Module
1

Objectives and Methods of Analysis and Design, and Properties of Concrete and Steel

Lesson
2
Properties of Concrete and Steel

Instructional Objectives:

At the end of this lesson, the student should be able to:

- know the properties of concrete in respect of strength, deformation and durability
- know the properties of steel used as reinforcement in concrete structures
- understand the importance of quality control, inspection and testing of concrete and steel in several steps from its basic preparation to the removal of formwork after the construction
- recommend the acceptance of good concrete based on sample test of specimens, core tests, load test and non-destructive tests

1.2.1 Introduction

It is essential that the designer has to acquire a fair knowledge of the materials to be used in the design of reinforced concrete structure. This lesson summarises the characteristic properties of concrete and steel, the two basic materials used for the design. This summary, though not exhaustive, provides the minimum information needed for the design.

1.2.2 Properties of Concrete

Plain concrete is prepared by mixing cement, sand (also known as fine aggregate), gravel (also known as coarse aggregate) and water with specific proportions. Mineral admixtures may also be added to improve certain properties of concrete. Thus, the properties of concrete regarding its strength and deformations depend on the individual properties of cement, sand, gravel, water and admixtures. Clauses 5 and 6 of IS 456:2000 stipulate the standards and requirements of the individual material and concrete, respectively. Plain concrete after preparation and placement needs curing to attain strength. However, plain concrete is very good in compression but weak in tension. That is why steel is used as reinforcing material to make the composite sustainable in tension also. Plain concrete, thus when reinforced with steel bars in appropriate locations is known as reinforced concrete.

The strength and deformation characteristics of concrete thus depend on the grade and type of cement, aggregates, admixtures, environmental conditions and curing. The increase of strength with its age during curing is considered to be marginal after 28 days. Blended cements (like fly ash cement) have slower rate of strength gain than ordinary Portland cement as recognized by code, Depending on several factors during its preparation, placement and curing, concrete has a wide range of compressive strength and the material is graded on the basis of its compressive strength on 28th day also known as "characteristic strength" as defined below while discussing various strength and deformation properties.

(a) Characteristic strength property

Characteristic strength is defined as the strength below which not more than five per cent of the test results are expected to fall. Concrete is graded on the basis of its characteristic compressive strength of 150 mm size cube at 28 days and expressed in N/mm^2. The grades are designated by one letter M (for mix) and a number from 10 to 80 indicating the characteristic compressive strength (f_{ck}) in N/mm^2. As per IS 456 (Table 2), concrete has three groups as (i) ordinary concrete (M 10 to M 20), (ii) standard concrete (M 25 to M 55) and (iii) high strength concrete (M 60 to M 80). The size of specimen for determining characteristic strength may be different in different countries.

(b) Other strengths of concrete

In addition to its good compressive strength, concrete has flexural and splitting tensile strengths too. The flexural and splitting tensile strengths are obtained as described in IS 516 and IS 5816, respectively. However, the following expression gives an estimation of flexural strength (f_{cr}) of concrete from its characteristic compressive strength (cl. 6.2.2)

$$f_{cr} = 0.7\sqrt{f_{ck}} \quad \text{in N/mm}^2 \qquad (1.1)$$

(c) Elastic deformation of concrete

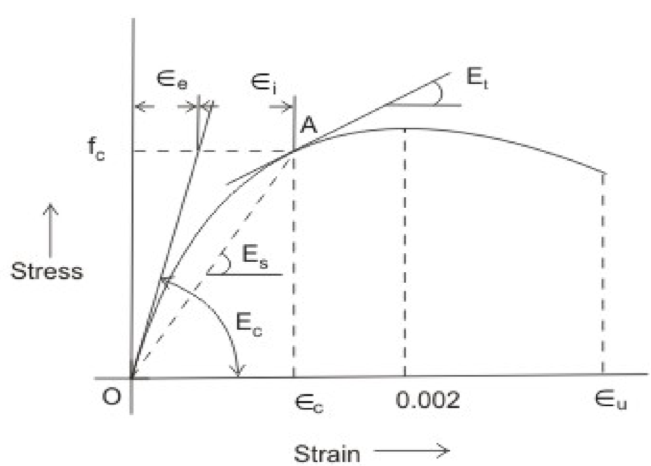

Fig. 1.2.1 : Stress - Strain curve of concrete

Figure 1.2.1 shows a typical stress-strain curve of concrete in compression, where

E_c = initial tangent modulus at the origin, also known as short term static modulus

E_s = secant modulus at *A*

E_t = tangent modulus at *A*

ε_e = elastic strain at *A*

ε_i = inelastic strain at *A*

It is seen that the initial tangent modulus is much higher than E_t (tangent modulus at *A*). Near the failure, the actual strain consists of both ε_e and ε_i (elastic and inelastic respectively) components of strain. The initial tangent modulus E_c in N/mm^2 is estimated from

$$E_c = 5000\sqrt{f_{ck}} \qquad (1.2)$$

where f_{ck} = characteristic compressive strength of concrete at 28 days

The initial tangent modulus E_c is also known as short term static modulus of elasticity of concrete in N/mm^2 and is used to calculate the elastic deflections.

(d) Shrinkage of concrete

Shrinkage is the time dependent deformation, generally compressive in nature. The constituents of concrete, size of the member and environmental conditions are the factors on which the total shrinkage of concrete depends. However, the total shrinkage of concrete is most influenced by the total amount of water present in the concrete at the time of mixing for a given humidity and temperature. The cement content, however, influences the total shrinkage of concrete to a lesser extent. The approximate value of the total shrinkage strain for design is taken as 0.0003 in the absence of test data (cl. 6.2.4.1).

(e) Creep of concrete

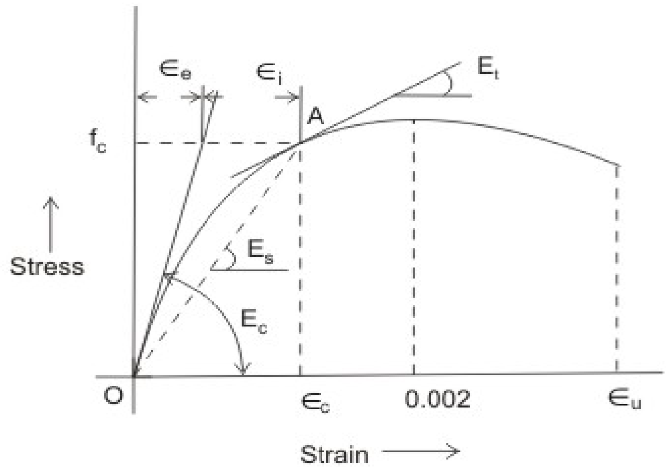

Fig. 1.2.1 : Stress - Strain curve of concrete

Creep is another time dependent deformation of concrete by which it continues to deform, usually under compressive stress. The creep strains recover partly when the stresses are released. Figure 1.2.2 shows the creep recovery in two parts. The elastic recovery is immediate and the creep recovery is slow in nature.

Thus, the long term deflection will be added to the short term deflection to get the total deflection of the structure. Accordingly, the long term modulus E_{ce} or the effective modulus of concrete will be needed to include the effect of creep due to permanent loads. The relationship between E_{ce} and E_c is obtained as follows:

$$\varepsilon_c = f_c/E_c \qquad (1.3)$$

where ε_c = short term strain at the age of loading at a stress value of f_c

ε_{cr} = ultimate creep strain

$$\theta = \text{creep coefficient} = \frac{\varepsilon_{cr}}{\varepsilon_c} \quad \text{(cl. 6.2.5.1 of IS 456)} \qquad (1.4)$$

The values of θ on 7th, 28th and 365th day of loading are 2.2, 1.6 and 1.1 respectively.

Then the total strain = $\varepsilon_c + \varepsilon_{cr} = \frac{f_c}{E_{ce}}$

(1.5)

where E_{ce} = effective modulus of concrete

From the above Eq. (1.5), we have

$$E_{ce} = \frac{f_c}{\varepsilon_c + \varepsilon_{cr}} = \frac{\varepsilon_c E_c}{\varepsilon_c + \varepsilon_{cr}} = \frac{E_c}{1+\theta}$$

(1.6)

The effective modulus of E_{ce} of concrete is used only in the calculation of creep deflection.

It is seen that the value of creep coefficient θ (Eq. 1.4) is reducing with the age of concrete at loading. It may also be noted that the ultimate creep strain ε_{cr} does not include short term strain ε_c. The creep of concrete is influenced by

- Properties of concrete
- Water/cement ratio
- Humidity and temperature of curing
- Humidity during the period of use
- Age of concrete at first loading
- Magnitude of stress and its duration
- Surface-volume ratio of the member

(f) Thermal expansion of concrete

The knowledge of thermal expansion of concrete is very important as it is prepared and remains in service at a wide range of temperature in different countries having very hot or cold climates. Moreover, concrete will be having its effect of high temperature during fire. The coefficient of thermal expansion depends on the nature of cement, aggregate, cement content, relative humidity and size of the section. IS 456 stipulates (cl. 6.2.6) the values of coefficient of thermal expansion for concrete / ^oC for different types of aggregate.

1.2.3Workability and Durability of Concrete

Workability and durability of concrete are important properties to be considered. The relevant issues are discussed in the following:

(a) Concrete mix proportioning

The selected mix proportions of cement, aggregates (fine and coarse) and water ensure:

- the workability of fresh concrete,
- required strength, durability and surface finish when concrete is hardened.

Recently more than forty per cent of concrete poured world over would contain admixtures.

(b) Workability

It is the property which determines the ease and homogeneity with which concrete can be mixed, placed, compacted and finished. A workable concrete will not have any segregation or bleeding. Segregation causes large voids and hence concrete becomes less durable. Bleeding results in several small pores on the surface due to excess water coming up. Bleeding also makes concrete less durable. The degree of workability of concrete is classified from very low to very high with the corresponding value of slump in mm (cl. 7 of IS 456).

(c) Durability of concrete

A durable concrete performs satisfactorily in the working environment during its anticipated exposure conditions during service. The durable concrete should have low permeability with adequate cement content, sufficient low free water/cement ratio and ensured complete compaction of concrete by adequate curing. For more information, please refer to cl. 8 of IS 456.

(d) Design mix and nominal mix concrete

In design mix, the proportions of cement, aggregates (sand and gravel), water and mineral admixtures, if any, are actually designed, while in nominal mix, the proportions are nominally adopted. The design mix concrete is preferred to the nominal mix as the former results in the grade of concrete having the specified workability and characteristic strength (vide cl. 9 of IS 456).

(e) Batching

Mass and volume are the two types of batching for measuring cement, sand, coarse aggregates, admixtures and water. Coarse aggregates may be gravel, grade stone chips or other man made aggregates. The quantities of cement, sand, coarse aggregates and solid admixtures shall be measured by mass. Liquid admixtures and water are measured either by volume or by mass (cl. 10 of IS 456).

1.2.4 Properties of Steel

As mentioned earlier in sec. 1.2.2, steel is used as the reinforcing material in concrete to make it good in tension. Steel as such is good in tension as well as in compression. Unlike concrete, steel reinforcement rods are produced in steel plants. Moreover, the reinforcing bars or rods are commercially available in some specific diameters. Normally, steel bars up to 12 mm in diameter are designated as bars which can be coiled for transportation. Bars more than 12 mm in diameter are termed as rods and they are transported in standard lengths.

Like concrete, steel also has several types or grades. The four types of steel used in concrete structures as specified in cl. 5.6 of IS 456 are given below:

(i) Mild steel and medium tensile steel bars conforming to IS 432 (Part 1)

(ii) High yield strength deformed (HYSD) steel bars conforming to IS 1786

(iii) Hard-drawn steel wire fabric conforming to IS 1566

(iv) Structural steel conforming to Grade A of IS 2062.

Mild steel bars had been progressively replaced by HYSD bars and subsequently TMT bars are promoted in our country. The implications of adopting different kinds of blended cement and reinforcing steel should be examined before adopting.

Stress-strain curves for reinforcement

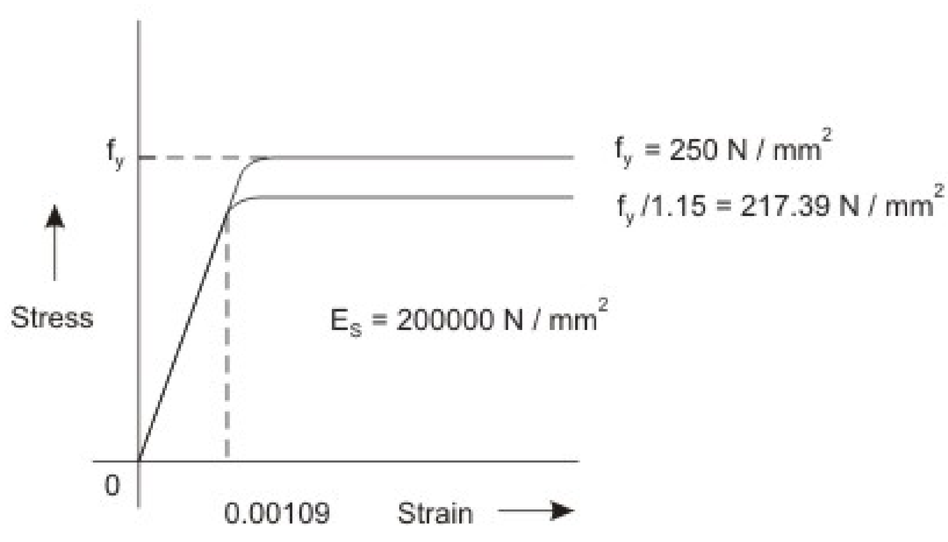

Fig. 1.2.3 : Stress - Strain curve for mild steel (idealised) (Fe 250) with definite yield point.

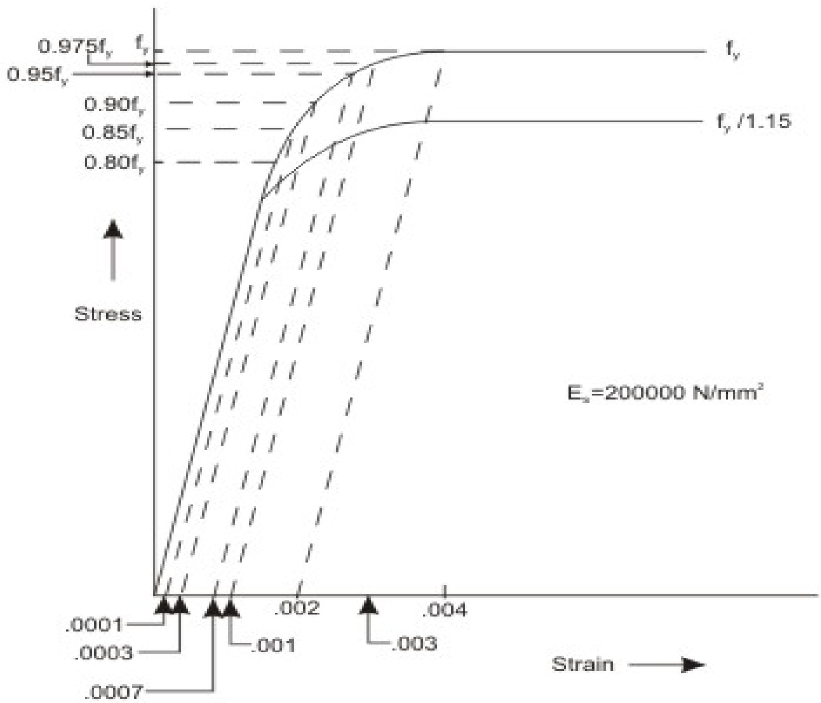

Fig. 1.2.4 : Stress-Strain Curve for cold worked deformed bar

Figures 1.2.3 and 1.2.4 show the representative stress-strain curves for steel having definite yield point and not having definite yield point, respectively. The characteristic yield strength f_y of steel is assumed as the minimum yield stress or 0.2 per cent of proof stress for steel having no definite yield point. The modulus of elasticity of steel is taken to be 200000 N/mm^2.

For mild steel (Fig. 1.2.3), the stress is proportional to the strain up to the yield point. Thereafter, post yield strain increases faster while the stress is assumed to remain at constant value of f_y.

For cold-worked bars (Fig. 1.2.4), the stress is proportional to the strain up to a stress of 0.8 f_y. Thereafter, the inelastic curve is defined as given below:

Stress	**Inelastic strain**
0.80 f_y	Nil
0.85 f_y 0.90 f_y	0.0001 0.0003
0.95 f_y 0.975 f_y	0.0007 0.0010
1.00 f_y	0.0020

Linear interpolation is to be done for intermediate values. The two grades of cold-worked bars used as steel reinforcement are Fe 415 and Fe 500 with the values of f_y as 415 N/mm^2 and 500 N/mm^2, respectively.

Considering the material safety factor γ_m (vide sec. 2.3.2.3 of Lesson 3) of steel as 1.15, the design yield stress (f_{yd}) of both mild steel and cold worked bars is computed from

$$f_{yd} = f_y / \gamma_m \tag{1.7}$$

Accordingly, the representative stress-strain curve for the design is obtained by substituting f_{yd} for f_y in Figs. 1.2.3 and 1.2.4 for the two types of steel with or without the definite yield point, respectively.

1.2.5 Other Important Factors

The following are some of the important factors to be followed properly as per the stipulations in IS 456 even for the design mix concrete with materials free from impurities in order to achieve the desired strength and quality of concrete. The relevant clause numbers of IS 456 are also mentioned as ready references for each of the factors.

(a) Mixing (cl. 10.3)

Concrete is mixed in a mechanical mixer at least for two minutes so as to have uniform distribution of the materials having uniform colour and consistency.

(b) Formwork (cl. 11)

Properly designed formwork shall be used to maintain its rigidity during placing and compaction of concrete. It should prevent the loss of slurry from the concrete. The stripping time of formwork should be such that the concrete attains strength of at least twice the stress that the concrete may be subjected at the time of removing the formwork. As a ready reference IS 456 specifies the minimum period before striking formwork.

There is a scope for good design of formwork system so that stripping off is efficient without undue shock to concrete and facilitating reuse of formwork.

(c) Assembly of reinforcement (cl. 12)

The required reinforcement bars for the bending moment, shear force and axial thrust are to be accommodated together and proper bar bending schedules shall be prepared. The reinforcement bars should be placed over blocks, spacers, supporting bars etc. to maintain their positions so that they have the required covers. High strength deformed steel bars should not be re-bent. The reinforcement bars should be assembled to have proper flow of concrete without obstruction or segregation during placing, compacting and vibrating.

(d) Transporting, placing, compaction and curing (cl. 13)

Concrete should be transported to the formwork immediately after mixing to avoid segregation, loss of any of the ingredients, mixing of any foreign matter or loss of workability. Proper protections should be taken to prevent evaporation loss of water in hot weather and loss of heat in cold weather.

To avoid rehandling, concrete should be deposited very near to the final position of its placing. The compaction should start before the initial setting time and should not be disturbed once the initial setting has started. While placing concrete, reinforcement bars should not be displaced and the formwork should not be moved.

The compaction of concrete using only mechanical vibrators is very important, particularly around the reinforcement, embedded fixtures and the corners of the formwork to prevent honeycomb type of concreting. Excessive vibration leads to segregation.

Proper curing prevents loss of moisture from the concrete and maintains a satisfactory temperature regime. In moist curing, the exposed concrete surface is kept in a damp or wet condition by ponding or covering with a layer of sacking, canvas, hessian etc. and kept constantly wet for a period of 7-14 days depending on the type of cement and weather conditions. Blended cement needs extended curing. In some situations, polyethylene sheets or similar impermeable membranes may be used to cover the concrete surface closely to prevent evaporation.

(e) Sampling and strength of designed concrete mix (cl. 15)

Random samples of concrete cubes shall be cast from fresh concrete, cured and tested at 28 days as laid down in IS 516. Additional tests on beams for modulus of rupture at 3 or 7 days, or compressive strength tests at 7 days shall also be conducted. The number of samples would depend on the total quantity of concrete as given in cl. 15.2.2 and there should be three test specimens in each sample for testing at 28 days, and additional tests at 3 or 7 days.

(f) Acceptance criteria (cl. 16)

Concrete should be considered satisfactory when both the mean strength of any group of four consecutive test results and any individual test result of compressive strength and flexural strength comply the limits prescribed in IS 456.

(g) Inspection and testing of structures (cl. 17)

Inspection of the construction is very important to ensure that it complies the design. Such inspection should follow a systematic procedure covering materials, records, workmanship and construction.

All the materials of concrete and reinforcement are to be tested following the relevant standards. It is important to see that the design and detailing are capable of execution maintaining a standard with due allowance for the dimensional tolerances. The quality of the individual parts of the structure should be verified. If needed, suitable quality assurance schemes should be used. The concrete should be inspected immediately after the removal of formwork to remove any defective work before concrete has hardened.

Standard core tests (IS 516) are to be conducted at three or more points to represent the whole concrete work in case of any doubt regarding the grade of concrete during inspection either due to poor workmanship or unsatisfactory results on cube strength obtained following the standard procedure. If the average equivalent cube strength of cores is equal to at least 85 per cent of the cube strength of that grade of concrete at that age and each of the individual cores has strength of at least 75 per cent, then only the concrete represented by the core test is considered acceptable. For unsatisfactory core test results, load tests should be conducted for the flexural members and proper analytical investigations should be made for non-flexural members.

Such load tests should be done as soon as possible after expiry of 28 days from the date of casting of the flexural members subjected to full dead load and 1.25 times the imposed load for 24 hours and then the imposed load shall be removed. The maximum deflection of the member during 24 hours under imposed load in mm should be less than 40 l^2/D, where l is the effective span in m and D is the overall depth of the member in mm. For members showing more deflection, the recovery of the deflection within 24 hours of removal of the imposed load has to be noted. If the recovery is less than 75 per cent of the deflection under imposed load, the test should be repeated after a lapse of 72 hours. The structure is considered unacceptable if the recovery is less than 80 per cent.

There are further provisions of conducting non-destructive tests like ultrasonic pulse velocity (UPV), rebound hammer, probe penetration, pull out and maturity, as options to core tests or to supplement the data obtained from a limited number of cores. However, it is important that the acceptance criteria shall be agreed upon prior to these non-destructive testing. There are reports that UPV tests conducted three days after casting after removal of side formwork give very dependable insight about the quality of concrete.

1.2.6 Concluding Remarks

The reinforced concrete consisting of plain concrete and steel reinforcement opened a new vista fulfilling the imaginations of architect with a unified approach of the architect and structural engineer. This has been made possible due to mouldability and monolithicity of concrete in addition to its strength in both tension and compression when reinforced with steel. However, concrete is produced by mixing cement, sand, gravel, water and mineral admixtures, if needed. Therefore, the final strength of concrete depends not only on the individual properties of its constituent materials, but also on the proportions of the material and the manner in which it is prepared, transported, placed, compacted and cured. Moreover, durability of the concrete is also largely influenced by all the steps of its preparation.

Steel reinforcement though produced in steel plants and made available in form of bars and rods of specific diameter also influences the final strength of reinforced concrete by its quality and durability due to environmental effects.

Concrete cover provides the protective environment to embedded steel from rusting that would need presence of both oxygen and moisture. Not only the extent of cover but the quality of cover is important for this reason.

Accordingly, inspection of concrete work, sample testing of specimens, core tests, load tests and non-destructive tests are very important to maintain the quality, strength and durability of reinforced concrete structures. Moreover, it is equally important to remove small defects or make good of it after removing the formwork before it has thoroughly hardened.

Thus, starting from the selection of each constitutive material to the satisfactory construction of the structure, the designer's responsibility will only produce the desired concrete structure which will satisfy the functional requirements as well as will have its aesthetic values exploiting all the good properties of this highly potential material.

1.2.7 Practice Questions and Problems with Answers

Q.1: What are the constituent materials of plain concrete?

A.1: The constituent materials of plain concrete are cement, sand (fine aggregate), gravel (coarse aggregate), water and mineral admixtures in some special cases.

Q.2: Define characteristic strength f_{ck} of concrete.

A.2: Characteristic strength of concrete is defined as the compressive strength of 150 mm size cube at 28 days and expressed in N/mm^2 below which not more than five per cent of the test results are expected to fall.

Q.3: How and when the characteristic compressive strength f_{ck} is determined?

A.3: Characteristic compressive strength is determined by conducting compressive strength tests on specified number of 150 mm concrete cubes at 28 days after casting. It is expressed in N/mm^2.

Q.4: What do the symbols *M* and 20 mean for grade M 20 concrete?

A.4: The symbol *M* refers to mix and the number 20 indicates that the characteristic strength f_{ck} of grade M 20 is 20 N/mm^2.

Q.5: Express the relation between flexural strength (f_{cr}) and characteristic compression strength f_{ck} of concrete.

A.5: The generally accepted relation is: $f_{cr} = 0.7\sqrt{f_{ck}}$ where f_{cr} and f_{ck} are in N/mm^2.

Q.6: Draw stress-strain curve of concrete and show the following:

(a) Initial tangent modulus E_c, (b) Secant modulus E_s at any point *A* on the stress-strain curve, (c) Tangent modulus E_t at *A* and (d) elastic and inelastic strain components of the total strain at *A*.

A.6: Please refer to Fig. 1.2.1

Q.7: Express the short term static modulus E_c in terms of the characteristic compressive strength f_{ck} of concrete.

A.7: The suggested expression is : $E_c = 5000\sqrt{f_{ck}}$ where E_c and f_{ck} are in N/mm^2.

Q.8: State the approximate value of total shrinkage strain of concrete to be taken for the design purpose and mention the relevant clause no. of IS code.

A.8: As per cl. 6.2.4.1 of IS 456:2000, the approximate value of total shrinkage strain of concrete is to be taken as 0.0003.

Q.9: Define creep coefficient θ of concrete and express the relation between the effective modulus E_{ce}, short term static modulus E_c and creep coefficient θ of concrete.

A.9: Creep coefficient θ is the ratio of ultimate creep strain ε_{cr} and short term strain at the age of loading ($\theta = \varepsilon_{cr}/\varepsilon_c$).

The required relation is $E_{ce} = \frac{E_c}{1+\theta}$. {The derivation of Eq. 1.6 is given in sec. 1.2.2 part (e)}.

Q.10: Define workability of concrete.

A.10: Workability of concrete is the property which determines the ease and homogeneity with which concrete can be mixed, placed, compacted and finished.

Q.11: Differentiate between design mix and nominal mix concrete.

A.11: In design mix, the proportions of cement, aggregates (sand and gravel), water and mineral admixtures, if any are actually determined by actual design to have a desired strength. In nominal mix, however, these proportions are nominally adopted.

Q.12: What are the different types of batching in mixing the constituent materials of concrete and name the type of batching to be adopted for different materials?

A.12: Mass and volume are the two types of batching. The quantities of cement, aggregates (sand and gravel) and solid admixtures shall be measured by mass batching. Liquid admixtures and water are measured either by mass or volume batching.

Q.13: Differentiate between steel bars and rods.

A.13: Bars are steel bars of diameter up to 12 mm which are coiled during transportation. Rods are steel bars of diameter greater than 12 mm and cannot be coiled. They are transported in standard lengths.

Q.14: Name the types of steel and their relevant IS standards to be used as reinforcement in concrete.

A.14: Please refer to sec. 1.2.4(i), (ii), (iii) and (iv).

Q.15: Draw stress-strain curve of steel bars with or without definite yield point and indicate the yield stress f_y of them.

A.15: Please refer to Figs. 1.2.3 and 1.2.4. For steel bars of Fig. 1.2.3, f_y = 250 N/mm^2 and for steel bars of Fig. 1.2.4, f_y = 415 and 500 N/mm^2 for the two different grades.

Q.16: What are the criteria of properly mixed concrete and how to achieve them?

A.16: Properly mixed concrete will have uniform distribution of materials having uniform colour and consistency.

These are achieved by mixing the constituent materials in a mechanical mixer at least for two minutes or such time till those qualities are achieved.

Q.17: What should be the expected strength of concrete structure at the time of removal of formwork?

A.17: The concrete at the time of removing the formwork should have strength of at least twice the stress that it may be subjected to at the time of removal of formwork.

Q.18: Name the sample tests to be performed for checking the strength of concrete.

A.18: The main test to be performed is 150 mm cube strength at 28 days made of fresh concrete and cured. Additional tests should also be conducted on 150 mm cubes at 7 days and beam tests to determine modulus of rupture at 3 or 7 days. There should be at least 3 or more samples of such specimens to represent the entire concrete work. Each sample should have at least three specimens for conducting each of the above-mentioned tests.

Q.19: Mention the specific acceptance criteria of the sample tests of cubes and beams.

A.19: Concrete should be considered satisfactory when both the mean strength determined from any group of four consecutive test results and any individual test result of compressive and flexural strength tests comply the prescribed limits of cl. 16 of IS 456.

Q.20: When is it essential to conduct standard core test?

A.20: Standard core tests are needed if the inspection of concrete work raises doubt regarding the grade of concrete either due to poor workmanship or unsatisfactory cube strength results performed following standard procedure.

Q.21: When do you consider core test results as satisfactory?

A.21: The core test results are considered satisfactory if:
(i) the average equivalent cube strength of the cores is at least 85 per cent of the cube strength of the grade of concrete at that age, and
(ii) each of the individual cores has strength of at least 75 per cent of the concrete cube strength at that age.

Q.22: What are to be done for unsatisfactory core test results?

A.22: Load tests are to be conducted for the flexural members and analytical investigations are to be performed for non-flexural members.

Q.23: Prescribe the loading conditions and age of structure for conducting load tests.

A.23: Load tests are to be conducted as soon as possible after expiry of 28 days from the date of casting. The flexural member is subjected to full dead load and 1.25 times the imposed load for 24 hours and then the imposed load has to be removed.

Q.24: When do you conclude the load tests as satisfactory?

A.24: Load tests are considered satisfactory if the maximum deflection in mm of the member during 24 hours under load is less than 40 l^2/D, where l = effective span in m and D = overall depth of the member in mm.

For members showing more deflection, the recovery of the deflection within 24 hours of removal of the imposed load has to be noted. If the recovery is less than 75 per cent of the deflection under imposed load, the tests should be repeated after a lapse of 72 hours. The structure is considered unacceptable if the recovery is less than 80 per cent.

Q.25: Name the acceptable non-destructive tests to be performed on structures.

A.25: The acceptable non-destructive tests are ultrasonic pulse velocity, rebound hammer, probe penetration, pull out and maturity.

1.2.8 References

1. Reinforced Concrete Limit State Design, 6th Edition, by Ashok K. Jain, Nem Chand & Bros, Roorkee, 2002.
2. Limit State Design of Reinforced Concrete, 2nd Edition, by P.C.Varghese, Prentice-Hall of India Pvt. Ltd., New Delhi, 2002.
3. Advanced Reinforced Concrete Design, by P.C.Varghese, Prentice-Hall of India Pvt. Ltd., New Delhi, 2001.

4. Reinforced Concrete Design, 2nd Edition, by S.Unnikrishna Pillai and Devdas Menon, Tata McGraw-Hill Publishing Company Limited, New Delhi, 2003.
5. Limit State Design of Reinforced Concrete Structures, by P.Dayaratnam, Oxford & I.B.H. Publishing Company Pvt. Ltd., New Delhi, 2004.
6. Reinforced Concrete Design, 1st Revised Edition, by S.N.Sinha, Tata McGraw-Hill Publishing Company. New Delhi, 1990.
7. Reinforced Concrete, 6th Edition, by S.K.Mallick and A.P.Gupta, Oxford & IBH Publishing Co. Pvt. Ltd. New Delhi, 1996.
8. Behaviour, Analysis & Design of Reinforced Concrete Structural Elements, by I.C.Syal and R.K.Ummat, A.H.Wheeler & Co. Ltd., Allahabad, 1989.
9. Reinforced Concrete Structures, 3rd Edition, by I.C.Syal and A.K.Goel, A.H.Wheeler & Co. Ltd., Allahabad, 1992.
10. Textbook of R.C.C, by G.S.Birdie and J.S.Birdie, Wiley Eastern Limited, New Delhi, 1993.
11. Design of Concrete Structures, 13th Edition, by Arthur H. Nilson, David Darwin and Charles W. Dolan, Tata McGraw-Hill Publishing Company Limited, New Delhi, 2004.
12. Concrete Technology, by A.M.Neville and J.J.Brooks, ELBS with Longman, 1994.
13. Properties of Concrete, 4th Edition, 1st Indian reprint, by A.M.Neville, Longman, 2000.
14. Reinforced Concrete Designer's Handbook, 10th Edition, by C.E.Reynolds and J.C.Steedman, E & FN SPON, London, 1997.
15. Indian Standard Plain and Reinforced Concrete – Code of Practice (4th Revision), IS 456: 2000, BIS, New Delhi.
16. Design Aids for Reinforced Concrete to IS: 456 – 1978, BIS, New Delhi.

1.2.9 Test 2 with Solutions

Maximum Marks = 50, Maximum Time = 30 minutes

Answer all questions. Each question carries five marks.

TQ.1: Define characteristic strength (f_{ck}) of concrete

A.TQ.1: See Ans. 2 of sec. 1.2.7.

TQ.2: How and when the characteristic compressive strength (f_{ck}) is determined?

A.TQ.2: See Ans. 3 of sec. 1.2.7.

TQ.3: What do the symbols M and 20 mean for grade M 20 concrete?

A.TQ.3: See Ans. 4 of sec. 1.2.7.

TQ.4: Express the short term static modulus (E_c) in terms of the characteristic compressive strength (f_{ck}) of concrete.

A.TQ.4: See Ans. 7 of sec. 1.2.7.

TQ.5: Define creep coefficient θ of concrete and express the relation between the effective modulus (E_{ce}), short term static modulus (E_c) and creep coefficient (θ) of concrete.

A.TQ.5: See Ans. 9 of sec. 1.2.7.

TQ.6: Differentiate between design mix and nominal mix concrete.

A.TQ.6: See Ans. 11 of sec. 1.2.7.

TQ.7: Draw stress-strain curve of steel bars with or without definite yield point and indicate the yield stress f_y of them.

A.TQ.7: See Ans. 15 of sec. 1.2.7.

TQ.8: Mention the specific acceptance criteria of the sample tests of cubes and beams.

A.TQ.8: See Ans. 19 of sec. 1.2.7.

TQ.9: When do you consider core test results as satisfactory?

A.TQ.9: See Ans. 21 of sec. 1.2.7.

TQ.10: Prescribe the loading conditions and age of structure for conducting load tests.

A.TQ.10: See Ans. 23 of sec. 1.2.7.

1.2.10 Summary of this Lesson

Properties of concrete and steel are essential to be thoroughly known and understood by the designer. These properties in respect of strength, deformation and durability are summarised in this lesson. The importance of quality control, inspection and testing are emphasised starting from the basic preparation of concrete to the removal of formwork after the construction. The recommendations of Indian Standards are discussed regarding the acceptance of good concrete based on sample tests of specimens, core tests and other non-destructive tests.