Chapter 7

HARDENED CONCRETE

Shrinkage

Shrinkage of concrete is caused by the;

1. settlement of solids and the loss of free water from the plastic concrete (**plastic shrinkage**),
2. chemical combination of cement with water (**autogenous shrinkage**) and
3. drying concrete (**drying shrinkage**).

CRACKING: Where movement of the concrete is restrained, shrinkage will produce tensile stress within the concrete, which may cause cracking.

Plastic Shrinkage

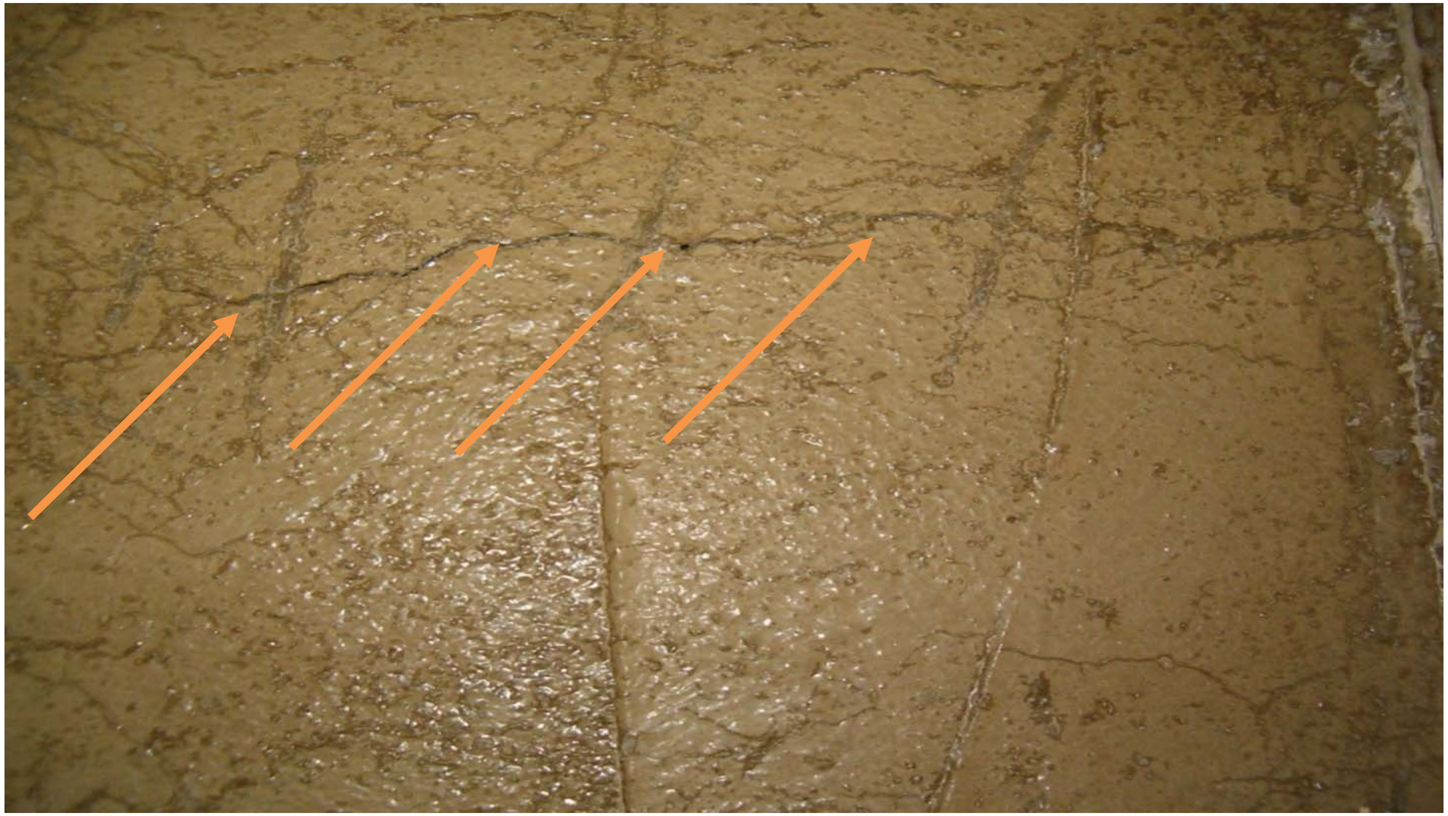
- Shrinkage, which takes place before concrete has set, is known as plastic shrinkage.
  - Occurs as a result of the loss of free water and the settlement of solids in the mix.

- Plastic shrinkage is most common in slab construction and is characterized by the appearance of surface cracks which can extend quite deeply into the concrete.
  - **Preventive measures**:

Reduce water loss by any curing methods (cover concrete with wet polythene sheets or by spraying a membrane-curing compound).

Plastic Concrete

Plastic Shrinkage Cracks



Autogenous Shrinkage

- As hydration continues in an environment where the water content is constant, such as inside a large mass of concrete, this decrease in volume of the cement paste results in shrinkage of the concrete.

- This is known as **autogenous shrinkage** (self-produced by the hydration of cement).
  - Factors influencing the rate and magnitude of autogenous shrinkage:

    Chemical composition of cement,

    Initial water content,

    Temperature and time.

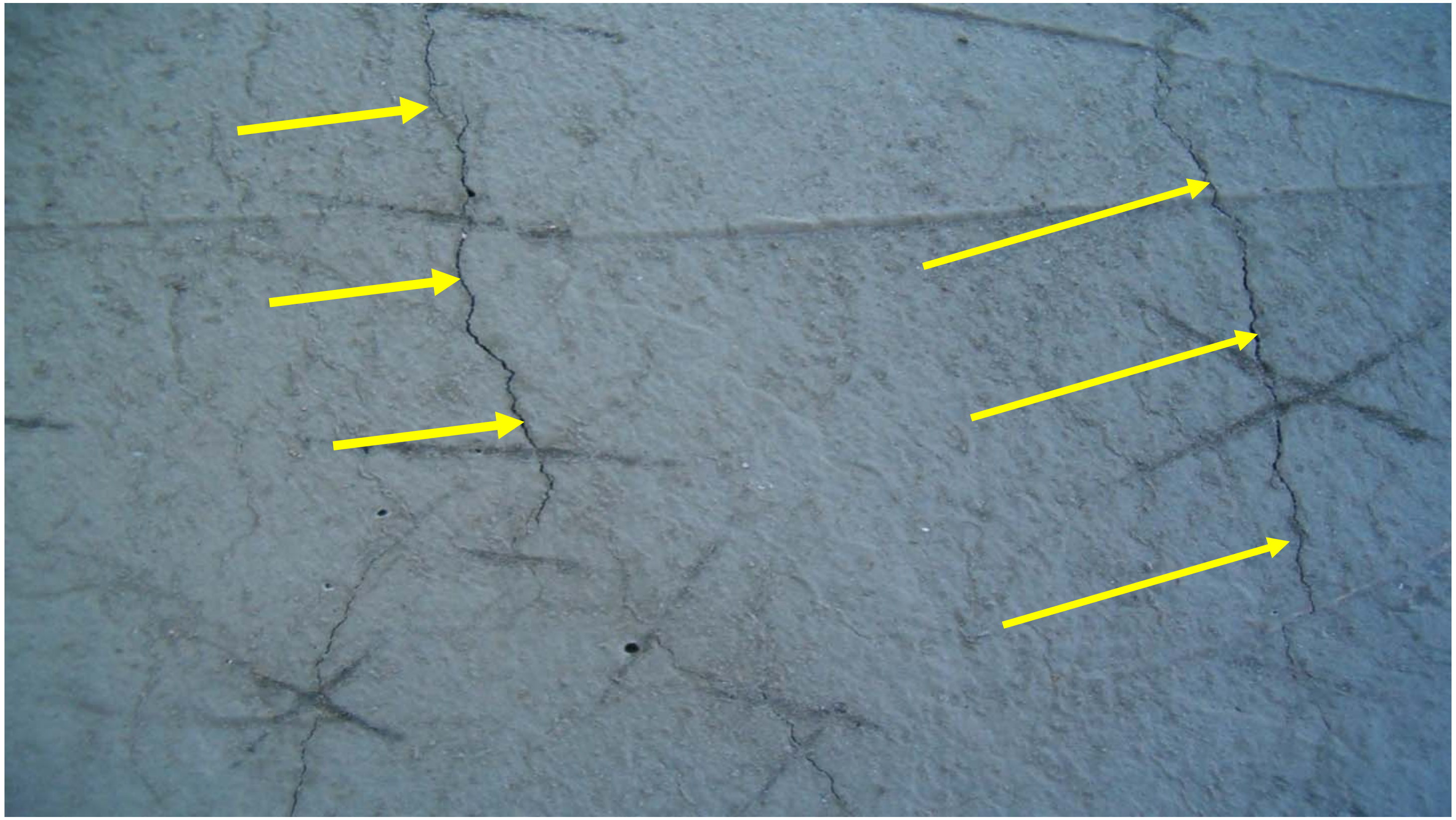
Drying Shrinkage

- When a hardened concrete, cured in water, is allowed to dry it first loses water from its voids and capillary pores and only starts to shrink during further drying when water is drawn, out of its cement gel. This is known as **drying shrinkage**.

- After an initial high rate of drying shrinkage concrete continues to shrink for a long period of time, but at a continuously decreasing rate.

- For practical purposes, it may be assumed that for small sections 50 per cent of the total shrinkage occurs in the first year.

Drying Shrinkage Cracks



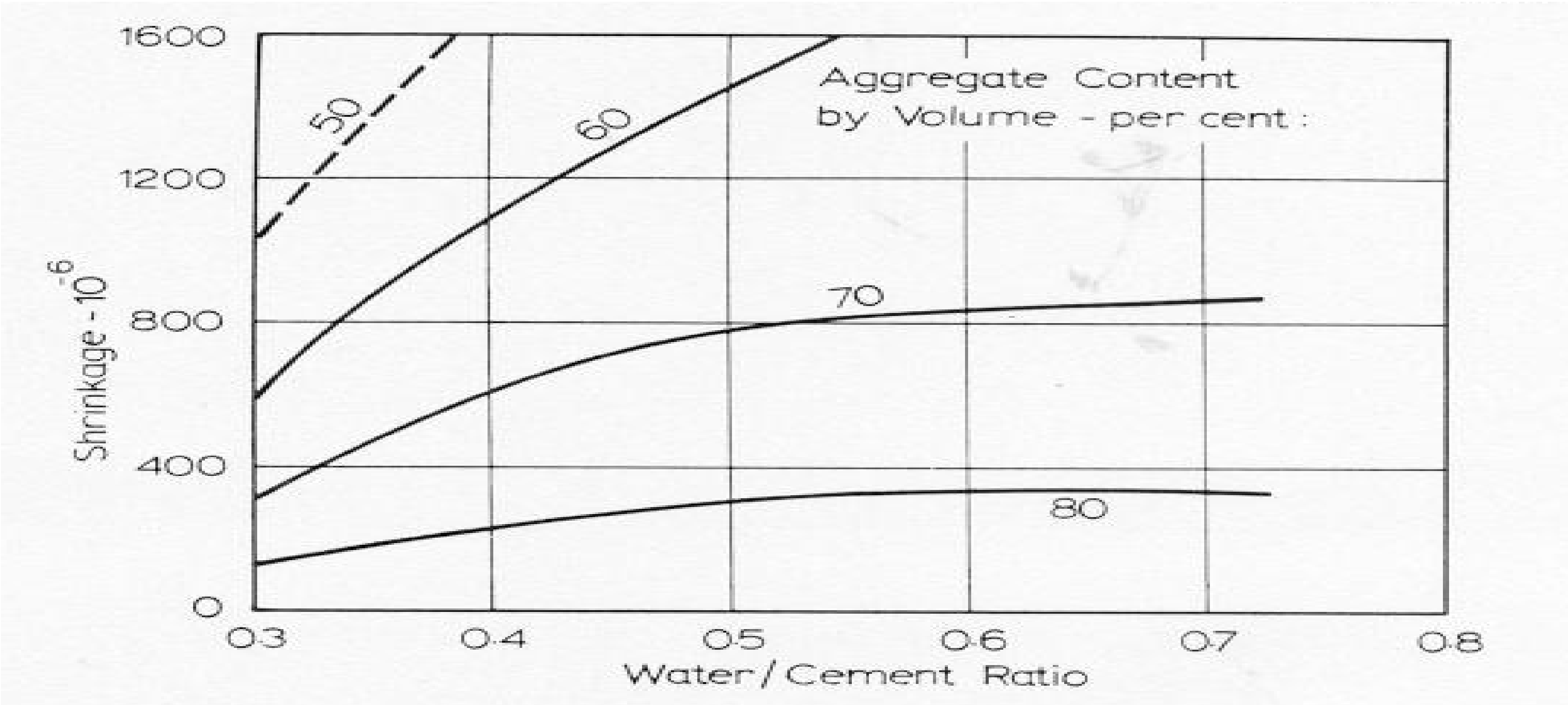
Factors Affecting Drying Shrinkage

- Type, content and proportion of the constituent materials of concrete (cement, water, aggregates, etc),
- Size and shape of the concrete structure,
- Amount and distribution of reinforcement,
- Relative humidity of the environment.

Drying shrinkage is directly proportional to the water-cement ratio and inversely proportional to the aggregate-cement ratio (Figure 1).

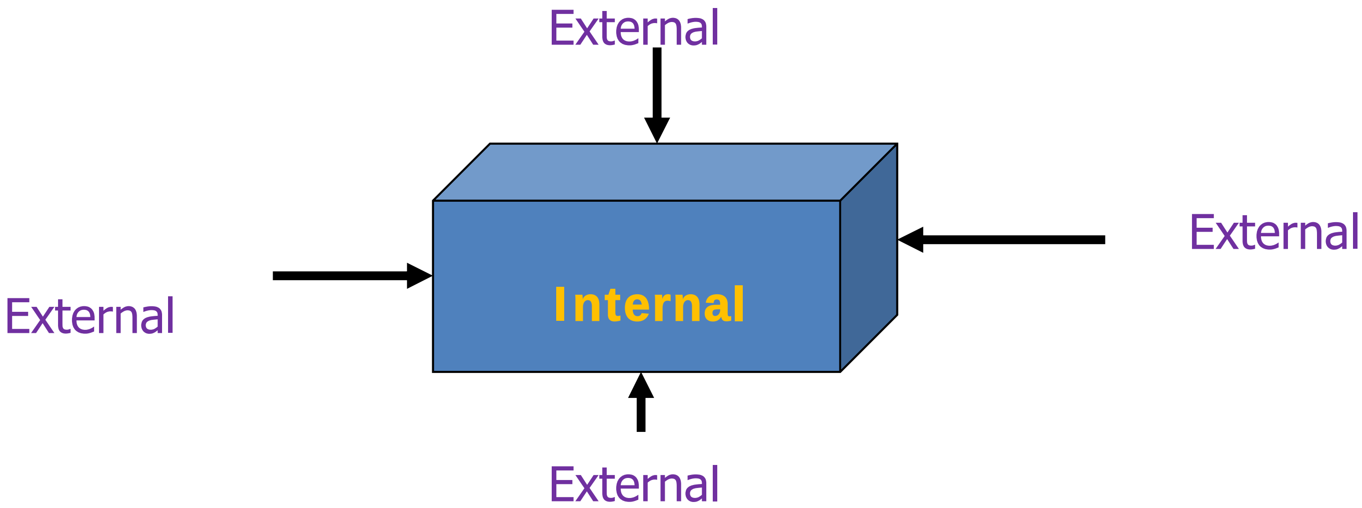
- *Because of the interaction of the effects of aggregate-cement and water-cement ratios, it is possible to have a rich mix with a low water-cement ratio giving higher shrinkage than a leaner mix with a higher water-cement ratio*.

Figure 1. Influence of water/cement ratio and aggregate content on shrinkage.



Durability

- The durability of concrete can be defined as its resistance to deterioration resulting from **external** and **internal** causes.



Factors Affecting Durability

External Causes

1. Physical, chemical or mechanical:
   - a) Leaching out of cement (Ca(OH)2)
   - b) Actions of sulphates, seawater and natural slightly acidic water. *The resistance to these attacks varies with the type of cement used and increases in the order; OPC and RHC (rapid hardening cement)*

2. Environmental such as occurrence of extreme temperatures, abrasion and electrostatic action.

3. Attack by natural or industrial liquids and gasses.

Internal Causes:

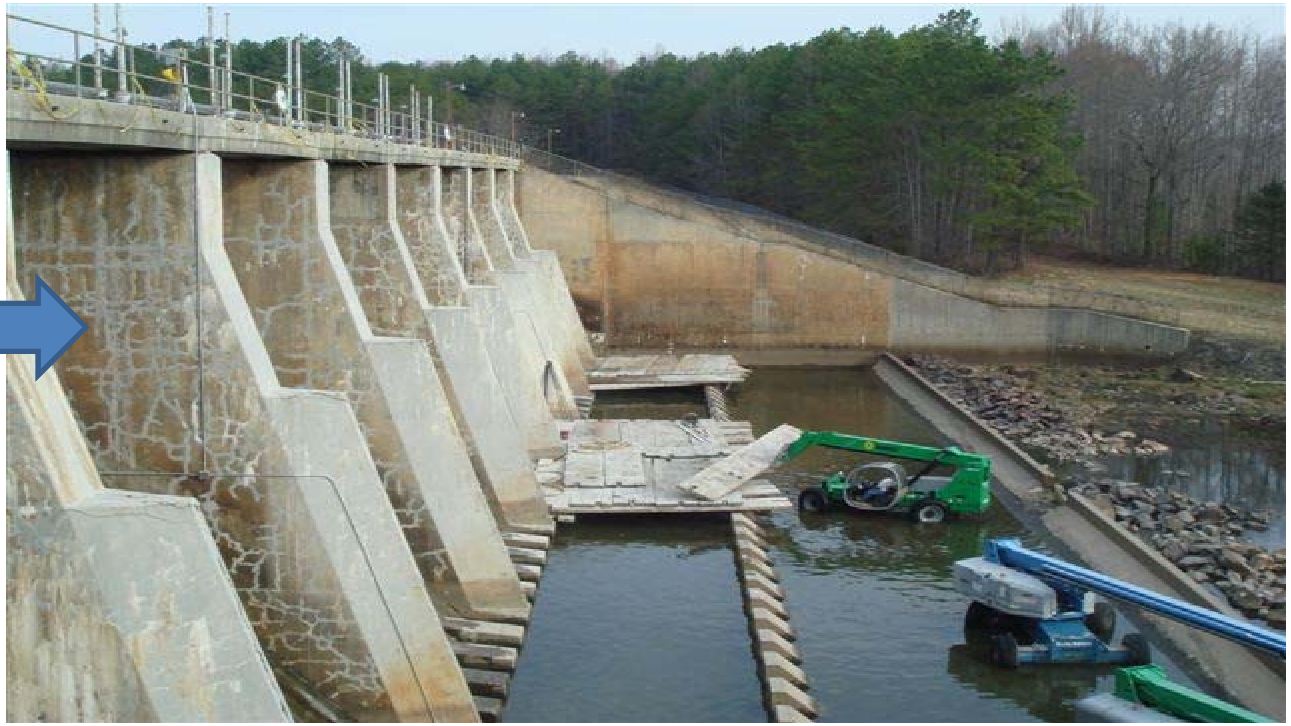
1. Alkali-aggregate reactions
2. Volume change due to difference in thermal properties of the aggregate and cement paste.
3. Permeability of concrete.

Alkali-Aggregate Reactions (AAR or ASR):

– Is the reactions between the active SILICA constituents of the aggregate, and ALKALIES in cement. As a result of these reactions expansion of cement gel causes cracks.

– Reactive form of SILICA occurs in OPALINE.

CRACKS AFTER ALKALI-AGGREGATE REACTION



cracks

–***Recommended Protective Treatments***:

- Low w/c ratios (less than 0.5)
- Suitable workability
- Thorough mixing
- Proper placing and compaction
- Adequate and timely curing.

Testing of Hardened Concrete

Compressive Strength

- Most important property of hardened concrete. Generally considered in the design of concrete mixtures.

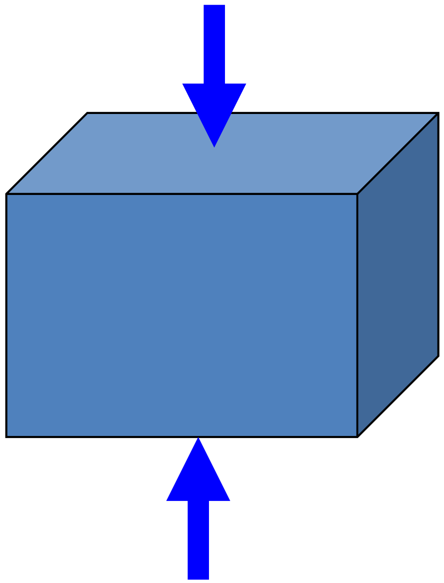
- Dimensions of the concrete specimens usually have the following sizes:

Cylindrical specimens : 7.5, 10, 15 cm diameters

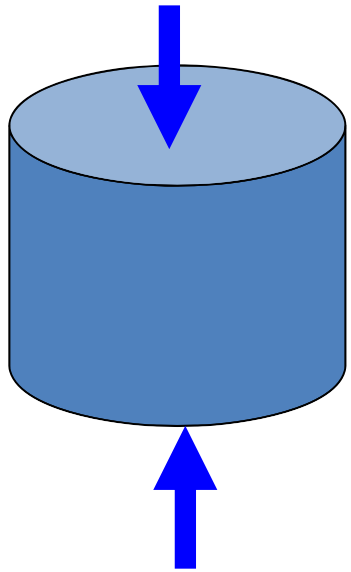
Cubic specimens : 5, 10, 15 cm

- Compressive strength is affected by many factors (environmental, curing condition). Therefore, the actual strength of concrete will not be the same as the strength of specimen.

Cube & Cylinder Samples



a = 5, 10, 15 cm



Diameter = 7.5, 10, 15 cm

https://www.youtube.com/watch?v=iYmil0luMEs

Testing for Compressive Strength

- Cylindrical/cubic specimens.
- Empty moulds are filled with fresh concrete using a standard procedure.
- After 24 hours the specimens are taken out of the moulds and moist cured for 28 days at the end of the curing period they are tested.

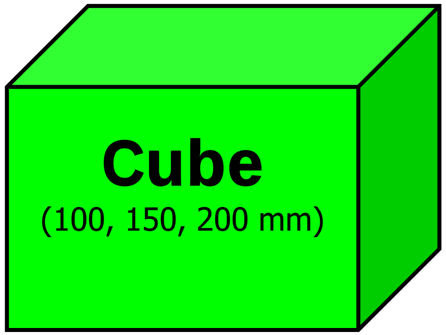
Compressive strength

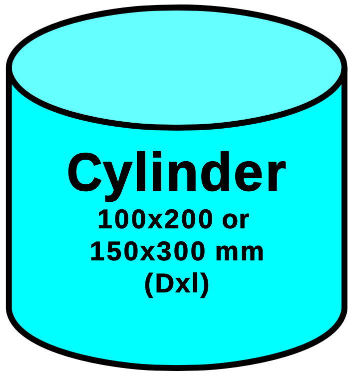
- **P = failure load**
- **D = diameter of cylinder**
- **a = one side of cube**

$$f_c = \frac{failure \quad load}{cross - \sec \; tional \quad area}$$

$$f_c = \frac{4P}{\pi D^2} \quad cylinder$$

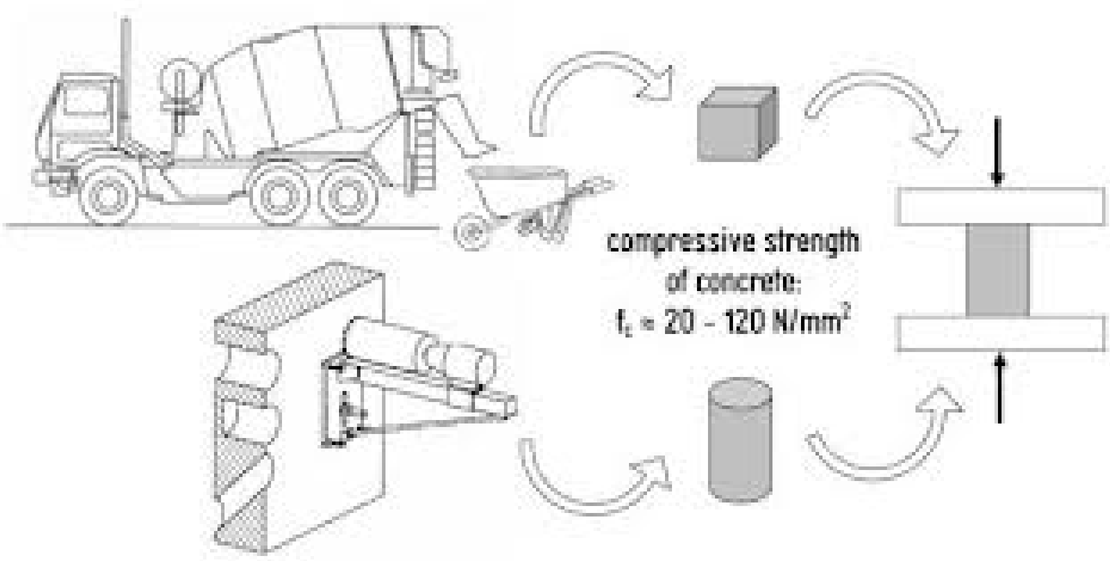
$$f_c = \frac{P}{a^2} \quad cube$$





Testing concrete for compression

TESTING SAMPLES



Conversion table

	divide by			
	100 mm cube	150 mm cube	200 mm cube	150x300 mm cylinder
100 mm cube	1	1.01	1.05	1.22
150 mm cube	-	1.00	1.04	1.20
200 mm cube	-	-	1.00	1.15
100x200 mm cylinder	-	-	-	1.06

Divide by ...

28-Day Cylinder compressive strengths of concrete classes C14-C35

Concrete class	Characteristic compressive strength (MPa)	Mean Strength (MPa)	Minimum Strength Required (any sample, field) (MPa)	Minimum Mean Strength required (MPa)
C14	14	18	11	17
C16	16	20	13	19
C18	18	-	14	22
C20	20	26	17	23
C25	25	31	22	28
C30	30	36	27	33
C35	35	43	32	38

Tensile Strength

- The tensile strength of concrete is important to resist cracking from shrinkage and temperature changes.

a) Direct Tensile Strength:

Difficult to measure and is not usually done.

b) Splitting Tensile Strength:

The cylindrical specimens (on cube) (placed with its axis horizontal) is subjected to a line load (uniform) along the length of the specimen (Figure 4).

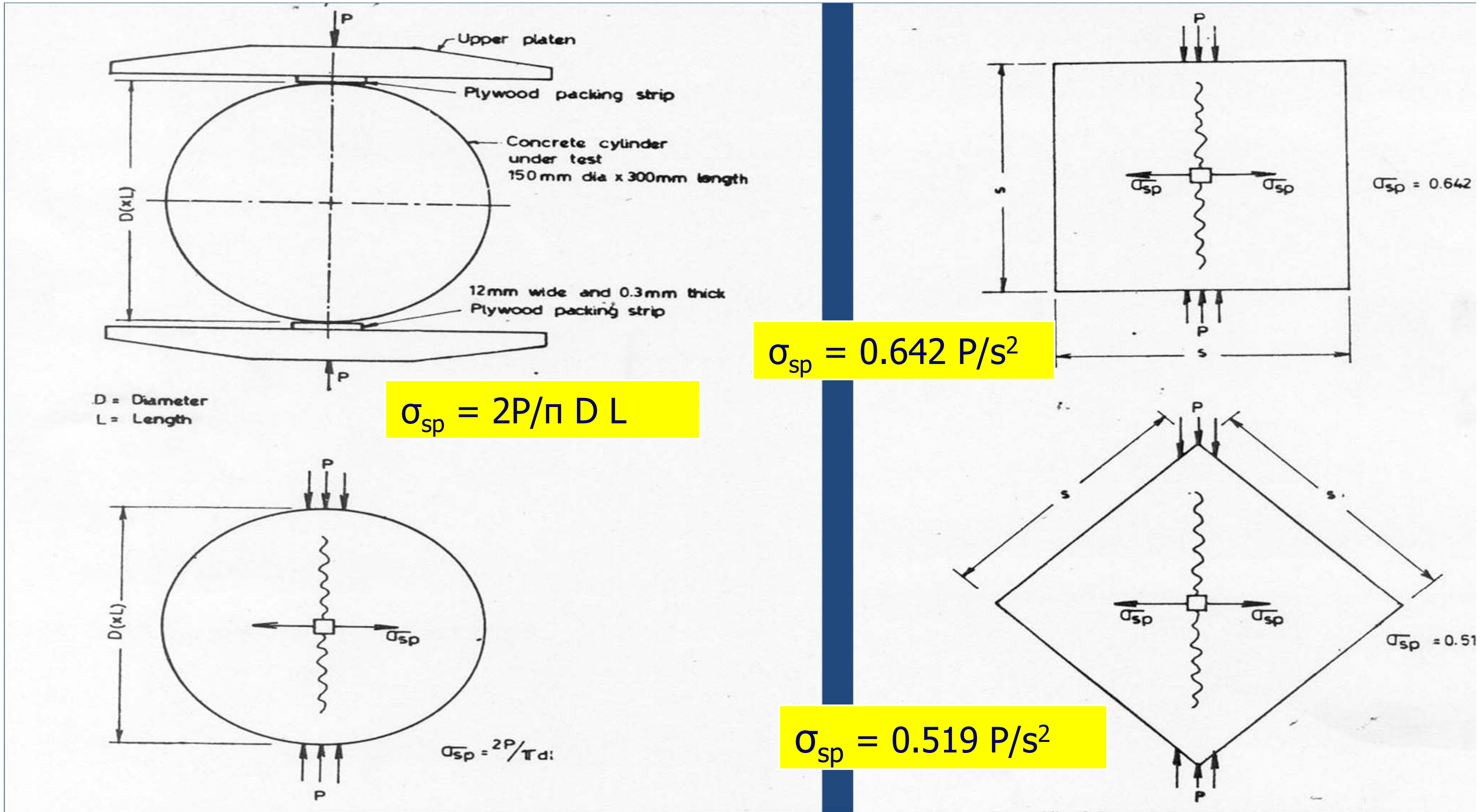


Figure 4 Splitting tensile test styles.

Splitting tensile strength (Brazillian Test)

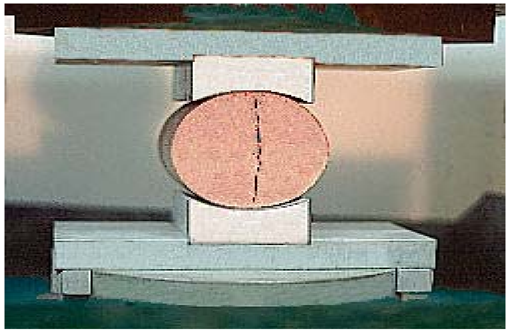
$$\sigma_{sp} = \frac{2P}{\pi l d} \quad cylinder$$

l : length of cylinder

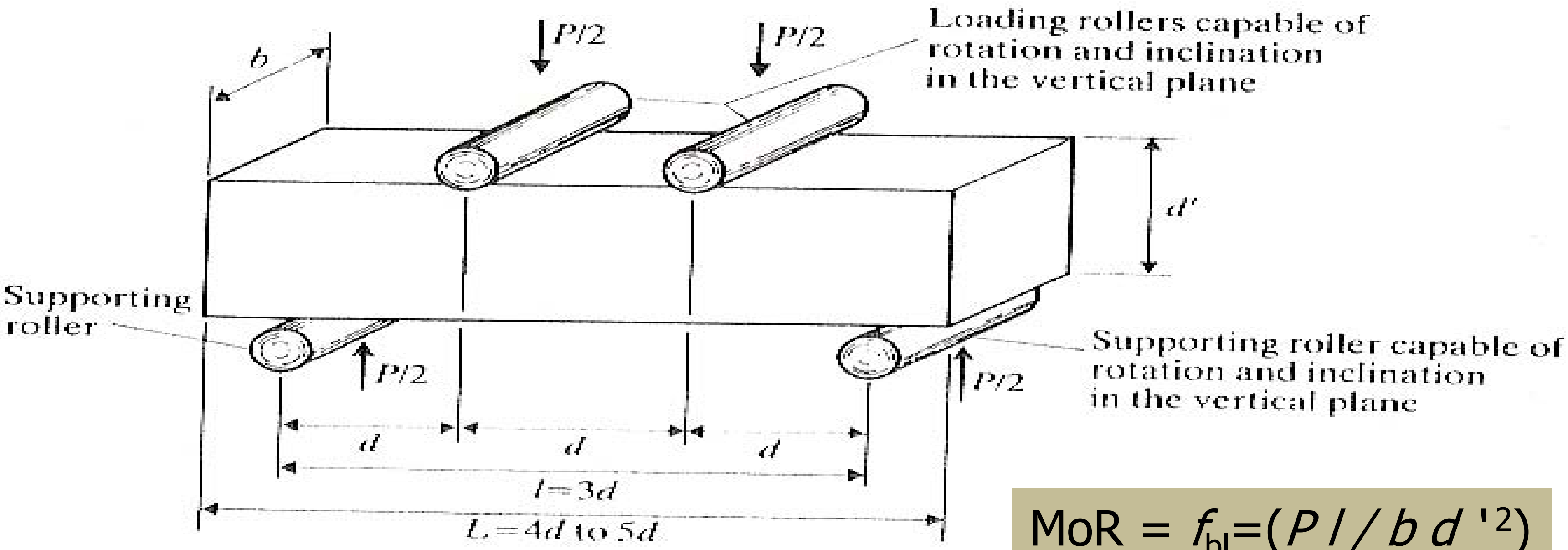
d : diameter of cylinder

P: Failure load

σ_{sp} : splitting tensile strength (10% of compressive strength)



Tensile Test on Beams (Modulus of Rupture-MOR)



MoR = $f_{bl} = (P\, l \,/\, b\, d'^2)$

http://www.youtube.com/watch?v=_U1ZIb4c5oA&feature=related

Relations used for MOR

- If fracture occurs within the middle-third one of the beam;

MoR = f_{bl}=(Pl/bd^2)

Where P=maximum total load; l = span; d = depth of the beam; b = width of the beam.

  - If fracture takes place outside the middle one-third; RESULTS SHOULD BE DISCARDED

Problems on Hardened Concrete (compressive strength)

Sample size (mm)	Failure load (kN)	calculation	Compressive strength (MPa)
Cube (100x100x100)	300	300x1000 (N) / 100x100 (mm^2)	30.00
Cube (150x150x150)	560	560x1000 (N) / 150x150 (mm^2)	24.89
Cylinder (100x200)	730	730x1000x4 (N) / 3.14x100^2 (mm^2)	92.99
Cylinder (150x300)	850	850x1000x4 (N) / 3.14x150^2 (mm^2)	48.12

Problems on Hardened Concrete (splitting tensile strength)

Style of Splitting tensile test	Sample Size (mm)	Failure load (kN)	calculation	Splitting tensile strength (MPa)
Normal	Cube 100	150	0.642x150 000/100x100	9.63
Normal	Cube 150	185	0.642x185 000/150x150	5.27
diagonal	Cube 150	250	0.519x250 000/150x150	5.76
normal	Cyl. 150x300	375	2x375 000/3.14x150X300	5.30

Problems

1. The 150 mm cubic concrete specimen is crushed under an axial compressive load of 778 kN at 28 days age. Estimate the 28-day 150x300 mm cylinder compressive strength of the same concrete. (**answ: 28.8 MPa**)

2. A 200 mm cubic concrete specimen is crushed under a compressive load of 641 kN. Calculate the compressive load necessary to crush a 150x300 mm cylindrical specimen prepared from the same mix tested at the same age. (**answ: 13.9 MPa**)

3. Three 150 mm cubic concrete specimens prepared from the same mix were crushed under uniaxial compressive loads of 560 kN, 570 kN and 558 kN. Calculate the average compressive strength of concrete. If the split tensile strength of concrete is 15% that of the average compressive strength, what will be minimum split tensile load necessary to crush the same cubic specimens. (**answ: 131 kN**)

4. Flexural strength test (third point loading) is applied on a beam to find modulus of rupture. The failure load was recorded to be 17500 N. Calculate MOR (b=150mm, d'=150 mm, L=500 mm (d=100 mm). (**answ: 1.6 MPa**)

Soutions to problems

The 150 mm cubic concrete specimen is crushed under an axial compressive load of 778 kN at 28 days age. Estimate the 28-day 150x300 mm cylinder compressive strength of the same concrete.

Compressive strength of cubic sample = (778x1000 N) / (150x150) mm^2

Compressive strength of cubic sample = 34.58 N/mm^2

In order to calculate compressive strength of cylinder sample from the same concrete, conversion factors should be used: 34.58/1.20 = 28.81 N/mm^2

	divide by			
	100 mm cube	150 mm cube	200 mm cube	150x300 mm cylinder
100 mm cube	1	1.01	1.05	1.22
150 mm cube	-	1.00	1.04	1.20
200 mm cube	-	-	1.00	1.15
100x200 mm cylinder	-	-	-	1.06

A 200 mm cubic concrete specimen is crushed under a compressive load of 641 kN. Calculate the compressive load necessary to crush a 150x300 mm cylindrical specimen prepared from the same mix tested at the same age.

Compresssive strength of cubic sample = (641x1000 N) / (200x200 mm^2)

Compresssive strength of cubic sample = 16.03 N/mm^2

In order to calculate compressive strength of cylinder sample from the same concrete, conversion factors should be used: 16.03/1.15 = 13.93 N/mm^2

So, 13.93 = Px4/3.14x150x150, P=246038 N = 246 kN

	divide by			
	100 mm cube	150 mm cube	200 mm cube	150x300 mm cylinder
100 mm cube	1	1.01	1.05	1.22
150 mm cube	-	1.00	1.04	1.20
200 mm cube	-	-	1.00	1.15
100x200 mm cylinder	-	-	-	1.06

Three 150 mm cubic concrete specimens prepared from the same mix were crushed under uniaxial compressive loads of 560 kN, 570 kN and 558 kN. Calculate the average compressive strength of concrete. If the split tensile strength of concrete is 15% that of the average compressive strength, what will be minimum split tensile load necessary to crush the same cubic specimens.

- Average compressive strength of 150 mm cubic samples: [(560+570+558)/3]x1000 N / [150x150 mm^2] = 25 N/ mm^2
- Splitting tensile strength = 15% x 25 N/ mm^2 = 3.75 N/ mm^2
- Below quation can be used to obtain required splitting tensile load.

$\sigma_{sp} = 0.642 \, P/s^2$

- 3.75 = 0.642 P/ 150^2 Therefore, P can be obtained:
- P = 3.75 x 150^2/ 0.642 = 131 425 N = 131 kN

Flexural strength test (third point loading) is applied on a beam to find modulus of rupture. The failure load was recorded to be 17500 N. Calculate MOR (b=150mm, d'=150 mm, L=500 mm (d=100 mm).

In order to calculate MoR, equation below can be used.

$$\text{MoR} = f_{bl} = (P\,l\,/\,b\,d'^2)$$

MoR = (17500 x 3x100)/(150x150^2) = 1.56 N/mm^2