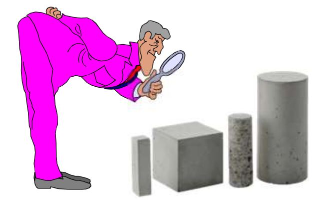
Welcome

CDC

Concrete Cube Testing & NDT



RAVI RANADE

(NDT, Repair / Rehab. Consultant, Concrete Technologist)

CDC **Construction Diagnostic Centre Pvt. Ltd.**

Understanding Concrete Strength

- **Standard Cube Strength**
  The measured compressive strength of a cube made, cured and tested in accordance with IS – 516

- **Core Strength**
  The compressive strength of a core, cut, prepared and tested in accordance with the requirements of IS– 516 - Part 4 - 2018, for a stated length/diameter ratio

- **Estimated in-situ Cube Strength (Equivalent Cube Strength)**
  The strength of concrete at a location in a structural member estimated from indirect means and expressed in terms of specimens of cubic shape

CDC

Understanding Concrete Strength

- **Potential Cube Strength (BS 6089 – 2010)**

  Determining the average potential strength is a method for estimating the 28-day compressive strength of the concrete supplied to the structure.

  It takes the corrected core strength and modifies it to take account of excess voidage, differences caused by different curing conditions and differences between the maturity of the core at testing and 28 days at 20˚C.

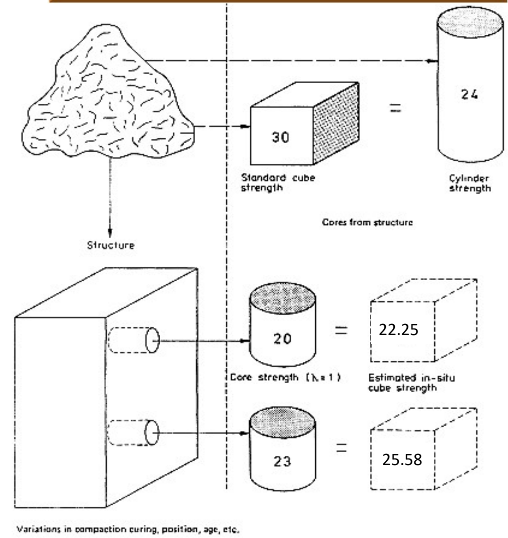
CDC

Understanding Concrete Strength

✓ **Most direct method of assessing in-situ strength of concrete in a structural element is by *Core tests.***

CDC

Understanding Concrete Strength



CDC

Cube Strength v/s In-Situ Strength

- *When Cube test is carried out according to standard procedures, the results of the Cubes compression test represent the potential strength of the concrete as delivered to a site. (Ref : ACI 228.1R-19)*
- *The test is used mainly as a basis for quality control of the concrete to ensure that contract requirements are met.*
- *It is not intended for determining the in-place strength of the concrete because, it makes no allowance for the effects of placing, compaction, or curing. It is unusual for the concrete in a structure to have the same properties as a standard-cured cube at the same test age.*

CDC

Cube Strength v/s In-Situ Strength

- *Sometimes, the strength of the concrete in the structure can be obtained by using field cured cylinders (Cube) prepared and cured in accordance with ASTM C 31/C 31M.*
- *These Cubes are cured on or in the structure under, as nearly as possible, the same conditions as the concrete in the structure (Normally kept over slab).*
- *Still, measured strengths of field cured cubes may be significantly different from in-place strengths because it is difficult, and often impossible, to have identical bleeding, consolidation, and curing conditions for concrete in Cube and concrete in structures*

CDC

Sampling of Concrete

- *Sample of concrete for test specimen shall be taken at the <u>end discharge point</u>*
- *For final acceptance of concrete for Structural strength purpose, the samples should only be taken at end discharge point.*
- *If pumping / placing is not in the scope of the RMC supplier, then RMC supplier may collect additional sample for his contractual requirements.*

CDC

We believe ONLY on Cube strength

But !!!
The millennium dollar question is does a cube strength truly represent the in-situ concrete strength??.

CDC

The parameters on which the CUBE strength of concrete depends

Age – Blended cement concrete- slower strength development

Size of cube- Higher the size -> lower the strength

Shape – Cube or Cylinder V/s Shape of RCC members – Cube Strength = 1.25 x Cylinder Strength

Mould material & Texture of moulds - Compared to Cast Iron moulds – strength of concrete casted in M.S., Timber, Plywood and PVC moulds is found to be on lower side.

Compaction – Layers, no. of blows, dia. of compaction rod.

Curing temperature – 27 ^{0} C (+- 2 ^{0} C) – Higher Temp -> Higher strength

Curing period – 28 days for cubes , Site - 10 days for OPC, 15 days for Blended

Moisture conditions at the time of testing – SSD – Air dried cubes yield 20 -25 % more strength

Type of compression testing machine – (Rocker & roller plate) – The tolerance for cube dimensions as per IS : 10086 – 1981 is ONLY +- 0.2 mm

Direction of casting & Direction of Testing - Normally the strength is more in the casting direction

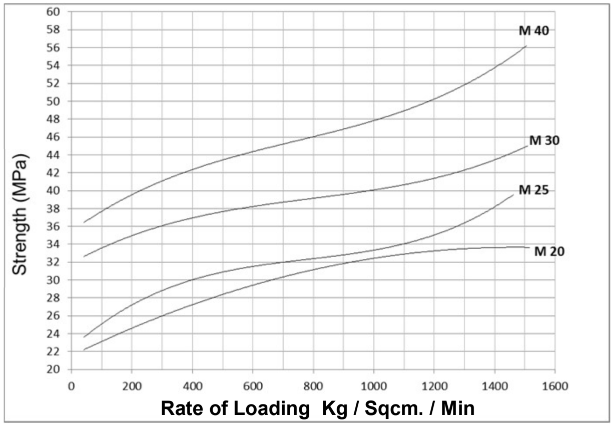
Rate of loading – 140 Kg/Sqcm/ Min @ 315 KN/Min. At field the cubes are crushed with a speed of more than 500 to 1500 Kg/Sqcm/Min. With such an increase in rate of loading a compressive strength can get increased up to 55 %.

Does cube really fail in pure axial compression ?

CDC

Rate of Loading

- **As per IS – 516 the standard rate of loading should be – 140 Kg/Sqcm/ Min i.e. @ 315 KN/Min for 150x150x150 cube**



CDC

Cube Testing - Observations

- A truly representative concrete is not used for filling the cubes. A special batch with lower w/c ratio and higher cement content is made to cast the cubes.
- The samples are very rarely collected at the end discharge point.
- The sample size is always less than the IS – 456 requirements.
- The cube samples do not have the correct size and shape.
- It is very important to measure the dimensions of the specimens to the nearest 0.2 mm as per IS – 516. In most of cases dimensions not are not measured, but are simply assumed be perfect 150 x 150 x 150 mm, which is NEVER the case.
- It is very important to know the type of fracture, which can indicate that, whether testing is properly carried out or not or whether the size and shape of the cube is responsible for erroneous results.

CDC

Cube Testing - Observations

- At almost ALL sites, temperature control facility for curing tanks is not available.
- Most of the time, cubes are taken out from the tank much before the testing , and they do not have the saturated surface condition (SSD). The resulted strength is on higher side.
- Very few labs in India have Rate of loading controlled testing machines. As reported above, rate of loading with which cubes are tested at site or in labs is much higher than the required. Thus the resulted strength is on very much higher side.
- The curing of concrete at site is simply an eye wash
- **The entire procedure from Cube casting, Cube testing and interpretation is taken very very casually.**

CDC

Why NDT ?

a) Lower Cube Strength

b) Doubt concerning workmanship involved in batching, mixing, placing, compacting or curing of concrete.

c) Deterioration of concrete due to:
overloading;
fatigue;
chemical action;
fire;
explosion;
weathering.

d) To ascertain whether the in-situ strength of Concrete is acceptable for:
the designed / actual / Projected loading system;

CDC

What is the reliability of NDT ??

- Accuracy of @ $\pm$ 75 to 85 %
- Remember – We are dealing with a complex and heterogeneous material - Concrete

CDC

NDT Results

The Accuracy & Reliability depends upon -

- Proper selection of ND Tests
- Proper surface preparation for every test
- Combination of various ND Tests
- Sampling & Extent of Testing
- Co-relation of ND Tests with standard site samples
- Cognizance of various factors and site conditions affecting the test
- Site Conditions accuracy and reliability of available correlations (e.g. between pulse velocity and strength).

CDC

NDT Results

Always -

Combine two or more NDT methods like –

- ✓ Rebound Hammer + UPV
- ✓ Rebound Hammer + UPV + Core
- ✓ Half-Cell Potential + Resistivity
- ✓ Half-Cell Potential + Resistivity + Carbonation + Sulphate & Chloride Test
- ✓ Pile Integrity + UPV + Core
- ✓ Pile Integrity + Pile Load test (Static / Dynamic)
- ✓ RADAR + Thermography
- ✓ Maturity test + Pullout Test

CDC

EN 13791:2019

Table A.1 — Relative merits and limitations of various tests for measuring *in situ* compressive strength

Region tested	Test	Standard	Accuracy of strength estimate	Speed of test	Ease of test	Economy of test	Lack of damage to structure
In depth	Core	EN 12504-1	****	**	**	*	*
	Ultrasonic pulse velocity	EN 12504-4	** a	***	***	***	****
Near to surface	Pull-out	EN 12504-3	** b	**	**	**	*
Immediate surface	Rebound number	EN 12504-2	** a	****	****	****	***

NOTE More asterisks indicate a better performance.

a Only if calibrated for the particular concrete under investigation.

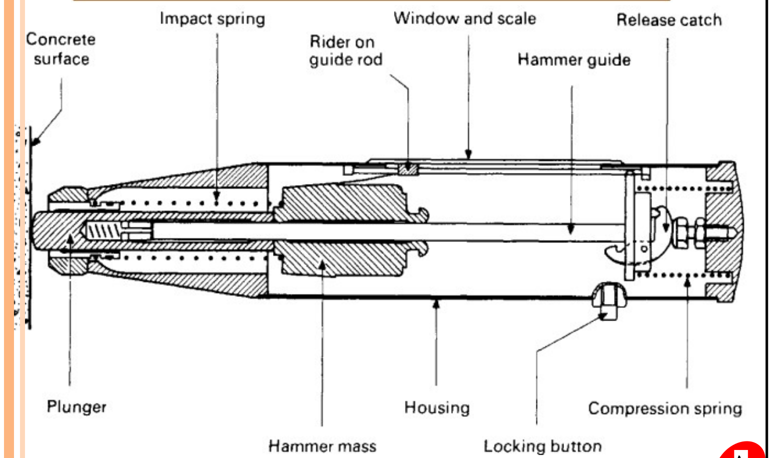
b Pull-out testing is more commonly used to determine the strength of young concrete and for this use the accuracy of the strength estimation is higher than given in this table. A lower accuracy is given for the applications covered in Clause 8 as carbonation and incipient delamination may affect the accuracy.

CDC

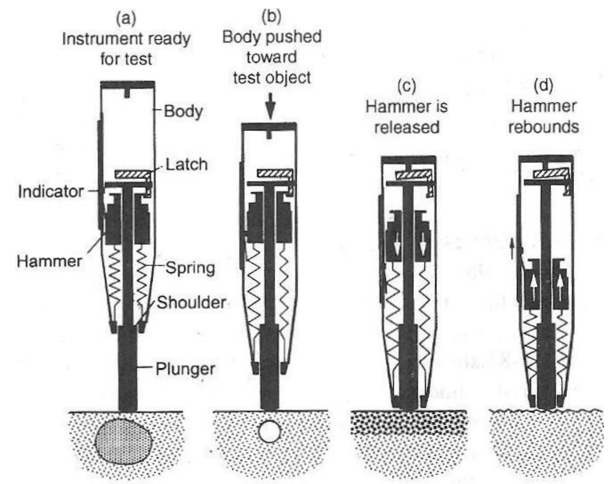
REBOUND HAMMERS / CALIBRATION ANVIL

CDC

REBOUND HAMMER TEST (IS- 516 - Part 5 Sec 4- 2020)



REBOUND HAMMER OPERATION



REBOUND HAMMER TEST

Hardness measurement of surface layer of 25 to 50 mm

Influenced by –

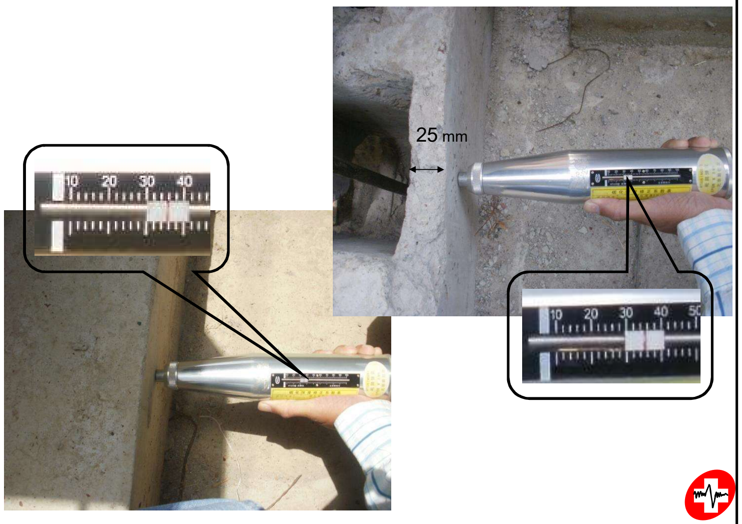
- **Smoothness of test surface,**
- **Size, shape, and rigidity of the specimens,**
- **Age of test specimens,**
- **Surface and internal moisture conditions of the concrete,**
- **Type of coarse aggregate,**
- **Type of cement,**
- **Type of mould,**
- **Carbonation of the concrete surface** ***(Calcium Bi Carbonate a Harder substance)***

Prediction of strength ± 25 %

Silver Schmidt V/s Classical Rebound Hammer

Parameter	Silver Schmidt	Classical Rebound Hammer
Rebound Value	Q	R
Measurement	Rebound Velocity	Rebound Distance
Friction & Gravity Effect	Negligible (Measures velocity immediately before and after impact)	Present
Weight of hammer & plunger	Weight of hammer reduced & that of plunger adjusted accordingly	Standard
Correction for impact direction	Not required	Required
Rebound Value as against "R" value	> "R" value	

Rebound Hammer – ONLY a surface Test



ULTRASONIC PULSE VELOCITY TEST (IS- 516 - Part 5 Sec 1- 2018)

ULTRASONIC PULSE VELOCITY TEST

$$V^2 = \sqrt{\frac{E_d \quad (1-v)}{p\ (1+v)\ (1-2v)}}$$

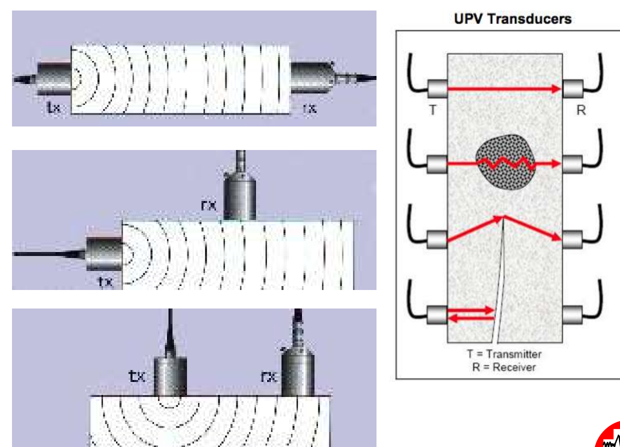
Thus $V \propto E_d$

$Ed \propto Es$

and $Es = 5000\sqrt{f_{ck}}$

Thus $V \propto f_{ck}$

ULTRASONIC PULSE VELOCITY TEST - Methods



ULTRASONIC PULSE VELOCITY TEST

Gradation of Quality of concrete - as per IS 516 (part 5/Sec1) : 2018 AMENDMENT NO. 1 NOVEMBER 2019 - Direct velocity Km/Sec		
Quality of Concrete	Grade <= M - 25	> M - 25
Excellent	Above 4.500	More than 4.500
Good	3.500 to 4.500	3.750 to 4.500
Doubtful	Below 3.500	Less than 3.750

CDC

ULTRASONIC PULSE VELOCITY TEST

Gradation of Quality of concrete (as per CDC) - Direct & Semi Direct velocity Km/Sec				
Quality of Concrete	Grade < M - 15	M - 20 to M - 25	M - 30 to M - 35	> M - 40
Excellent	Above 4.250	More than 4.400	More than 4.600	More than 4.900
Good	3.500 to 4.250	3.750 to 4.400	3.900 to 4.600	4.150 to 4.900
Medium	3.000 to 3.500	3.400 to 3.750	3.600 to 3.900	3.800 to 4.150
Doubtful	Below 3.000	Less than 3.400	Less than 3.600	Less than 3.800

CDC

ULTRASONIC PULSE VELOCITY TEST

Influenced by –

- Type of cement
- Type of Aggregate
- Surface condition & moisture content,
- Type of Mix & water / cement ratio,
- Reinforcement,
- Stress level

CDC

ULTRASONIC PULSE VELOCITY TEST

Applications:-

- The ultrasonic pulse velocity method is used to assess
- The homogeneity / Quality of the concrete
- The presence of cracks, voids and other imperfections, depth of crack
- Changes in the structure of the concrete which may occur with time
- The quality / compressive strength of concrete of one element in relation to another element / standard requirement.
- The values of dynamic elastic modulus of concrete

CDC

ULTRASONIC PULSE VELOCITY TEST

ULTRASONIC PULSE VELOCITY TEST

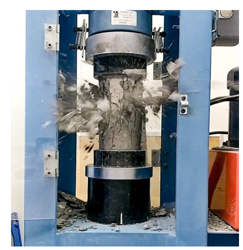
Core Test (IS -516 - Part 4 – 2018, IS - 456)

"Core Tests

Easy to Perform ,

Not Easy to Interpret"

- Adam Neville



Core Test - IS -516-Part 4 – 2018 - Test requirements -

- ✓ Age – Upto M-25 more than 14 days, for higher grades can be less
- ✓ Location –
  - Not near construction joints,
  - Preferably from the middle part of the member
  - For Slab or from foundation top, trim top 15 to 20 % depth as top part of the core may not contain uniform distribution of aggregates (maximum up to 60 mm).
  - In case of cores which are not across full depth of member, trim 10 to 15 % portion of the bottom side, as the portion near to the broken end may contain some micro cracks/fractures
  - From Compression zone

CDC

Core Test - IS -516-Part 4 – 2018 - Test requirements -

- ✓ Number of Cores – Minimum 3 Nos
- ✓ Diameter of Cores –
  - Minimum Dia. Of Core shall be 3 times nominal Aggregate Size
  - The core diameter shall generally be 100 mm to 150 mm ($\pm$ 10 mm), with the preferred diameter being 100 mm for nominal maximum aggregate size up to 20 mm.
- ✓ Length of Cores –
  - Core length to Dia. Ratio shall be between 1.0 to 2.0
  - For l/d ratio lower than 2.0 correct the compressive strength
- ✓ Reinforcement – No reinforcement in the core sample to be tested

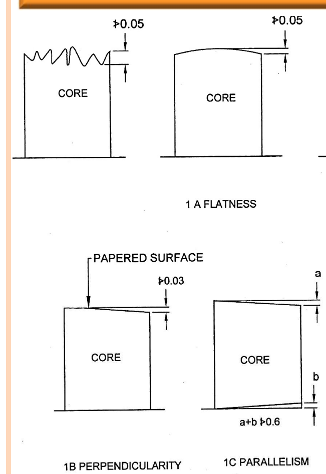
CDC

Core Test - IS -516-Part 4 – 2018 - Test requirements -

- ✓ Preparation of Core sample –
  - *Grinding (Most precise method)* - (For any value of strength) – Grinding after curing , Why not before curing ??
  - *Capping* –
    - Up to 50 Mpa - Capping with calcium aluminate cement mortar), Capping with sulphur mixture
    - Up to 100 MPa Capping with high strength sulphur mixture
    - Or Other capping materials may also be used provided that, at the time of testing, it has a strength at least equal to the anticipated strength of concrete.
- ✓ Cores may be tested generally in saturated condition except if specifically required to be tested in air dry condition.
  - Specimen shall be soaked in water for at least 40 hours to maximum of 48 hours before testing at 27 $\pm$ 3˚C

CDC

Core Test - IS -516-Part 4 – 2018 - Test requirements -



All dimensions in millimetres.

FIG. 1 PERMISSIBLE TOLERANCES FOR PREPARED CORE SPECIMENS

All for 100 mm dia core

IS : 10086 - 1982

TABLE 2 DIMENSIONS AND TOLERANCES OF CUBE MOULDS

(*Clause* 4 1)

SL No.	DESCRIPTION	CUBE MOULD SIZE 50	100	150	225	300
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	Distance between opposite faces (C^*), mm	50±0 1	100±0·2	150±0·2	225±0·3	300±0·4
ii)	Height of mould (F^*), mm	50±0 1	100±0·2	150±0 2	225±0·3	300±0 4
iii)	Thickness of wall plate (D^*), mm	6	8	8	10	10
iv)	Angle between adjacent interior faces and between interior faces and top and bottom plates of mould	90±0 5°	90±0·5°	90±0·5°	90±0 5°	90±0·5°

Perpendicularity Tolerance for 0.5 ^{0} θ for

100 mm dia core - 0.87 mm

75 mm dia core - 0.65 mm

60 mm dia core - 0.52 mm

CDC

Core Test - IS -516-Part 4 – 2018 - Test requirements -

- ✓ **Diameter correction factor for less than 100 mm dia.**

Diameter of Core (No. of Cores ≥ 3) mm	Correction Factor
75 ± 5	1.03
< 70	1.06

- ***What about diameters from 80 to 100 mm ??***

- ✓ **Correction factor according to the l/d ratio –**

$$F = 0.11N + 0.78$$

where

F = correction factor, and

N = length /diameter ratio.

- ✓ **The equivalent cube strength of the concrete = 1.25 x corrected cylinder strength**

Core Test - IS -516-Part 4 – 2018 - Test requirements -

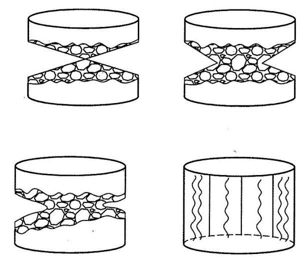


Fig. 2 Satisfactory Failure of Specimen

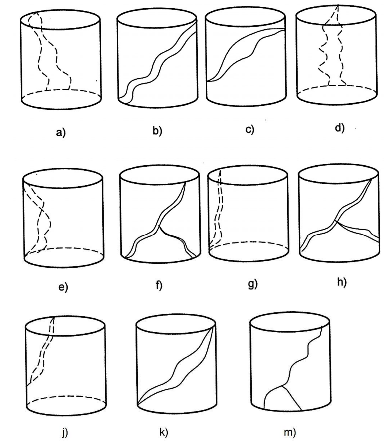


Fig. 3 Unsatisfactory Failure of Specimen

Core Test – Acceptance Criteria

- ✓ *As per IS 456- 2000 Cl – 17.4.3*
  - ***Min. Avg. equivalent cube strength of core shall be***
    - ***> 85 % of design grade of concrete***
    - ***But no individual core shall have strength < 75 %***
- ✓ *As per IS -516-Part 4 – 2018 Cl - B-2.5.2*
  - ❑ ***For assessing strength of a particular member by taking THREE cores***
  - ***Min. Avg. equivalent cube strength of core shall be***
    - ***> 85 % of design grade of concrete***
    - ***But no individual core shall have strength < 75 %***
  - ❑ ***For overall assessment requirement or where large number of cube sets (each set consisting of 4 consecutive samples) have failed , by taking TEN cores***
  - ***Min. Avg. equivalent cube strength of core shall be***
    - $f'_{(avg)} > 0.85\ (f_{ck} + 3)$
    - $F'_{(i)} > 0.75\ (f_{ck})$

Factors affecting Core Test

Variation of In-place concrete strength in structures (ACI - 214.4R-4)

- **Core test results may not represent the quality of concrete as delivered to the site if mixing water was added at the site, or poor placing, consolidation, or curing practices were followed**

❑ **Consolidation**

- **Strength is reduced by approximately 7% for each percent by volume of entrapped air remaining when concrete is insufficiently consolidated**

❑ **Curing**

- **Low initial curing temperatures reduce initial strength development rate but can result in higher long-term strength. Conversely, high initial-curing temperatures increase initial strength development but reduce long-term strength**

Factors affecting Core Test

Variation of In-place concrete strength in structures (ACI - 214.4R-4)

- **Micro-Cracking**
  - Micro-cracks can be present in regions of the structure that were subjected to stress from applied loads or restraint of imposed deformations. Rough handling of the core specimen can also cause micro-cracking.
- **Curing**
  - Low initial curing temperatures reduce initial strength development rate but can result in higher long-term strength. Conversely, high initial-curing temperatures increase initial strength development but reduce long-term strength

CDC

Factors affecting Core Test

- **Where to take the cores**
  - At a number of locations spread over the whole structure
  - Load carrying capacity of the structure is not impaired by removing some concrete
- **Length/diameter preferred ratios**
  - a) 2,0 if the strength result is to be compared to cylinder strength;
  - b) 1,0 if the strength result is to be compared to cube strength.
  - a) To be classified as a 2:1 core the capped or ground length to diameter ratio shall be within the range between 1.95 to 1 and 2.05 to 1.0
  - b) To be classified as a 1:1 core the capped or ground length to diameter ratio shall be within the range between 0.90 to 1 and 1.10 to 1.0

CDC

Factors affecting Core Test

- **Correction factor for *l/d* ratio**
  - stronger concretes are less affected by the value of L/D than concretes of lower strength; this is shown in Fig. 1.

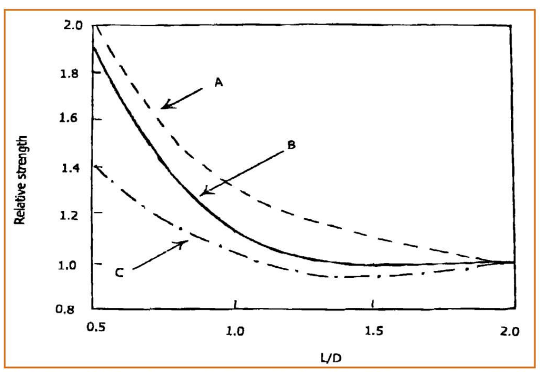


Fig. 1: Effect of *L/D* on the strength of test cylinders.[6] The 28-day strength at *L/D* = 2 in MPa (psi) is: A, 14 (2000); B, 26 (3700); C, 52 (7500)

CDC

Factors affecting Core Test

- **Effect of Reinforcement**
  - In general, reinforcement reduces the strength of a core,
  - The exceptions being 1:1 cores with not more than 2.0 % volume fraction of reinforcement and 2:1 cores where the reinforcement is completely within 30 mm of the ends of the core and the volume fraction of reinforcement is not more than 2.0 %. In these cases, the presence of reinforcement may be regarded as having no impact on the core strength
- **Which Moisture Condition ?**
  - Dried core samples give about 5 to 10 percent more strength than saturated samples. Therefore, for comparison with the cube test results, saturated sample testing is recommended in the test procedure of IS -516-Part 4 – 2018

CDC

Factors affecting Core Test

Direction of Core Drilling

- In one of the experiment, upto 7 – 8 % less strength is noticed for horizontally drilled cores
- Bartlett and MacGregor found that the direction of the core axis relative to the direction of casting has no effect on the strength of cores taken from high-strength Concrete
- IS -516-Part 4-2018 & EN 13791:2019, does not differentiate between either direction of coring
- In case of Slip formed Concrete there would be no lowering of the apparent strength of concrete in cores drilled horizontally.

CDC

Core Test – Some Observations

Corrections for excess voidage

- Estimating excess voidage, BS EN 12504-1 National Annex NA. An indication of the adequacy of placing and compaction.
- From BS EN 13791 National Annex NA an estimate of in situ strength assuming fully compacted concrete may be calculated from: = $k_v \times f_{c,is}$

Correction factor for excess voidage, k_v	
Estimated excess voidage, %	Correction factor to fully compacted in situ strength k_v
0.0	1.00
0.5	1.03
1.0	1.06
1.5	1.09
2.0	1.12
2.5 A)	1.15

A) Where the excess voidage exceeds 2.5% it is unlikely that any estimate of the fully compacted *in situ* cube strength using an assumed voidage correction factor is reliable.

CDC

Core Test – Some Observations

Consensus and Unanimity

- Before any Test program is commenced, it is desirable that there is complete agreement between the interested parties on the validity of the proposed testing procedure, the criteria for acceptance, and the appointment of a person and/or laboratory

Variability of Strength –

- For 100 mm diameter cores with ends prepared by grinding, there is a 95 % probability that the true mean value is within ±14% / √ n of the calculated value *(Ref: EN 13791:2019) e.g. -*

for 03 cores - 8.1 %

for 10 cores - 4.4 %

for 30 cores - 2.6 %

CDC

EN – 13791 – 2019 - Estimation of compressive strength

Abbreviations used for compressive strength	
Abbreviation	Description and explanation
$f_{c,is}$	Compressive strength of a core taken at a test location within a structural element or precast concrete component expressed in terms of the strength of a 2:1 core of diameter ≥ 75 mm. NOTE 1 If more than one core is taken at a test location, the test result is the mean of the individual test measurements. NOTE 2 This value is based on the *in situ* moisture condition and it is not adjusted to a standard moisture condition.
$f_{ck,is}$	Characteristic *in situ* compressive strength (expressed as the strength of a 2:1 core of diameter ≥ 75 mm), i.e. the in situ compressive strength below which 5 % of test results are expected to fall if all the volume of concrete under consideration had been cored and tested. NOTE 1 These values are not normalized to a standard moisture condition. NOTE 2 The *in situ* volume of concrete under consideration is unlikely to be the same volume used to determine the conformity of the fresh concrete in accordance with EN 206. It is generally a smaller volume.
$f_{ck,spec}$	Minimum characteristic strength of 2:1 cylindrical test specimens associated with the specified compressive strength class. NOTE For example $f_{ck,spec}$ is 30 MPa for compressive strength class C30/37. See EN 206 for all strength classes.

CDC

EN – 13791 – 2019 - Estimation of compressive strength

- Introduces the two applications of in situ strength assessment
  - a) to estimate in situ characteristic compressive strength $f_{ck,is}$ of a test region and/or in situ strength at specific locations (Clause 8)
  - b) assessment of compressive strength class of concrete supplied to a structure under construction where there is doubt about the compressive strength based on results of standard tests or doubt about the quality of execution (Clause 9)

CDC

EN – 13791 – 2019 - Test regions, test location and number of tests

Test region

The test region shall be defined:

- a single concrete
- a series of similar elements, or a large element
- may include concrete from different production units using the same materials

- *Clause 8*

  Small test region

- Shall not include significantly different concrete
- ≤10 m^3, or ≤30 m^3 where there are no supply issues and where indirect testing is used to identify locations of lower compressive strength

- *Clause 9*

- a volume is not more than about 30 m^3, supplied in a single day and no indication that any load is different to the others
- The region may comprise up to six volumes, so ≤180 m^3

CDC

EN – 13791 – 2019 - Estimation of compressive strength for structural assessment of an existing structure

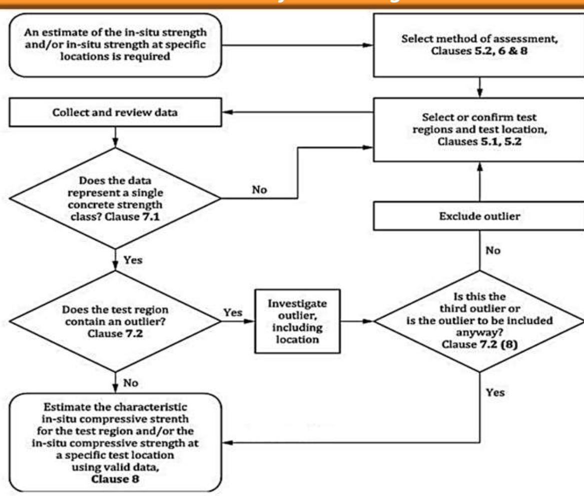


Figure 1 — Flowchart for the estimation of characteristic *in situ* compressive strength for the test region and the *in situ* compressive strength at specific locations

CDC

EN 13791:2018 (E)

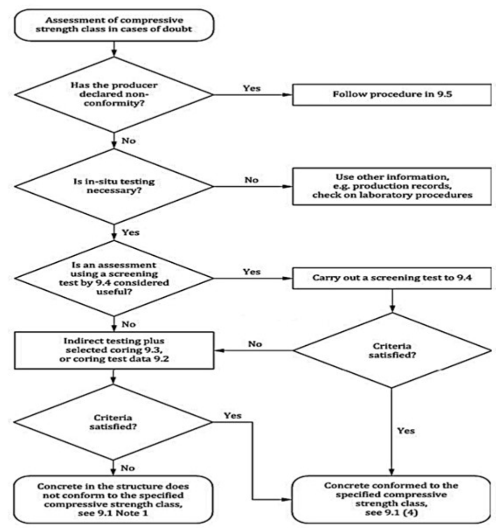


Figure 2 — Flowchart for assessment of compressive strength class of supplied concrete in cases of doubt

CDC

Table 3 — Types of test and their relationship between test locations and regions

Test	Location	Region
Compressive strength from cores (EN 12504-1)	A test result may be the strength of a single core, the mean core strength if more than one core is taken at the test location, e.g. when a long core is divided into two or more shorter cores. See also Clause 6 for requirements for cores with diameters less than 75 mm.	The minimum number of valid test results for estimating the characteristic *in situ* compressive strength of a test region is eight provided the core diameter ≥ 75 mm, see 8.1 (2), where it is recommended to core at least ten test locations, to allow for possible outliers. For a small test region a lower number of valid test results may be permitted, see 8.1 (6). The minimum number of valid test results from ≥ 75 mm diameter cores for use in combination with indirect testing is three, see 8.3, where at least four test locations should be cored to allow for a possible outlier.
Rebound number[a] (EN 12504-2)	The test result in accordance with EN 12504-2 is the rebound number and it comprises the median of a minimum of 9 valid readings at a test location.	A regularly spaced rebound hammer survey will show variations in concrete surface hardness over the structure and identify parts of the test region where cores should be taken or further investigations undertaken.
UPV[a] (EN 12504-4)	A test result may be a single measurement of the ultrasonic pulse velocity measured directly or indirectly, through a section of concrete, or the mean ultrasonic pulse velocity if more than one measurement is taken at the test location.	A regularly spaced UPV survey will show variations in concrete density over the structure and identify parts of the test region where cores should be taken or further investigations undertaken.

EN – 13791 – 2019 - Core testing and the determination of the in situ compressive strength

Table 4 — Requirements to achieve a test result for a test location

Requirement	Core diameter	Core diameter	
	50 mm[a]	≥ 75 mm	
Length : diameter ratio	**Nominal: 1:1[b] Permitted range: 0,90:1 to 1,10:1**	**Nominal: 2:1 Permitted range: 1,95:1 to 2,05:1**	**Nominal: 1:1 Permitted range: 0,90:1 to 1,10:1**
Minimum number of core compressive strength values to achieve a test result at a test location	3	1	1
In situ compressive strength at test location ($f_{c,is}$)	*CLF*[c] (mean of $f_{c,1:1core}$ values)	mean of $f_{c,2:1core}$ values[d]	*CLF*[c] (mean of $f_{c,1:1core}$ values)[d]

core length factor *(CLF')*.

EN – 13791 – 2019 - Estimation of compressive strength for structural assessment of an existing structure - Based only on Core test data

The characteristic *in situ* strength ($f_{ck,is}$) is the lower of both:

$$f_{ck,is} = f_{c,m(n)is} - k_n s$$

$$f_{ck,is} = f_{c,is,lowest} + M$$

Where:

$f_{c,m,(n)\,is}$ Mean value of eight or more valid test results
k_n Coefficient whose value depend on the number valid results, n, see Table 1.
s Sample standard deviation of the test result for the region, but not less than that equivalent to a coefficient of variation of 8%.
$f_{c,is.lowest}$ Lowest value of the eight or more test results
M 4 for mean strength ≥20 MPa
3 for mean strength ≥16 <20 MPa
2 for mean strength ≥12 <16 MPa
1 for mean strength <10 MPa

Table 1– k_n values

n	8	10	12	16	20	30	∞
k_n	2.00	1.92	1.87	1.81	1.76	1.73	1.64

— eight valid test results of *in situ* compressive strength based on ≥ 75 mm diameter cores in accordance with Table 4 or

— twelve valid values of *in situ* compressive strength each based on a single 50 mm diameter cores from concrete with a upper aggregate size ≤ 16 mm.

For test region comprising not more than 30 m³ –

Take the mean value of three or more cores (provided the spread of test results is not more than 15 % of the mean value) as the in situ compressive strength ($f_{ck,is}$)

EN – 13791 – 2019 - Estimation of compressive strength for structural assessment of an existing structure - Based only on Core test data

Small Test Region

- **Less than around 10 m³**
  - **At least three cores, and at least one core from each element. The lowest value of the three or more cores may be assumed to be $f_{ck,is}$ for structural assessment purposes.**
- **Less than around 30 m³**
  - **Indirect testing is used to determine variability and locations of lower strength. The mean value of the three or more cores may be assumed to be $f_{ck,is}$ for structural assessment purposes.**
- **Provided:**
  - **Each core represents concrete that is to remain in the structure and the spread of results is less than 15% of the mean value result. A wider spread of results indicate further investigation is required.**

EN – 13791 – 2019 - Estimation of compressive strength for structural assessment of an existing structure - Based on a combination of Indirect test data and Core test data

The regression equations of Indirect Tests values shall be used to estimate the characteristic *in situ* compressive strength

Estimation of the characteristic *in situ* compressive strength for a test region

(1) The mean *in situ* compressive strength is estimated as:

$$f_{c,m(m)is} = \Sigma\left(f_{c,is,reg}\right)/m$$

m is the number of estimated strength values.

Estimation of the *in situ* compressive strength at a specific location

(2) For structural assessment purposes, the estimated *in situ* compressive strength at a specific test location ($f_{c,is,est}$) is calculated using the following formula:

$$f_{c,is,est} = f_{c,is,reg} - t_{(0,05,\ n-2)}\, s_c \sqrt{1 + \frac{1}{n} + \frac{\left(x_0 - \bar{x}\right)^2}{\sum_{i=1}^{n}\left(x_{i,cor} - \bar{x}\right)^2}} \qquad (10)$$

where 0,05 in $t_{(0,05,n-2)}$ is the alpha value for a one-tailed test with (n – 2) degrees of freedom.

EN – 13791 – 2019 - Assessment of compressive strength class of concrete in case of doubt

Doubt about the in situ quality may arise from doubts about the quality of the concrete supplied to the site, problems during the execution of the works or after some exceptional event on site.

Doubt often includes, but is not limited to, the following:

- **insufficient compressive strength of samples taken for identity testing e.g. poorly made or cured cubes;**
- **workability is excess of that specified, e.g. addition of water at behest of site personnel**
- **problems during execution of the works, e.g. movement of forms, too few internal vibrators**

The assessment criteria are based on concrete that is under production control certification.

EN – 13791 – 2019 - Assessment of compressive strength class of concrete in case of doubt

Where doubt remains there are three practical methods to assess the compressive strength class from in situ concrete:

- **Comparative indirect test testing - The recommendation is to take not less than 20 indirect test measurements, rebound hammer or UPV, in the region under investigation and compare with a 20 indirect test measurements for a reference region for which the compressive strength class is confirmed.**
- **Indirect testing combined with a minimum or cores, 9 –20 indirect tests with 3 cores for up to 180 m³ (2 cores for a single ≤ 30 m³ volume)**
- **Cores only, 3 to 12 cores for 30 to 180 m³ insufficient compressive strength of samples taken for identity testing e.g. poorly made or cured cubes;**

EN – 13791 – 2019 - Assessment of compressive strength class of concrete in case of doubt - Based only on Core test data

Minimum of three core results for a single ≤30 m³ volume placed in a single day, where there is no indication that any load is different to the others delivered to that volume.

Up to 12 core results required to assess up to 180 m³.

Minimum core requirements and assessment criteria for a region of concrete up to 180 m³.

Number of volumes in region, all <30 m³	Minimum number of 1:1 cores for each volume	Minimum number of 1:1 cores for region	Assessment criteria Note: Both criteria need to be satisfied — Mean of all core results from the region:	Assessment criteria — Lowest core result
1	3	3	–	$\geq 0.85(f_{ck,spec,cube} - 4^{E)})$
2	2	4	$\geq 0.85(f_{ck,spec,cube} + 1)$	
3	2	6		
4	2	8		
5	2	10	$\geq 0.85(f_{ck,spec,cube} + 2)$	
6	2	12		

A) For specified strength C16/20 the constant is reduced to 3, for specified strength C12/15 the constant is reduced to 2, and for specified strength C8/10 the constant is reduced to 1.

EN – 13791 – 2019 - Assessment of compressive strength class of concrete in case of doubt - Based on Indirect testing and minimum cores

Minimum 9 –20 indirect tests with 3 core results for up to 180 m^3

2 cores for a single ≤ 30 m^3 volume placed in a single day, where there is no indication that any load is different to the others delivered to that volume.

Note - 10m^3 a day for three days is to be treated as three different volumes.

Indirect test locations, cores and assessment criteria for a region of concrete up to 180 m^3.

Number of volumes in region, all ≤30 m^3	Minimum total number indirect-test locations for region	Minimum number of 1:1 core results and locations for coring	Assessment criteria. Note: Both criteria need to be satisfied — Mean of core test results at the locations closest to the to the median rebound number or the mean UPV for the test region.	Assessment criteria — Lowest core result
1	9	**2 cores:** One core at each of the two lowest indirect test values for the test region	—	$\geq 0.85(f_{ck,spec,cube} - 4^{A)})$
2, 3, 4	12	**3 cores:** One core at the lowest indirect test value for the test region, and one core at each of the test locations closest to the median rebound number or the mean UPV for the test region.	$\geq 0.85(f_{ck,spec,cube} + 1)$	$\geq 0.85(f_{ck,spec,cube} - 4^{A)})$
5, 6	20	**3 cores:** (as above)	$\geq 0.85(f_{ck,spec,cube} + 2)$	$\geq 0.85(f_{ck,spec,cube} - 4^{A)})$

A) For specified strength C16/20 the constant is reduced to 3, for specified strength C12/15 the constant is reduced to 2, and for specified strength C8/10 the constant is reduced to 1.

EN – 13791 – 2019 - Estimation of compressive strength

- **Do not confuse the Clause 8 Estimation of compressive strength for structural assessment of an existing structure procedures with Clause 9 Assessment of compressive strength class of concrete in case of doubt procedures,**
- **They have different approaches that may lead to significantly different outcomes.**

Concrete Complexities

- ✓ **The potential strength is of interest when we want to know that the mixture used in construction conforms to what is specified.**
- ✓ **The actual strength is of interest when we want to know how good the concrete in the structure is**

And the Reality is -

The intrinsic or "true" strength of concrete cannot be measured.

R & D is required

- ✓ **Most of the R & D was done on OPC 33 cement and M-15 grade of concrete**
- ✓ **There is an immediate need to reinvent the Concrete**
- ✓ **Extensive National level R & D is required to find out –**
  - **Effect of Size of Cube , Cylinder on strength**
  - **Effect of length to diameter ratio**
  - **Correlation of Cylinder strength v/c Cube strength**
  - **Effect of Cube Mould material and texture on compressive strength and on Rebound number**
  - **Effect of Compaction**
  - **Effect of curing period, temperature and curing regime**

R & D is required

✓ Extensive National level R & D is required to find out –

- Moisture condition of core sample
- Effect of direction of core drilling – Direction of Casting and Direction of Testing
- Effect of Rate of Loading on concrete testing
- Effect of Location of coring in the member
- Effect of reinforcement in the core sample
- Effect of Grinding and different capping materials
- Effect of flatness, Perpendicularity , Parallality on Cube and Core strength

✓ And our Indian Standards shall be based on the outcome of this R & D

Concrete

Seems to be Easy to Prepare & Cast

but

Very Difficult to Understand

Contacts

020 – 2543 2643
94220 07479

cdc@ndtconcrete.com
info@concretepune.com

W **www.ndtconcrete.com**
www.ndtconcrete.net

RAVI RANADE

CDC

Construction Diagnostic Centre Pvt. Ltd.