THE UNIVERISTY OF ZAMBIA

School of Engineering

Department of Civil and Environmental Engineering

CEE 3111 - CIVIL ENGINEERING MATERIALS AND CONSTRUCTION PRACTICES

2023 ACADEMIC YEAR
SEMESTER 1

TOPIC 3

Concrete and its constituents

Part 3

Concrete Mix Design

- The properties of concrete depend on:
  - ✓ mix proportions
  - ✓ placing and curing methods.

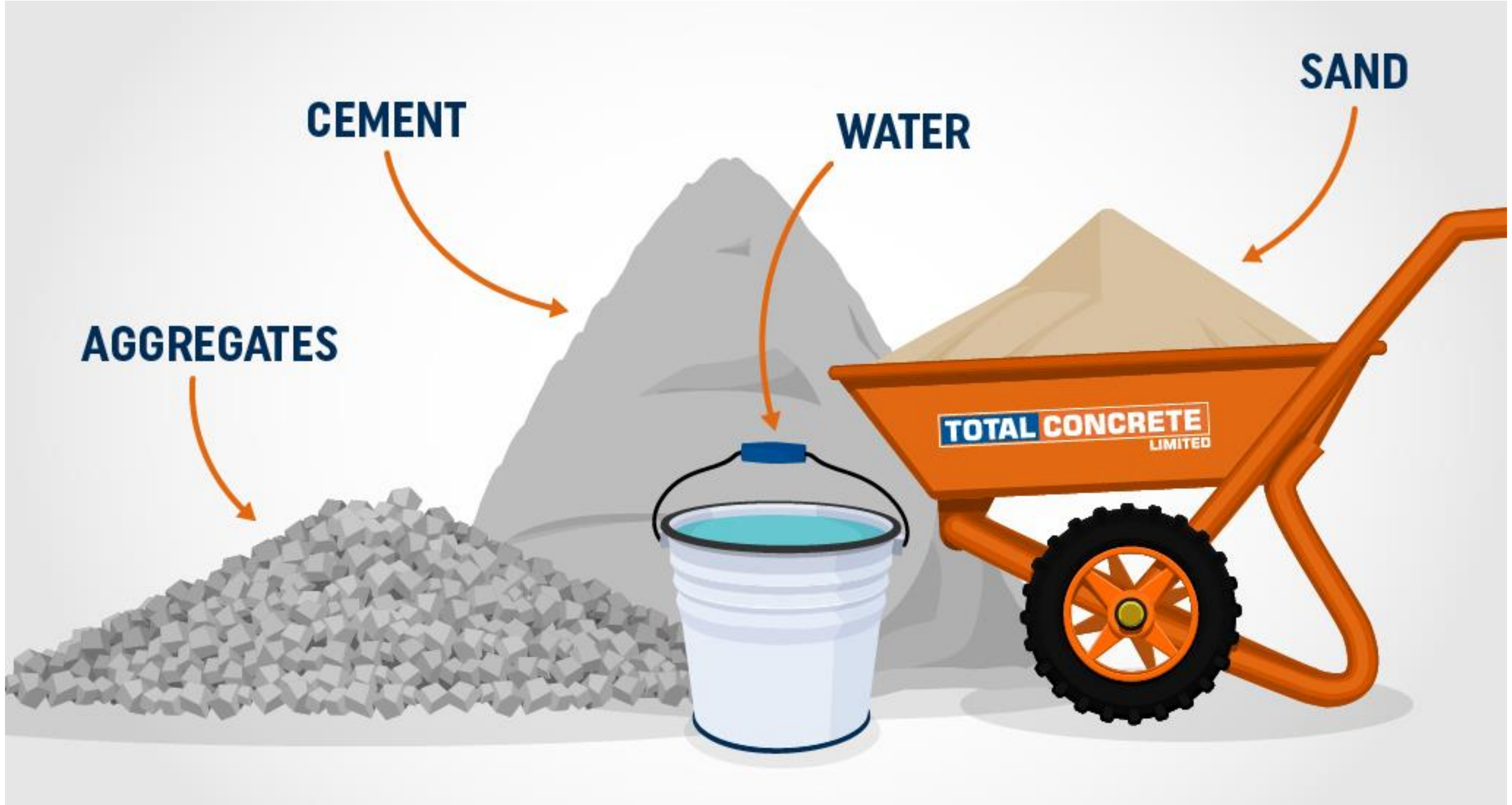
- Designers usually define or assume a concrete strength or modulus of elasticity when estimating structural parameters.

- Several mix design methods have been developed over the years:
  1. arbitrary volume method (1:2:3 C:FA:CA)
  2. weight and absolute volume methods prescribed by the ACI 211.

Concrete Mix Design

- The weight method provides relatively simple techniques for estimating mix proportions, using an assumed or known unit weight of concrete.

- The absolute volume method uses the specific gravity of each ingredient to calculate the unit volume each will occupy in a unit volume of concrete.



Concrete Mix Design

The absolute volume method is more accurate than the weight method. The mix design process for the weight and absolute volume methods differs only in how the amount of fine aggregates is determined.

The concrete mix design steps provided in this section are according to the ACI mix design steps.

- The ACI specifies three qualities required of properly proportioned concrete mixtures:

Acceptable workability of freshly mixed concrete

Durability, strength, and uniform appearance of hardened concrete

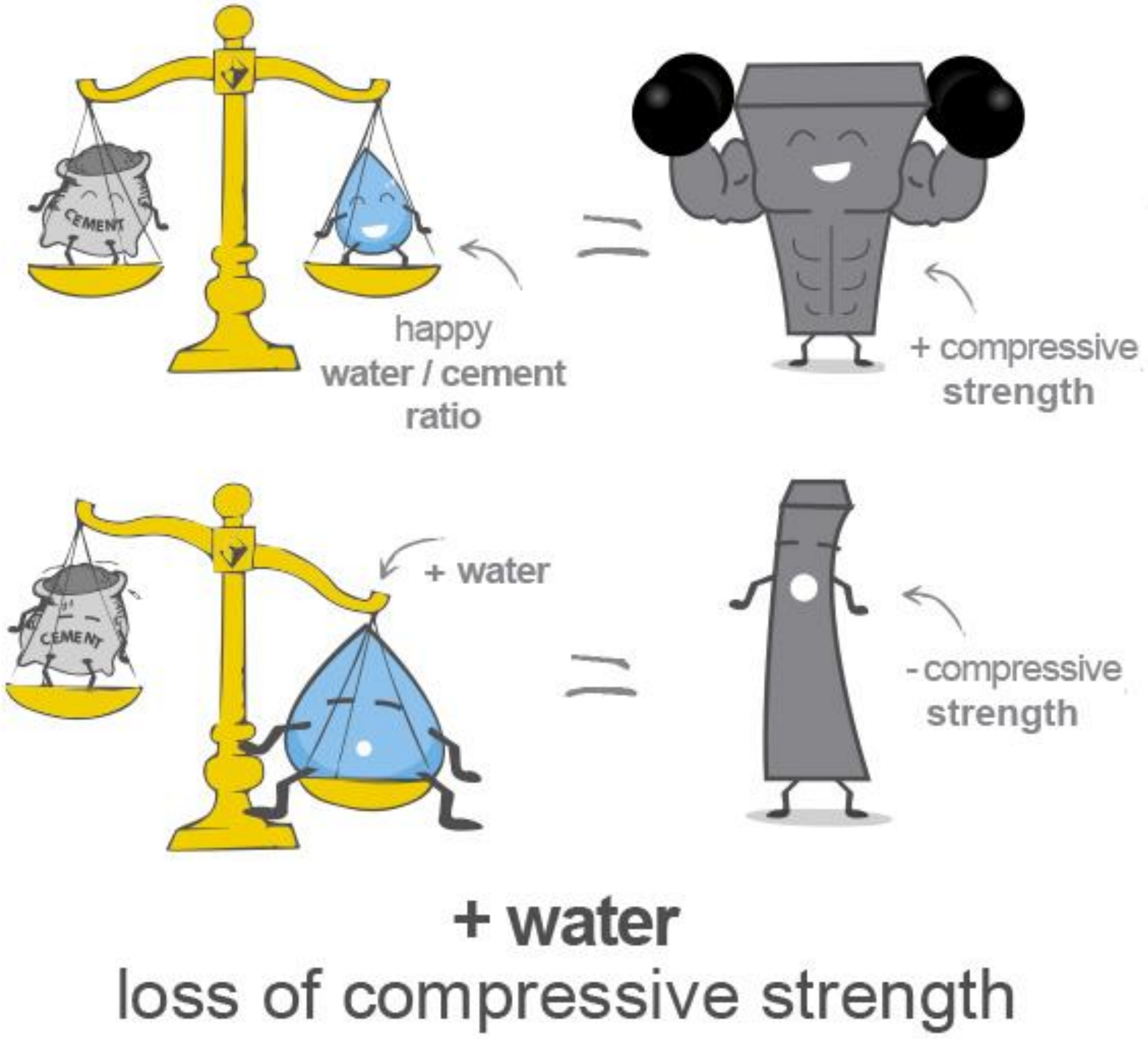
Economy

Concrete Mix Design

Water Cement Ratio

- The weight of water to the weight of cement, water–cement ratio, influences all the desirable qualities of concrete.

- For fully compacted concrete made with sound and clean aggregates, strength and other desirable properties are improved by reducing the weight of water used per unit weight of cement.



Concrete Mix Design

Water Cement Ratio

- Hydration requires approximately 0.22 kg to 0.25 kg of water per 1 kg of cement, excluding evaporable water and water absorbed by the aggregate.

- Concrete mixes generally require excess moisture, beyond the hydration needs, for workability.

- Excess water causes the development of capillary voids in the concrete.

- These voids increase the porosity and permeability of the concrete and reduce strength.

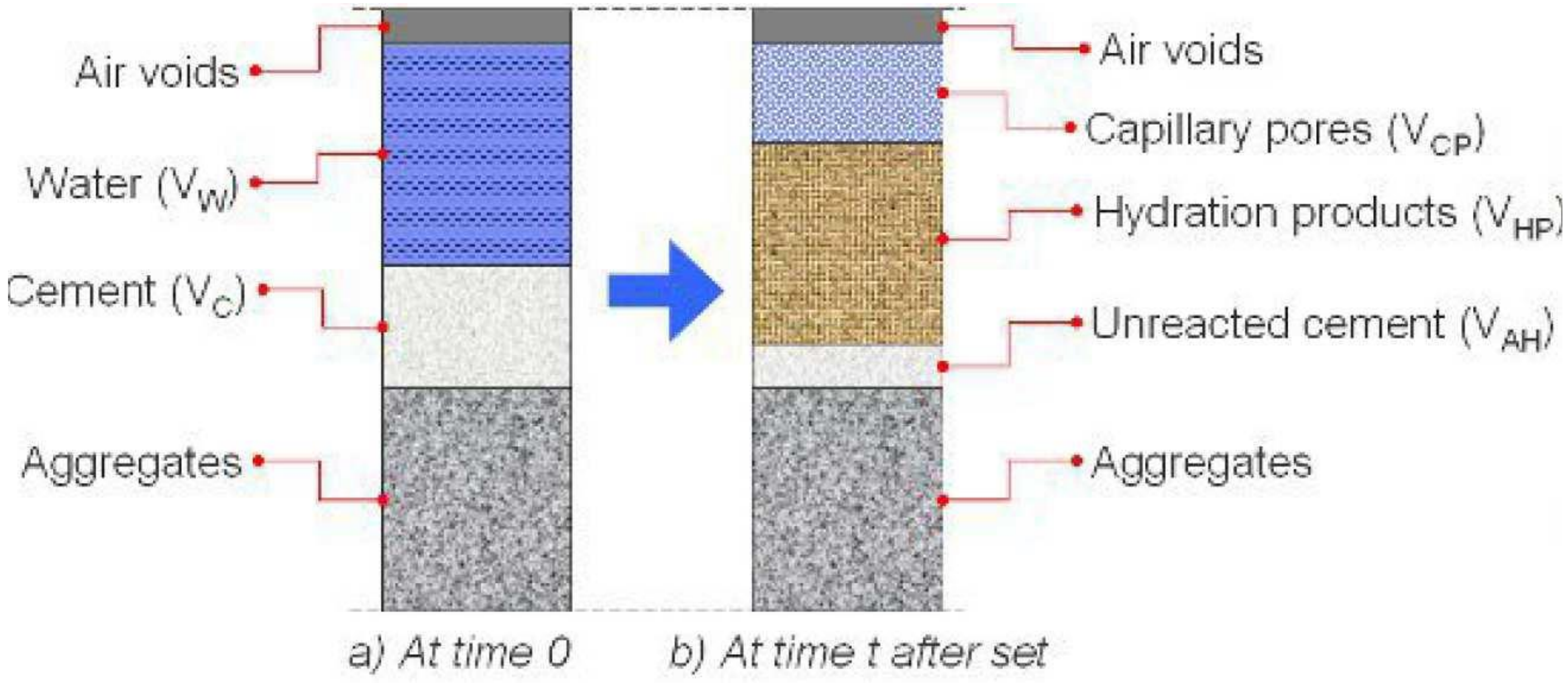
- Increasing the water–cement ratio decreases the compressive strength of the concrete for various curing times.

Concrete Mix Design

Water Cement Ratio

- A low water–cement ratio also increases resistance to weathering, provides a good bond between successive concrete layers, provides a good bond between concrete and steel reinforcement, and limits volume change due to wetting and drying.

- Air-entrained concrete includes an air entraining agent, an admixture, which is used to increase the concrete's resistance to freezing and thawing



Click Here to See Video

Concrete Mix Design

ACI Committee 211.1-91 Method – Worked Example

Design a concrete mix for construction of an elevated water tank. The specified design strength of concrete (characteristic strength) is 30 MPa at 28 days measured on standard cylinders. Standard deviation can be taken as 4 MPa. The specific gravity of FA and C.A. are 2.65 and 2.7 respectively. The dry rodded bulk density of C.A. is 1600 kg/m3, and fineness modulus of FA is 2.80. Maximum aggregate size is 20 mm. Ordinary Portland cement (Type 1) will be used. A slump of 50mm is necessary. C.A. is found to be absorptive to the extent of 1% and free surface moisture in sand is found to be 2%. Assume any other essential data.

Solution

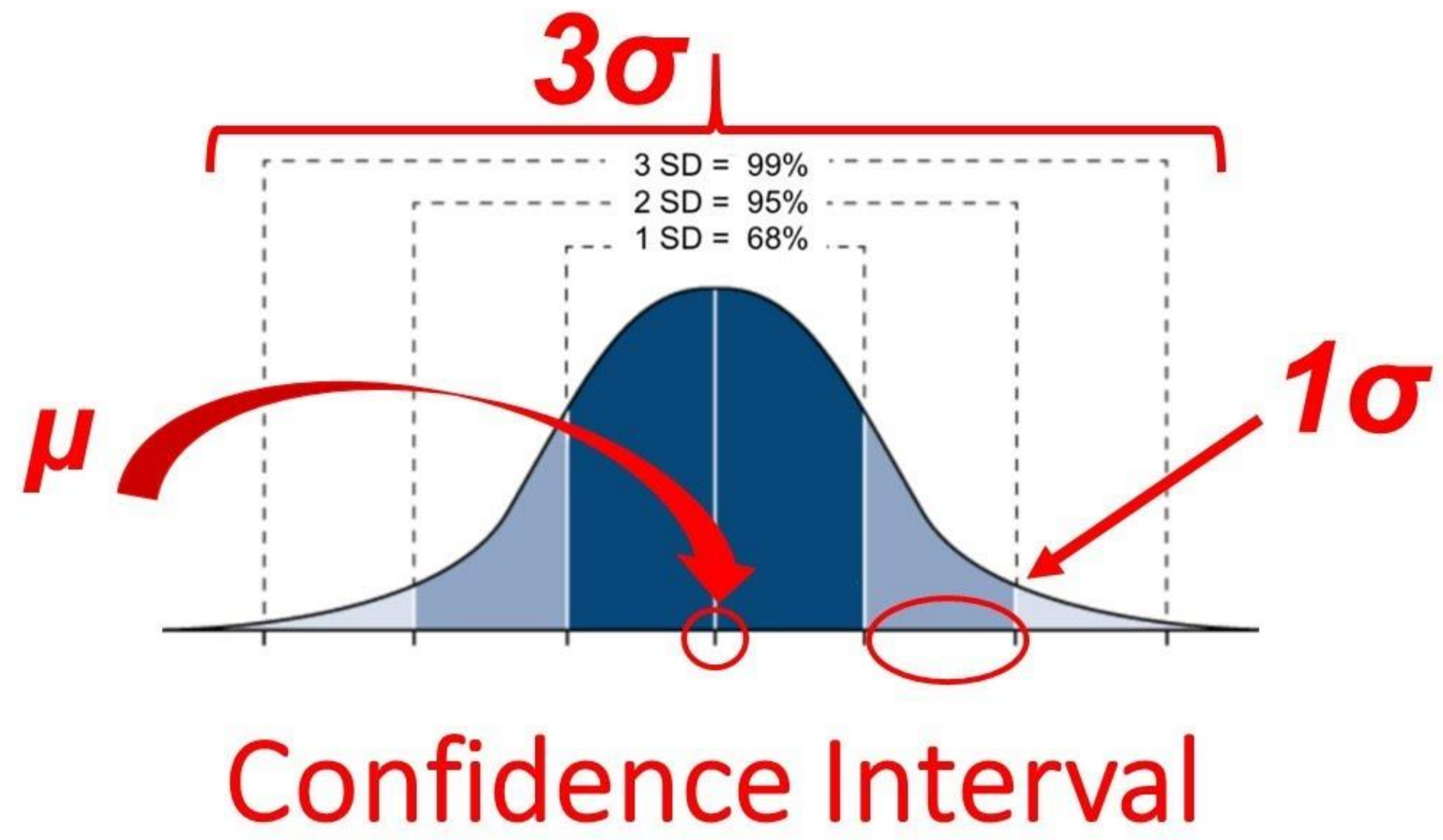
Step 1 – Required Average Strength

Required average strength, $fave = fmin + k\sigma$

Assume 5% results are allowed to be below specified design strength ($fmin$)

Concrete Mix Design

ACI Committee 211.1-91 Method – Worked Example



Concrete Mix Design

ACI Committee 211.1-91 Method – Worked Example

Value for the Factor K Himsworth Constants

Percentage of results allowed to fall below the minimum			*Value K*
0.1	...	...	3.09
0.6	...	...	2.50
1.0	...	...	2.33
2.5	...	...	1.96
6.6	...	...	1.50
16.00	...	...	1.00

Interpolate to obtain k=1.68 for 5%

$$f_{ave} = 30 + 1.68 * 4 = 36.72\ MPa$$

Concrete Mix Design

ACI Committee 211.1-91 Method – Worked Example

Step 2 – Estimate water-cement ratio

Use average strength, $fave = 36.7\ MPa$ and interpolate to obtain w/c ratio of 0.46

Average compressive strength at 28 days	*Effective water/cement ratio (by mass)*	
MPa	*Non-air entrained concrete*	*Air-entrained concrete*
45	0.38	–
40	0.43	–
35	0.48	0.40
30	0.55	0.46
25	0.62	0.53
20	0.70	0.61
15	0.80	0.71

Concrete Mix Design

ACI Committee 211.1-91 Method – Worked Example

Step 2 – Estimate water-cement ratio

Check obtained w/c ratio against maximum w/c ratio given for special exposure conditions

	Exposure Condition	Maximum W/C ratio, normal density aggregate concrete	Minimum design strength, low density aggregate concrete MPa
I.	Concrete Intended to be Watertight		
	(a) Exposed to fresh water	0.5	25
	(b) exposed to brackish or sea water	0.45	
II	Concrete exposed to freezing and thawing in a moist condition:		
	(a) kerbs, gutters, gaurd rails or thin sections	0.45	30
	(b) other elements	0.50	25
	(c) in presense of de-icing chemicals	0.45	30
III.	For corrosion protection of reinforced concrete exposed to de-icing salts, brackish water, sea water or spray from these sources	0.40	33

Exposure condition is Type I (a) with maximum w/c ratio of 0.5. Thus, adopt w/c ratio of 0.46

Concrete Mix Design

ACI Committee 211.1-91 Method – Worked Example

Step 3 – Determine Water Content

Use Slump = 50 mm and Maximum aggregate size = 20 mm

Workability or Air content	Water Content, Kg/m³ of concrete for indicated maximum aggregate size							
	10 mm	12.5 mm	20mm	25 mm	40 mm	50 mm	70 mm	150 mm
Non-air-entrained concrete								
Slump								
30–50 mm	205	200	185	180	160	155	145	125
80–100 mm	225	215	[illegible]	195	175	170	160	140
150–180 mm	240	230	210	205	185	180	170	–
Approximate entrapped air content per cent	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-entrained Concrete								
Slump								
30–50 mm	180	175	165	160	145	140	135	120
80–100 mm	200	190	180	175	160	155	150	135
150–180 mm	215	205	190	185	170	165	160	–
Recommended average total air content percent								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5	3.0
Extreme exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

Mixing water

= 185 kg/ m^3 of concrete

Concrete Mix Design

ACI Committee 211.1-91 Method – Worked Example

Step 3 – Determine Water Content

$$0.46 = \frac{Water}{Cement}$$

$$\frac{Cement}{m^3} of\ concrete = \frac{185kg/m^3}{0.46} = 402kg/m^3$$

Step 4 – Determine weight of C.A per m³ of concrete

Use:

Maximum aggregate size = 20 mm,

F.M =2.80, and

Dry Rodded Density of C.A = 1600 kg/m^3

Aggregates

ACI Committee 211.1-91 Method – Worked Example

Step 4 – Determine weight of C.A per m^3 of concrete

Maximum Size of Aggregate	Bulk volume of dry rodded coarse aggregate per unit volume of concrete for fineness modulus of sand of			
F.M.	2.40	2.60	2.80	3.00
10	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
20	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
40	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
70	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

Aggregates

ACI Committee 211.1-91 Method – Worked Example

Step 4 – Determine weight of C.A per m^3 of concrete

Use:

1 m^3 of concrete has 0.62 m^3 of C.A

$$Density = \frac{Mass}{Volume}$$

$$Mass = 1600\frac{kg}{m^3} \times 0.62m^3 = \frac{992kg}{m^3} of\ concrete$$

Aggregates

ACI Committee 211.1-91 Method – Worked Example

Step 5 – Estimate the density of freshly made concrete

Use maximum aggregate size = 20 mm

Maximum size of aggregate mm	First estimate of density (unit weight) of fresh concrete Non-air-entrained kg/m^3	Air-entrained kg/m^3
10	2285	2190
12.5	2315	2235
20	2355	2280
25	2375	2315
40	2420	2355
50	2445	2375
70	2465	2400
150	2505	2435

Estimate of

Density of fresh concrete

= 2355 kg/ m^3

Aggregates

ACI Committee 211.1-91 Method – Worked Example

Step 6 – Determine the weight of F.A

1. Weight of Water = 185 kg/ m^3
2. Weight of Cement = 402 kg/ m^3
3. Weight of C.A = 992 kg/ m^3
4. Weight of F.A= 2355 –(185+402+ 992)= 776 kg/ m^3

Note: Slump specified depends on the nature of the construction works.

Slump test for concrete

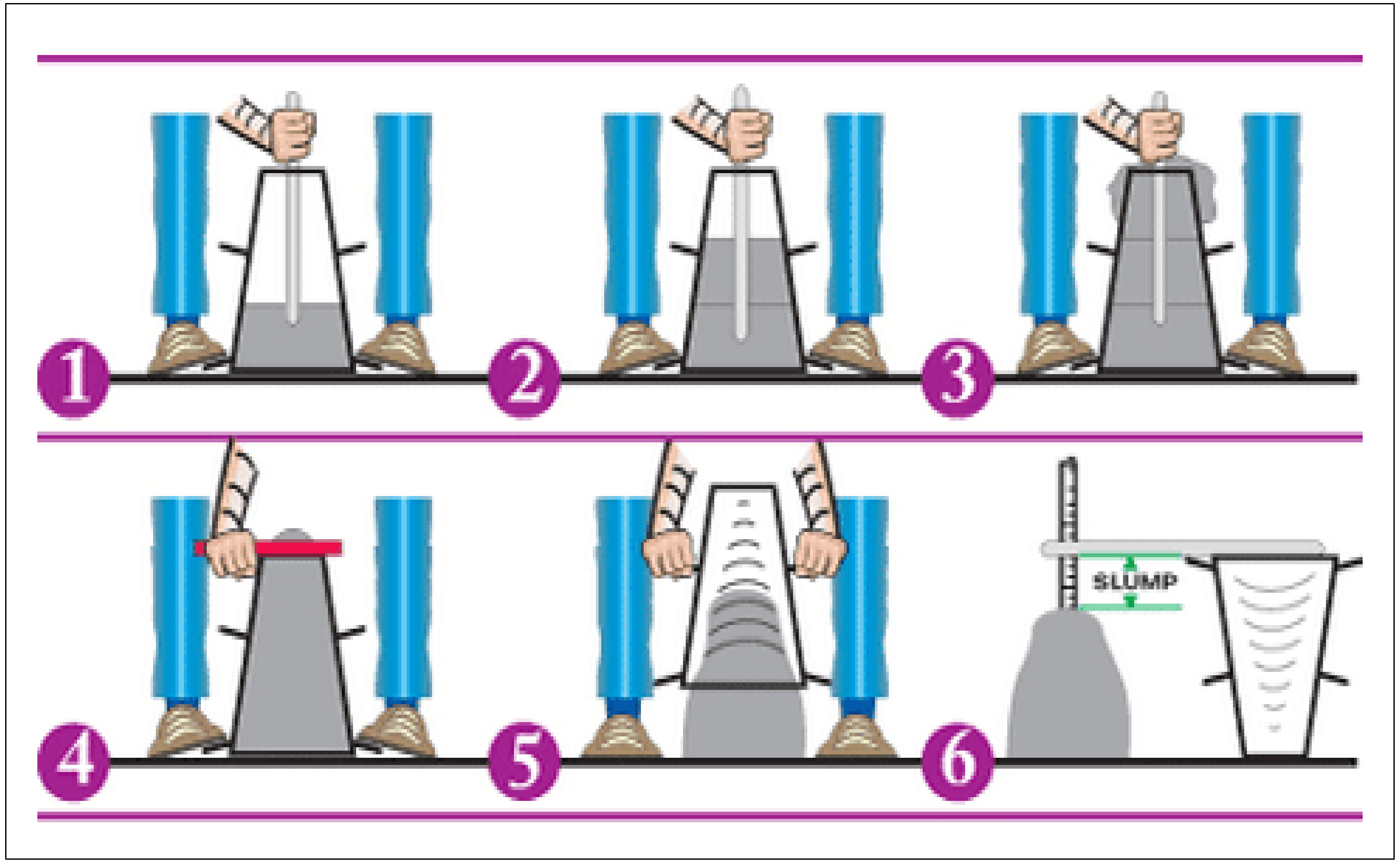
- Measures the consistency of freshly mixed portland concrete cement (PCC).
- This test indicates how easily concrete can be placed and compacted, or the workability of concrete.
- This test is used both in the laboratory and in the field for quality control.

Apparatus

Click here to watch video for ACI Slump Test: ASTM C143 Concrete Slump 2019

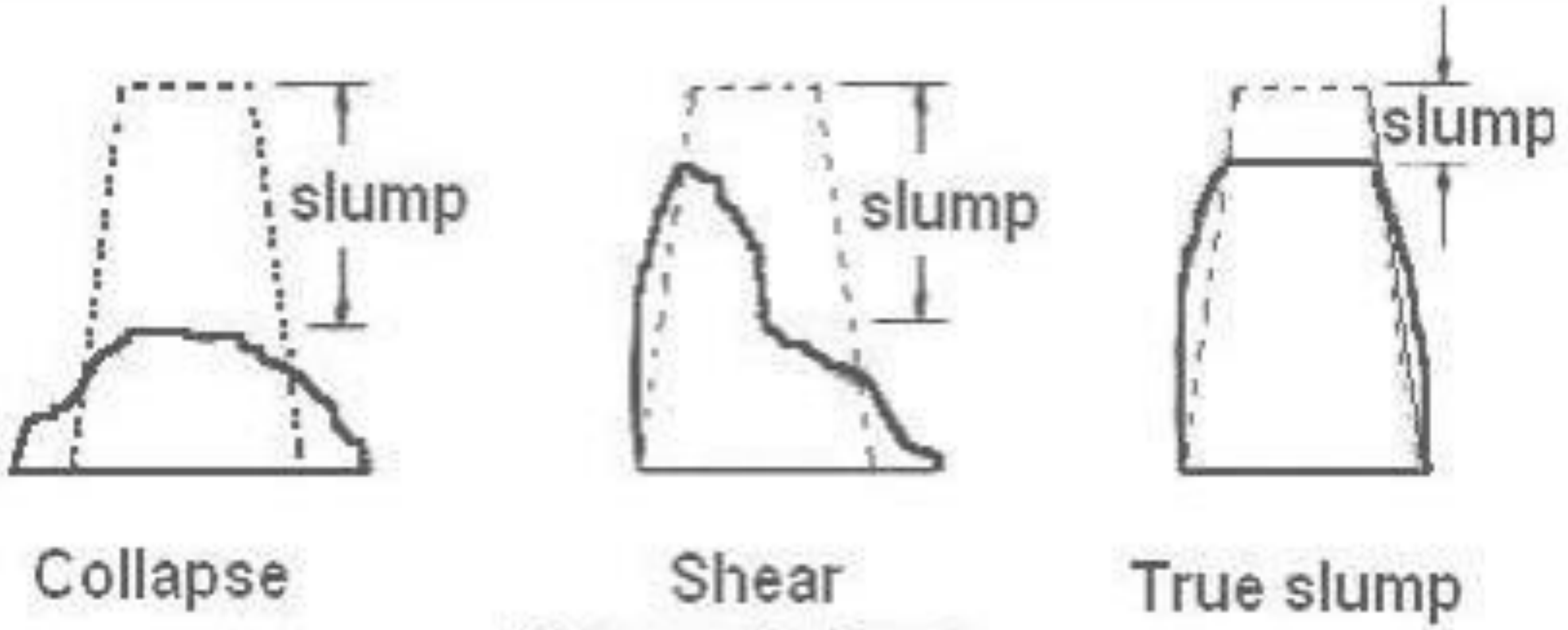
Slump test for concrete

Procedure



Slump test for concrete

Interpretation of slump results



Types of slump

Collapse	Shear	True
In a collapse slump the concrete collapses completely.	In a shear slump the top portion of the concrete shears off and slips sideways.	In a true slump the concrete simply subsides, keeping more or less to shape.

Curing of Concrete

Curing is the process of maintaining satisfactory moisture content and temperature in the concrete for a definite period of time.

Cement hydration takes time and requires water at the right temperature. Curing allows ongoing hydration and concrete strength improvements.

Once curing stops, the concrete dries out, and the strength gain stops.

If uncured concrete is allowed to dry in air, it will gain 50% of the strength of continuously cured concrete.

Concrete cured for three days will reach 60% of the strength of continuously cured concrete; cured for seven days would reach 80%.

When curing stops and restarts, strength gain stops and restarts.

Curing of Concrete

- Increasing temperature accelerates hydration and strength gain. Avoid temperatures below 10°C (50°F) for hydration, especially at young ages.

- Curing can be performed by any of the following approaches:

  ✓ **maintaining the presence of water** in the concrete during early ages. Methods to maintain the water pressure include ponding or immersion, spraying or fogging, and wet coverings.

  ✓ **preventing loss of mixing water from the concrete by sealing the surface**. Methods to prevent water loss include impervious papers or plastic sheets, membrane- forming compounds, and leaving the forms in place.

  ✓ **accelerating the strength gain by supplying heat and additional moisture to the concrete**. Accelerated curing methods include steam curing, insulating blankets or covers, and various heating techniques.

Curing of Concrete

Curing By Ponding

Curing By Sprinkling

Curing By Covering Gunny Bags

Curing By Covering Membrane

Testing of Hardened Concrete

- Compressive strength test is the test most commonly performed on hardened concrete.

- In the United States, the test is performed on cylindrical specimens and is standardized by ASTM C39. BS uses cubes.

- Following ASTM C42, structure cores can be drilled. The conventional specimen size is 0.15 m (6 in.) in diameter and 0.30 m (12 in.) high, however various sizes with a height–diameter ratio of two can be utilized. Specimen diameter must be at least three times the nominal maximum size of concrete coarse aggregate.

Summary-Strength of Concrete

- Concrete gains almost 80% of its ultimate strength 28 days after the mixing.

- The strength of concrete depends on:
  - ✓ water cement ratio (w/c),
  - ✓ air content,
  - ✓ cement type,
  - ✓ aggregate type, and
  - ✓ aggregate gradation.

- The lower w/c, the higher strength).

- High levels of air in concrete reduce the strength of concrete.

- A good gradation of aggregates contributes the strength significantly.

QUIZ 6

Thank You!!!