PROPERTIES of CONCRETE

Concrete

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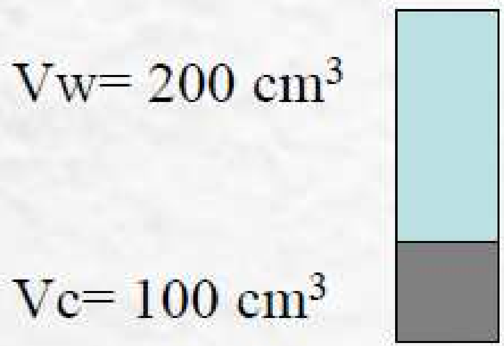
Let's study a cement paste with $w/c = 0.63$

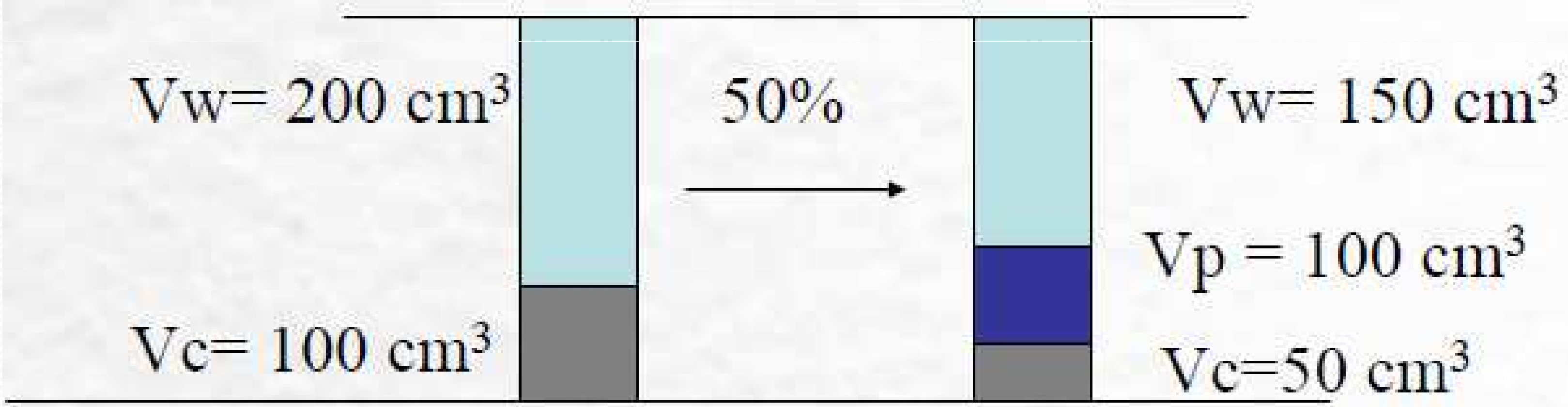
Start with 100 cm^3 of cement.

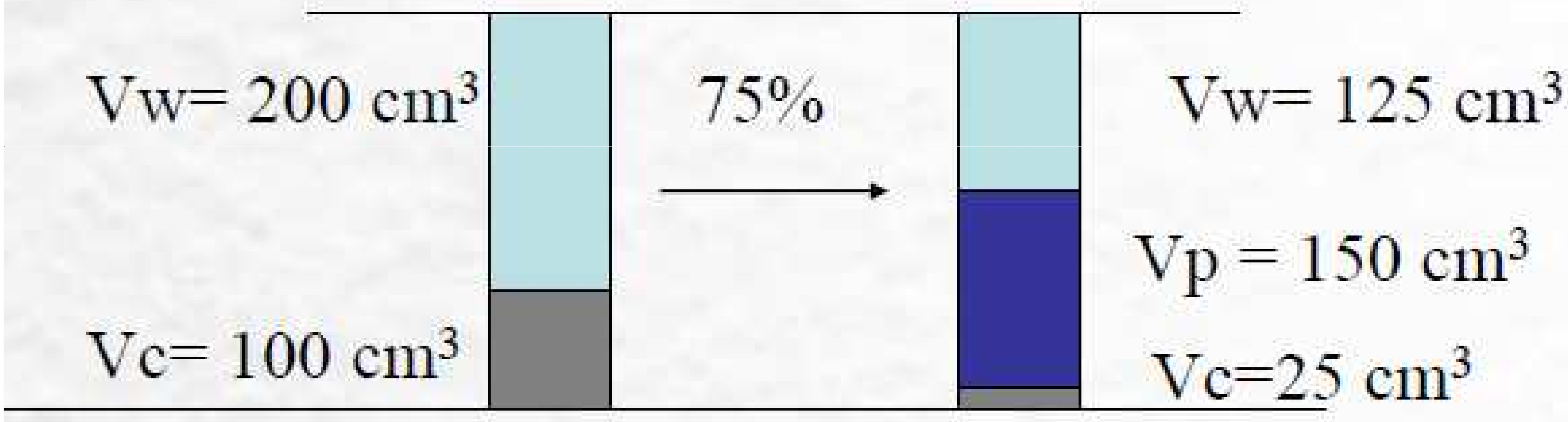
Compute the mass of cement: $M_c = 3.14 * 100 = 314$ g

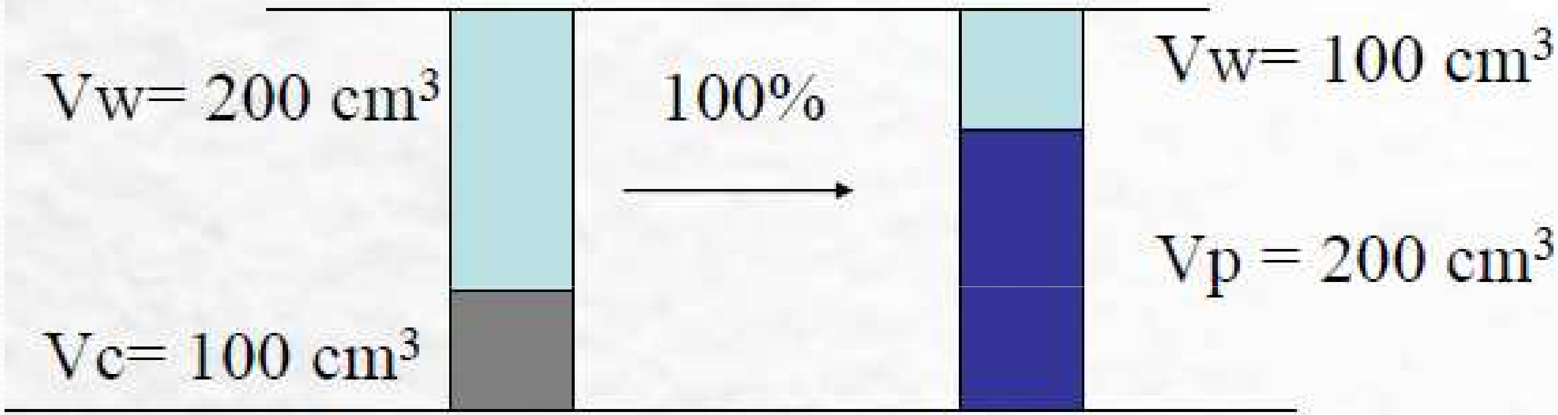
Compute the mass of water: $M_w = 0.63 * 314 = 200$ g

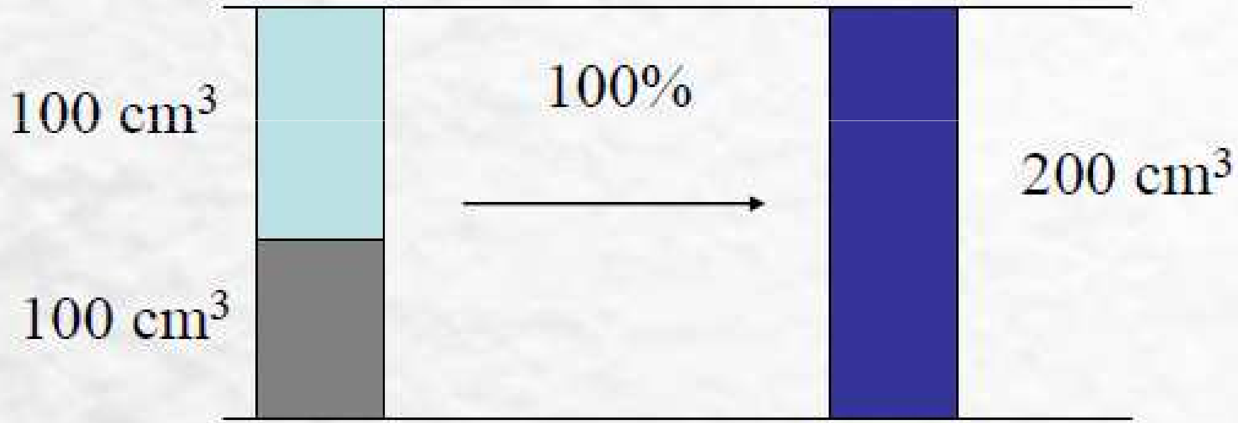


Miracle of hydration: $V_p = 2 V_c$




Vw= 200 cm3
Vc= 100 cm3
75%
Vw= 125 cm3
Vp = 150 cm3
Vc=25 cm3


Vw= 200 cm3
Vc= 100 cm3
100%
Vw= 100 cm3
Vp = 200 cm3



W/c = 100/100*3.14

W/c= 0.32

P.K. Mehta and P.J.M. Monteiro, Concrete: Microstructure, Properties, and Materials

- **Interlayer space in CSH**

  size = 5 to 25 Å

  No adverse effect on strength and permeability

  Some effect on drying shrinkage and creep

- **Capillary Voids**

  > 50 nm : detrimental to strength and impermeability

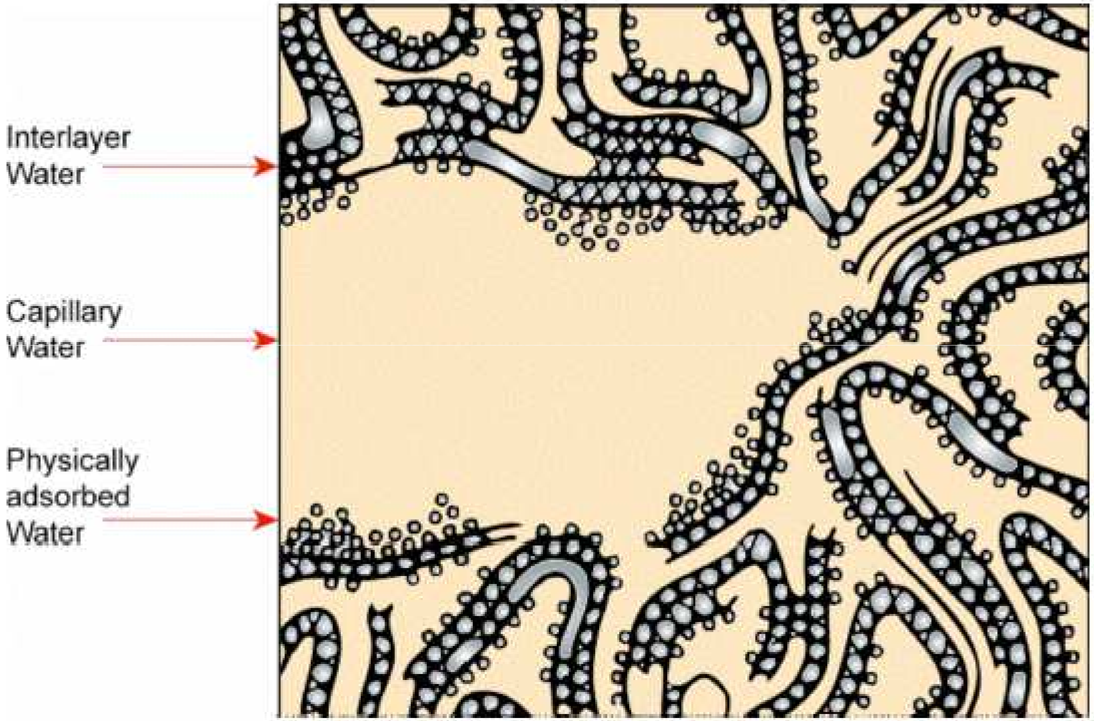
  < 50 nm: important to drying shrinkage and creep.

- **Air Voids**

  entrapped air: ~ 3 mm

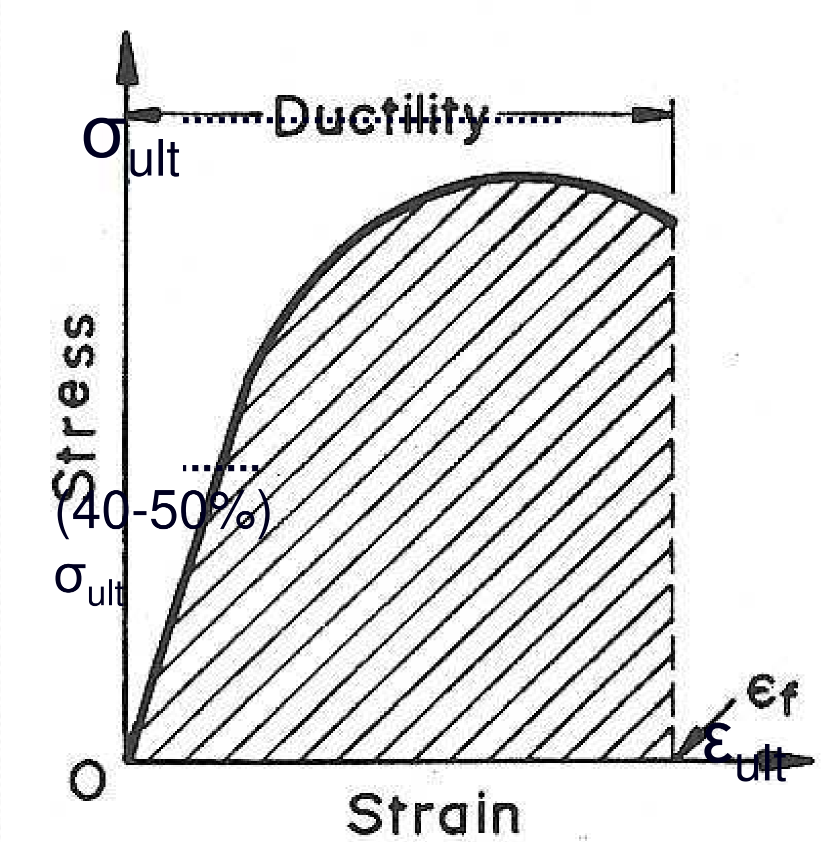
  entrained air: 50 to 200 microns

P.K. Mehta and P.J.M. Monteiro, Concrete: Microstructure, Properties, and Materials



Interlayer Water
Capillary Water
Physically adsorbed Water

STRESS-STRAIN RELATIONS IN CONCRETE

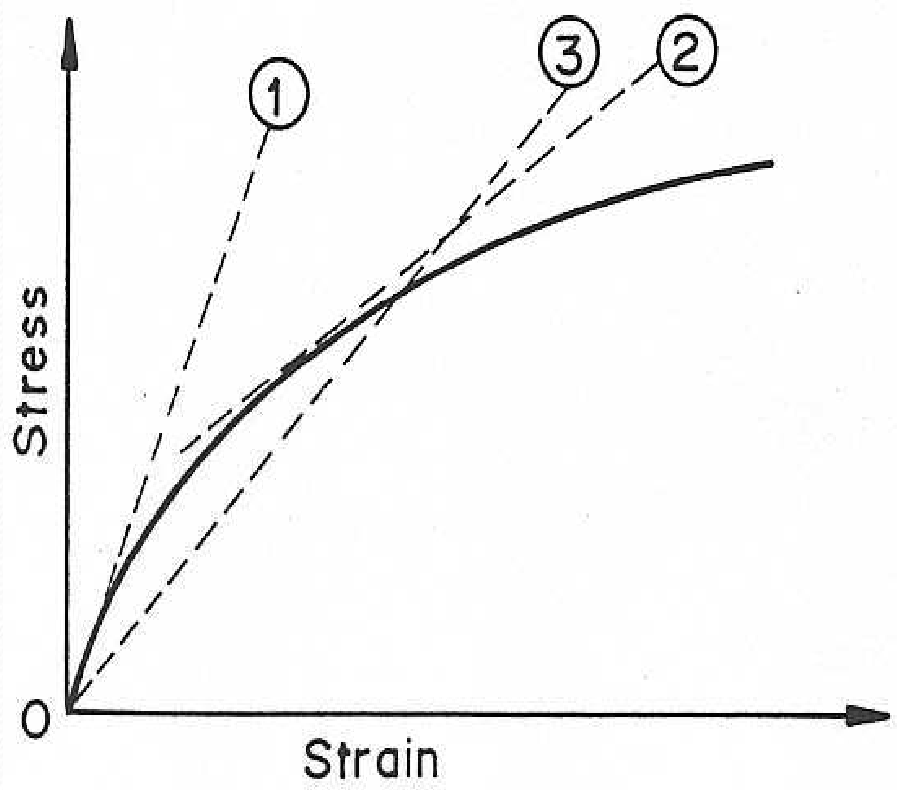


σ-ε relationship for concrete is nonlinear. However, specially for cylindrical specimens with h/D=2, it can be assumed as linear upto 40-50% of σ_{ult}

MODULUS OF ELASTICITY OF CONCRETE

Due to the nonlinearity of the σ-ε diagram, E is the defined by:

1. Initial Tangent Method
2. Tangent Method
3. Secant Method



ACI → E=15200 $\sigma_{ult}^{1/2}$ → 28-D cylindrical comp.str. (kgf/cm²)

TS → E=15500 W $^{1/2}$→ 28-D cubic comp.str. (kgf/cm²)

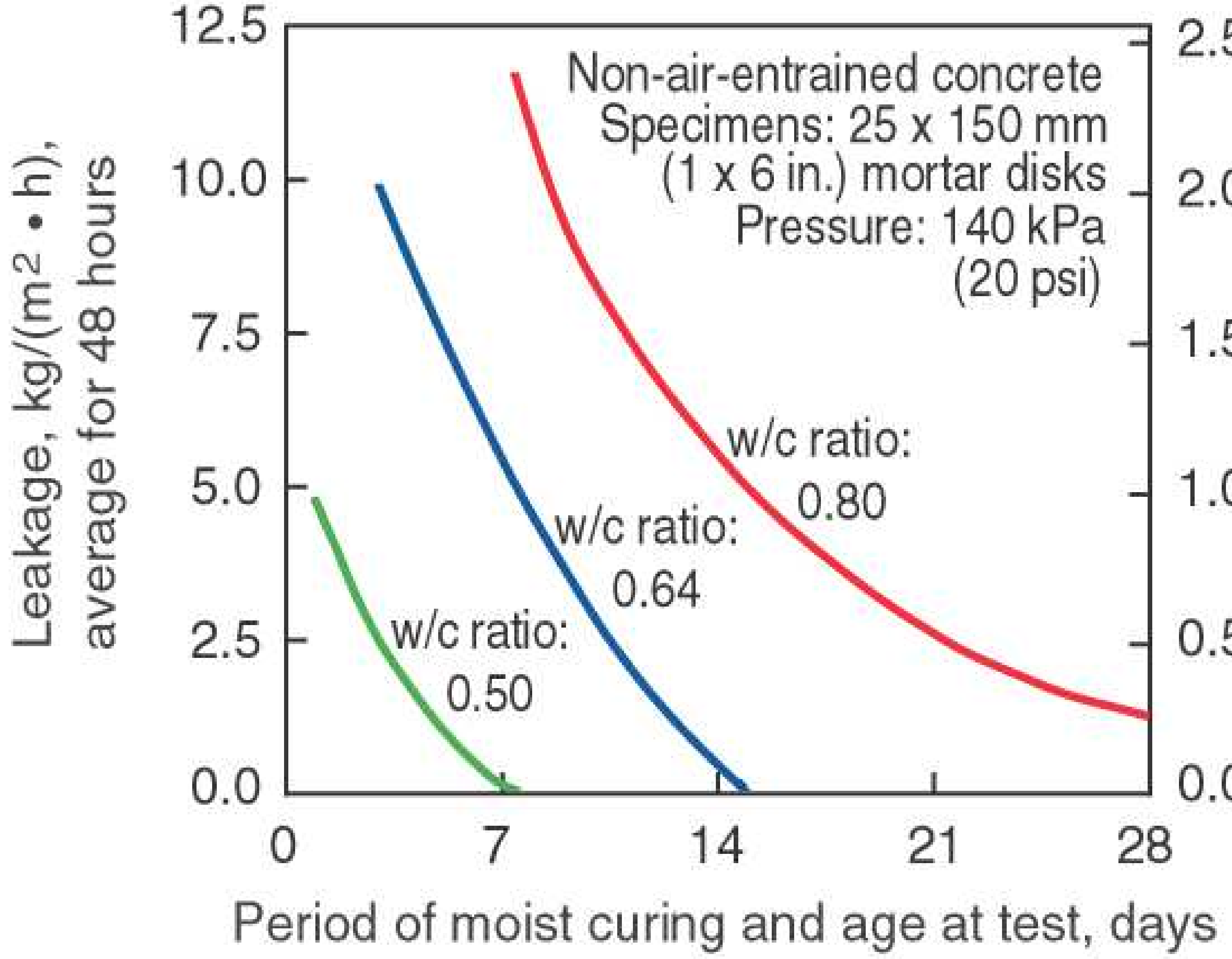
PERMEABILITY OF CONCRETE

- Permeability is important because:

1. The penetration of some aggresive solution may result in leaching out of $Ca(OH)_2$ which adversely affects the durability of concrete.
2. In R/C ingress of moisture of air into concrete causes corrosion of reinforcement and results in the volume expansion of steel bars, consequently causing cracks & spalling of concrete cover.
3. The moisture penetration depends on permeability & if concrete becomes saturated it is more liable to frost-action.
4. In some structural members permeability itself is of importance, such as, dams, water retaining tanks.

PERMEABILITY OF CONCRETE

- The permeability of concrete is controlled by capillary pores. The permeability depends mostly on w/c, age, degree of hydration.
- In general the higher the strength of cement paste, the higher is the durability & the lower is the permeability.


Non-air-entrained concrete
Specimens: 25 x 150 mm
(1 x 6 in.) mortar disks
Pressure: 140 kPa
(20 psi)
w/c ratio:
0.80
w/c ratio:
0.64
w/c ratio:
0.50
Leakage, kg/(m2 • h), average for 48 hours
Leakage, psf per hour
Period of moist curing and age at test, days
12.5
10.0
7.5
5.0
2.5
0.0
2.5
2.0
1.5
1.0
0.5
0.0
0
7
14
21
28

MIXTURES

- W+C+C.Agg.+F.Agg.+Admixtures → Weights / Volumes?
- There are two sets of requirements which enable the engineer to design a concrete mix.

1. The requirements of concrete in hardened state. These are specified by the structural engineer.

2. The requirements of fresh concrete such as workability, setting time. These are specified by the construction engineer (type of construction, placing methods, compacting techniques and transportation)

PROPORTIONING CONCRETE MIXTURES

- Mix design is the process of selecting suitable ingredients of concrete & determining their relative quantities with the objective of producing as economically as possible concrete of certain minimum properties such as workability, strength & durability.

- So, basic considerations in a mix design is cost & min. properties.

- Cost → Material + Labor

↓

Water+Cement+Aggregate+Admixtures

↓

Most expensive (optimize)

Using less cement causes a decrease in shrinkage and increase in volume stability.

- Min.Properties →Strength has to be more than..

Durability→Permeability has to be

Workability→Slump has to be...

- In the past specifications for concrete mix design prescribed the proportions of cement, fine agg. & coarse agg.
- 1 : 2 : 4

↓	↓	↓
Weight of cement	Fine Agg.	Coarse Agg.

- However, modern specifications do not use these fixed ratios.

- Modern specifications specify min compressive strength, grading of agg, max w/c ratio, min/max cement content, min entrained air & etc.

- Most of the time job specifications dictate the following data:
  - Max w/c
  - Min cement content
  - Min air content
  - Slump
  - Strength
  - Durability
  - Type of cement
  - Admixtures
  - Max agg. size

PROCEDURE FOR MIX DESIGN

1. Choice of slump (Table 14.5)

Table 14.5 Recommended Slumps for Various Types of Construction

Type of Construction	Slump, mm	
	Maximum	Minimum
Reinforced foundation walls	75	25
Reinforced footings	75	25
Plain footings	75	25
Substructure walls	75	25
Pavement and slabs	75	25
Mass concrete	50	25
Building columns	100	25
Beams	100	25
Reinforced walls	100	25

PROCEDURE FOR MIX DESIGN

2. Choice of max agg. size
   - 1/5 of the narrowest dimension of the mold
   - 1/3 of the depth of the slab
   - ¾ of the clear spacing between reinforcement
   - Dmax < 40mm

PROCEDURE FOR MIX DESIGN

3. Estimation of mixing water & air content (Table 14.6 and 14.7)

Table 14.6 Approximate Amounts of Mixing Water and Air Content Requirements for Non-Air Entrained Concrete

Slump, mm	Water Content kg/m³ (Maximum Aggregate Size, mm) 9.5	12.5	19	25	37.5	50	75
25-50	207	199	190	179	166	154	130
75-100	228	216	205	193	181	169	145
150-175	243	228	216	202	190	178	160
Entrapped Air(%)	3	2.5	2	1.5	1	0.5	0.3

Table 14.7 Approximate Mixing Water and Air Content Requirements for Air- Entrained Concrete

Slump, mm	Water Content kg/m³ (Maximum Aggregate Size, mm) 9.5	12.5	19	25	37.5	50	75
25 50	181	175	168	160	150	142	122
75 - 100	202	193	184	175	165	157	133
150 - 175	216	205	197	184	174	166	154
Recommended total air content for level of exposure (%):							
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5
Severe exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5

PROCEDURE FOR MIX DESIGN

4. Selection of w/c ratio (Table 14.8 or 14.9)

Table 14.8 Relationship between the "Water/Cement" Ratio and Compressive Strength of Concrete

Compressive Strength at 28 days, MPa	"Water/Cement" Ratio, by weight	
	Non-air-entrained concrete	Air-entrained concrete
40	0.42	
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.60
15	0.79	0.70

Table 14.9 Maximum Permissible "Water/Cement" Ratios for Concretes in Severe Exposure

Type of Structure	Structures that will be wet continuously and exposed to freezing and thawing	Structures exposed to seawater or sulfates
Thin sections and sections with less than 25 mm cover over steel	0.45	0.40
All other structures	0.50	0.45

PROCEDURE FOR MIX DESIGN

5. Calculation of cement content with selected water amount (step 3) and w/c (step 4)
6. Estimation of coarse agg. content (Table 14.10)

Table 14.10 Volume of Coarse Aggregate per Unit Volume of Concrete

Maximum size of aggregate, mm	Volume of dry-rodded coarse aggregate per unit volume of concrete			
	Fineness Moduli of Fine Aggregate			
	2.40	2.60	2.80	3.00
9.5	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19.0	0.66	0.64	0.62	0.60
25.0	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50.0	0.78	0.76	0.74	0.72
75.0	0.82	0.80	0.78	0.76

PROCEDURE FOR MIX DESIGN

7. Calculation of fine aggregate content with known volumes of coarse aggregate, water, cement and air
8. Adjustions for aggregate field moisture

PROCEDURE FOR MIX DESIGN

9. Trial batch adjustments
   - The properties of the mixes in trial batches are checked and necessary adjustments are made to end up with the minimum required properties of concrete.
   - Moreover, a lab trial batch may not always provide the final answer. Only the mix made and used in the job can guarantee that all properties of concrete are satisfactory in every detail for the particular job at hand. That's why we get samples from the field mixes for testing the properties.

Example:

- Slump → 75-100 mm
- D_{max} → 25 mm
- $f'_{c,28}$ = 25 MPa
- Specific Gravity of cement = 3.15
- Non-air entrained concrete

	Coarse Agg.	Fine Agg.
SSD Bulk Sp.Gravity	2.68	2.62
Absorption	0.5%	1.0%
Total Moist.Content	2.0%	5.0%
Dry rodded Unit Weight	1600 kg/m^3	–
Fineness Modulus	–	2.6

1. Slump is given as 75-100 mm
2. D_{max} is given as 25 mm
3. Estimate the water and air content (Table 14.6)

Table 14.6 Approximate Amounts of Mixing Water and Air Content Requirements for Non-Air Entrained Concrete

Slump, mm	Water Content kg/m³ (Maximum Aggregate Size, mm)						
	9.5	12.5	19	25	37.5	50	75
25-50	207	199	190	179	166	154	130
75-100	228	216	205	193	181	169	145
150-175	243	228	216	202	190	178	160
Entrapped Air(%)	3	2.5	2	1.5	1	0.5	0.3

Slump and D_{max} → W=193 kg/m³

Entrapped Air → 1.5%

4. Estimate w/c ratio (Table 14.8)

Table 14.8 Relationship between the "Water/Cement" Ratio and Compressive Strength of Concrete

Compressive Strength at 28 days, MPa	"Water/Cement" Ratio, by weight	
	Non-air-entrained concrete	Air-entrained concrete
40	0.42	
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.60
15	0.79	0.70

f'_c & non-air entrained → w/c=0.61 (by wt)

5. Calculation of cement content

$W = 193\ kg/m^3$ and $w/c = 0.61$

$C = 193 / 0.61 = 316\ kg/m^3$

6. Coarse Agg. from Table 14.10

D_{max} and F.M. → $V_{C.A}$=0.69 m^3

Table 14.10 Volume of Coarse Aggregate per Unit Volume of Concrete

Maximum size of aggregate, mm	Volume of dry-rodded coarse aggregate per unit volume of concrete			
	Fineness Moduli of Fine Aggregate			
	2.40	2.60	2.80	3.00
9.5	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19.0	0.66	0.64	0.62	0.60
25.0	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50.0	0.78	0.76	0.74	0.72
75.0	0.82	0.80	0.78	0.76

Dry $W_{C.A.}$ = 1600*0.69 = 1104 kg/m^3

SSD $W_{C.A.}$ = 1104*(1+0.005) = 1110 kg/m^3

7. To calculate the F.Agg. content the volumes of other ingredients have to be determined.

$$V = \frac{M}{Sp.Gr.*\rho_w}$$

$$V_{water} = \frac{193}{1.0*1000} = 0.193\ m^3$$

$$V_{cement} = \frac{316}{3.15*1000} = 0.100\ m^3$$

$$V_{C.Agg.} = \frac{1110}{2.68*1000} = 0.414\ m^3$$

$$V_{air} = 0.015\ m^3\ (1.5\%*1)$$

$$\Sigma V = 0.722\ m^3 \rightarrow V_{F.Agg} = 1\text{-}0.722 = 0.278\ m^3$$

$$W_{F.Agg} = 0.278*2.62*1000 = 728\ kg/m^3$$

Summary of Mix Design

- Based on SSD weight of aggregates

	Sp. Gr.	Weight (kg/m^3)	Volume (m^3)
Cement	3.15	316	0.100
Water	1	193	0.193
Coarse Agg.	2.68	1110	0.414
Fine Agg.	2.62	728	0.278
Air		-	0.015
Total		2347	1.000

8. Adjustment for Field Moisture of Aggregates

$W_{SSD} = W_{Dry} * (1+a)$ $\quad$ $W_{Field} = W_{Dry} * (1+m)$

Aggregates	Absorption	Moisture	Weight (kg/m^3)		
			SSD	Dry	Field
Coarse	0.005	0.02	1110	1104	1127
Fine	0.01	0.05	728	721	759

Correction for water

From coarse aggregate: 1127-1110 = 17

From fine aggregate: 759-728 = 31

48 kg extra

Corrected water amount : 193 – 48 = 145 kg

Summary of Mix Design

- Based on field weight of aggregates

Ingredient amount	Weight (kg/m^3)	
	SSD	Field
Cement	316	316
Water	193	145
Coarse Agg.	1110	1127
Fine Agg.	728	759
Total	2347	2347

9. Trial Batch

Usually a 0.02 m^3 of concrete is sufficient to verify the slump and air content of the mix. If the slump and air content are different readjustments of the proportions should be made.

Ingredient amount	Field Weight (kg/m^3)
Cement	6.3
Water	2.9
Coarse Agg.	22.5
Fine Agg.	15.2
Total	46.9

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Concrete mix design

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