardened concrete takes place in the following three stages:

1. **Fresh stage** In this stage, concrete is plastic. It is workable and capable of being moulded.
2. **Transition stage** In this stage, the workability of concrete reduces and the process of setting begins. The excess water evaporates along with heat of evolution, and its strength slowly develops.
3. **Hardened stage** In the final stage, concrete becomes stiff and gains enough strength to support a load. Therefore, it has sufficient load-carrying capacity as per design.

The strength on the 28th day of this process is taken as the reference strength for hardened concrete. The 28th day is chosen because this gives an even four weeks' time ($7 \times 4 = 28$). For assessing the strength of concrete, cubes are tested on the same day of the week. That is, cubes made on a Monday are tested on the Monday four weeks later. In 28 days, most of the strength of normal concrete made with standard ordinary Portland cement is developed.

The strength development of concrete depends on its age, water–cement ratio (w/c), air content, cement type, aggregate type, paste aggregate bond, and the curing and environmental conditions in which it was made.

1.4 Different Types of Concrete

Concrete can be classified into various categories depending on the density and strength recommended by IS: 456-2000.

Based on density, concrete is classified as lightweight, normal-weight, and heavyweight concrete. The densities of these concretes are given in Table 1.2.

Table 1.2 Classification of concrete based on density

Classification	Density (kN/m^3)
Lightweight concrete	18
Normal-weight concrete	24
Heavyweight concrete	32

The aggregates used in making concrete contribute mainly to its density. Normal-weight concrete is produced using natural sand and crushed stone (granite). For lightweight concrete, either lightweight aggregates, such as pumice, or pyro-processed and bloated aggregates, are used. These concretes are used for applications in which the load of gravity is to be reduced, e.g., for reducing the load on foundations. Heavyweight concrete is produced using high-density aggregates such as hematite or scrap steel pieces. These concretes are used for radiation shielding or increasing the weight of a structure for stability purposes.

The standard code of practice for plain and reinforced concrete, IS: 456-2000, has classified concrete on the basis of strength. Table 1.3 shows the three main categories based on strength.

Table 1.3 Classification of concrete based on strength

Classification	Maximum strength (MPa)	Type
Ordinary concrete	<20	Low-strength
Standard concrete	20–40	Medium-strength
High-strength concrete	40–80	High-strength

Table 1.4 Typical proportions of materials used in concretes of different grades

Material	Ordinary		Standard		High-strength	
	kg/m^3	% vol.	kg/m^3	% vol.	kg/m^3	% vol.
Cement	255	8.1	356	11.3	510†	16.2
Water	178	17.6	178	19.7	178	17.7
Fine aggregate	800	29.9	848	31.7	889	32.6
Coarse aggregate	1170	43.7	1032	38.5	872	32.5
Cement paste						
Mass %	18		22		28	
Volume %	25		30		35	
w/c ratio by mass	0.69		0.50		0.35	
Strength*	15		30		55	

*Strength refers to the 28-day cube compressive strength as per IS specification.
†The cement content may be reduced using suitable admixtures.
Note: 100 kg/m^3 = 1 kN/m^3.

The typical proportions of constituent materials used to produce concretes of different types are shown in Table 1.4. These values are based on tests conducted with available aggregates and the standard OPC 43 grade cement. These values are only for comparison, not for field use. For field use, proper mix design, which has been explained in a later chapter, should be implemented and used based on field trial mixes. These values are based on the commercial mix designs used by the Building Technology Centre, Anna University.

There are many other special concretes such as fibre-reinforced concrete, latex-modified concrete, and roller-compacted concrete. The properties of these concretes are discussed in later chapters.

1.5 Units of Measurement

Most of the original developments in concrete technology occurred in Europe and the USA. The system of measurement used for centuries in the UK, the Commonwealth, and the USA has been the Imperial (British) system, based on the foot-pound-second (FPS) system. During the French Revolution, a system known as the metric system, based on the centimetre-gram-second (CGS) system, was introduced in France. Most countries have now switched over to the modernized form of the metric system known as the Systeme International d' Units (SI) or the International System of Units. It was agreed to adopt this system at the General Conference on Weights and Measures in 1960 by as many as 30 participating countries.

Today, however, the USA is the only country in the world using English units—feet (ft) for length, pounds (lb) for weight, and pounds per square inch (psi) for stress. Though in India we have generally adopted SI units, the FPS system is still in use in the construction industry; for example, a wall is still referred to as a 9" wall. This is primarily due to our brick size being in FPS units (9" × 4.5" × 3"). To enable our construction industry to participate in multinational activity, it is necessary to adopt the accepted SI system of measurement.

Table 1.5 Multiples of 10 and prefixes used in SI measurement

Multiplication factor expressed as a number	Multiplication factor expressed as a power of 10	Prefix	SI prefix symbol
10	10^1	deca	da
100	10^2	hecto	h
1000	10^3	kilo	k
1,000,000	10^6	Mega	M
1,000,000,000	10^9	Giga	G

Table 1.6 Sub-multiples of 10 and prefixes used in SI measurement

Sub-multiplication factor expressed as a number	Sub-multiplication factor expressed as a power of 10	Prefix	SI prefix symbol
0.1	10^{-1}	deci	d
0.01	10^{-2}	centi	c
0.001	10^{-3}	milli	m
0.000001	10^{-6}	micro	μ
0.000000001	10^{-9}	nano	n

Since both these systems are prevalent in the field of concrete construction, one must be conversant with English as well as SI units until a complete change to SI units takes place. That is, when we manufacture metric bricks, metric sieves, and think and act metric.

The SI system is based on the metre, the kilogram, and the second. Multiplying or dividing the basic quantities by multiples of 10 provides larger or smaller units. Each quantity thus formed has a prefix. Kilo denotes thousand times, Mega denotes million times, micro denotes a millionth part, and milli denotes a thousandth part. A complete list of the symbols and names of these prefixes expressed as multiplication and sub-multiplication factors of 10 and its powers is given in Tables 1.5 and 1.6, respectively.

In this book, we will be extensively using units for length, force, and pressure. The unit of force is Newton (N) and that of pressure is Pascal (Pa). One newton is the force required to accelerate 1 kg of mass by 1 m/s^2. A stress of 1 N/m^2 is expressed as 1 Pa. In order to represent very large or very small quantities, accepted prefixes are used for units. A list of commonly required conversion factors is given in Table 1.7.

1.6 New Developments and Future Trends

The many changes that have taken place in concrete technology over the last decade have led to the development of high-strength, high-performance concretes. Although the chemical composition of ordinary Portland cement has remained more or less the same, the proportions of the elements have been modified and the manufacturing techniques have been refined. This has led to the development of cements with higher strengths. The development of high-strength cements has made it possible to achieve economy since lesser quantities of high-strength cement are needed to provide much stronger and durable structures. New supplementary cementitious materials and pozzolans such as ground blast-furnace slag, metakaolin, fly ash, and silica fume are being increasingly used as additives along with new varieties of superplasticizers and viscosity modifying agents. These have helped in producing very efficient high-performance concretes.

The aforementioned developments in construction technology have led to the introduction of newer methods for efficient mixing, transportation, and placing of wet concrete. These include computer-controlled mixing, concrete pumping, and improvements in shotcreting and formwork technologies.

Table 1.7 Conversion table

To convert	Into	Multiply by	To convert	Into	Multiply by
Length			Fluid ounces (fl. oz)	Millilitres (mL)	28.41
Inches (in.)	Millimetres (mm)	25.4	Pints (p)	Litres (L)	0.568
Inches (in.)	Centimetres (cm)	2.54	Gallons (G)	Litres (L)	4.55
Feet (ft)	Metres (m)	0.3048	*Mass/weight*		
Yards (yd)	Metres (m)	0.9144	Ounces (oz)	Grams (g)	28.35
Miles	Kilometres (km)	1.6093	Pound-mass (lb)	Kilogram (kg)	0.45359
Area			Tons	Tonnes (t)	1.016
Square inches (sq. in.)	Square centimetres (sq. cm)	6.4516	Pound-force (lb-f)	Newtons (N)	4.448
Square feet (sq. ft)	Square metres (sq. m)	0.093	Kilogram force (kg-f)	Newtons (N)	9.807
Square yards (sq. yd)	Square metres (sq. m)	0.836	*Density*		
Acres (ac)	Hectares (ha)	0.405	Pounds per cubic yard (lb/cu. yd)	Kilograms per cubic metre (kg/m^3)	0.5933
Square miles (sq. m)	Square kilometres (sq. km)	2.58999			
Volume			*Pressure*		
Cubic inches (cu. in.)	Cubic centimetres (cm^3)	16.387	Kips per square inch (ksi)	Megapascal (MPa or N/mm^2)	6.895
Cubic ft (cu. ft)	Cubic metres (m^3)	0.0283	*Temperature*		
Cubic yards (cu. yd)	Cubic metres (m^3)	0.7646	Degrees Fahrenheit (°F)	Degrees centigrade (°C)	(°F – 32)/1.8

Today, concrete can be designed for high strength, high performance, or both. Specially desired characteristics such as low heat of hydration, low shrinkage, and high durability in a hostile environment can be designed and achieved. There has also been progress due to the availability of ready-mixed concrete as well as changes in specification, leading towards desired performance rather than desired strength.

Exercises

Review Questions

1. List three reasons for the use of concrete as a building material.
2. Trace the historical development of concrete technology.
3. Why are different units used for measuring strength?
4. What is a transition zone?
5. How is concrete classified according to strength in IS: 456-2000?
6. What are the constituents of concrete? State their relative proportions.
7. How are lightweight and heavyweight concrete produced?
8. How can the use of concrete in rural India be increased?
9. Distinguish between different types of concrete and their behaviours.
10. List some of the important concrete structures built in India, describing their significance.
11. List a few landmark structures built in concrete which may be described as milestones in the development of concrete technology around the world.
12. What are the stages of transformation of fresh concrete to hardened concrete?
13. Why is concrete tested on the 28th day after casting?

Multiple Choice Questions

1. How many distinct phases does the hardened concrete exhibit?
   a. One
   b. Two
   c. Three
   d. Four

2. In the hardened concrete the weakest portion is
   a. Aggregate
   b. Hardened cement paste
   c. Transition zone
   d. All of these
3. The density of concrete is largely influenced by
   a. Aggregates
   b. Water–cement ratio
   c. Cement
   d. Admixtures
4. Admixtures are added to concrete to
   a. Modify the properties
   b. Act as a filler
   c. Reduce the cost
   d. Act as replacement for fine aggregate
5. Before 19th century the binder used to make concrete was
   a. Portland cement
   b. Lime
   c. Admixture
   d. Surki
6. Portland cement was patented by
   a. I.C. Johnson
   b. Coloumb
   c. John Smeaton
   d. Joseph Aspdin
7. The first prestressed concrete bridge was built in India
   a. Near Chennai
   b. In Assam
   c. Near Delhi
   d. Near Mumbai
8. FPS system is still used in
   a. UK
   b. India
   c. USA
   d. China
9. The strength of concrete is based on the cube crushing strength on the
   a. 30th day b. 7th day c. 14th day d. 28th day
10. As per IS: 456-2000, standard concrete should have a strength range of
    a. <20 MPa b. 20 to 40 MPa c. 40 to 89 MPa d. >80 MPa
11. The weight of a cubic metre of normal concrete is about
    a. 24 kN b. 18 kN c. 30 kN d. 6 kN
12. In SI units, compressive strength of concrete is expressed in
    a. psi b. ksc c. MPa d. ksm
13. The major constituent of concrete is
    a. Cement b. Water c. Air d. Aggregates
14. Concrete in a structural member has to pass through
    a. Fresh stage b. Transition stage c. Hardened stage d. All of these
15. Water–cement ratio used to produce high-strength concrete is of the order of
    a. 0.69 b. 0.50 c. 0.35 d. 0.20

Answers to Multiple Choice Questions

1. c	5. b	9. d	13. d
2. c	6. d	10. b	14. d
3. a	7. b	11. a	15. c
4. a	8. c	12. c	