Strength of Concrete

General:

Strength of concrete is commonly considered its most valuable property, although in many practical cases, other characteristics, such as durability and permeability may in fact be more important. Nevertheless strength usually gives an overall picture of the quality of concrete because strength is directly related to the structure of the hydrated cement paste. In general, high-strength concrete characterized by being more rigid, less permeable to water, and highly resistant to weather changes and other external factors. On the other hand, high-strength concrete exhibits higher shrinkage and low ductility, making it more susceptible to cracking.

Strength of concrete could be defined as the ultimate load that causes failure (or is its resistance to rupture) and its units are force units divided by area (N/mm^2, lb/in^2).

The strength of concrete results from:

• mortar resistance.

• Bond strength between mortar and coarse aggregate.

• Resistance of coarse aggregate particles to the applied stresses.

Nature of strength of concrete:

Concrete is considered a brittle material, although it exhibits a small amount of plastic behavior as it undergoes cracking and a slight amount of strain under a constant load. It should be noted that, at failure, a strain of 0.001-0.005 is considered the upper limit for brittle behavior. Therefore, the tensile and shear strength of concrete is weaker than its compressive strength.

Types of concrete strength:

1. Compressive strength
2. Tensile strength
3. Flexural strength
4. Shear strength
5. Fatigue strength

1. Compressive strength:

To determine the compressive strength of concrete, a cylindrical model with a height twice its diameter or a cubic model with dimensions of 100 mm or 150 mm is commonly used. The specimens are cured using the wet curing method at a temperature of 20°C for a period of 28 days. Afterward, the specimens are subjected to loading using a standard testing machine at a specific rate until they crack, typically within two or three minutes of loading. There are three types of loading in compression test:

a. uniaxial loading.
b. biaxial loading.
c. triaxial loading.

The uniaxial loading case represents the most conservative system and yields the lowest values in compression. There are three types of failure in uniaxial compression test as shown in Fig. 6.1. They are:

a. splitting failure.
b. shear failure.
c. combined (splitting and shear) failure.

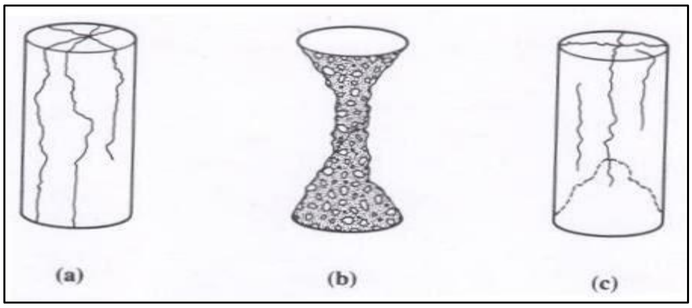

Fig. 6.1: Types of failure in uniaxial compression.

The effect of steel of testing machine in uniaxial loading:

In compression test, tangential forces being developed between the end surfaces of the concrete specimen and the adjacent steel plates of the testing machine. These forces will cause lateral expansion in concrete. The steel plate will restrain the lateral expansion of the concrete in the parts of the specimen near its ends: the degree of restraint depends on the friction actually developed. When the friction is eliminated, by applying a layer of graphite or paraffin wax on the bearing surfaces, the specimen exhibits a large lateral expansion then it will split along its length. But the friction is present under normal testing conditions, and every part in the specimen is subjected to a shear stress as well as to compression. The magnitude of the shear stress decreases and the lateral expansion increases, with increasing the distance from the plate.

If the specimen is longer than about 1.7d, a part of it will be free from the restraining effect of the plates. We can note that specimens whose length is less than 1.5d show a considerably higher strength than those with a greater length (see Fig. 6.2).

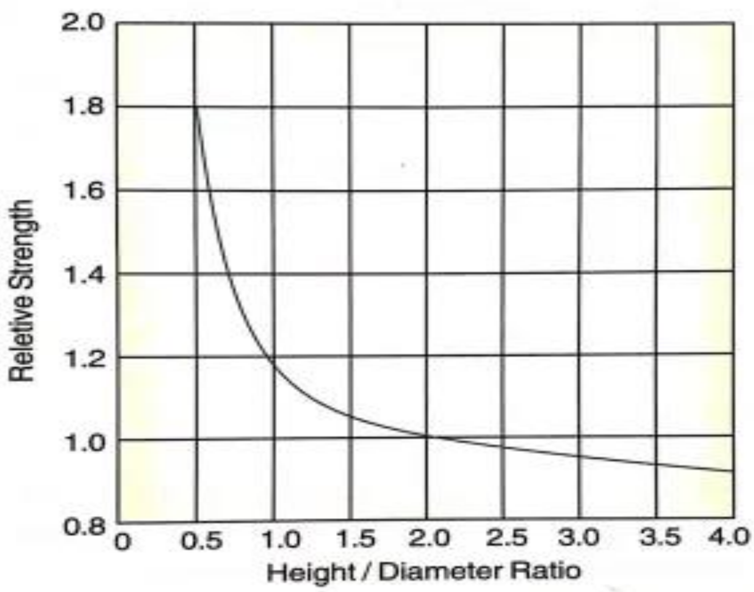

Fig. 6.2: General pattern of influence of the height to diameter ratio on apparent strength of a cylinder.

2. **Tensile strength:**

Normally, concrete is not expected to resist direct tensile force due to its relatively weak tensile strength and brittle nature. However, knowing the tensile strength is important for estimating the cracking load. The absence of cracks is of great importance for maintaining the durability of the concrete structure and, in many cases, preventing the corrosion of steel reinforcement. On the other hand, estimating the tensile strength of concrete helps in understanding the behavior of reinforced concrete.

There are two types of test for strength in tension: direct tension test, and splitting tension test.

a. **Direct tension test:**

It is rare to use direct tensile tests to estimate the strength of concrete, mainly due to the difficulty of securing and gripping the specimens and the unclear secondary stresses that occur due to the gripping method used in the testing apparatus. Therefore, direct tensile testing is never used for quality control purposes of concrete, and there is no standardized test even for research purposes.

b. Splitting tension test:

In this test, a concrete cylinder with a standard dimensions (150*300 mm), prepared and cured in the same manner as the compression strength specimens. The cylinder is subjected to compressive forces in two opposing and radial directions through the loading platen, which is composed of plywood, along two axial lines. The plywood support distributes the compressive force over a small width, which is sufficient to avoid any unacceptable stress concentration and compensate for any irregularities in the surface.

Without packing strips, the recorded strength is lower, typically by 8 percent. ASTM C 496-90 prescribes plywood strips, 3 mm (3/8 in.) thick and 25 mm (1 in.) wide. British Standard B.S 1881:117:1983 specifies a hardboard strips, 4 mm thick and 15 mm wide. With such an arrangement; the distribution of the horizontal stress will be almost uniform. The strength determined in the splitting test is believed to be close to the direct tensile strength of concrete, being 15 percent higher.

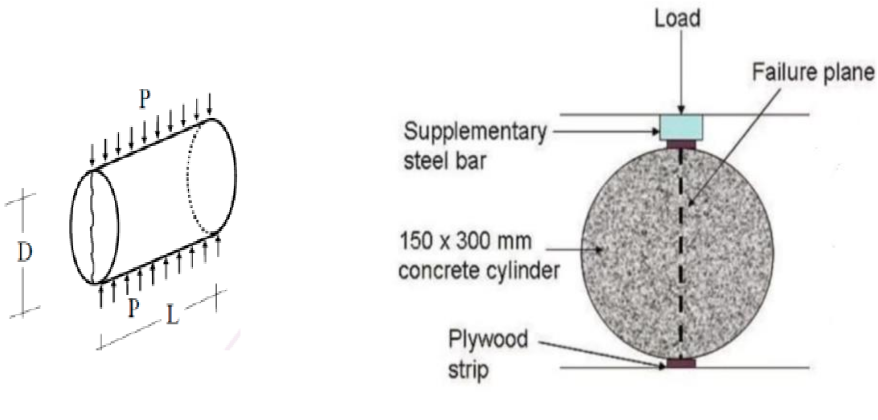

Fig. 6.3 : The splitting test of concrete.

The horizontal tensile stress will be : **[$\sigma t = 2P/\pi LD$]**

3. **Flexural strength (modulus of rupture):**

The value of modulus of rupture depends on the dimensions of the beam as well as the locations of the applied loads. There are two methods for load applications, the first of which uses a central point, giving a triangular distribution of bending moment, and the maximum stress occurs in only one section of the beam.

In the second method, two symmetric points along the beam are used, resulting in a constant bending moment between them. In this load distribution, a portion of the bottom surface of the beam, usually the middle third of the span, is subjected to the maximum stress. As a result, critical cracks initiate in any sufficiently weak section to resist this stress. On the other hand, in the case of the central load point, failure generally occurs only when the resistance of the fibers directly under the load point is exceeded. This indicates that the probability of having a weak section subjected to critical stress is much higher when using the two-point load method compared to the central load method. Since concrete is composed of different strength components (non-homogeneous material), it is expected that the modulus of rupture for the two-point load method will be lower than that obtained with the central load method. Knowing that the central load method is generally neglected as a standard test in international specifications.

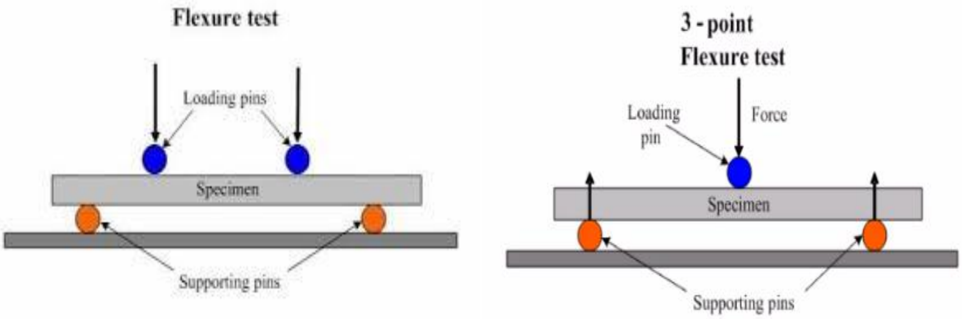

Fig. 6.4: flexure test of concrete.

The modulus of rupture is calculated on the basis of ordinary elastic theory, and is thus equal to:

$\sigma = (M.C/I) = (P\ L/b\ d^2)$

Where

P: maximum total load on the beam.

L: span length.

b: width of the beam, d: depth of the beam.