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IS 456 Indian Standard Code of Practice for Plain and Reinforced Concrete

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Structural Concrete

Chapter 10:
INSPECTION, TESTING AND MONITORING

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Chapter 10
INSPECTION, TESTING AND MONITORING

100. INSPECTION, TESTING AND MONITORING

Inspection, Testing and Monitoring of concrete structures shall be performed as per the provisions provided hereunder.

C100. INSPECTION, TESTING AND MONITORING

Inspection, Testing and Monitoring shall be during or after construction.

101. INSPECTION

All construction shall be inspected for compliance with the design intent provided through the good for construction drawings. The inspection shall:

(1) Address materials, design, workmanship and construction,
(2) Be undertaken *before*, *during* and *after* the construction, as required, and
(3) Follow procedures laid down hereunder.

Suitable quality assurance schemes shall be put in place to ensure the above.

C101. INSPECTION

The intent is clarified of inspecting the all steps in the process of construction.

101.1 Materials

The materials chosen for construction shall be compliant with the relevant Indian Standards, especially:

(1) All constituent materials of concrete before the making concrete; and

(2) Concrete, reinforcing steel and prestressing steel, where applicable,

C101.1 Materials

Concrete will be deemed not to comply with the strength requirements, if:

(1) There are cases of *extremely low* strength; and

(2) The average is *extremely low* of properties ascertained from all the samples.

When the above is noticed, cases *Core Tests* (as per **Clause 102.1**) should be performed to decide further measures.

In case *Core Test* fails, Load Test should be performed on the structure (as per **Clause 102.1.1**) to decide further measures. Alternately, change the usage of building by reducing live load, but if this is not possible, then the structure should be strengthened/retrofit.

101.2 Good for Construction Drawings

The design and detail provided in the *good for construction drawings* shall:

(1) Be capable of being *executed* with due allowance for dimensional tolerances;
(2) Have clear instructions on *inspection* standards applicable;
(3) Have clear instructions on permissible *deviations*; and
(4) Identify elements critical to *workmanship*, *structural performance*, *durability* and *appearance*; and
(5) Be implemented with a system to verify that the quality is satisfactory in individual parts of the structure, especially the critical ones.

C101.2 Good for Construction Drawings

This Clause seeks competent professionals to be engaged in the design and detail of structures, so that the good for construction drawings are of easily implementable quality.

101.3 Construction

Immediately after stripping the formwork,

(1) All concrete members shall be carefully inspected, and

(2) Any defective work or unacceptable defects either *removed* or *made good* before concrete hardens thoroughly.

C101.3 Construction

The Clause lays down the process to be adopted for inspecting concrete structures when they are stripped off the formwork.

102. TESTING

The tests specified hereunder shall be performed on the existing structures to:

(1) Assess quality and quantity of concrete and steel;
(2) Insitu properties of the whole structure; and
(3) Qualify a structure for the gravity loads (*i.e.,* dead and imposed loads) that it is designed for.

Two sets of tests may be performed, namely:

(1) Tests at *Existing Structures*, and
(2) Tests on Materials for *New Structures*.

C102. TESTING

These tests are different from the routine tests that are performed to establish the quality of materials as per provisions given hereunder. Already built concrete structures are tested for many reasons including:

(1) Verifying the quality of materials (locally), when a dispute arises,
(2) Improving understanding on their in-situ behaviour, and
(3) Validating the capacity of a structure to sustain the gravity loads. This test does not address the remaining Force Loads and Displacement Loads.

102.1 Non-Destructive Tests on Existing Structures

Non-Destructive Tests shall be used prior to performing *Destructive Core Tests* for estimating select properties of existing concrete structures, or for supplementing the data obtained from a limited number of *Destructive Tests* (**Clause 102.2**).

Results of *Non-Destructive Tests* are only indicative and not confirmatory. Also, where *Core Tests* and *Non-Destructive Tests* have been conducted, results of *Core Tests* alone shall be used for assessment of strength.

Correlation between results of *Core Tests* and *Non-Destructive Tests* developed for one project shall be not applicable for other projects.

C102.1 Non-Destructive Tests

Non-Destructive Tests are used to obtain estimation of the physical properties of concrete structures. These are used for estimating:

(1) The *strength* of concrete in a structure for verification of in situ *quality* and *strength*, as supporting tests to concrete *cube tests*; and
(2) The *strength* and *quality* of concrete quality, which are in doubt due to failure of cube tests or otherwise, as supporting tests to concrete *Core Tests* (or where *Core Tests cannot* be conducted).

The methods adopted, include *ultrasonic pulse velocity* [**IS 1199**], *rebound hammer*, *probe penetration*, *pullout* and *maturity*. These methods are based on measuring a concrete property that bears some relationship to its *stiffness* or *strength* characteristics. The accuracy of these methods, in part, depends on the degree of correlation between *strength* or *stiffness* and the *physical quality measured* by the *Non-Destructive Tests*.

Any of these methods may be adopted, in which case the acceptance criteria shall be agreed upon prior to testing. Where correlation between cube strengths and *Non-Destructive Tests* had been established during construction, same can be used.

102.1.1 Vibration Tests

Vibration test may be performed to ascertain the dynamic characteristics of an existing concrete structure. When doing so, accelerations, velocity and/or displacement sensors of high sensitivity shall be:
(1) Placed at critical locations on the structure;
(2) Oriented along the directions in which the shaking is experienced to be dominant.

The *Engineer-in-Charge* shall decide:
(1) The critical locations where measurements are made, and
(2) The orientation of sensors,
such that the core concretes taken represent the whole of concrete concerned.

(a) Ambient Vibration Test

No external oscillation or disturbance shall be employed to vibrate the structure. The inherent vibrations are sufficient for recording the low inherent oscillations.

(b) Forced Vibration Test

Specifically designed electro-dynamic shakers or mechanical mass shakers shall be employed to induce vibrations in the structure. When doing so, the following precautions shall be taken:
(1) They shall be secured at any location in the structure, but preferably at the topmost surface of the structure.
(2) They shall be used with an electrical controller so that the frequency of shaking is maintained precisely at a desired value.

C102.1.1 *Vibration Tests*

These tests should be used to capture the following dynamic characteristics of existing concrete structures:
(1) Natural Periods,
(2) Natural Mode Shapes, and
(3) Inherent Structural Damping.
These tests are particularly used for studying damage in the structure or calibrating analytical methods.

Concrete structures resting on pile foundations, have non-zero mode shape at the ground level, because the ground level still rests on a pile cap that is floating over the natural ground.

(a) Ambient Vibration Test

Typically, these tests are performed on flexible structures, like buildings in the lateral directions and concrete chimneys; and

(b) Forced Vibration Test

Typically, these tests are performed on stiffer structures, like concrete dams and bridge superstructures.

102.1.2 *Local Tests*

Any of the following Local Tests may be adopted:

(1) *Ultrasonic Pulse Velocity Test* as specified in **IS 13311 (Part l)**,
(2) *Rebound Hammer Test* as specified in **IS 13311 (Part 2)**,
(3) *Probe Penetration Test* as specified in **IS** __________,
(4) *Pullout Test* as specified in **IS** __________,
(5) *Maturity Test* as specified in **IS** __________,
(6) *Cover or Rebar Locator Test* as specified in **IS** __________,
(7) *Water Permeability Test* as specified in **IS** __________, and
(8) *Rapid Chloride Ion Permissibility Test* as specified in **IS** __________.

But, the acceptance criteria shall be agreed upon prior to start of the Test.

C102.1.2 *Local Tests*

The use of Non-Destructive Tests, such as the *Ultrasonic Pulse Velocity Test* or *Rebound Hammer Test*, can be helpful in comparing the strength of doubtful concrete in the project that is considered otherwise to be satisfactory.

Rebound Hammer Test measurements should be taken on smoothed test patches of about 150 mm diameter with about 10 readings being taken uniformly over each test area. Due to variations, such as aggregate, surface smoothness and mode of operation of the *Rebound Hammer Test*, a 20% variation is common in strength reading.

102.1.3 *Load Tests*

Load Tests shall be performed on prototype:

(1) *Flexural Members* that are suspect of concrete structures. Other members shall be investigated by detailed structural analysis by the *nonlinear Finite Element Method*.
(2) *Whole structure* that is designed on the basis of being approved only after the whole structure is tested after construction.

The following procedure shall be followed for conducting the *Load Test* on a structure:

(1) The *Load Test* shall be performed only after 28 days from the time of placing of concrete.
(2) The structure shall be subjected to the following load for a period of 24 hours equal to:
   (a) *RC Structure* : $(\gamma_L)_{DL}$ DL + 1.25 $(\gamma_L)_{LL}$ × IL, and
   (b) *PSC Structure:* $(\gamma_L)_{DL}$ DL + $(\gamma_L)_{LL}$ IL,

   and then the IL shall be removed, where DL (namely *Dead Load*, which includes self-weight of the structural members *plus* weight of finishes, walls or partitions, if any, as considered in the design) and IL (namely *Imposed Load*) shall be taken as specified in **Clauses 51.1 and 51.2**, respectively, and $(\gamma_L)_{DL}$ and $(\gamma_L)_{LL}$ are the partial safety factor for loads specified in **Table 5.2**;
(3) The deflection due to imposed load only shall be recorded. Within 24 hours of removal of the IL, if the structure does not recover at least:
   (a) *RC Structure:* 75% of the deflection under DL, then the test may be repeated after a lapse of 72 hours. Even then, if the recovery is less than 80% of the deflection under DL, the structure shall be deemed to be unacceptable.
   (b) *PSC Structure:*
      (i) *Type 1 and Type 2 Structures*: 85% of the deflection under DL, then the test may be repeated after a lapse of 72 hours. Even then, if the recovery is less than 90% of the deflection under DL, the structure shall be deemed to be unacceptable.
      (ii) *Type 3 Structures*: 75% of the deflection under DL, then the test may be repeated after a lapse of 72 hours. Even then, if the recovery is less than 80% of the deflection under DL, the structure shall be deemed to be unacceptable.
(4) If the maximum deflection (in mm), shown during 24 hours under load is less than $40l^2/D$, where l is the effective span (in m); and D the overall depth of the section (in mm), it is not necessary for the recovery to be measured and the recovery provisions mentioned in (2) above shall not apply.
(5) The structure shall satisfy both of the following conditions:
   (a) *Deflection:*

   The *deflection* measured in member(s) shall be less than the limits specified in **Clause 84.1.1**. If the maximum deflection in flexural members is less than $40(l^2/D)$, then it is not necessary for the recovery to be measured and the recovery provisions of **Clause 102.1.3(3)** shall not apply, where l is the effective span (in *m*); and D the overall depth of the section (in *mm*), and
   (b) *Crack Width:*

   The *crack width* measured in member(s) shall be less than the limits specified in **Clause 84.1.3**.

C102.1.3 *Load Tests*

This clause is intended to provide reassurance or otherwise as to the adequacy of doubtful: (a) structural members, and (b) structures, after they are constructed. These rules are not to be used as a substitute for normal design procedure. When it is required that a Static Load Test is to be carried out cognizance should be taken of the effect on the test of the loading pattern. The loading medium should not be stored temporarily on any part of the structure where it could affect the test. Members other than flexural members should be investigated by analytical procedures due to problems of load application and the difficulty of detecting incipient failure.

The loads specified in the loading protocol should be applied and removed incrementally. The procedure for load test and the interpretation of results should be under the supervision of an experienced *Structural Engineer*.

Testing before 28 days from the date of placing concrete is undesirable, because it may lead to permanent weakening of the structure.

IL mentioned implies all imposed gravity loads other than the DL of permanent construction. The IL applied is in a rest and should include the static equivalent of the appropriate dynamic augment (impact) of any moving load. Compensating loads should be added, whenever full DL is yet to come on the structure. The increase of 25% in IL in RC structures is intended to provide a reasonable overload to assure safety, but not so severe, as to damage a satisfactory structure.

Effects of temperature and humidity on the deformation of the structure are minimized by adopting a 24 hour cycle for measurements.

During the 24 hours under the test load, a RC structure will show a progressively increasing deflection, owing to the creep of concrete. Members constructed with low strength concretes (say M15) are likely to show a progressive deflection (in 24 hours), almost equal to the initial elastic deflection and may not show a 75% recovery immediately on removal of load. But, some subsequent recovery should take place, bringing it within the prescribed limits, and, therefore a recovery period of 24 hours is specified. If within 24 hours this recovery does not take place, the second test should be made. Creep will be less during the second test, and a sound structure is likely to experience no difficulty in conforming to the recovery requirements. In unsound members, evidence of weakness will be apparent in other ways, generally in the form of excessive cracking. Any recovery deformation should be viewed with suspicion, if it progresses faster in a short period of time and does not give deflections proportional to the loading. For the second test, the datum is the deflection or the permanent set that remains at the end of first test.

The provision that the maximum deflection is less than $40l^2/D$, the requirement for recovery do not apply, allows for the behavior of very stiff structures or those in which significant membrane action develops (*e.g.,* shells). In such cases, the absolute deflection will be small and of the same order as expected from thermal and moisture effects. A true appraisal of the elastic behavior of the structure then becomes difficult and, therefore, unnecessary.

102.2 Destructive Tests

These tests shall be used only in limited cases, under the direction of *Engineer-in-Charge*.

C102.2 Destructive Tests

Core tests cause *local loss of structural properties* and impact tests cause *global loss of structural properties*. The *Engineer-in-Charge* should assess the consequence of these actions and determine the need and extent of these tests.

102.2.1 *Tests on Materials*

The testing as s specified hereunder in chapter 60 on materials and chapter 90 clause 93 (Quality Control and Quality Assurance) shall be used to establish the said mechanical properties of the constituent materials of concrete, reinforcement and concrete making materials.

(a) Concrete

Tests of concrete required for any of the following purposes:

(1) Designing *concrete mix* before construction,

(2) Assessing *concrete used during construction*, or

(3) Developing *design provisions* through detailed research studies,

shall be performed as specified hereunder.

(1) Sampling Frequency

The sampling scheme mentioned hereunder shall be applicable *only* for *design mix* concretes.

(a) Procedure

A random sampling procedure shall be adopted as specified in **IS 4905**. It shall be ensured that each concrete batch has a reasonable chance of being tested, *i.e.,* the sampling shall be spread over the entire period of concreting and cover all mixing units.

Samples from fresh concrete shall be taken as specified in **IS 1199**. When samples are standard cubes or standard flexure test specimen, they shall be *made, cured* and *tested* at 28 days as specified in **IS 516 and IS ____,** respectively.

(b) Frequency

The minimum frequency of sampling of fresh concrete of each grade shall be in accordance with **Table 10.1**.

(2) Test Specimen

Three test specimens shall be made for testing at 28 days from each sample. Additional samples shall be taken as required for:

(a) Testing strength of concrete for removing formwork, but shall not be less than at least one sample of three test specimen as specified in **IS ______**; and

(b) Testing strength of concrete cured by *accelerated methods* as specified in **IS 9103.**

(3) Test Results

The specimen shall be tested as specified in **IS 516**.The load shall be applied on the top and bottom faces of the specimen (in the as cast orientation) with rate of loading of shall be 14 MPa/minute till failure of cube. The type of failure shall be noted.

The test result of a sample shall be the average of the values from the 3 specimens within that sample. The individual variation shall not be more than ±15% of the *Mean Strength* μ for the test result to be valid.

A reliable value for *Standard Deviation* σ shall be obtained only after testing fairly large number of samples, say 32 to 40. Alternately, a reasonable value of σ shall be assumed based on past experience.

Table 10.1: Frequency of Sampling of Fresh Concrete

S.No.	*Purpose*	*Parameter*	*Number of Samples*
1.	**Designing Concrete Mix before construction**		At least 32 samples per grade per batch of concrete, with each sample having at least 3 specimen
2.	**Assessing Concrete used during Construction**	*Quantity of Concrete in the work*	
		1 – 5	1
		6 – 15	2
		16 – 30	3
		31 – 50	4
		51 and above	4 + One additional sample for each additional *50m*^{3} or part thereof
3.	**Developing Design Provisions through detailed studies**	Any stiffness or strength related quantity of concrete	At least 32 samples per grade of concrete per batch of concrete per each parameter being studied, with each sample having at least 3 specimen

Note:

(a) At least one sample shall be taken from each shift.

(b) Where concrete is produced at a continuous production unit, such as *Ready Mix Concrete Plant* or *Batching Plant* at site, the frequency of sampling may be agreed upon mutually by the suppliers and purchasers. In any case, the minimum number of samples shall be 3 per truck.

(c) Where concrete is used in *PSC* members, additional cube tests shall be conducted at appropriate intervals to ensure that the concrete strength in the member at transfer conforms to the design requirements.

(d) When the quality of concrete is in doubt, the rate of sampling shall be increased at the start of the construction work to establish the level of quality, quickly, *i.e.*, until 32 samples are obtained, or during periods of production.

(e) When specimens are made manually, then concrete shall be placed in 3 layers and each layer is rodded 35 times with a 16mm rod of 60 cm length. Alternately, if concrete is harsh, then it shall be placed in the mould by a vibrator in the same way as placed in field.

(f) First, the cubes shall be stored under wet straw or gunny bags for the first 24 hours. Then, they shall be de-moulded and stored at room temperature of 24°C-30°C (average of 27°C) for 7, 14, 21 and 28 days, till it is required to be tested under saturated (wiped dry) conditions.

(g) The dimensions of cube shall be measured first, the cubes shall be weighed next, and tested finally.

(4) Acceptance Criteria

The following three criteria shall be complied with for *accepting* or *rejecting* concrete during construction:

(1) *Strength* of Concrete,

(2) *Quantity* of Concrete, and

(3) *Quality* of Construction.

Concrete of each grade shall be assessed separately.

(a) Strength of Concrete

(i) Target Mean Strength shall be estimated as:

$$\mu_T = f_{ck} + 1.65\sigma,$$

where

μ_T = Target Mean Strength,

f_{ck} = Characteristic Strength, and

σ = Standard Deviation.

σ can be assessed from past experience in similar works, or alternatively it may be taken from **Table 10.2**, in case sufficient number of test results is not available for a particular grade of concrete.

Table 10.2: Assumed Standard Deviation

Grade of Concrete	*Assumed Standard Deviation (MPa)*
M 10	*3.5*
M 15	
M 20	*4.0*
M 25	
M 30	*5.0*
M 35	
M 40	
M 45	
M 50	
M 60	*6.5*
M 70	
M 80	
M 90	
M 100	

Notes:

(1) The above values correspond to the site control having:

(a) proper storage of cement;

(b) weigh batching of all material;

(c) controlled addition of water;

(d) regular checking of all materials, aggregate grading and moisture content; and

(e) Periodical checking of workability and strength.

(2) Where there is deviation from the above, the values given in the above table shall increased by 1 MPa.

(ii) Compressive Strength

Concrete shall be deemed to comply with the *Compressive Strength* requirements when its *Compressive Strength* at 28 days meets the requirements specified in **Table ____**. To get a quicker idea of the strength of concrete *during construction*, optional tests may be carried out in addition to the *Compressive Strength* test at *28 days*, namely:

(1) *Modulus of Rupture* test on flexure (beam) specimen at *72±2 hours* or at *7 days*, and

(2) *Compressive Strength* test at *7 days*.

Notwithstanding the above, the *Compressive Strength* and *Modulus of Rupture Tests* at 28 days shall is only final criterion for accepting or rejecting of concrete.

Concrete shall be deemed to comply with the *Compressive Strength* requirements when both of the following both conditions are met with:

(a) The *Mean Strength* μ determined from any group of four consecutive test results exceeds the specified characteristic strength by at least *0.3 MPa or* exceeds (f_{ck}+0.825 times established standard deviation), which is rounded off to nearest 0.5 *MPa*; and

(b) The individual test result is not less than the specified *Characteristic Strength* f_{ck} by *0.3 MPa*.

(iii) Flexural Strength

Concrete shall be deemed to comply with the *Flexural Strength* requirements when both of the following conditions are met with:

(a) The *Mean Strength* μ determined from any group of four consecutive test results exceeds the specified characteristic strength by at least *0.3 MPa*, or exceeds (f_{ck}+0.825 times established standard deviation), which is rounded off to nearest 0.5 *MPa*; and

(b) The individual test result is not less than the specified *Characteristic Strength* f_{ck} by *0.3 MPa*.

Also, for the individual test result requirements given in **Table 10.3** or in item (b) above, only the particular batch from which the sample was taken shall be at risk.

Table 10.3: Characteristic Compressive Strength *Compliance Requirement* of Concrete

Grade of Concrete	*Mean of the Group of 4 Non-overlapping Consecutive Results (Rounded off to the nearest 0.5MPa)*	*Individual Test Result*
(1)	(2)	(3)
M 15	$\geq Max[(f_{ck}+0.825\sigma); f_{ck}+3MPa]$	$\geq (f_{ck}-3MPa)$
M 20	$\geq Max[(f_{ck}+0.825\sigma); f_{ck}+3MPa]$	$\geq (f_{ck}-3MPa)$
Note: In the absence of established value of Standard Deviation σ, the values given in **Table 10.2** shall be assumed, and attempt shall be made to obtain results of 32 samples as early as possible to establish the actual value of σ.		

Where sufficient test results are not available for a particular grade of concrete, the value of *Standard Deviation* σ given in **Table 10.2** may be assumed for design of mix in the first instance. As soon as the results of samples are available, actual calculated σ shall be used and the mix designed properly. But, when adequate past records for a similar grade exist and justify to the designer a value of σ different from that given in **Table 10.2**, it shall be permissible to use that value.

(b) Quantity of Concrete represented by Strength Test Results

The quantity of concrete represented by a group of four consecutive test results shall include the batches from which these samples were taken together with all intervening batches. Where the mean rate of sampling is not specified the maximum quantity of concrete that four consecutive test results represent shall be limited to *60 m*^{3}. If concrete is deemed not to comply with this requirement of compressive strength and flexural strength, as the case may be, the structural adequacy of the parts affected shall be investigated and consequential action taken, as needed.

(c) Quality of Construction

Concrete is liable to be rejected, if:

(i) It is porous or honey-combed;
(ii) Its placing has been interrupted without providing a proper construction joint;
(iii) The reinforcement has been displaced beyond the tolerances specified; or
(iv) Construction tolerances have not been met.

But, hardened concrete may be accepted after carrying out suitable remedial measures to the satisfaction of the *Engineer in Charge*.

(b) Reinforcing Steel

The following tests shall be performed on reinforcement bars:

(1) *Tensile Test* shall be performed as per requirements of **IS 1786**, wherein the following properties shall be ascertained:
(a) Yield Strength
(b) Ultimate Tensile Strength
(c) Percentage Elongation at failure
(d) Percent total elongation at maximum force

(2) *Bend Test* shall be performed as per requirements of **IS 1599** and the mandrel diameter for different grades shall be as specified in **Table 4 of IS 1599**. The test piece, when cold, shall be doubled over the mandrel by continuous pressure until the sides are parallel. The specimen shall be considered to have passed the test, if there is no rupture or cracks visible to a person of normal or corrected vision on the bent portion.

(3) *Reverse Bend Test* shall be performed as per requirements of **IS 1599**. The test piece shall be bent to an inclined angle of 135° (as per **Figure 2 of IS 1599**) using a mandrel of appropriate diameter (**Clause 9.4.1 of IS 1599**). The bent piece shall be aged by keeping in boiling water (100°C) for 30 min and then allowed to cool. The piece shall then be bent back to have an included angle of 157.5°. The specimen shall be considered to have passed the test, if there is no rupture or cracks visible to a person of normal or corrected vision on the bent portion. This test shall not be made mandatory for reinforcing bars of size higher than 25 mm.

(4) *Bond Test* shall be performed as per requirements of **IS 2770 (Part 1)**. The bars/wires satisfying the requirements of **Clause 5 of IS 1786** shall be deemed to have satisfied the bond requirements of a deformed bar/wire, when the bond strength estimated from the load at a measured slip of 0.025 mm and 0.25 mm for deformed bars/wires exceed that of a plain round bar of the same nominal size by 40% and 80%, respectively.

(5) Nominal cross-sectional area and Nominal Mass shall be assessed as per requirements of **IS 1786**. The specimen shall be considered to have passed the test, if nominal cross-sectional area of individual bars/wires meets the requirements given in **Table 1 of IS 1786** and nominal mass that given in **Table 2 of IS 1786**.

(1) Sampling Frequency

For examining the nominal mass and mechanical properties, and for performing *Bend* and *Re-bend Tests*, the test specimen of sufficient length shall be cut from each size of the finished bar/wire at random at a frequency not less than that specified in **Table 10.4**. Also, unless otherwise specified in **IS 1786**, the requirements of **IS 2062** shall apply.

Table 10.4: Frequency of sampling steel specimen for testing

S.No.	*Nominal Size*	*Quantity of Sampling for Casts/Heats*	
		below 100 tonnes	*100 tonnes or more*
1	For all sizes	2 per cast/heat	3 per cast or heat

(2) Test Specimen

Unless otherwise specified in this standard, the requirements of **1S 2062** shall apply.

All test specimens shall be selected by the purchaser or his authorized representative, from:

(a) The cuttings of bars/wires, or

(b) Any bar/wire after it has been cut to the required or specified size and the test piece taken from any part of it.

In either case, the test piece shall be detached from the bar/wire except in the presence of the purchaser or his authorized representative.

The test specimen obtained in accordance with above shall be full sections of the bars/wires and shall be subjected to physical tests without any further modifications. No reduction in size by machining or otherwise shall be permissible, except in bars of size 28 mm and more.

No test piece shall be annealed or otherwise subjected to heat treatment except as provided above. Any straightening which a test piece may require shall be done cold.

For the purpose of carrying out tests for tensile strength, proof stress, percentage elongation and percentage elongation at maximum force for bars of diameter 28 mm and more, deformations of the bars only may be machined. For such bars, the physical properties shall be estimated using the actual area obtained after machining.

Before the test pieces are selected, the manufacturer or supplier shall furnish the purchaser or his authorized representative with copies of the mill records giving the mass of bars/wires in each bundle cast with sizes as well as the identification marks, whereby the bars/wires from that cast can be identified

(3) Test Results

The…

(4) Acceptance Criteria

The…

(a) Strength

The…

(b) Elongation

The…

~~(c) Prestressing Steel Tendons~~

~~The…~~

~~(1) Sampling Frequency~~

~~The…~~

~~(2) Test Specimen~~

~~The…~~

~~(3) Test Results~~

~~The…~~

~~(4) Acceptance Criteria~~

~~The…~~

~~(a) Strength~~

~~The…~~

~~(b) Elongation~~

~~The…~~

C101.2.1 *Tests on Materials*

The…

(This commentary to be shifted to relevant chapters – mchapter 06 /chapter 09 wherein these aspects are covered)

C(a) Concrete

The clause identifies different sampling for different purposes of the use of concrete. Provisions were available already in the *Fourth Revision* of the Standard for assessing the strength of concrete *during construction*. The revision introduces two more purposes, one for finalizing the design mix and the other for research purposes. This is necessary because the impact is vast in these two cases; any *approximation* or *error* in judgment based on results from fewer specimen will affect the *whole project* when finalizing the design mix, or the whole nation when *developing design provisions*.

(1) Sampling

The clause discourages implicitly the use of *nominal mix* concretes in formal construction; the quality control is poor in with these.

(a) Procedure

The random sampling procedure should ensure that each batch, in a given day or period, has the same chance of being sampled, as any other of the other batches. Samples drawn at equal intervals of time should not be construed to be random sampling. The procedure for random sampling should be employed as described in **IS 4905**.

(b) Frequency

Although desirable in theory, generally strict adherence to statistical random sampling procedure is not possible in practice. Sampling should be arranged in such a manner as to avoid conscious bias and provide a reasonable representation of the concrete concerned. Sampling records must indicate in a suitable manner, which batches of concrete were chosen for testing.

The quantity of concrete that may be considered for a single lot of statistical treatment of the results of tests on the samples taken from it must depend upon engineering judgment. For batches of volume less than $1m^3$, it will not be necessary to obtain a sample for every batch or every day, but it is preferable to ensure that at least one sample (consisting of 3 specimens) is available for every $5m^3$ of concrete placed. On the other hand, for highly stressed but isolated members of volume less than $1\ m^3$, it may be desirable to increase the rate of sampling to ensure that the concrete in such members is of adequate strength. Clearly, when the *Engineer-in-Charge* is expecting the quality of concrete to be poor, the clause requires more detailed investigation of the same by seeking at least 32 samples in a shorter period of time, before a large part of the structure is completed.

(2) Specimen

The term *test specimen* should be distinguished from *test samples*. In this standard, strength of a sample refers to the *mean* strength of concrete of the values of the three specimens. And, the range of the values *within the sample*, *i.e.*, the difference between the highest and the lowest values of the three values for the specimen, indicates the uniformity of procedures adopted in *fabricating*, *curing* and *testing* the specimens.

IS 1199 requires that the sample should be:
(a) of at least *0.02 m*^{3} in volume, and
(b) made up by collecting the concrete from 3 to 5 intervals or locations.
The composite sample of *0.02 m*^{3} volume should be mixed to ensure uniformity. This volume of the sample should be about twice that required for moulding three specimens of 150 mm cubes. **IS 516** covers tests for determination of *Compressive Strength* and *Modulus of Rupture*. A difference in the preparation of specimens can be noticed when **IS 516** is compared with the clause. The former requires that 3 specimens to be made from 3 *different* samples, whereas this clause stipulates that 3 specimens to be made from *1 sample* taken from a particular batch.

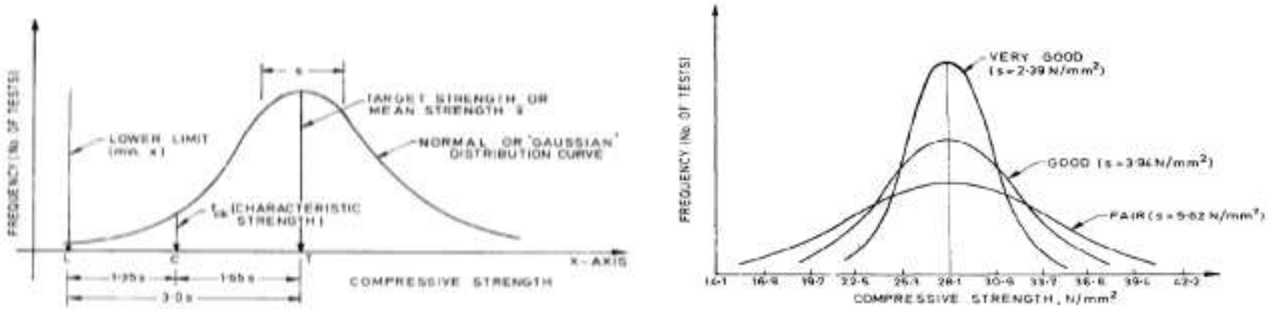
Additional samples may be required for various purposes, such as to:
(a) Determine the strength of concrete at 7 days or at the time of *striking* the formwork, or
(b) Determine the duration of curing, or
(c) Check the testing error.
Early strength test results may be used for early remedial measures, such as the changing of mix design, if necessary, but should not be used for assessment of strength by any method of projection of strength over time. But, the random sampling procedure (**Clause 102.2.1(a)(1)**) does not apply for the additional cubes; suitable sampling shall be adopted that is in keeping with the intent of (**Clause 102.2.1(a)**.

(3) Test Results

IS 516 stipulates that the individual variation in the compressive strength of cubes in a sample should not be more than ±15% of the average. In other words, the range of the test values should not exceed 30% of the average. This *within-test-range* limitation ensures that the procedures for fabrication, curing and testing of specimens are of an acceptable quality. When this range is exceeded, the procedures for fabrication of specimens and the calibration of the testing machines should be checked.

Even when the concrete is sampled and tested strictly in accordance with the relevant procedures, several factors can influence the strength of a test specimen and the strengths of two or more specimens representing a sample of concrete may not be the same. These factors include the heterogeneous nature of concrete, and the human element in: (a) obtaining the sample, (b) in *casting*, *curing* and *testing* of each specimen, and (c) rounding off subsequently of the calculated test strength. The difference between the strength of specimens from one sample tested at the same age should be within ±15%.

The *Standard Deviation* σ of the results is in focus here, because it is an *index* of *the scatter* and consequently of the *degree of site control*. The clause recognizes that when testing a large number of samples of a given grade of concrete manufactured even under stable conditions of control, the results show some variation. For the strength of concrete, it is usual to assume that a graph of the *Compressive Strength* (on the X-axis) and the *Frequency* (*i.e.,* number of samples) having strength in a given band (on the Y-axis) follows the *Normal* or *Gaussian* distribution. The graph is a *bell-shaped* curve (**Figure C10.1a**). Throughout this standard, the *characteristic strength*, which is *less than* the *Mean Strength* μ (which is the *Target Strength*), is taken as a reference for designating the grade of concrete, as say M20. The acceptance criteria given in **Clause 102.2.1(a)(4)** are based on the requirement that the dispersion in the test strength of samples should be allowed for. The *Mean Strength* μ can be taken as a measure of central tendency, and the *Standard Deviation* σ as a measure of dispersion. A small value of σ will result in a curve with a dominant peak, and a large value a flatter curve depending upon the level of control exercised in manufacture of concrete **(Figure C10.1(b))**.



(a) **(b)**

Figure C10.1: Normal distribution of concrete strengths: (a) Definition of *Characteristic Strength*, and (b) Impact of *Quality Control*

(REDRAW USING DATA FROM INDIA AND IN LARGE SIZE)

Characteristic strength has been used as specification to provide for the inherent variability of the material property, arising during its manufacture. This standard recognizes that when a large number of samples, say of a given grade of concrete manufactured, even under stable conditions of control are tested, the results will show some variation. For the strength of concrete, it is usual to assume that the graph of *compressive strength* on *X-axis* and *frequency of occurrence* on *Y-axis* will follow the *normal* or *Gaussian* distribution. Then, the *Characteristic Strength* f_{ck} *of concrete*, is given by:

$$f_{ck} = f_m - 1.65\sigma,$$

where

f_m = Arithmetic mean of the test results, and

σ = Standard deviation of the test results.

The concrete mix should be designed for the *Target Mean Strength* greater than the specified *Characteristic Strength.* The characteristic strength is used as a reference value for specifications as well as design purpose throughout this standard, and as far as possible, all requirements are given in terms of characteristic strength. Some examples follow:

Standard Deviation σ should be calculated afresh, whenever there is a change in mix design. The alternate option of assuming a reasonable σ to be assumed based on past experience refers to minor changes in the mix when the materials remain the same, and particularly the water-cement ratio.

The calculation of σ is illustrated in the following example. For illustration, 10 samples are considered, even though at least 30 samples should be used as per **Clause 102.2.1(a)(1)**. The test results on specimens are obtained from the field as the concreting proceeds **(Table C10.1)**. Grade of concrete is M15. Samples 9 and 10 do not meet the requirement of *individual strength* of a cube not varying from the *mean strength* of the sample (of three cubes) by more than 15%.

Table C10.1: Determination of Standard Deviation σ as per this Standard for M30 Grade of Concrete

Sample Number	*28-day Compressive Strength (MPa)*			*Average*	*Deviation*	*Square of Deviation*
	Cube 1	*Cube 2*	*Cube 3*			
	x_1	x_2	x_3	$\overline{x}$	$\overline{x}-x_i$	$(\overline{x}-x_i)^2$
1	30	32	31	31.00	-0.19	0.04
2	29	32	31	30.67	-0.53	0.28
3	24	22	32	26.00	-5.19	26.98
4	22	23	31	25.33	-5.86	34.34
5	30	24	34	29.33	-1.86	3.46
6	33	29	34	32.00	0.81	0.65
7	38	30	39	35.67	4.47	20.01
8	34	30	24	29.33	-1.86	3.46
9	24	25	26	25.00	-6.19	38.36
10	28	36	35	33.00	1.81	3.26
11	25	24	37	28.67	-2.53	6.39
12	24	24	38	28.67	-2.53	6.39
13	38	37	35	36.67	5.47	29.95
14	27	24	28	26.33	-4.86	23.62
15	37	36	34	35.67	4.47	20.01
16	39	36	37	37.33	6.14	37.69
17	30	26	24	26.67	-4.53	20.49
18	39	38	37	38.00	6.81	46.33
19	28	27	24	26.33	-4.86	23.62
20	39	37	38	38.00	6.81	46.33
21	28	24	28	26.67	-4.53	20.49
22	27	26	27	26.67	-4.53	20.49
23	24	30	26	26.67	-4.53	20.49
24	25	28	26	26.33	-4.86	23.62
25	30	31	32	31.00	-0.19	0.04
26	31	32	33	32.00	0.81	0.65
27	30	33	31	31.33	0.14	0.02
28	30	32	34	32.00	0.81	0.65
29	34	34	34	34.20	3.01	9.04
30	38	37	37	37.33	6.14	37.69
31	38	38	33	36.33	5.14	26.42
32	38	38	38	38.00	6.81	46.33
Total				*998.20*		*597.59*

$$\textit{Mean Strength}\ \ \mu = \frac{998.20}{32} = 31.19$$

$$\textit{Standard Deviation}\ \ \sigma = \sqrt{\frac{\sum_{i=1}^{32}\left[(\mu-\overline{x})^2\right]}{n-1}} = Sqrt(\frac{597.59}{31}) = 4.39 = 4.4 = 4.5MPa$$

When test results available are insufficient (less than 32 samples), an assumed *Standard Deviation* σ has to be used. The values of σ given in **Table 10.1** may be used as an initial estimate, which may be slightly conservative. They may be more conservative at higher strengths, where strength may be more important.

The Table of four consecutive overlapping (Table C6.102 to 105) and four non-consecutive overlapping (Table C6.105 to 108) is done based on the *Acceptance Criteria*. The Acceptance criteria can be divided in following two categories:

(a) Clear Compliance

(i) For Sample 32 in **Table C10.2**, every specimen has strength 38MPa, which is more than f_{ck} and also equal to or slightly more than the Target Mean Strength of Concrete (= $f_{ck}+1.65\sigma = 30+1.65\times4.5 =$) 37.43MPa (where σ is the Standard Deviation) as per **Clause 102.2.1(a)(4)**. Hence, this is a case of *clear compliance*, and no further check is required.

(ii) For Sample 32 in **Table C10.3**, the average strength of specimen is >(f_{ck}-3), *i.e.,* 37MPa > 27MPa, as per Column 3 of **Table 6.4**. Hence, specimen passes.

(iii) For Sample 32 in **Table C10.4**, the individual strength is greater than ($f_{ck}+0.825\sigma$) or (f_{ck}+3), *i.e.,* 38MPa > 27MPa. Thus, all individual results of Sample 32 pass.

(iv) For Sample 32 in **Table C10.5**, results pass **Clause 102.2.1(a)(3),** Column 2 of **Table 10.2** and Column 3 of **Table 10.2**. Hence, the sample is Accepted.

(b) Non Compliance

(i) For Sample 2 in **Table C10.2,** first specimen has strength 29 MPa, which is below the characteristic value of 30 MPa, but above 15% of average, *i.e.,* 30.67-4.6=26.02 MPa. Thus, an additional requirement should be satisfied simultaneously, namely the individual strength of the sample, *i.e.,* 29 MPa should be equal to or more than the characteristic strength by (f_{ck}-3), *i.e.,* more than 30-3=27 MPa. Thus, Specimen 2 *passes* individually.

(ii) For Sample 2 in **Table C10.2,** second specimen has strength 22 MPa, which is below the characteristic value of 30 MPa, and also below 15% of average, *i.e.,* not below 26.0-3.9=22.1MPa. Thus, an additional requirement should be satisfied simultaneously, namely the individual strength of the specimen, *i.e..,* 22 MPa, should be equal to or more than the characteristic strength by (f_{ck}-3), *i.e.,* more than 30-3= 27 MPa. Thus, Specimen 2 *fails* individually

(iii) For Sample 3 in **Table C10.2**, second specimen has strength 22 MPa, which is below the characteristic value of 30 MPa, also below __________________.

(iv) For Sample 12 in **Table C10.2,** Specimen 1 and 2 have strengths less than the characteristic value, *i.e.,* 30MPa, and Specimen 3 has a strength more than the characteristic value, *i.e.,* 30MPa. Further, results of Specimen 1 and 2 have strengths 24 MPa, which is less than 15% of average (=28.67–4.3=24.37MPa). Hence, Specimen 1 and 2 fail individually. Specimen 3 has strength of 38MPa, which is more than 15% of average (=29.67+4.3=33.97MPa). Hence, Specimen 3 also fails leading to a case of non-compliance.

Table C10.2: Consecutive and Non-Overlapping Samples of Concrete of Grade M30

Sample	Specimen			Clause 61.3.3 Compliance						
Sr No.	Cube-1	Cube-2	Cube-3	Average of 3 specimens (B+C+D)/3 ($\bar{x}$)	Sample Average +- 15% of E		Individual Cube-1 B	Individual Cube-2 C	Individual Cube-1 D	Sample Results
A	B	C	D	E	-15%	+15%	F	G	H	I
1	30	32	31	31.00	26.35	35.65	Pass	Pass	Pass	Pass
2	29	32	31	30.67	26.07	35.27	Fail	Pass	Pass	Fail
3	24	22	32	26.00	22.10	29.90	Pass	Fail	Fail	Fail
4	22	23	31	25.33	21.53	29.13	Pass	Pass	Fail	Fail
5	30	24	34	29.33	24.93	33.73	Pass	Fail	Fail	Fail
6	33	29	34	32.00	27.20	36.80	Pass	Pass	Pass	Pass
7	38	30	39	35.67	30.32	41.02	Pass	Fail	Pass	Fail
8	34	30	24	29.33	24.93	33.73	Fail	Pass	Fail	Fail
9	24	25	26	25.00	21.25	28.75	Pass	Pass	Pass	Pass
10	28	36	35	33.00	28.05	37.95	Fail	Pass	Pass	Fail
11	25	24	37	28.67	24.37	32.97	Pass	Fail	Fail	Fail
12	24	24	38	28.67	24.37	32.97	Fail	Fail	Fail	Fail
13	38	37	35	36.67	31.17	42.17	Pass	Pass	Pass	Pass
14	27	24	28	26.33	22.38	30.28	Pass	Pass	Pass	Pass
15	37	36	34	35.67	30.32	41.02	Pass	Pass	Pass	Pass
16	39	36	37	37.33	31.73	42.93	Pass	Pass	Pass	Pass
17	30	26	24	26.67	22.67	30.67	Pass	Pass	Pass	Pass
18	39	38	37	38.00	32.30	43.70	Pass	Pass	Pass	Pass
19	28	27	24	26.33	22.38	30.28	Pass	Pass	Pass	Pass
20	39	37	38	38.00	32.30	43.70	Pass	Pass	Pass	Pass
21	28	24	28	26.67	22.67	30.67	Pass	Pass	Pass	Pass
22	27	26	27	26.67	22.67	30.67	Pass	Pass	Pass	Pass
23	24	30	26	26.67	22.67	30.67	Pass	Pass	Pass	Pass
24	25	28	26	26.33	22.38	30.28	Pass	Pass	Pass	Pass
25	30	31	32	31.00	26.35	35.65	Pass	Pass	Pass	Pass
26	31	32	33	32.00	27.20	36.80	Pass	Pass	Pass	Pass
27	30	33	31	31.33	26.63	36.03	Pass	Pass	Pass	Pass
28	30	32	34	32.00	27.20	36.80	Pass	Pass	Pass	Pass
29	34	34	34	34.20	29.07	39.33	Pass	Pass	Pass	Pass
30	38	37	37	37.33	31.73	42.93	Pass	Pass	Pass	Pass
31	38	38	33	36.33	30.88	41.78	Pass	Pass	Pass	Pass
32	38	38	38	38.00	32.30	43.70	Pass	Pass	Pass	Pass

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Table C10.2: Consecutive and Non-Overlapping Samples of Concrete of Grade M30

Sample	Specimen			Table 6.4 Column 3 Compliance					
Sr No.	Cube-1	Cube-2	Cube-3	Average of 3 specimens (B+C+D)/3 ($\bar{x}$)	f_{ck} - 3 N/mm²	Individual Cube-1 B	Individual Cube-2 C	Individual Cube-1 D	Sample
A	B	C	D	E	P	Q	R	S	T
1	30	32	31	31.00	27	Pass	Pass	Pass	Pass
2	29	32	31	30.67	27	Fail	Pass	Pass	Fail
3	24	22	32	26.00	27	Fail	Fail	Pass	Fail
4	22	23	31	25.33	27	Fail	Fail	Pass	Fail
5	30	24	34	29.33	27	Pass	Fail	Pass	Fail
6	33	29	34	32.00	27	Pass	Pass	Pass	Pass
7	38	30	39	35.67	27	Pass	Pass	Pass	Pass
8	34	30	24	29.33	27	Pass	Pass	Fail	Fail
9	24	25	26	25.00	27	Fail	Fail	Fail	Fail
10	28	36	35	33.00	27	Pass	Pass	Pass	Pass
11	25	24	37	28.67	27	Fail	Fail	Pass	Fail
12	24	24	38	28.67	27	Fail	Fail	Pass	Fail
13	38	37	35	36.67	27	Pass	Pass	Pass	Pass
14	27	24	28	26.33	27	Pass	Fail	Pass	Fail
15	37	36	34	35.67	27	Pass	Pass	Pass	Pass
16	39	36	37	37.33	27	Pass	Pass	Pass	Pass
17	30	26	24	26.67	27	Pass	Fail	Fail	Fail
18	39	38	37	38.00	27	Pass	Pass	Pass	Pass
19	28	27	24	26.33	27	Pass	Pass	Fail	Fail
20	39	37	38	38.00	27	Pass	Pass	Pass	Pass
21	28	24	28	26.67	27	Pass	Fail	Pass	Fail
22	27	26	27	26.67	27	Pass	Fail	Pass	Fail
23	24	30	26	26.67	27	Fail	Pass	Fail	Fail
24	25	28	26	26.33	27	Fail	Pass	Fail	Fail
25	30	31	32	31.00	27	Pass	Pass	Pass	Pass
26	31	32	33	32.00	27	Pass	Pass	Pass	Pass
27	30	33	31	31.33	27	Pass	Pass	Pass	Pass
28	30	32	34	32.00	27	Pass	Pass	Pass	Pass
29	34	34	34	34.20	27	Pass	Pass	Pass	Pass
30	38	37	37	37.33	27	Pass	Pass	Pass	Pass
31	38	38	33	36.33	27	Pass	Pass	Pass	Pass
32	38	38	38	38.00	27	Pass	Pass	Pass	Pass

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Table C10.4: Consecutive and Non-Overlapping Samples of Concrete of Grade M30

Sr	**Specimen**			**Table 6.4 Column 2 Compliance**						
Sample = n	**Cube-1**	**Cube-2**	**Cube-3**	**Average of 3 specimens (B+C+D)/3 ($\overline{x}$)**	**Mean group of 4 Non-overlapping test results**	**μ=(ΣE/n)**	$(\mu-\overline{x})^2$	**SD =** $\sqrt{\frac{\sum(\mu-\overline{x})^2}{(n-1)}}$	**Greater f_{ck} + 0.825 *SD OR fck+3**	**Result for 4 Samples**
A	**B**	**C**	**D**	**E**	**J**	**K**	**L**	**M**	**N**	**O**
1	30	32	31	31.00	27.84	31.11	0.01	4.50	33.63	Fail
2	24	32	31	29.00			4.45			
3	24	22	32	26.00			26.12			
4	22	23	31	25.33			33.37			
5	30	24	34	29.33	31.59		3.16		33.63	Fail
6	33	29	34	32.00			0.79			
7	38	30	39	35.67			20.76			
8	34	30	24	29.33			3.16			
9	24	25	26	25.00	28.84		37.34		33.63	Fail
10	28	36	35	33.00			3.57			
11	25	24	37	28.67			5.97			
12	24	24	38	28.67			5.97			
13	38	37	35	36.67	34		30.87		33.63	Pass
14	27	24	28	26.33			22.82			
15	37	36	34	35.67			20.76			
16	39	36	37	37.33			38.72			
17	30	26	24	26.67	32.25		19.75		33.63	Fail
18	39	38	37	38.00			47.47			
19	28	27	24	26.33			22.82			
20	39	37	38	38.00			47.47			
21	28	24	28	26.67	26.59		19.75		33.63	Fail
22	27	26	27	26.67			19.75			
23	24	30	26	26.67			19.75			
24	25	28	26	26.33			22.82			
25	30	31	32	31.00	31.59		0.01		33.63	Fail
26	31	32	33	32.00			0.79			
27	30	33	31	31.33			0.05			
28	30	32	34	32.00			0.79			
29	34	34	34	34.20	36.22		9.55		33.63	Pass
30	38	37	37	37.33			38.72			
31	38	38	33	36.33			27.28			
32	37	37	37	37.00			34.69			

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Table C10.5: Consecutive and Non-Overlapping Samples of Concrete of Grade M30

Sample	Specimen			Compliance			Acceptance
				Clause 61.3.3	Table 6.4 Column 2	Table 6.4 Column 3	
Sr No.	Cube-1	Cube-2	Cube-3	Sample Results	Result for 4 Samples	Sample Results	of Sample
A	B	C	D	I	O	T	U
1	30	32	31	Pass	Fail	Pass	Reject
2	29	32	31	Fail		Fail	Reject
3	24	22	32	Fail		Fail	Reject
4	22	23	31	Fail		Fail	Reject
5	30	24	34	Fail	Fail	Fail	Reject
6	33	29	34	Pass		Pass	Reject
7	38	30	39	Fail		Pass	Reject
8	34	30	24	Fail		Fail	Reject
9	24	25	26	Pass	Fail	Fail	Reject
10	28	36	35	Fail		Pass	Reject
11	25	24	37	Fail		Fail	Reject
12	24	24	38	Fail		Fail	Reject
13	38	37	35	Pass	Pass	Pass	Accept
14	27	24	28	Pass		Fail	Reject
15	37	36	34	Pass		Pass	Accept
16	39	36	37	Pass		Pass	Accept
17	30	26	24	Pass	Fail	Fail	Reject
18	39	38	37	Pass		Pass	Reject
19	28	27	24	Pass		Fail	Reject
20	39	37	38	Pass		Pass	Reject
21	28	24	28	Pass	Fail	Fail	Reject
22	27	26	27	Pass		Fail	Reject
23	24	30	26	Pass		Fail	Reject
24	25	28	26	Pass		Fail	Reject
25	30	31	32	Pass	Fail	Pass	Reject
26	31	32	33	Pass		Pass	Reject
27	30	33	31	Pass		Pass	Reject
28	30	32	34	Pass		Pass	Reject
29	34	34	34	Pass	Pass	Pass	Accept
30	38	37	37	Pass		Pass	Accept
31	38	38	33	Pass		Pass	Accept
32	38	38	38	Pass		Pass	Accept

(Make Table, not image)

(3) Acceptance Criteria

As with sampling, these criteria also are applicable *only* to *design mix concrete*.

When determining the acceptance or rejection of concrete during construction, three factors are crucial:
(1) *Strength* of Concrete,
(2) *Quantity* of Concrete, and
(3) *Quality* of Construction.
Only when all three of these criteria are passed, the concrete shall be accepted.

(1) Strength of Concrete

Mean Strength μ, which is called also as the *Target Mean Strength* f_t, of every sample should comply with:

$$f_t > f_{ck} + \kappa\sigma,$$

where

f_{ck} = *Characteristic Strength* of concrete,

κ = Factor to determine that not more than 5% of the test results are expected to fall below the *Characteristic Strength* of concrete,
= 1.65, and

σ = Standard Deviation.

For example, for *M20* Grade (f_{ck}=20 MPa), concrete is expected to have a standard deviation of 4.6 MPa. Thus, μ_T =20+1.65×4.6= 27.6MPa.

The main statistical features of the acceptance criteria are as follows (**Figure C10.2**):

(a) The strength S of each sample is more than f_{ck}; or

(b) The strength S of each sample falls below f_{ck}, but not less than $(\mu - 6\sigma)$ or $0.8f_{ck}$, if the mean of all values is above $(\mu - 6\sigma)$.

Concrete is deemed not to comply with the strength requirements, if the strength of sample is 3σ below the μ, which in turn approximately corresponds to a probability of *0.001*. Such strengths are extremely unlikely and, therefore, they call for further investigation.

Understandably, the clause leaves to the judgment of the designer the consequential action that should be taken. The following remarks should be taken only as hints in the spirit of the clause, and not necessarily as binding on the Designer, who should take other factors into account. The action, in the event of non-compliance of the strength requirements, may vary from qualified acceptance in marginal or less severe cases to rejection and removal in extremely severe cases. The clause deals only with technical recommendations and the phrase *consequential action* refers only to the *technical* consideration, and not to *legal actions*, which are outside the purview of the standard. In determining the steps to be taken, the Designer should consider the technical consequences (*e.g.*, durability, strength, serviceability, and the economic consequences, such as cost of replacement, and cost of strengthening the weak portions). In investigating the suspected portions of the structure, and before the remedial steps are taken, the following points should be considered:

(a) An appraisal of the sampling and testing procedures, to ensure that they are valid;
(b) The mix proportions actually used in concrete. These may effect durability;
(c) The influence of any reduction in concrete quality on the strength, serviceability and durability of the affected portion of the structure. *Core tests* and *load tests* should be used as guides for deciding upon the technical measures to be taken. Favorable results from the above tests will be helpful for avoiding costly replacement or strengthening measures.

The acceptance criteria specified is based on a one-in-20 chance that the cube strength of a sample may fall below the specified characteristic strength. Further, assuming a Gaussian or normal distribution of the test results, the following relation holds good:

$$\mu_T = f_{ck} + 1.65\sigma ,$$

where
μ_T = Target Mean Strength,
f_{ck} = Characteristic Strength, and
σ = Standard Deviation.
The σ can be assessed from past experience in similar works, or alternatively it may be taken from **Table 6.5**, in case sufficient number of test results is not available already for a particular grade of concrete. For example, for Grade *M 20* (f_{ck} = 20 MPa), concrete may be expected to have a standard deviation of 4.6 MPa. Thus, μ_T =20+1.65×4.6 = 27.6 MPa.

Therefore, the mix should be designed for a specific strength (of say 28 MPa) and verified by trial mixes. When this designed mix is adopted in the field, the average strength will be around 28 MPa, but a few test results (say 1 out of 20 results) are likely to fall below 20 MPa. By the same reasoning, it will be seen that the nominal mix proportions, suggested are likely to give average strengths somewhat higher than the characteristic strengths given by the grade designation. Therefore, if the nominal mix corresponding to *M 15* gives an average, strength of say 25 MPa, the grade of concrete should not be assumed as *M 25* or *M 20*. Rather, if the test results are consistently high, advantage may be taken of this fact only by changing over to the design mix concrete.

(2) Quantity of Concrete

The…

(3) Quality of Concrete

The requirements of this clause relates to workmanship. Porous or honeycombed concrete is an outcome of incorrect mix proportion (incorrect consistency of concrete) or improper compaction technique. This defect can be made good either by patching, if the pockets are located near the surface, or by grouting in other cases.

Defects that are likely to be noticed at the improperly made construction joints are:

(a) *Horizontal Joints*:

(1) Laitance formation, along with weak and porous layer at the top of the bottom pour; and

(2) Deficiency of cement and excess of aggregates, both due to segregation at the bottom of the top pour.

(b) *Vertical Joints*:

(1) Formation of *feather-edges*; and

(2) Shrinkage cracks along the jointed surface.

Tolerances for reinforcements are specified in **Clause 82.2.5**. Once the concrete is placed, it is difficult to check the tolerance of reinforcements. But, the position of steel near the surface of concrete (say within *70 mm*) can be determined by using a magnetic cover meter.

C(b) Reinforcing Steel Bars

The…

(1) Sampling Frequency

The…

(2) Test Specimen

The…

(3) Test Results

The…

(4) Acceptance Criteria

The…

.

(a) Strength

The…

(b) Elongation

The…

C(c) Prestressing Steel Tendons

The…

(1) Sampling Frequency

The…

(2) Test Specimen

The…

(3) Test Results

The…

(4) Acceptance Criteria

The…

.

(a) Strength

The…

(b) Elongation

The…

C(d) Water

The ...

(1) Basic Tests

The…

(2) Additional Tests

The…

(3) Curing Water

The…

(4) Sampling of Water

The…

102.2.2 *Tests on Prestressing Systems*

The…

C102.2.2 *Tests on Prestressing Systems*

The…

102.2.3 *Test on Samples from Structures*

Core Tests shall be carried out on the structure, when the *grade of concrete* is suspected to be deficient due to:

(1) *Poor workmanship* observed visually, or

(2) *Low cube strengths* obtained from compressive strength tests of concrete.

Cores shall be prepared and *Core Tests* performed as per **IS 516 (Part 4)** to determine *compressive strength* and in-situ *quality of concrete*.

Core Tests shall be conducted on a limited number of samples; these shall be supported by NDT tests (like RHT and UPV tests). In all cases, results of *Core Tests* alone shall be final and binding, notwithstanding those of the *Non-Destructive Tests*. *The locations* from where cores are to be taken and *the number* of cores required shall be at the discretion of the *Engineer-in-Charge*, and shall be representative of the whole of the concrete work of concern. The number of cores taken shall not be less than three, in no case.

Concrete in the member represented by samples of the *Core Test* shall be considered acceptable, if:

(1) If the individual member strength or where one set of cubes (set of 4 consecutive samples) has failed:

The *Core Test* results shall be considered to be satisfactory, if average of equivalent cube strength of a minimum three cores is more than $0.85 f_{ck}$ and no individual core has equivalent cube strength less than $0.75 f_{ck}$; here, f_{ck} is the specified cube strength, *i.e.,* characteristic strength, of concrete.

(2) If a large number of cube sets (each set consisting of 4 consecutive samples) has failed for the same grade of concrete within a batch to be assessed, say 2 consecutive sets or 3 scattered sets have failed,:

The *Core Test* results shall be considered to be satisfactory, if average of equivalent cube strength of a minimum 10 cores is more than $0.85(f_{ck} + X/2)$ and no individual core has equivalent cube strength less than $0.75 f_{ck}$; here, the average is average equivalent cube strength of all cores (of a minimum nine cores, after excluding outliers, if any). Out of every 10 cores tested, maximum one core test result can be outlier. Outlier can be detected by:

(i) Inspecting the load-machine displacement curves, or

(ii) Using statistics of results of *Core Tests*, if individual values are beyond $f_{ck,ave} \pm 2\sigma$, where σ is the standard deviation.

When the results of the *Core Test* do not satisfy the above requirements, or when such tests could not be performed, the *Load Test* (as per **Clause 102.1.3**) may be performed on the structure to ascertain its load carrying capacity.

Where there is doubt on strength, *Core Tests* could not be performed and *Load Test* has been carried out, additional *Non-Destructive Tests* shall be carried out to assess the *strength* and *durability* of concrete.

Normally, though there is a gain of strength beyond 28 days, the quantum of increase depends upon the grade of cement, type of cement, method of curing and prevalent environmental condition. Therefore, while assessing the strength of concrete based on cores extracted at a later age, *no increase in the strength of concrete* shall be considered, except where considered in design or included in the contract specifications.

C102.2.3 *Test on Samples from Structures*

Decision on location of *Core Tests* should be taken after conducting NDT. Based on their scatter, the results of the NDT can be placed in three categories, like *low*, *medium* and *high*. Then, the locations where cores need to be taken be decided to cover areas of all the categories.

After obtaining all the results of the Core Tests, in case of difficulty in interpretation of results, additional Core Tests may be carried out. In such case, all the results need to be considered for interpretation. Wherever Core Tests are repeated in a member, the results of the previous Core Tests cannot be ignored.

Generally, for new constructions, the acceptance of core test results is required for two purposes, namely:

(a) Acceptance for structural adequacy, but deviation from specification; and
(b) Contractual acceptance for conformance to specification; deviations from specifications also affects durability besides strength.

For existing structures, the requirement is to assess the *strength of concrete* in place**.**

Where the requirements of **Clause 102.2.3(a)(1) and (2),** as the case may be, have been met, the concrete can be said to be meeting requirements of specification of IS 456. But where, 10 or more cores are taken, but the results do not meet the criteria of **Clause 102.2.3(a)(2),** but results of average of cores from all the individual members tested have strength more than $0.85 f_{ck}$ and no individual core has strength less than $0.75 f_{ck}$, the concrete in the particular batch or member may be accepted for structural adequacy (for QA Level 1 and 2), but not conforming to specified grade or not conforming to specification of IS 456 and contractual acceptance, penalties and deductions, may be decided by the project authorities as per contract provisions.

Core cutting, *i.e.,* drilling, shall not be done across reinforcements. The procedures are given in **IS 516** for preparing and testing cores drilled from concrete. The cores should be undamaged representative of the concrete. The cores should be capped before testing, as specified in **IS 516**. Standard diameter of core is 150 mm. But, cores of other diameter also may be used. But, the length of core should be at least 95% of the core diameter. The equivalent cube strength (on 150 mm cubes) may be obtained by applying correction factors for size of core, age of concrete and type of cement; these factors are given in IS 516.

The number of test cores should be as many as possible with due regard to economic considerations. In practice, it is usual to secure only three cores (the minimum recommended by the clause) and mean the strength taken as the result. This mean of this sample is only an approximation of the strength of concrete in the structure and the results are dependent on the number of cores. Therefore, structure should not unnecessarily be declared unfit simply because the sample mean may fall below 85% of the required strength, especially when only a small number of cores are tested. The options available are:

(1) More *Core Tests* may be carried out;
(2) The *Load Test* may be resorted to; and
(3) The *load-carrying capacity* of the structure re-estimated using results of the *Core Tests*.

Generally, the specified compressive strength of concrete is the cube compressive strength f_{ck}, the results of *Core Tests* also are expressed as a fraction of f_{ck}. Accordingly, the *Acceptance Criteria* of *Core Test* results also are correlated to acceptance criteria of *Cube Tests*. The *Acceptance Criteria* of cube tests in the Indian Standards and other International Standards are based on statistical analysis.

In the expression for *Target Mean Strength* f_m,

$$f_m = f_{ck} + z\sigma ,$$

for 95 percent samples passing, z is 1.65. Therefore, for acceptance of results of Cube Test based on average of 4 consecutive samples (4×3= 12 cubes), the standard deviation σ becomes:

$$\text{Standard Deviation} = \frac{\sigma}{\sqrt{N}} = \frac{\sigma}{\sqrt{4}} = \frac{\sigma}{2} = 0.5\sigma .$$

Therefore,

$$f_{ck,\min} = f_m - 1.65\sigma_{\min} = (f_m + 1.65\sigma) - 1.65 \times 0.5\sigma = f_m + 0.825\sigma$$

For *Core Test also,* this expression may be valid only if large numbers of *cores* are tested and a reliable standard deviation computed. For simplicity, the expression

$$f_{ck,\min} = f_{ck} + \frac{X}{2}$$

has been adopted as Acceptance Criteria for the results of *Core Tests*.

102.2.4 *Impact Test on Structures*

A large mass suspended as a pendulum shall be dropped from a predetermined height to cause external impulse at a predetermined location of the structure. The resulting response of the structure shall be measured using digital sensors with time sampling of data with micro-second resolution.

The *Engineer-in-Charge* shall decide:
(1) The mass of the pendulum to be dropped, and
(2) The height from which the mass is to be dropped,
such that the impact is minimal enough to cause a measurable impact, but not too severe to destroy the structure.

C102.2.4 *Impact Test on Structures*

These test cause damage either locally or globally. This test should be performed to ascertain the dynamic characteristics of the structure.

103. MONITORING

The…

C103. MONITORING

The…

103.1 Instrumentation

The…

C103.1 Instrumentation

The…

103.2 Use of Data

The…

C103.1 Use of Data

The…

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