Testing of concrete strength

Chapter 12

Issues in Concrete strength testing

- **Why Testing?**
- Quality control and acceptance testing are indispensable parts of the construction process.
- Testing results provide important feedback on compliance with project specifications and may also be used to base decisions regarding any necessary adjustments to the concrete mixture.

- **Strength testing is done mainly after concrete hardening.** consequently, the strength of hardened concrete has to be determined after a considerable amount of suspect concrete may have been placed.

Issues in Concrete strength testing

- **Non-conformity of the hardened concrete.** It must be noted that non-conformity by a single test specimen, does not necessarily mean that the concrete from which the test specimens have been made is inferior to that specified; the engineer's reaction should be to investigate the concrete further.

- **Need For "Standard" Tests**. The strength, durability, and other mechanical properties of concrete should not be considered in any sense as "**fundamental**" material properties. This is because several factors will affect the observed behavior. Therefore, different test procedures would be expected to yield different results. to try to minimize the confusion that would result if everyone were to use different test procedures, various "standard" test methods have been proposed.

Compressive Strength Tests

- Compressive strength or compression strength of concrete is the **capacity of concrete to withstand compression loads** measured using standardized samples at the **age of 28 days**.
- It is a standard industrial practice that the concrete is classified based on compressive strength of the concrete cube or cylinder. This is what called concrete grade.

درجات الخرسانة واستعمالاتها

الاستعمالات	الحد الأقصى لنسبة الماء إلى الإسمنت (بالمائة)	محتوى الإسمنت (الأدنى) (كغم/م3)	المقاومة التصميمية (كغم/سم2)	درجة الخرسانة
خرسانة عادية، خرسانة نظافة	100	200	100	10
خرسانة عادية، مدات الميلان	85	220	150	15
الأساسات والأرضيات المصنوعة من الخرسانة العادية	77	260	180	18
خرسانة مسلحة	73 63	300 360	200 250	20 25
خرسانة مسلحة	57	400	300	30
خرسانة مسلحة	46	400	400	40

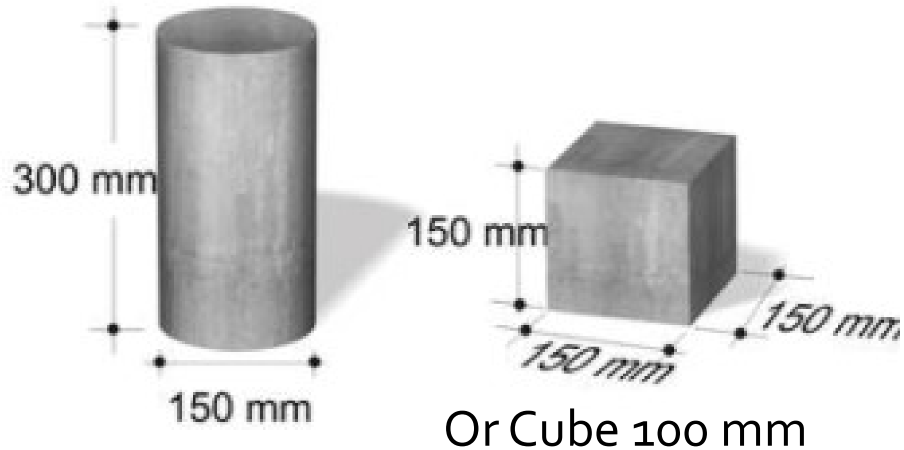
Compressive Strength Tests

- **Importance:** Compression test is the most common test conducted on hardened concrete, partly because it is an easy test to perform, and partly because most of the desirable characteristic properties of concrete are qualitatively related to its compressive strength.
- **Specimens**
  - The compression test is carried out on specimens cubical or cylindrical in shape. Prism is also sometimes used, but it is not common.
  - The cube specimen is of the size 15 x 15 x 15 cm while the Cylindrical test specimens have a length equal to twice the diameter. They are 15 cm in diameter and 30 cm long.

Compressive Strength Test

Testing machine

Specimens



Or Cube 100 mm

Note that: Testing machine and specimen type and size can have significant impact on the measured strength

Factor effecting measured Compressive strength

Concrete compressive strength measured experimentally (on the lab.) can be affected by the following factors:

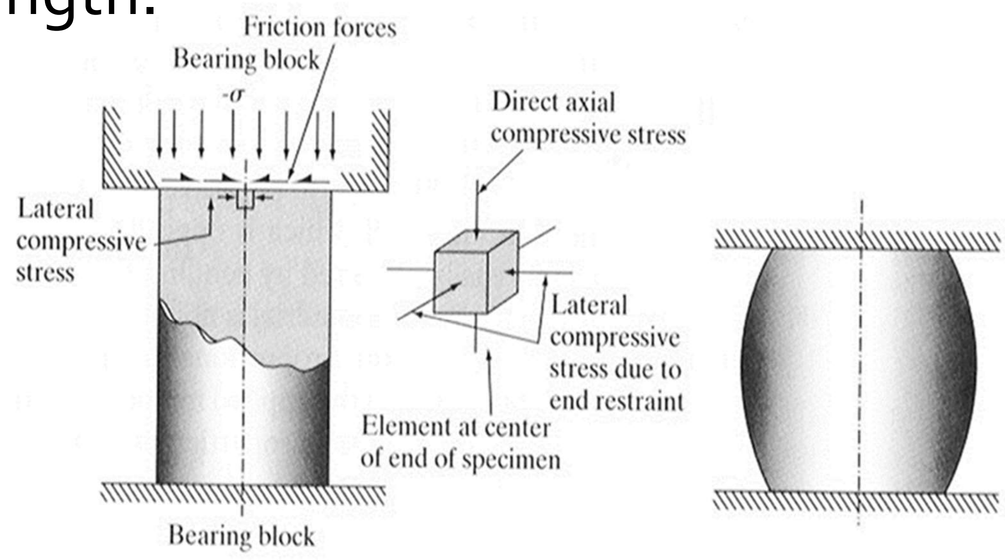
- Specimen end conditions and capping.
- Size, shape and the aspect ratio of the specimen.
- Rate of loading.
- The moisture conditions of the specimen.

Specimen end condition and capping

Those include:

- The end surfaces of the specimen shall be plane within 0.05 mm in order to avoid stress concentration and lower apparent strength.
- End restraint. The steel platens of the machine do not undergo lateral expansion to the same extent that of concrete, so it can provide lateral confining pressure near the specimen ends which can impact the measured strength.

This confining pressure is greatest right at the specimen end and gradually dies out at a distance from each end of approximately (√3/2)d, where d is the specimen diameter.



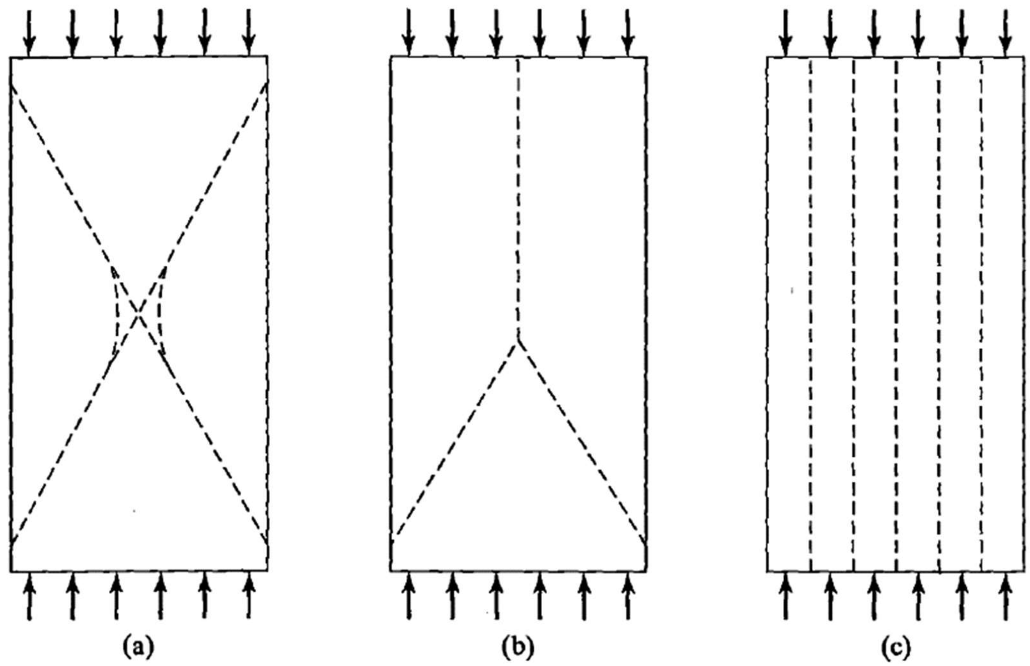
(a) End restraint in compression

(b) Barrel-shaped specimen resulting from end restraint

Specimen end condition and capping

Effect of end restraint (confining pressure near the specimen ends)

- Give an apparently higher strength than the "true" compressive strength.
- Cause the specimen to fail in conical shape.



Typical failure patterns for concrete cylinders in compression: (a) confinement at both ends;(b) confinement at one end and splitting failure at the other; (c) splitting failure.

Specimen end condition and capping

Capping (Surface preparation)

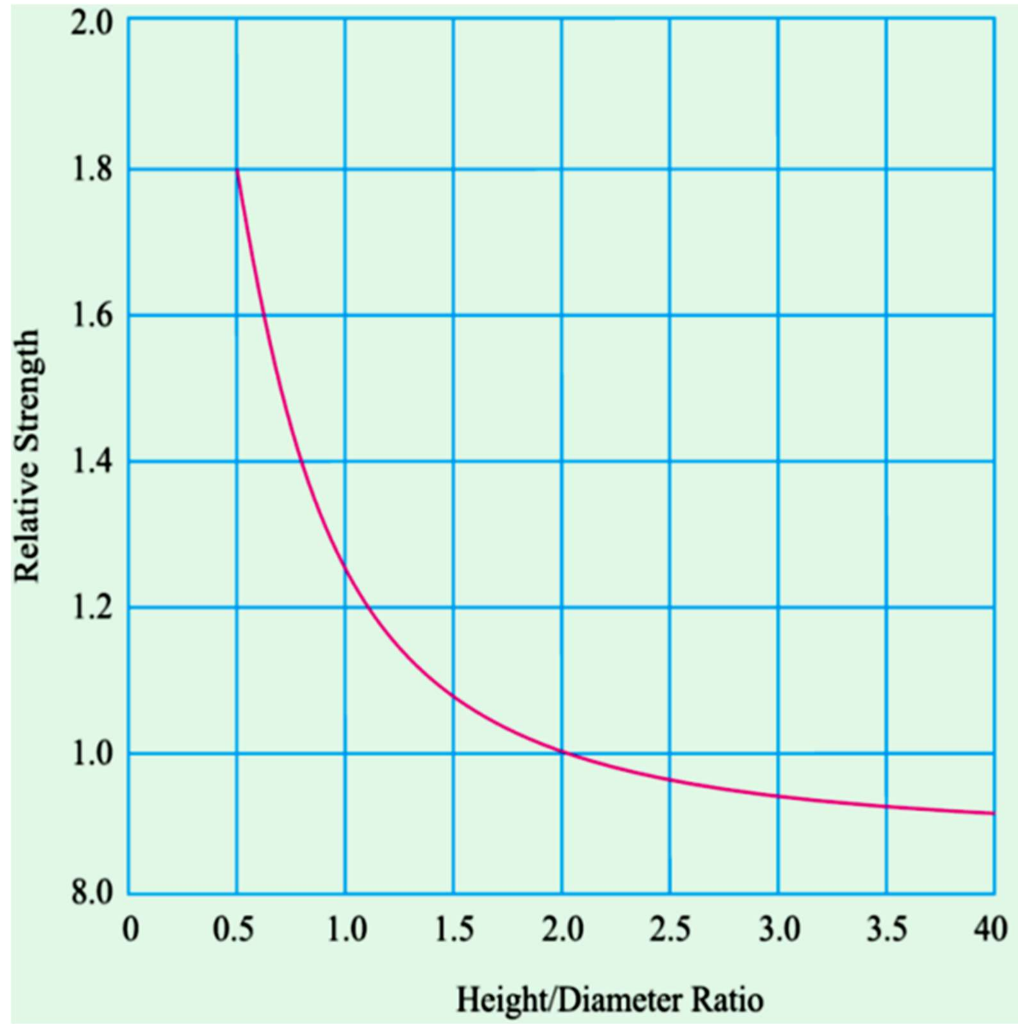
- Capping is the preparation of the ends of cylindrical concrete specimens to ensure that a test cylinder or core has smooth, parallel, uniform bearing surfaces that are perpendicular to the applied axial load during compressive strength testing.

- Materials such as a stiff Portland cement paste on freshly-cast concrete, and either a mixture of sulfur and a granular material or a high-strength gypsum plaster on hardened concrete can be used to cap concrete specimens.

- In case of cubes, no capping is required as the cube usually loaded at the face against the steel mold.

Size, shape and the aspect ratio of the specimen

- **Effect of l/d Ratio.** It has been found experimentally that the measured strength of concrete cylinder samples made from the same mix and cured under similar conditions varies as shown in the following curve when the length-to-diameter ratio (l/d) change. This observation can be explained by the specimen end effects.



Size, shape and the aspect ratio of the specimen

- **Specimen size.** Both the strength and the variability in strength of concrete decrease as the specimen size increases. This can be explained by the "weakest link" theory; the larger the size of the specimen, the more likely it is to contain an element that will fail at a (given) low load.

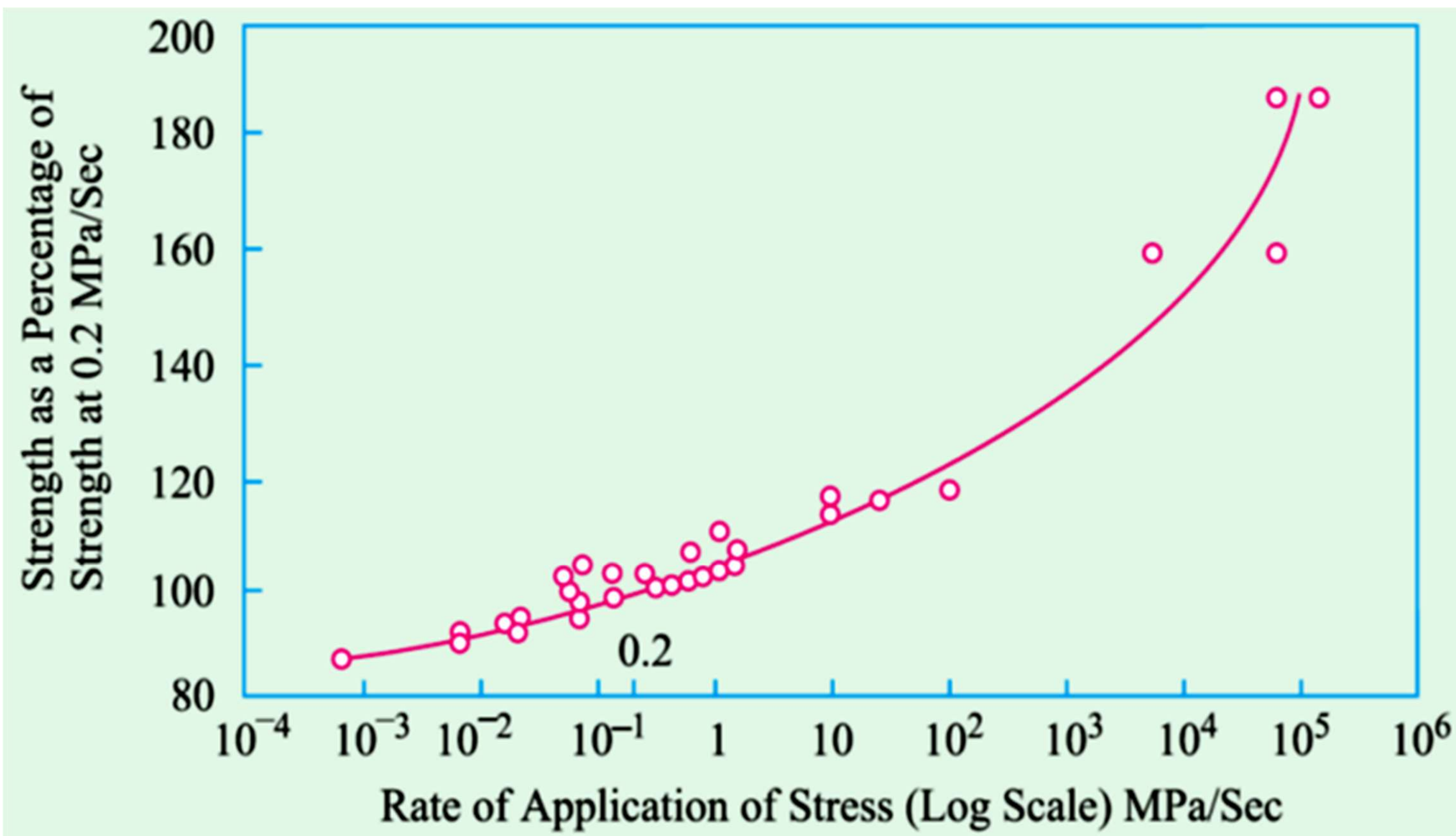
- **Specimen shape**. Cube and cylinder specimens are the most used specimens for hardened concrete compressive strength test. Cylinders give different values of strength when compared with cubes for the same mix. Normally strength of the cylinder is taken as 0.8 times the strength of the cube.

Comparison between Cube and Cylinder Strength

CUBE	CYLINDER
▪ Cubes are easier to test, as they does not require capping, whereas cylinder requires. ▪ The shape of the cube resembles the shape of the structural members often met with on the ground. ▪ Cubes are cast in one direction and tested from the other direction	▪ Cylinder is less affected by the end restrains and hence it seems to give more uniform results than cube. Therefore, the use of cylinder is becoming more popular, particularly in the research laboratories. ▪ Cylinders are cast and tested in the same position. As such, cylinder simulates the condition of the actual structural member in the field.

Rate of Loading

In general, the higher the rate of loading, the higher the measured strength. The reasons for this are not completely clear. One explanation is that it may be that slower loading rates allow more creep to occur, which will increase the amount of strain at a given load.



Moisture Content

- It has been found that concrete that has been dried shows an increase in strength. it may have something to do with the change in the structure of the C-S-H on drying, or it may simply indicates that moisture may have a "lubricating" effect, allowing particles to slip by each other in shear more easily.
- Most concrete specifications, such as ASTM require that concrete be maintained and tested in a saturated state.

Tensile Strength Tests

- The tensile strength of concrete is the capacity of concrete to withstand tensile loads. It is relevant to the design of highway and airfield pavements in addition to water retaining structures.
- Direct measurement of tensile strength of concrete is difficult. accordingly other indirect tests are used to determine tensile strength of concrete, they are: The splitting test and Modulus of rapture (MOR) test or The flexure test.
- Tensile strength of concrete is proportional to the square root of its compressive strength as shown below.

Direct tensile strength: $f_{ct} = 0.35\sqrt{f_c}$ (f_c in MPa)

Split tensile strength: $f_{cts} = 0.50\sqrt{f_c}$ (f_c in MPa)

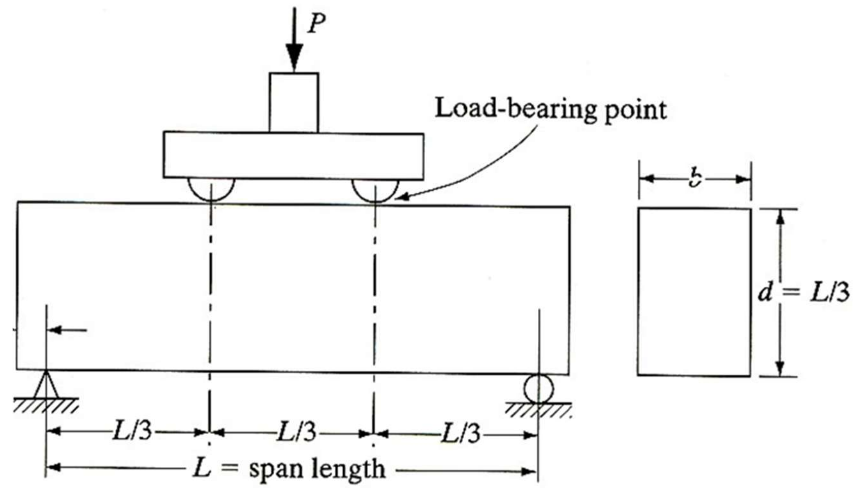
Flexural tensile strength: $f_{ct} = 0.64\sqrt{f_c}$ (f_c in MPa)

Modulus of rupture (MOR) test

In the MOR test, a concrete beam with span length (L) equal to three times the beam depth (d) is subjected to third-point loading as shown in the Figure.

Failure load P is noted and the tensile strength, called MOR, is then calculated using length (L), breadth (b) and depth (d) of the test beam, as follows:

$$MOR = \frac{PL}{bd^2}$$



Flexure test (third-point loading).

Split-cylinder test

In this test, a concrete cylinder specimen is subjected to a load to cause splitting of the specimen as shown below:

Failure load P is noted and the tensile strength, fst, is then calculated using length (L) and diameter (d) of the test cylinder, as follows:

$$f_{st} = \frac{2p}{\pi L d}$$

Where
P = maximum load
L = length of the specimen
d = diameter or width of the specimen

Core Test

The test is done by extracting cores of hardened concrete from the structure and testing it in order to estimate the potential strength of concrete used. The procedure is useful for

1. Resolving the argument that can immerge when the strength of the standard compression test specimens is below the specified value.
2. Evaluation of existing structures

3. Investigating the appearance of cracking or other signs of distress in the structure, furthermore the cores may also indicate segregation and honey combing of concrete.

Core Test

- ***Core Specimen:*** the preferred diameter of the core is 150 mm, and the ratio of diameter to the maximum size of aggregate should not be less than 3; the length should be between 1 and 2 times the diameter.
- **Acceptance of the test results:** according to ACI 318 if the average strength of three cores are at least 85% of f'c, and no single core has a strength less than 75% of f'c, then the concrete in the area represented by these cores is considered structurally adequate.
- In practice, the strength of the core is found to be less than that of the strength of standard cylinders/ cube. it is mainly because site curing is invariably inferior to curing under standard moist condition.

Core Test

- The strength of the core will depend on its position in the structure. cores taken near the top surface are weaker than those at the bottom, simply because of the effects of bleeding and of the settlement of the coarse aggregate.
- In order to obtain concrete strength from core test, the core test results shall be adjusted to account for
    - l/d ratio of the cores if less than 2.0.
    - The presence of any reinforcement in the core.
    - Direction of coring.

Nondestructive tests

- There are several nondestructive methods that can be used to evaluate hardened concrete strength. In these methods, the specimen are not loaded to failure and as such the strength estimated cannot be expected to yield absolute values of strength.
- However, Non-destructive methods are considered as a powerful tools for evaluating existing concrete structures with regard to their strength and durability apart from assessment and control of quality of hardened concrete.

Schmidt hammer test

- This test is also known as the rebound hammer or impact hammer. The test measures the rebound of a hardened steel hammer impacted on the concrete by a spring.

- Schmidt hammer test can be used to:
    - Assess the in-place uniformity of concrete.
    - Delineate regions in a structure of poor quality or deteriorated concrete
    - Estimate in-place strength of concrete where a correlation is developed.

Schmidt hammer test

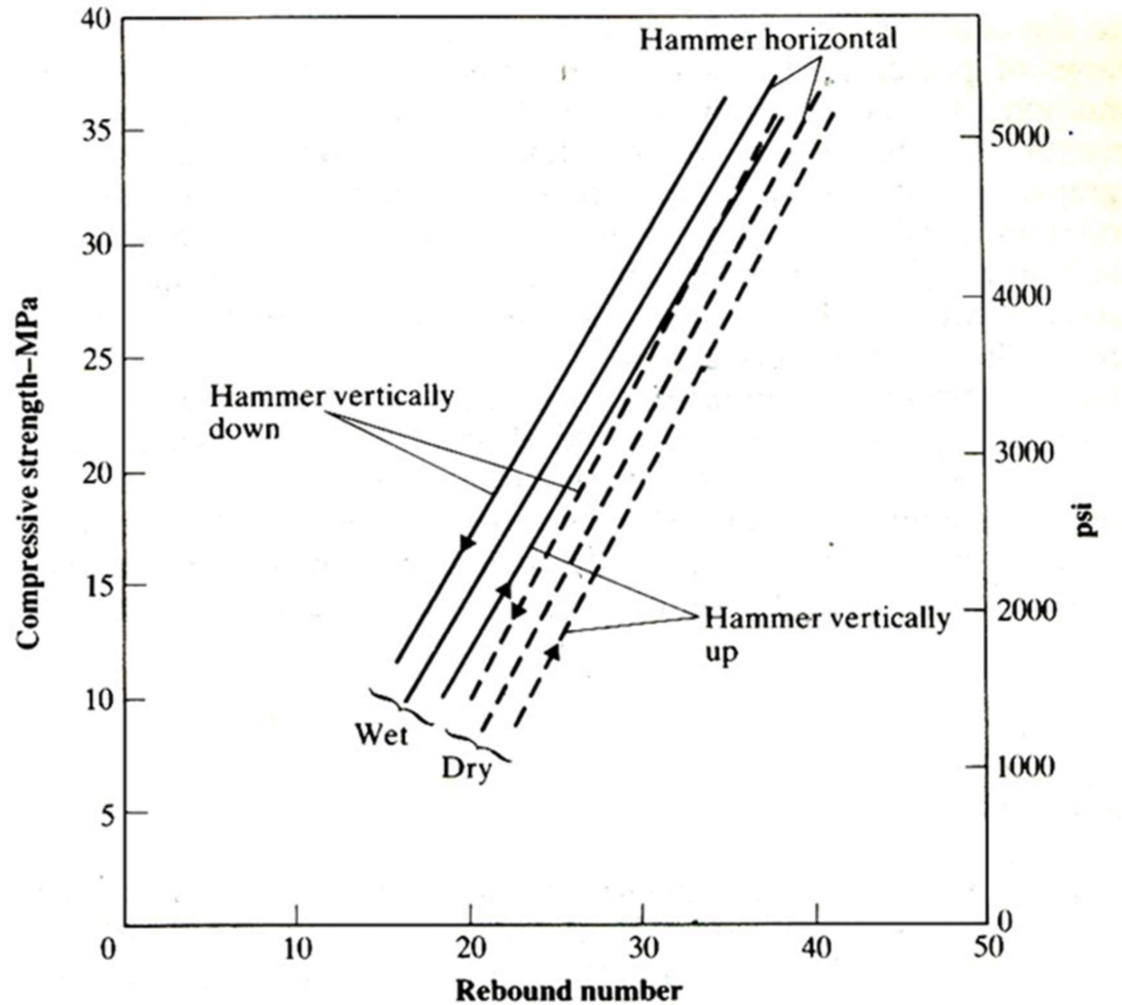
The test results can be affected by the following parameters:

1. Surface finish. The surface texture significantly affects the result obtained rough-textured finish will typically result in a lower number compared to hard, smooth texture surface.
2. Moisture content of the tested concrete. Dry concrete gives higher values than does wet concrete.
3. Surface Carbonation. With greater amounts of surface carbonation, higher rebound numbers will be obtained.
4. Rigidity of the member. Stiffer (more rigid) members will give higher readings.
5. Direction of impact. The orientation of the hammer (upward, downward, horizontally, or at an angle) affects the reading.

Schmidt hammer test

Procedure

The rebound number is recorded for 10 to 12 trial taken over the area to be tested to obtain the average number. The average number is then used to determine the compressive strength of concrete using the chart shown in the following figure.



Typical relations between compressive strength and rebound number with the hammer horizontal and vertical on a dry and a wet surface of concrete

Ultrasonic Pulse Velocity test

- The principle of this test is that the velocity of sound in a solid material, V, is a function of the square root of the ratio of its modulus of elasticity, E, to its density, ρ.
- Velocity of sound in a solid can be measured by measuring the travel time of short pulses of compressional waves through a test object. The result is reported as the ultrasonic pulse velocity in m/s, which in concrete typically ranges between 3500 m/s and 4500 m/s.
- In general, high velocities are indicative of good concrete and low velocities are indicative of poor concrete.
- The pulse velocity is affected greatly by the amount and type of aggregate and to a minor degree by the w/c.