Conventional Building Materials
Cement

Hisham Qasrawi

Examples on Building Materials

- Cement
- Aggregates (coarse and fine)
- Water
- Admixtures
- Mortar
- Concrete
- Steel

Examples on Building Materials

- Timber (wood)
- Lime
- Plastics
- Aluminum
- Asphalt
- Bricks
- Tiles
- ………etc

Types of cement-based materials

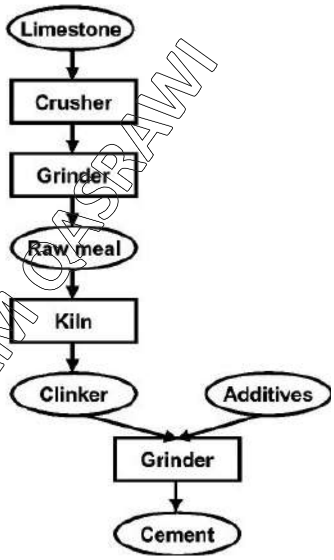
- Cement + water = cement paste
- Cement + water + fine aggregate = cement mortar
- Cement + water + fine aggregate + coarse aggregate + admixtures + pozzolans (optional) = concrete

Raw Materials Necessary for Portland Cement Manufacture Must Provide the Following

- Calcium (from calcite – $CaCO_3$)
- Silica (from clay and shale)
- Alumina (from clay and shale)
- Iron (from clay and shale)

Production of Cement

https://www.cemex.co.uk/cement-production-process.aspx



Main Steps

- **1. Mining the raw material**
  Limestone and clay are obtained from rock
- **2. Transporting the raw material**
  Once the huge rocks have been fragmented, they are transported to the plant in dump trucks or by conveyor belt.
- **3. Crushing**
  The quarry stone is delivered through chutes to the crushers, where it is reduced by crushing or pounding to chunks approximately 75mm.
- **4. Prehomogenization**
  Prehomogenization is the proportional mix of the different types of clay, limestones, or any other required material.

- **5. Raw material storage**
  Each of the raw materials is transported separately to silos, where it later will be added in specific amounts according to the particular type of cement being produced.
- **6. Raw material mill**
  This takes places in vertical steel mill, which grinds the material
- **7. Raw meal homogenization**
  This process takes place in silos equipped for obtaining a homogenous mix of the material.
- **8. Calcination**
  Calcination is the core portion of the process, in which huge rotary **kilns** come into play. Inside, at 1400 degrees C, the raw material is transformed into **clinker**: small, dark gray nodules 3-4 centimetres in diameter.

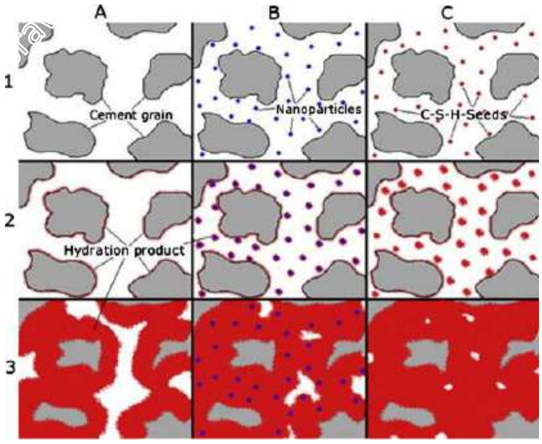
- **9. Cement milling**
  The clinker is ground by different-size steel balls while it works its way through the mill's two chambers, with **gypsum** being added by a ratio of **2 - 4 %** to extend cement setting times.
- **10. Cement packaging and shipping**
  The cement is then housed in storage silos, and then transported to facilities where it will be packaged in sacks or supplied in bulk. In either case, it can be shipped by rail car, freighter truck or ship.

Hydration of Cement

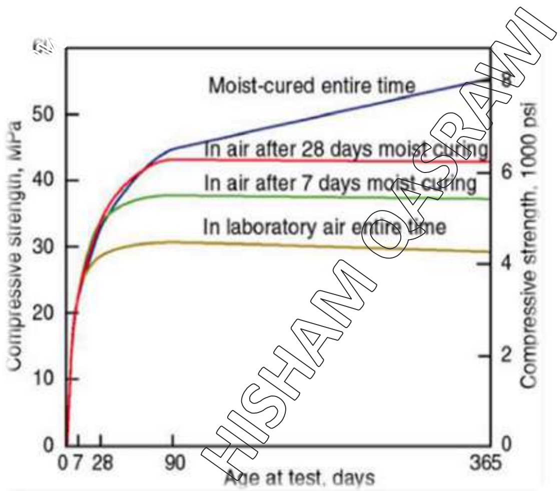
- Cement components + Water = Hydration products (C-S-H Gel) + Calcium hydroxide
  - Chemical reaction is slow.
  - Produces (generates) heat.
  - The undesirable part is Calcium hydroxide because it can leach.

  Also it reacts with other aggressive chemicals.
  - Desirable because it gives pH value to about 13, thus reduces corrosion of steel

Hydration
Note capillary and non-capillary pores

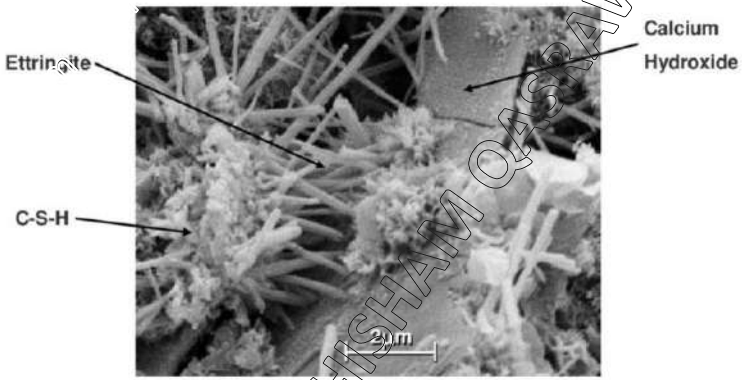


Strength development with time and curing



Under electron microscope

- C-S-H gel is a needle-like material



Basic Components: Chemical properties

Compound	Oxide Composition	≈ Ratio
Tricalcium silicate 3CaO.SiO2	C_3S	25 – 65
Dicalcium silicate 2CaO.SiO2	C_2S	10 – 50
Tricalcium aluminate 3CaO.Al2O3	C_3A	3 – 15
Tetracalcium aluminoferrite 4CaO.Al2O3.Fe2O3	C_4AF	5 – 15
Gypsum Alkalis	$CaSO_4$ Na_2O, K_2O	2 – 4 0.5 – 1.5

Basic Components: Effect on properties

Oxide	Effect on properties
C_3S	Responsible for strength at ages between 1 and 14 days
C_2S	Responsible for most strength late ages (after 14 days)
C_3A	Responsible for strength early ages (first 24 hours)
C_4AF	Minor effects
$CaSO_4$ 2 – 4 %	Prevents flash set by forming Ettringite in amounts that do not harm concrete

Minor Components

Depends on basic material and manufacturing process. The most common are

- Free CaO
- MgO
- Alkalis (K2O and Na2O)
- TiO2
- MnO2
- CrO2 (seldom found)
- ……. any other oxide

Ettringite

- Ettringite is the mineral name for calcium sulfoaluminate hydrate ($3CaO \bullet Al_2O_3 \bullet 3CaSO_4 \bullet 32H_2O$)
- Useful in delaying setting time.
- If its amount is high, Ettringite will increase in volume resulting in the disruption of concrete.
- Dangerous if sulfate from external sources is present

Chemical Composition

Bogue Composition

$C_3S = 4.07C - 7.60S - 6.72A - 1.43F - 2.85\bar{S}$

$C_2S = 2.87S - 0.75C_3S$

$C_3A = 2.65A - 1.69F$

$C_4AF = 3.04F$

(Only valid when $A/F \geq 0.64$)

After K. Kurtis

Bogue Composition: Example

Oxide Analysis

Oxide	%
SiO_2	20.6
Al_2O_3	5.07
Fe_2O_3	2.90
CaO	63.9
MgO	1.53
K_2O	0.73
Na_2O	0.15
SO_3	2.53
LOI	1.58

Calculated Phase Composition

C_3S = 4.07(63.9) – 7.60(20.6) – 6.72(5.07) – 1.43(2.90) - 2.85(2.53) = **58.1**

C_2S = 2.87(20.6) – 0.754(58.1) = **15.6**

C_3A = 2.65(5.07) – 1.69(F 2.90) = **8.5**

C_4AF = 3.04(2.90) = **8.8**

Bogue Potential Composition:

C_3S	58%
C_2S	16%
C_3A	9%
C_4AF	9%

After K. Kurtis

Soundness of cement

- It is the ability of a hardened cement paste to retain its volume after setting without delayed destructive expansion.

$$CaO + H_2O \rightarrow Ca(OH)_2$$
$$MgO + H_2O \rightarrow Mg(OH)_2$$

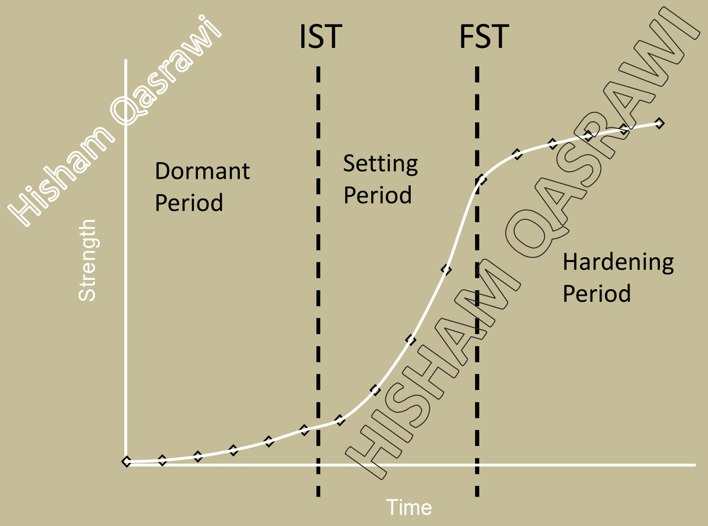
- This destructive expansion is caused by excessive amounts of free lime (CaO), or magnesia (MgO).

Soundness test
ASTM C151

- https://civilseek.com/soundness-of-cement/
- The maximum expansion should not exceed 0.8%

- Requirements
- It is advisable that the amount of free CaO and MgO do not exceed 5% (BS 12 1996) and 6% (ASTM C150-05) .

Setting of Cement

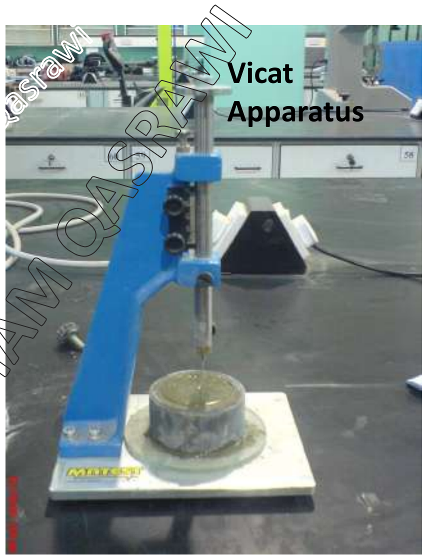


False and Flash Setting

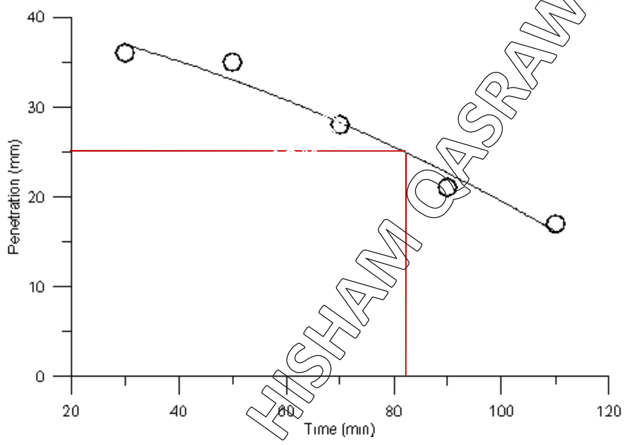
- **False set** is the rapid development of rigidity in freshly mixed paste, mortar, or concrete without the evolution of much heat. Plasticity **can** be regained by further mixing.
- **Flash set** is also the rapid development of rigidity, but with the evolution of considerable heat. Plasticity **cannot be** regained. Rapid development of rigidity would interfere with delivery and placement operations. Flash set would make concrete unusable, and concrete hardened in the mixer could not be removed easily.
  - **Flash set is prevented by adding gypsum by 2 to 4 %. To delay reactions.**

Tests of Cements

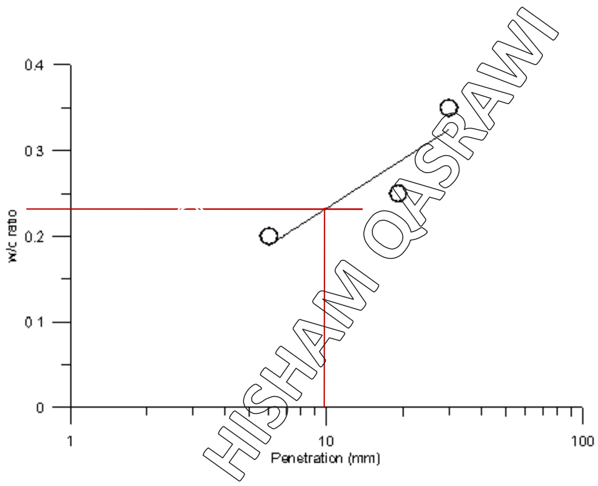
Consistency & Setting Times: Vicat Method



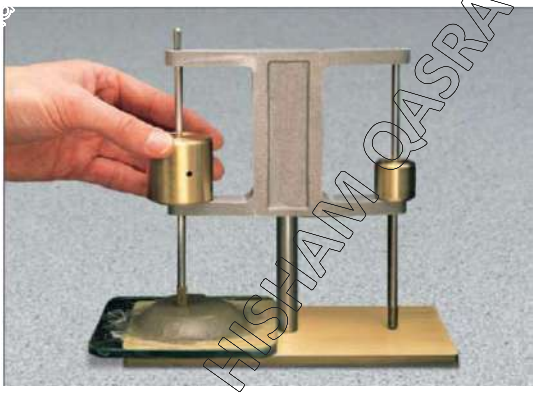
Setting Time by Vicat
Use 1-mm needle



Normal Consistency by Vicat
Use 10-mm rod



Tests of Cements
Setting Times: Gilmore Method



Compliance with specifications

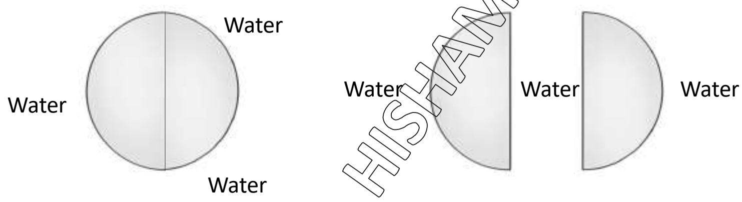
- According to ASTM,
  - Vicat Apparatus
    - IST must be >= 45 min
    - FST must be <= 6.25 hours
  - Gillmore Apparatus
    - IST must be >= 60 min
    - FST must be <= 10 hours

Approximate Empirical Relations Based on Vicat Test

- FST = 1.2 (IST) + 90 minutes
- FST = 1.5 (IST) + 45 minutes

Fineness

- Fineness is measured in by the specific surface in m^2 / kg or cm^2 / g
- The higher the fineness of cement, the higher rate of reaction and the higher the rate of heat evolution.



Common Methods of Testing the fineness of cement

Table 2.3: **Examples of specific surface of cement measured by different methods**

Cement	Specific surface (m²/kg) measured by:		
	Wagner method	Lea and Nurse method	Nitrogen adsorption method
A	180	260	790
B	230	415	1000

Heat of Hydration

- If I gm of C2S produces X calories, then C3S is about 2X and C3A is about 3.5X

Compound	Heat of hydration	
	J/g	Cal/g
C_3S	502	120
C_2S	260	62
C_3A	867	207
C_4AF	419	100

Specific gravity of cement

- Specific gravity is the ratio between the weight of a certain volume of the material to the weight of the same volume of water.
- For practical uses, SG of cement is taken 3.15.

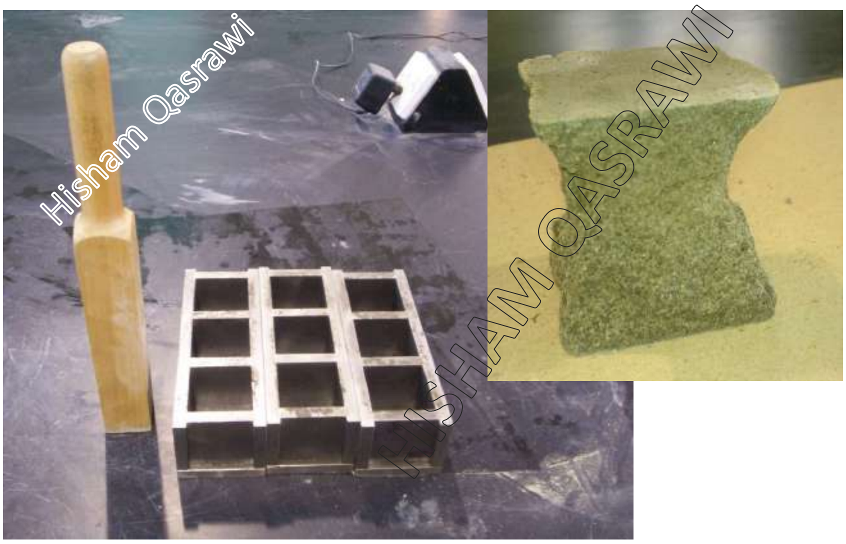
Strength of Cement

- Two types are considered:
  - Compressive strength
  - Tensile strength:
    - Direct
    - Indirect

Concrete is strong in compression and weak in tension.

GENERALLY, Compressive strength of concrete is about 10 times the tensile strength

Compressive strength of mortar



Compressive strength of cement

- The most common test is ASTM C 150.
- Test 2-inch (app. 50-mm) cement mortar cubes.
- A minimum of 3 cubes are required to obtain result.
- The strength of each is P/A.
- Take the average.
- Accepted values must be within 10% of the average.

Example

- Assume that 4 cubes are tested for strength at a certain age, the strength values recorded are 30, 32, 36 and 42 MPa.
  - The average is 35 MPa
  - The accepted range is 31.5 to 38.5 MPa
  - 32, 36 MPa are accepted. Others are rejected.
  - The new accepted average is 34 MPa

ASTM requirements for compressive strength

Age (days)	ASTM C 150–05 (mortar cube), cement type (Table 2.7)							
	I	IA	II#	IIA#	III	IIIA	IV	V
1	–	–	–	–	12.0	10.0	–	–
	–	–	–	–	(1740)	(1450)	–	–
3	12.0	10.0	10.0	8.0	24.0	19.0	–	8.0
	(1740)	(1450)	(450)	(1160)	(3480)	(2760)	–	(1160)
7	19.0	16.0	17.0	14.0	–	–	7.0	15.0
	(2760)	(2320)	(2470)	(2030)	–	–	(1020)	(2180)
28	28.0[a]	22.0[a]	28.0[a]	22.0[a]	–	–	17.0	21.0
	(4060)	(3190)	(4080)	(3190)	–	–	(2470)	(3050)

* and not more than 52.5 (7600); ** and not more than 62.5 (9100)

Strength values depend on specified heat of hydration or chemical limits of tricalcium silicate and tricalcium aluminate

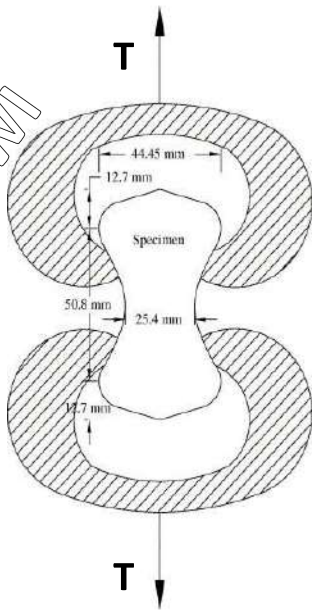
[a] Optional

Direct tensile strength of cement using Briquette Method

- ASTM C 190. CRD 260-01
- Test cement mortar Briquettes.
- A minimum of 3 samples are required to obtain result.
- The strength of each is P/A.
- Take the average.
- Accepted values must be within 15% of the average.

Direct tension

- Size is 1 inch by 1 inch; app 25 by 25 mm.



Tests of Cements
Tensile Strength of mortar

ASTM C 190 Withdrawn

Example

- Assume that 5 briquetts are tested for strength at a certain age, the strength values recorded are 3.0, 3.2, 3.5, 4.3 and 4.0 MPa.
  - The average is 3.6 MPa
  - The accepted range is 30.6 to 4.14 MPa
  - Therefore 3.2, 3.5 and 4 MPa are accepted. Others are rejected.
  - The new accepted average is 3.57 MPa

CRD 260-01 Requirements

	Cement Type				
	I	II	III	IV	V
1 day in moist air, psi (kPa)	. . .	. . .	275 (1896)	. . .	. . .
1 day in moist air, 2 days in water, psi (kPa)	150 (1034)	125 (862)	375 (2586)	. . .	. . .
1 day in moist air, 6 days in water, psi (kPa)	275 (1896)	250 (1724)	. . .	75 (1207)	250 (1724)
1 day in moist air, 27 days in water, psi (kPa)	350 (2413)	325 (2241)	. . .	300 (2068)	325 (2241)

[A] Taken from Specification C 150 - 58 without change.

Main Types of Cement

- Ordinary Portland cement (ASTM Type I) - OPC
- Rapid-hardening Portland cement (ASTM Type III) RHPC
- Special (Ultra, Extra) rapid-hardening Portland cement - URHPC
- Low-heat Portland cement Modified Portland cement (Type IV) - LHPC
- Sulfate-resisting Portland cement (ASTM Type V) - SRPC
- Moderate Sulfate-resisting Portland cement (ASTM Type II) - MSRPC
- Pozzolanic Portland cement – PPC

Some Special Cements

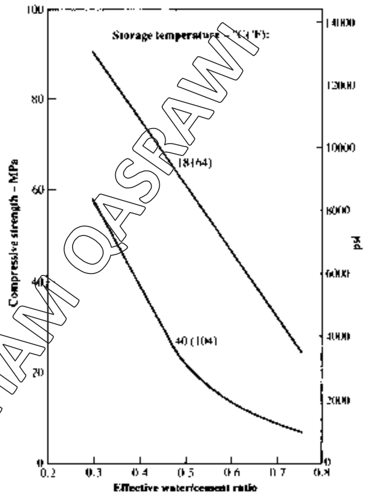
- White Portland cements – WPC
- Coloured Portland cements
- Expansive (Expanding cements)
  - Non shrinking cement
- Supersulfated slag cement
  - Granulated ground blast-furnace slag cement (slag cement) – GGBFSC

Special Types of Cement

- Quick setting cement
  - Produced by adding 1 to 3 % Aluminum sulfates to clinker.
- Bacterial cement
  - Used in self-healing concrete
- Hydrophobic Portland cement
- Air-entrained Portland cement (Type s IA, IIA and IIIA).

Special Types of Cement

- High-alumina cement
  – HAC
    – Decomposition occurs



Influence of the effective water/cement ratio (see page 541 on the strength of high-alumina cement concrete cubes cured in water at 18 °C (64 °F) and 40 °C (104 °F) for 100 days

Pozzolans

- A pozzolan is a material that does not posses cementitious properties.
- When it is fine, and in the presence of moisture, it chemically reacts with calcium hydroxide at ordinary temperatures to form compounds having cementitious properties. It is therefore classified as cementitious material.
- Types:
  Natural (Type N)
  Artificial (Types F and C)

Storage of cement

Correct

Bulk Storage of Cement

Corrected core strength to standard cylinder (textbook p 302)

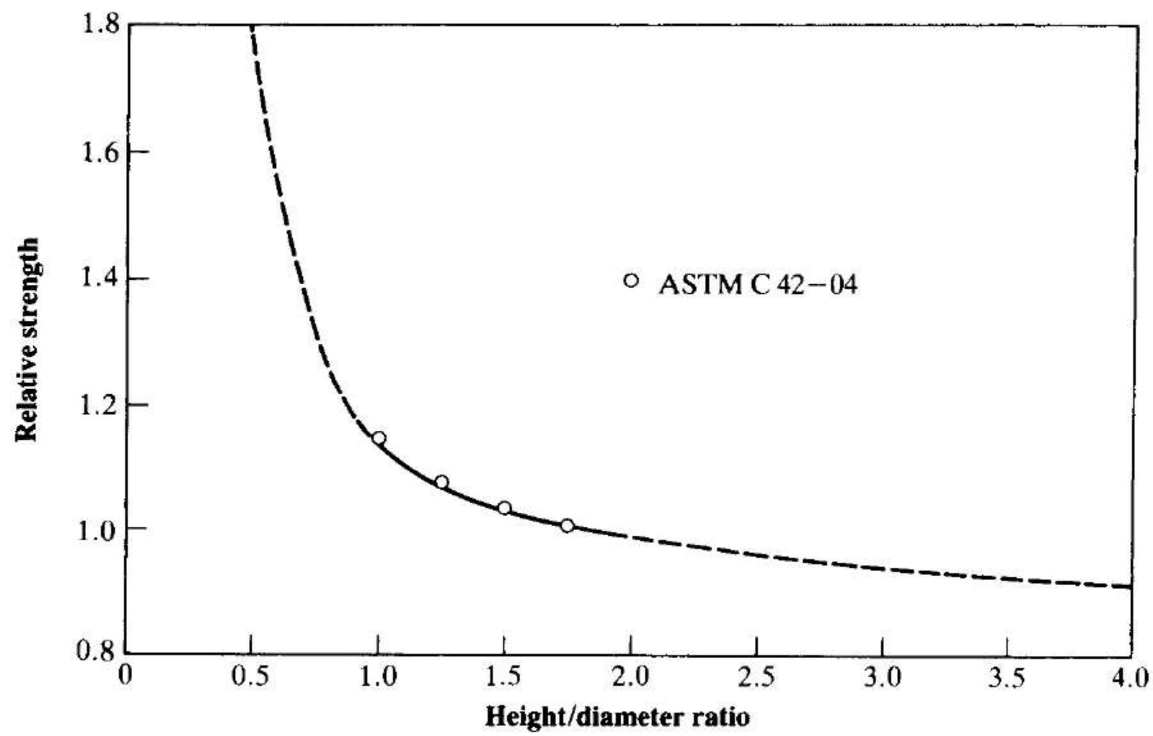


Fig. 16.3: Influence of height/diameter ratio on the apparent strength of a cylinder

Curing of Concrete

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Reference

Text book

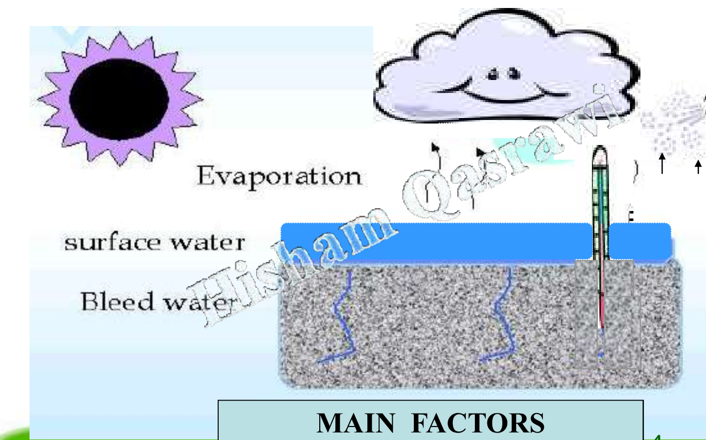
Chapter 10

Principle

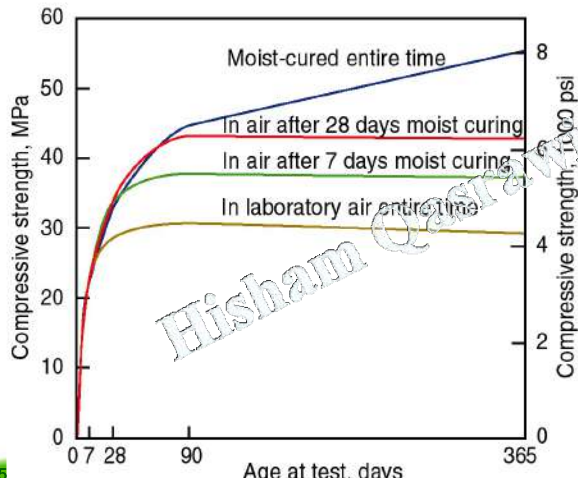
Curing is the process used to continue hydration of cement and block capillary pores to produce high quality concrete with

- **High strength**
- **High durability**
- **Low permeability**

**Factors affecting evaporation:
Concrete Temperature; Air Temperature; Humidity; wind velocity**



Effect of Moist Curing

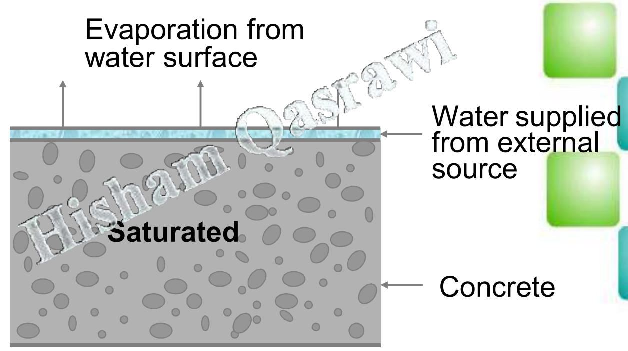


Importance of curing

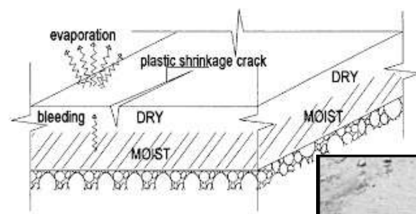
- **Approximate curing period for certain degree of hydration**

w/c	Degree of hydration	Curing
0.40	50 %	3 days
0.45	60 %	7 days
0.50	70 %	14 days
0.60	92 %	6 months
0.70	100 %	1 year
> 0.70	100 %	impossible

Curing of Concrete by Supplying Water



Typical Plastic: Shrinkage Cracks



Curing Methods
Sprinkle with water

- Special precautions must be considered

- What are the main disadvantages?

Curing Methods
Water ponding
(immersion with water)

Curing Methods

- Cover with wet sand.
  - Useful in hot weather.
  - Sand can be reused in construction
- Cover with sawdust (نشارة الخشب)
  - Make sure that it does not contain tanic acid or oxalic acid.
  - Not used in Jordan

Curing Methods
Cover with wet hessian or burlap

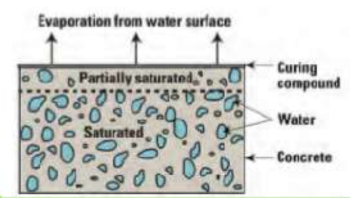
Curing Methods
Cover with wet hessian or burlap

Can be useful

Curing Methods
Cover with impermeable membrane

Curing Compounds

- Curing admixtures.
  - Added to concrete mixtures.
- Curing paints
  - Form impermeable membranes on the surface of concrete.
  - Correct application is a must.

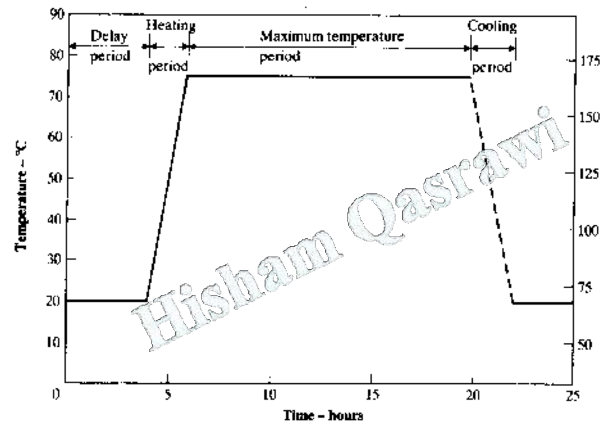


Keep formwork in-place

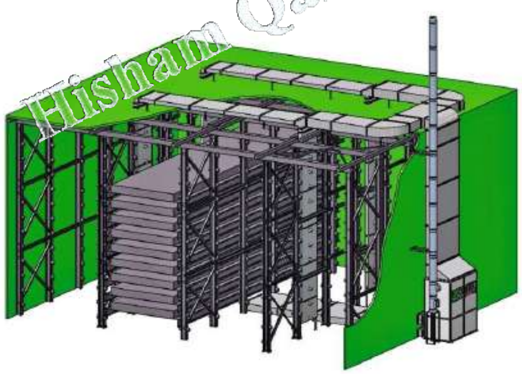
Keep concrete immersed in water

- Concrete samples.
- Precast concrete elements.

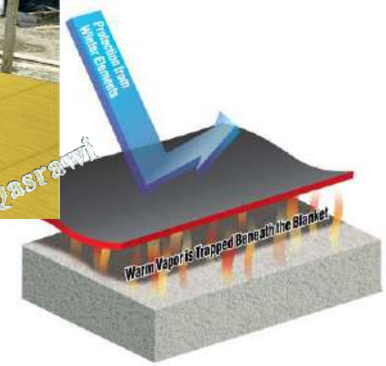
Steam Curing



Curing Chamber

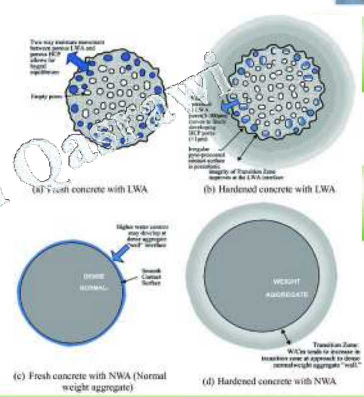


Electric Concrete Curing Blankets
Useful in cold weather or precast concrete



Self-curing concrete

- High absorbent light weight Aggregate
- Special admixtures



Self curing concrete

- Self curing concrete allows 'internal curing' by allowing for curing 'from the inside to outside' through the internal reservoirs:
- *saturated lightweight aggregates,*
- *super absorbent polymers, or*
- *saturated wood fibers (for special concretes)*

Microwave curing

- A new method for precast concrete elements.
- Microwaves have the potential to deeply penetrate a material, which enables heating from within the material.
- The current technology is suitable for heating medium-thick products.
- concrete can be cured in less than six hours without the use of chemical accelerants. This is almost three times faster than conventional steam and other heating methods, which can take between 12-24 hours

4 Photo of 100 mm concrete cube cast in PEEK mould in microw

Activity

- Contact some practicing engineers in Jordan and obtain the following information:
  - The methods of curing used in.
  - The period of curing that prevail in local projects for footings, columns, walls and roofs (beams and slabs).

Durability and Deterioration of Concrete

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What is durability?

- Durability is the ability of concrete to withstand the conditions for which it is designed for without deterioration for a long period of years.
- Durability of concrete may be defined as the ability of concrete to resist various deteriorating factors in its environment.

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Main Causes

- Chemical factors
- Physical factors
- Mechanical factors
- Biological factors

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Chemical Factors

- Sulfates
- Acids
- Alkali-silicate reaction (alkali-aggregate reaction)
- Carbonation
- Chlorides
- Corrosion of steel

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Sulfates

- External sources
- Internal sources

- $SO_4^{=} + C_3A + H_2O + Ca(OH)_2 \rightarrow$ Ettringite;
  Ettringite is a high-sulfate calcium sulfoaluminate hydrate mineral
  (3CaO • Al2O3 • 3CaSO4 • 32H2O)

Expansive and disruptive causing severe cracking

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Aggressive Sulfates

- Magnesium – most aggressive
- Sodium
- Potassium
- Calcium – least aggressive

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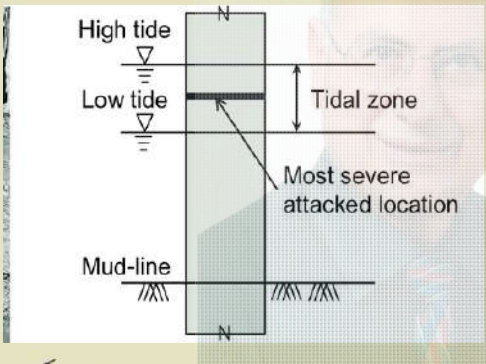
Discussion

- How to avoid or reduce sulfate attack on concrete?

Effect of sea-water

The most dangerous is the tidal zone



Acids

- Effect on $Ca(OH)_2$
- Concrete becomes soft
- Very dangerous when reaches steel

Most Dangerous Acids

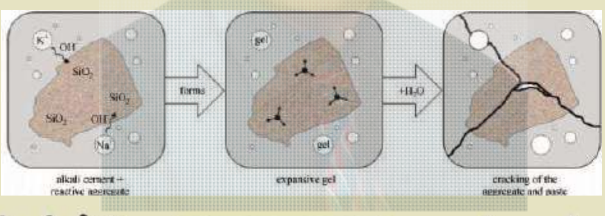
- Non organic
  - Nitric Acid
  - Sulfuric acid
  - Hydrochloric Acid
- Organic
  - Acetic Acid

Carbonation of Concrete

- Carbon dioxide (CO_2) dissolves in pore water (H_2O) to produce carbonic acid
  - (H_2CO_3): $CO_2 + H_2O \leftrightarrow H_2CO_3$
- Carbonic acid (H_2CO_3) reacts with calcium hydroxide ($Ca(OH)_2$) to produce calcium carbonate ($CaCO_3$) and water (H_2O):
  - $H_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + 2H_2O$
- Carbonation reduces pH value encouraging steel corrosion

Alkali-Silicate Reaction (ACR)
Alkali-Aggregate Reaction (AAR)
Concrete Cancer

- Alkali from cement or any other source + Water + free silica from aggregate → Alkali silicate hydrate gel
- Expansive and disruptive causing cracks



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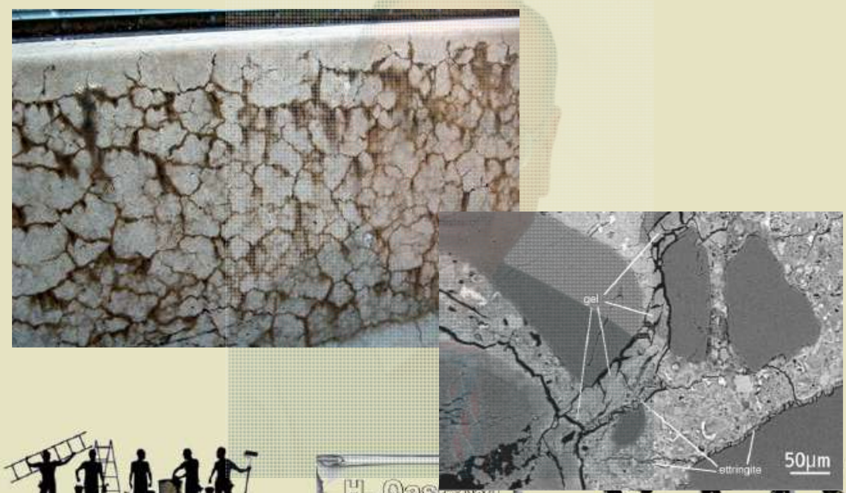
ASR



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How to reduce ASR

- Avoid high alkali content:
  - use low alkali Portland cement (≈ $Na_2O+2/3K_2O \leq 1\%$)
  - replace cement with pozzolanic materials.
- Avoid reactive aggregate with free silica (amorphous silica)
- Control access to water
- Use lithium additives prior to placement of concrete or as a treatment in already existing concrete.
- Limit total amount of alkalis in concrete to a max of $3kg/m^3$.

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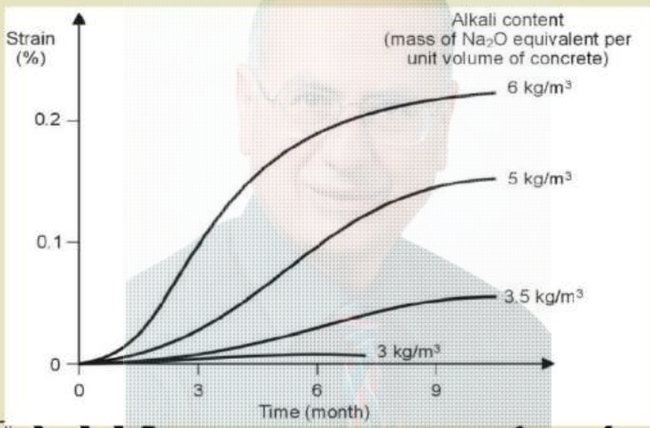
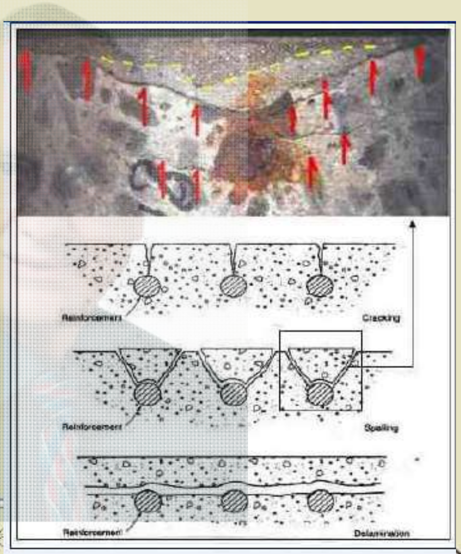
Alkali-Silica Reaction
Effect of Total Alkali content



After R. G. Sibbick, C. L. Page,

Corrosion of Reinforcement

Refer to previous lectures regarding the corrosion of steel bars and effect of pH value.



Corrosion of Reinforcement

Severe Corrosion of Reinforcement

Spalling of Concrete Cover and Exposure of Steel

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Presence and Effect of Chlorides

- Internal sources: Mainly sand
- External sources

- Provokes corrosion (Pitting corrosion)

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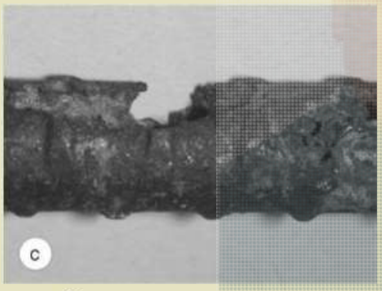
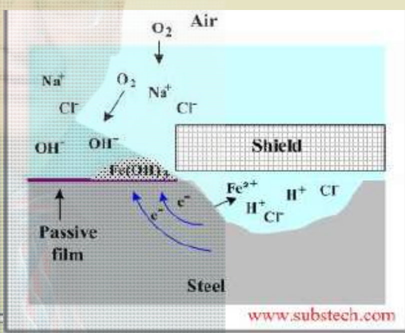
Results of Corrosion of Rebars Pitting corrosion due to alkalis

- *Reduction in Cross-Sectional Area and Pitting Corrosion*





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Activity

- How can we reduce corrosion of steel in concrete?

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Main Physical Factors

- Plastic settlement
- Shrinkage
  - Autogenous shrinkage
  - Plastic shrinkage
  - Drying shrinkage
- Temperature effects
- Freeze and thaw

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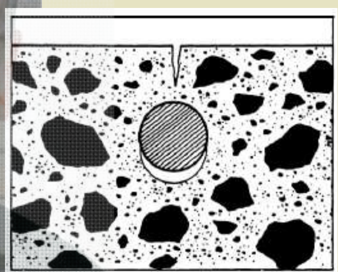
Plastic Settlement



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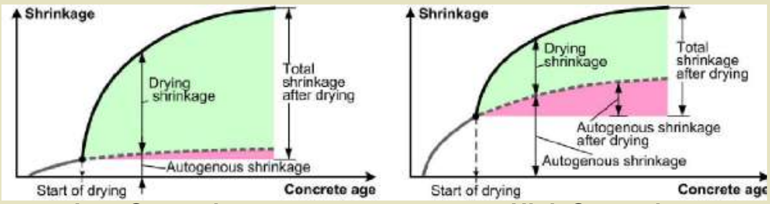
Autogenous shrinkage

- Autogeneous shrinkage, also known as "basic shrinkage," is the shrinkage due to chemical reactions (hydration) between cement with water.
- Its magnitude is usually ignored in low strength concretes. It is important in high strength concrete with w/c less than 0.40.



Low Strength High Strength

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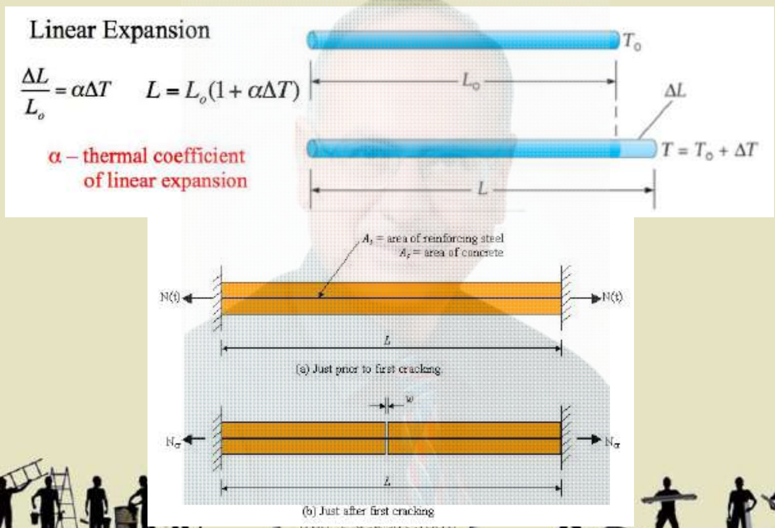
Temperature Cracking



When does cracking occur?

- When temperature and shrinkage act together, then
  - Total strain = temperature strain + shrinkage strain.
  - Stress = strain x modulus of elasticity
  - If the stress exceeds tensile strength of concrete, then concrete cracks

Note that temperature strain can be + or -

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Temperature and Drying Shrinkage Cracking

The stress will be:
(Temperature strain + shrinkage strain)
Multiplied by the modulus of elasticity

If the stress exceeds concrete tensile strength, concrete will crack

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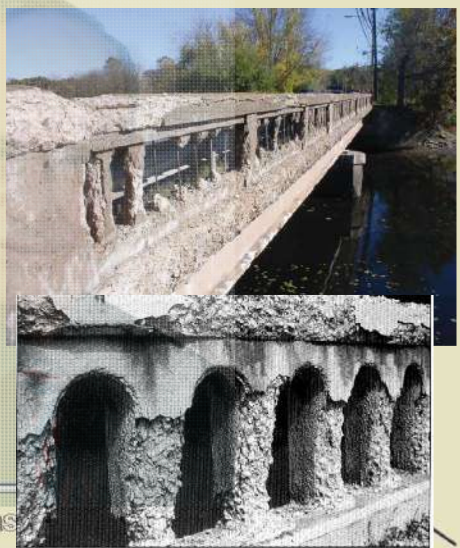
Freeze and Thaw (Frost action)

- **Refer to previous lectures on fresh concrete.**
- **Use Air-entrained concrete to avoid such deterioration**



H. Qas

Freeze-thaw cracking

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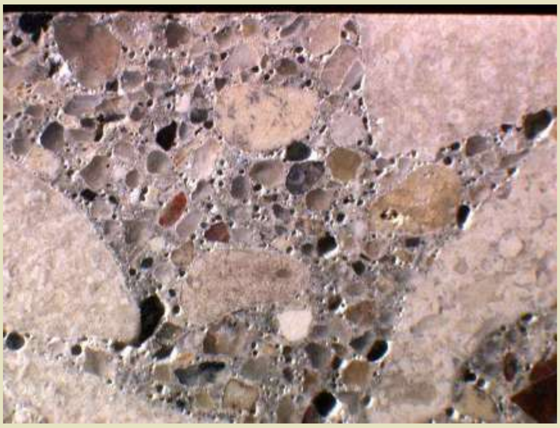
Reduce freeze-thaw effect Use air-entrained concrete



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Main Temperature Effects

- Elongation & shortening
- Heat of hydration (Refer to previous lectures)
- Others

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Mechanical Effects

- Abrasion
- Erosion
- Cavitations
- Impact
- Vibration

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Abrasion

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Cavitations

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Erosion

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Biological Effects

- Types of bacteria
  - Sulfate-reducing bacteria (SRB)
  - Sulfur-oxidizing bacteria (SOB)
  - Iron-oxidizing bacteria (IOB)
  - Oil-oxidizing bacteria (OOB)
  - *Self-healing bacteria (SHB)*

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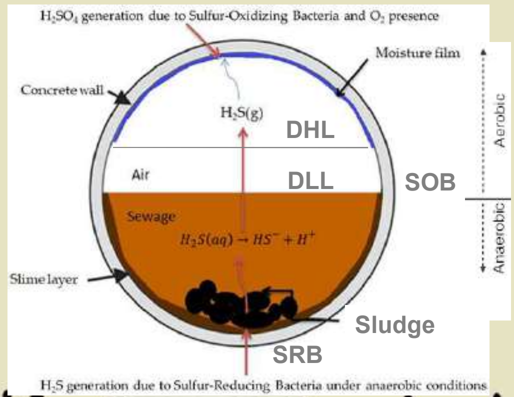
Steel Biocorrosion Tuberculoses (TB) of Pipes

Concrete Biodeterioration Mechanism in Sewers



Summary

- **Anaerobic SRB** in the bottom of pipe produces H_2S.
- H_2S is a mild acid that produces H_2SO4 causing acid attack in all upper parts of the pipe.
- SOB that are found in the DHL and LDL consumes H_2S and forms sulfuric acid in this zone.
- This zone becomes a putty-like material.
- A greenish color may be observed

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Concrete Biodeterioration

Some types of bacteria responsible for material biodeterioration

Fresh Concrete

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Workability Definition

- Workability is the easiness to **produce** concrete
- From engineering point of view, the concrete mix should be
  - Stable
  - Mobile
  - Compactable
  - Finishable

Definitions

- **Mobility**: Ability of concrete to flow, fill the forms and coat steel bars.
- **Stability**: Ability of concrete to remain cohesive and homogenous during production.
- **Compactability**: Ability of concrete to be compacted with the least effort.
- **Finishability**: The easiness to produce the required surface.

In all stages: Without segregation or bleeding

Columns

Segregation!

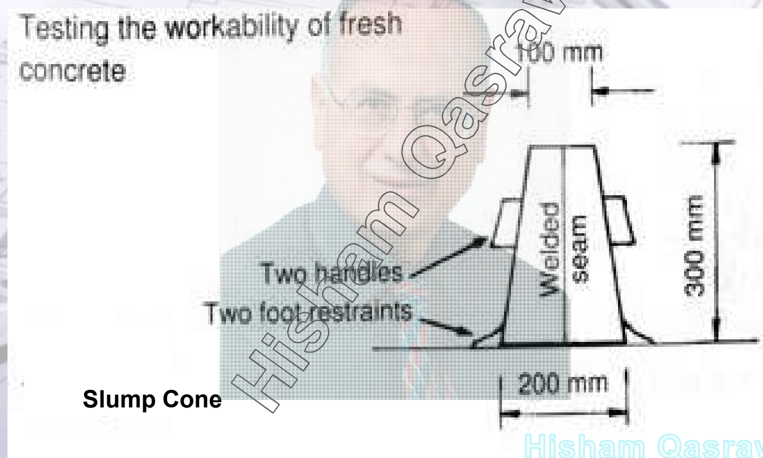
Retaining walls bleeding!

Workability
Most Common Tests

- Slump test
- Vebe test
- Compacting factor test
- Flow table test
- Kelley ball (ball penetration) test

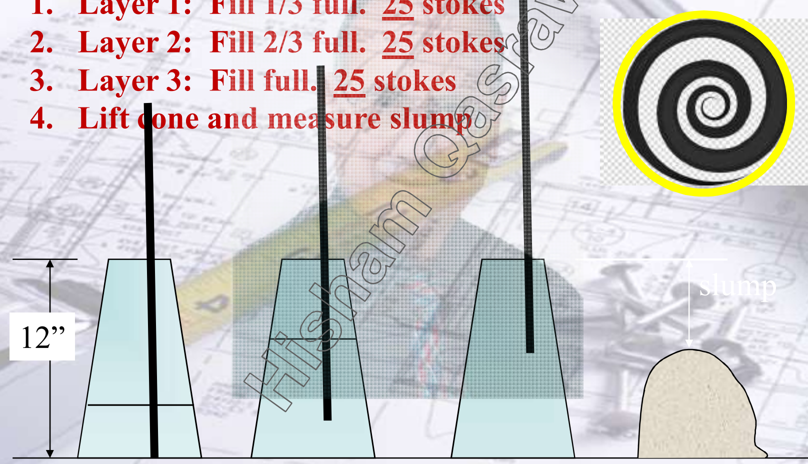
Workability
Slump Test

Testing the workability of fresh concrete



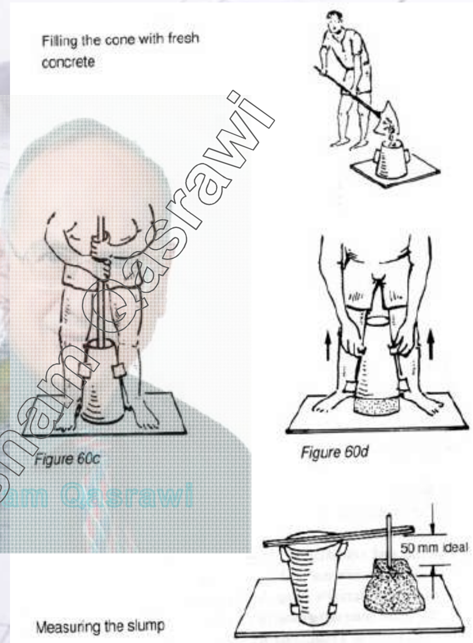
ASTM Procedure

1. Layer 1: Fill 1/3 full. 25 stokes
2. Layer 2: Fill 2/3 full. 25 stokes
3. Layer 3: Fill full. 25 stokes
4. Lift cone and measure slump



Workability Slump Test:

Procedure



Workability Slump Test:

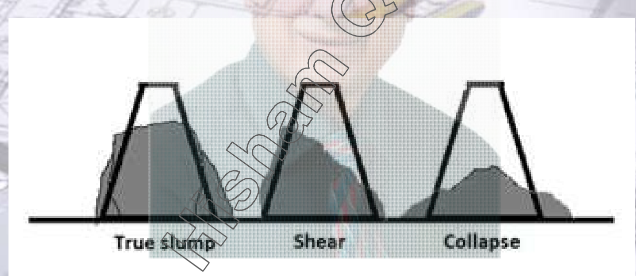
Types of slump

- https://theconstructor.org/concrete/site-slump-test-fails/176167/

What Should Site Engineer Do If On-site Slump Test Fails?

Discussion

- What is the indication of each type of slump?
  - Superplasticizer

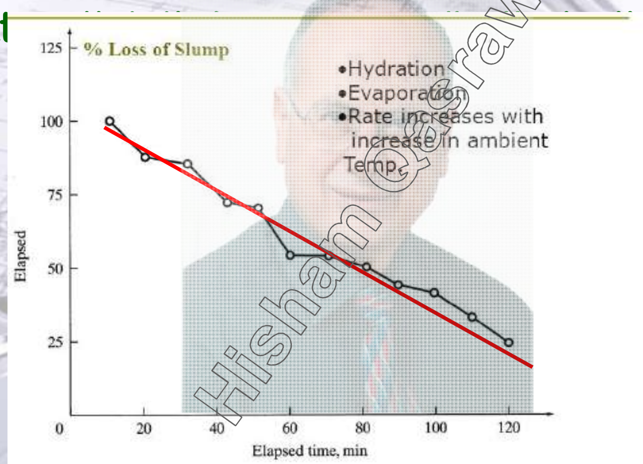


Degree of workability

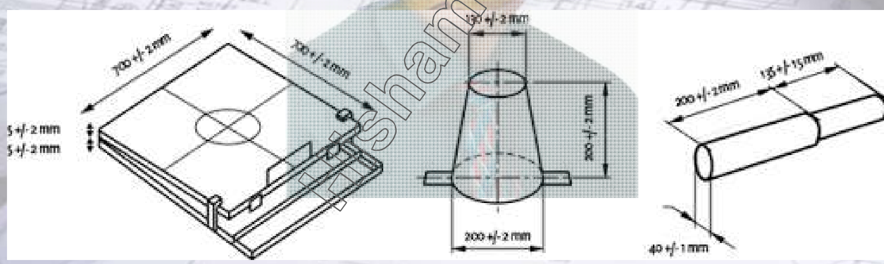
Slump (mm)	Degree of workability
Less than 20	Very low
30 to 50	Low
80 to 100	Medium
120 to 150	High
Greater than 180	Very high

Delay in casting
Loss in slump

- htt... test/

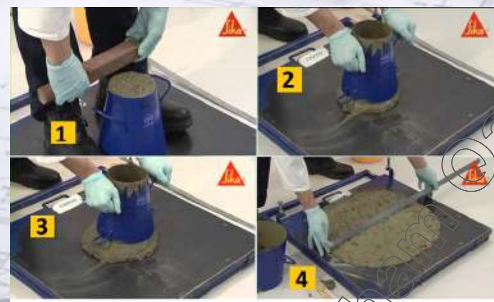


Workability
Flow Table Test



Workability
Flow Table Test

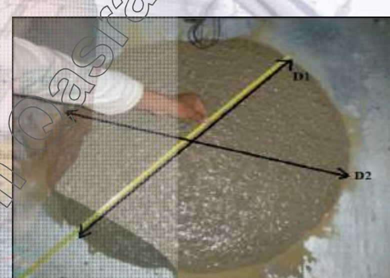
Steps of Test
EN Standards



Flow Table Test

- Flow = D (average)
- D (mm)=(D1+D2)/2

Homogeneity and segregation by flow table test



Workability
Flow Table Test
DIN

$$Flow\,(\%) = \frac{D_f - D_i}{D_i}\,x100\%$$

Percentage of flow	0 – 20%	15- 60 %	50-100 %	90-120%	110-150%
Concrete consistency & workability	Dry Very low	Stiff low	Plastic normal	Wet high	Sloppy very high

Workability
Vebe (V.B.) Test

Workability
Vebe (V.B.) Test

very low workability	>20 sec
Low workability	6-12 sec
Medium workability	3-6 sec
High workability	0-3 sec

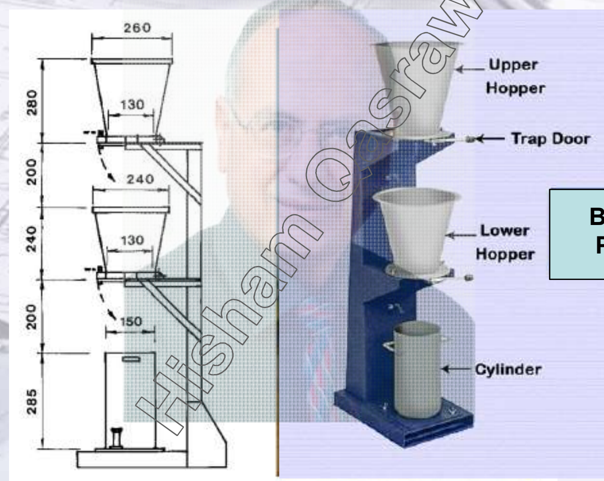
https://www.quora.com/What-is-the-workability-of-concrete

Degree of Workability

Consistency description	Slump, mm	Slump, in.	Vebe, s
Extremely dry	—	—	32 to 18
Very stiff	—	—	18 to 10
Stiff	0 to 25	0 to 1	10 to 5
Stiff plastic	25 to 75	1 to 3	5 to 3
Plastic	75 to 125	3 to 5	3 to 0
Very plastic	125 to 190	5 to 7-1/2	—

https://www.quora.com/What-is-the-workability-of-concrete

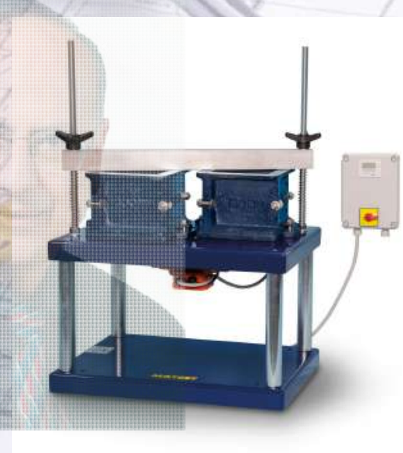
Workability
Compacting Factor Test



BS 1881: Part 103

Compaction

- Vibrating table
  or
- Hand (manual) Compaction



Calculations: CF

Apply any of the equations

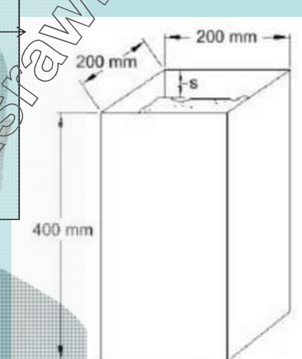
$$\text{Compacting factor (CF)} = \frac{\text{Weight of partially copmacted concrete}}{\text{Weight of fully copmacted concrete}}$$

$$= \frac{\text{Unit weight of partially compacted concrete}}{\text{Unit weight of fully compacted concrete}}$$

$$= \frac{\text{Density of partially compacted concrete}}{\text{Density of fully compacted concrete}}$$

Compacting Factor by EN 12350-4

- Fill the mold with uncompacted concrete.
- Measure the height at corners and take the average.
- The usual range is 1.02 to 1,5.



$$\text{Compacting factor (EN)} = \frac{\text{Height of the mold}}{\text{Height of fully copmacted concrete}}$$

Workability
Compacting Factor Test BS

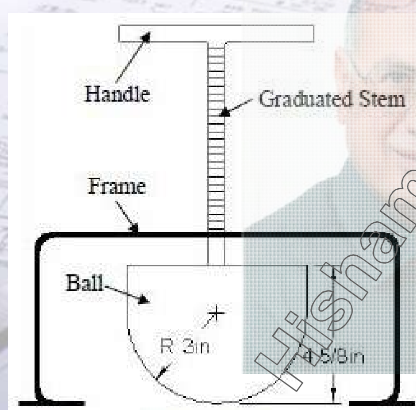
very low workability	0.7 to 0.8
Low workability	0.8 to 0.85
Medium workability	0.85 to 0.95
High workability	>0.95

https://www.quora.com/What-is-the-workability-of-concrete

Comparisons

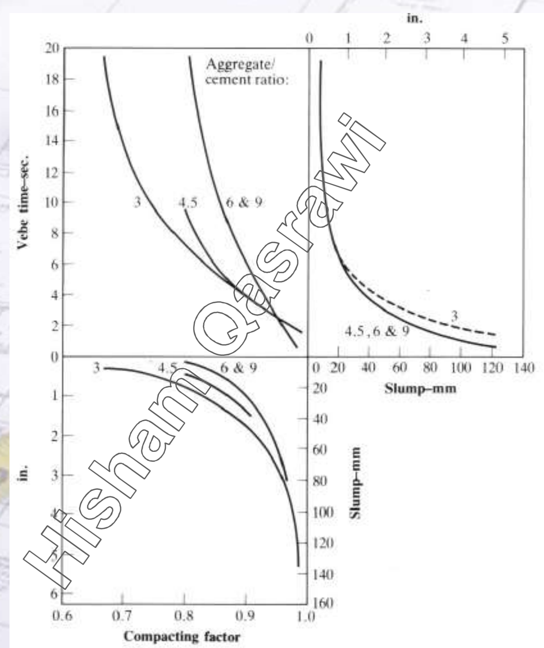
Description of workability	Compacting factor	Corresponding slump mm
Very low	0.78	0–25
Low	0.85	25–50
Medium	0.92	50–100
High	0.95	100–175

Workability
Kelley Ball Test (Ball Penetration Test}



Workability

Relationship between workability tests



Unit Weight (Density)

- Weigh the empty mold
- Fill with concrete
- Compact using a standard suitable method
- Weigh the mold filled with concrete
- Concrete weight = Filled – Empty

$$Unit\ Weight = \frac{Weight\ of\ Concrete}{Volume\ of\ the\ mold}$$

Volume of the mold

- The volume of the mold is calculated in one of two methods:
  - 1. Measure accurately the dimensions of the mold and then obtain the volume.
  - 2. Fill the mold with water, Obtain the volume as

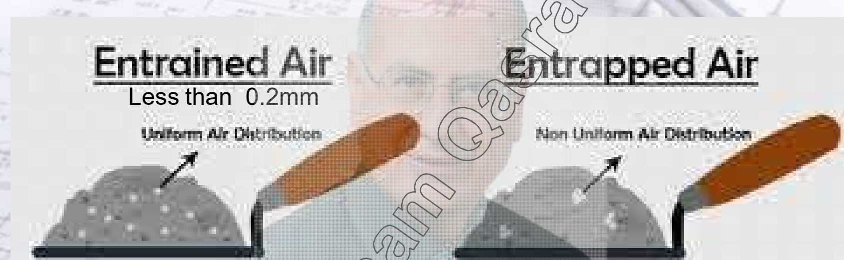
$$\text{V of mold} = \frac{\text{Weight of water filling the mold}}{\gamma_{water}}$$

Type of concrete according to density

	Density (approximately)
Normal Concrete	2200 to 2500 kg/m3
lightweight	Less than 2000 kg/m3
Heaveyweight	Greater than 2700 kg/m3

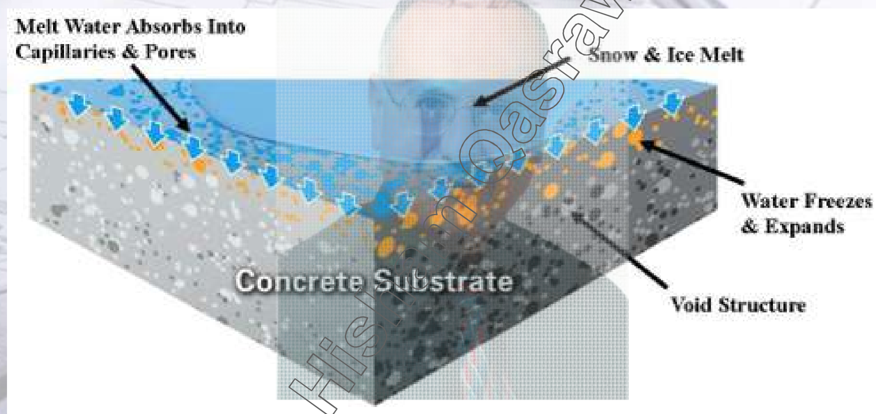
Air Content

1. Entrained air
2. Entrapped air

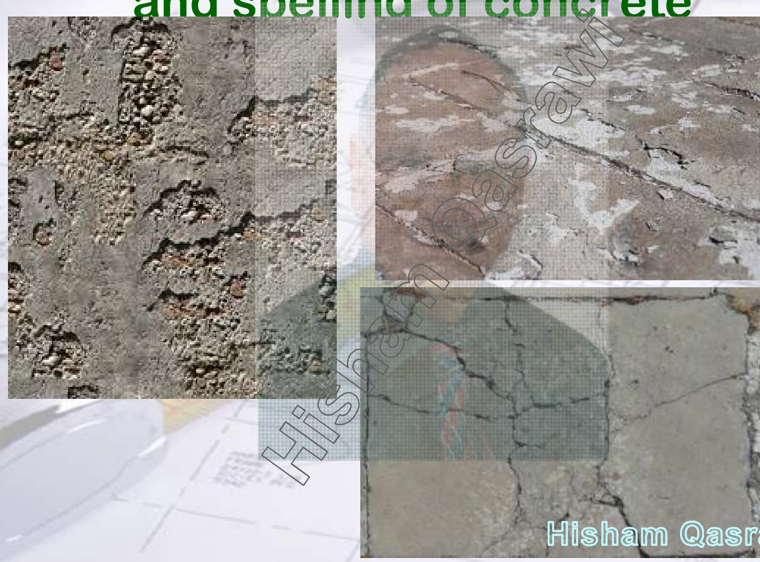


Use air-entraining admixture
Or/ Cement type IA, IIA, ---etc

Frost action (Freeze and thaw)

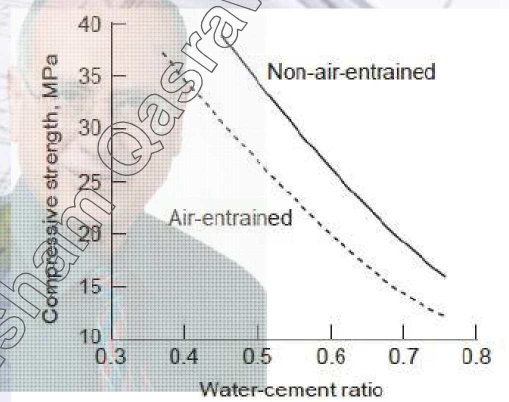


Repeated cycles results in cracking and spelling of concrete



Loss of strength due to air entrainment

- Any air voids reduce the strength of concrete,
  - Generally, 1% increase in the volume of air voids. Reduces strength by 5%



(a)

Air Content

- Pressure Method
- Volumetric Method
- Gravimetric Method

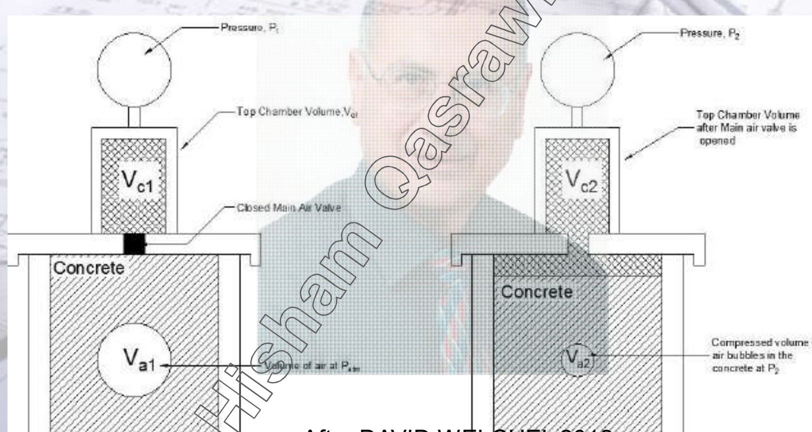
Air Content
Pressure Method: Apparatus

Apply pressure P. Loss on pressure is ΔP

$\Delta V = V_{c1} - V_{c2} = V_{a1} - V_{a2}$

$P_{a1}V_{a1} = P_{a2}V_{a2}$

$Air\ \% = \frac{V_{a1}}{V_b} * 100$



After DAVID WELCHEL 2012

Air Content
Air Compessometer

Air Content
Volumetric Method: Roll-A-Meter

Volumetric method
Roll-A-Meter

Air Content
Gravimetric Method

Use the absolute volume theory

$$Air = 1 - \left[\frac{W_C}{S_C \times \gamma_W} + \frac{W_W}{S_W \times \gamma_W} + \frac{W_{CA}}{S_{CA} \times \gamma_W} + \frac{W_{FA}}{S_{FA} \times \gamma_W} \right]$$

Air-free Density

$$\text{Air free density} = \frac{\text{Density of concrete}}{1 - \text{Air content}}$$

1 - air content

Approximate density of concrete

- The density equals the summation of all the weights of ingredients that produces 1 m3 of concrete.

Grading requirements for coarse aggregate according to J.S. (Jordanian Standards)

Sieve size			Percentage by mass passing sieve — Nominal size of graded aggregate			
mm	SI Eq.	in.	40mm (جوزية) ($1\frac{1}{2}$ in.)	25 mm (فولية) (1 in.)	20 mm (حمصية) ($\frac{3}{4}$ in.)	12 mm (عدسية) ($\frac{1}{2}$ in.)
51	50	2	100	-	-	-
38	40	$1\frac{1}{2}$	80 – 100	100	-	-
25.4	25	1	20 – 50	95 – 100	100	-
19	20	$\frac{3}{4}$	10 – 30	40 – 80	95 – 100	100
12.7	12-14	$\frac{1}{2}$	-	5 – 50	50 – 80	90 – 100
9.5	10	$\frac{3}{8}$	0 – 10	0 – 15	25 – 60	80 – 100
4.75	5	$\frac{3}{16}$	0 – 5	0 – 5	0 – 10	5 – 50
2.36	2.4	#8	0 – 2	0 – 5	0 – 10	0 – 25
0.075	#200	#200	0 – 2	0 – 2	0 – 2	0 – 2

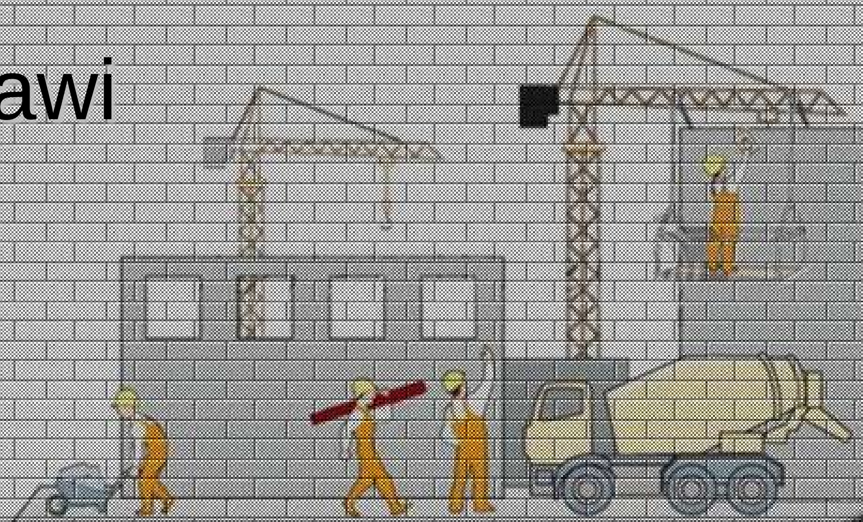
Grading requirements for fine aggregate according to J.S. (Jordanian Standards)

Sieve size		Percentage by mass passing sieve — Nominal size of graded aggregate		
mm	No.	9.5 mm (خشن) ($\frac{3}{8}$ in.)	4.75 mm (متوسط) (No. 4)	1.18 mm (ناعم) (No. 8)
9.5mm	$\frac{3}{8}$ in.	95 – 100	100	-
4.75 mm	4	80 – 100	90 – 100	-
2.36 mm	8	50 – 80	75 – 100	100
1.18 mm	16	20 – 70	55 – 90	90 – 100
600 µm	30	10 – 35	35 – 59	60 – 90
300 µm	50	5 – 15	8 – 30	20 – 60
150 µm	100	0 – 5	0 – 10	0 – 20
75 µm	200	0 – 5	0 – 5	0 – 10

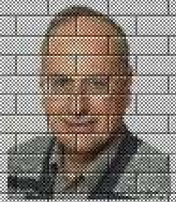
Main Steps of Mix Design Based on ACI 211.1 with Example

Absolute Volume Method

Hisham Qasrawi



Step 1: Choice of slump

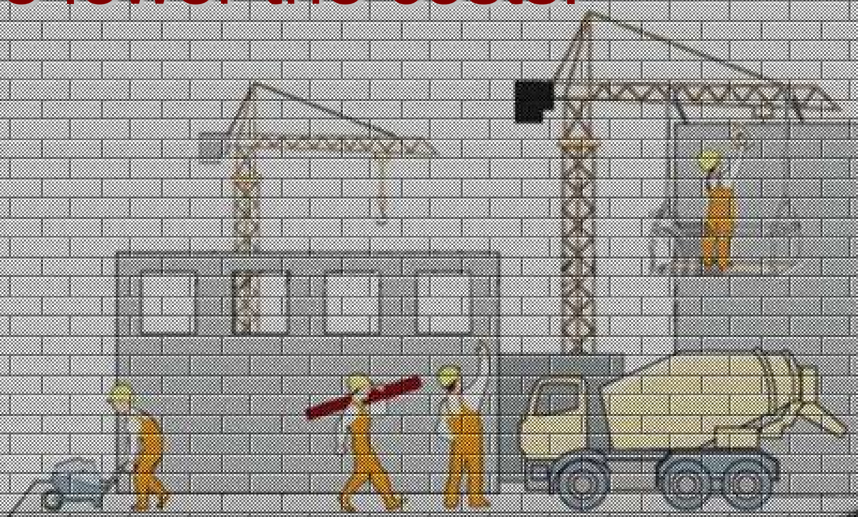


- Generally, the slump depends on the main site conditions and requirements.
  - Usually, the slump is specified in the project requirements.
  - Take care for section sizes. Narrow sections (such as ribs in slabs) require high workability while wide sections (such as foundations) require low workability.
  - Take care for environmental conditions.

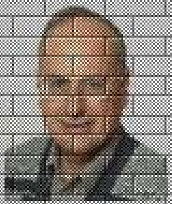
Step 2: Choice of NMSA

- Take care for section sizes. Narrow sections (such as ribs in slabs) require small NMSA while large sections (such as foundations) require high NMSA.

- The higher the NMSA, the lower the costs.



Step 3: Determine the strength of concrete

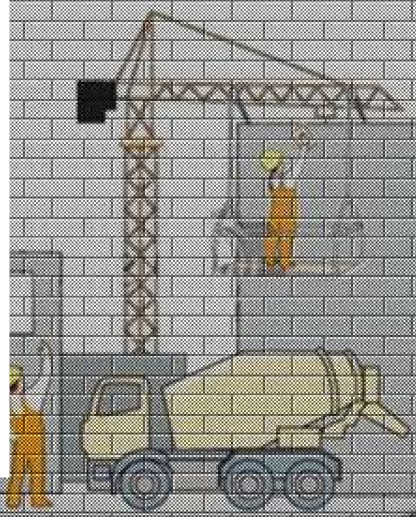


Margin

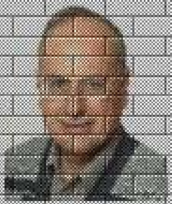
th is the

Table 17.3: **Required increase in strength for specified compressive strength when no tests records are available, according to ACI 318–05**

Specified compressive strength		Required increase in strength	
MPa	psi	MPa	psi
less than 21	less than 3000	7	1000
21 to 35	3000 to 5000	8.5	1200
35 or more	5000 or more	10.0	1400



Example



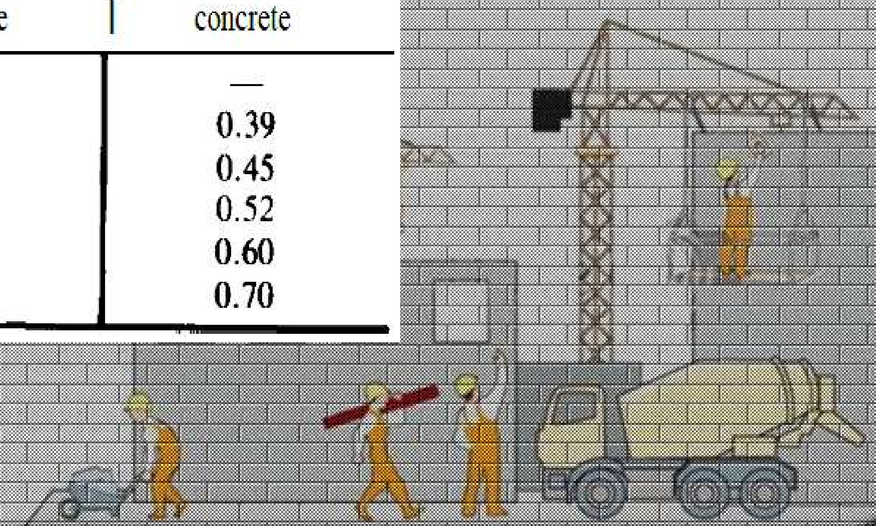
- Assume that a concrete mix will be designed for concrete columns at HU campus. The cylinder strength is 25MPa at 28days and the standard deviation is not known.
- Then the margin is 8.5MPa.
- The design strength is 25+8.5=33.5MPa.

Step 4: Determine the w/c ratio

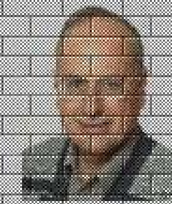
- The w/c ratio is the lowest of
  1. That required for strength (from table)

TABLE A1.5.3.4(a) — RELATIONSHIPS BETWEEN WATER-CEMENT RATIO AND COMPRESSIVE STRENGTH OF CONCRETE (SI)

Compressive strength at 28 days, MPa*	Water-cement ratio, by mass	
	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



Step 4 …..: Determine the w/c ratio if other requirements prevail.



2. That required for durability:

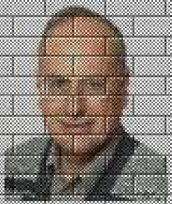
- $W/C \leq 0.5$ for moderate sulfate attack (use SRPC or MSRPC)
- $W/C \leq 0.45$ for severe sulfate attack (use SRPC)
- $W/C \leq 0.5$ to resist severe cold weather. Concrete must be air-entrained.

3. That required for permeability

$W/C \leq 0.5$ for permeability.

N.B: Although ACI allows the use of OPC and reduce w/c by 0.05, long term studies showed that concrete remains less durable

Example



- For strength 28.5 MPa, then the w/c ratio is between 0.54 and 0.47
- Interpolation will give that the w/c ratio is **approximately** 0.50
- Since there are no special durability requirements, the strength will control and the w/c is 0.50.

Step 5: Determine water content
Step 6: Determine the air content

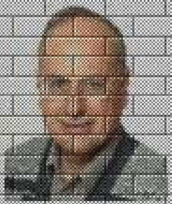


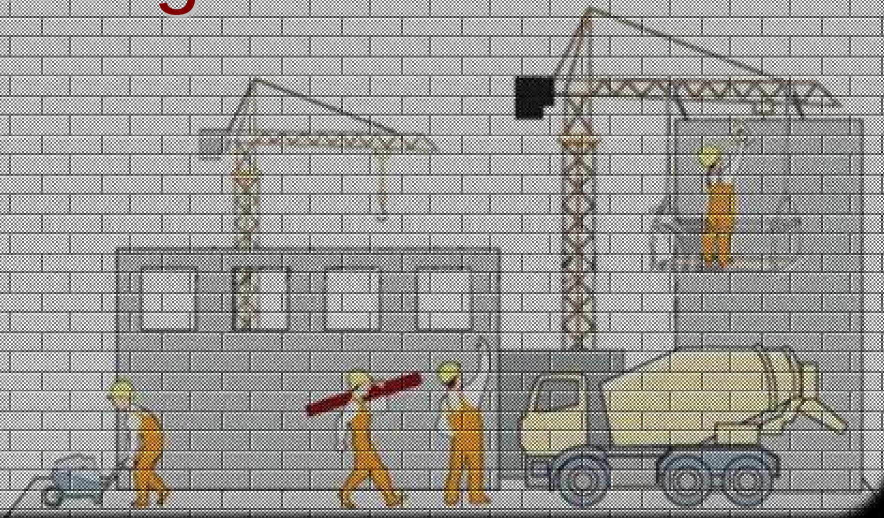
TABLE A1.533 — APPROXIMATE MIXING WATER AND AIR CONTENT REQUIREMENTS FOR DIFFERE SLUMPS AND NOMINAL MAXIMUM SIZES OF AGGREGATES (SI)

Slump, mm	Water, Kg/m³ of concrete for indicated nominal maximum sizes of aggregate							
	10	12	20	25	40	50	75	150
Non-air-entrained concrete								
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-entrained concrete								
25 to 50	181	175	168	160	150	142	122	107
75 to 100	202	193	184	175	165	157	133	119
150 to 175	216	205	197	184	174	166	154	—
Recommended average§total air content, percent for level of exposure:								
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**

Example

- A slump of 100mm will be suitable for the structure.
- NMSA of 20mm will be chosen.

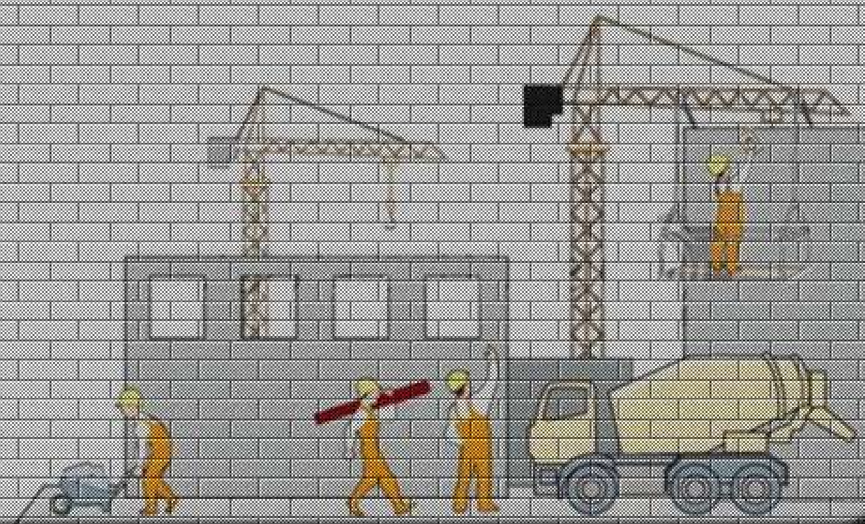
- The water content is 205kg/m^3
- The air content is 2%



Step 7: Cement content

$$\text{weight of cement} = \frac{\text{weight of water}}{w/c}$$

- Example:
- Cement content = 205/0.50=410kg/m^3



Step 8: The coarse aggregate content

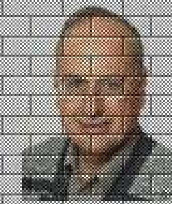
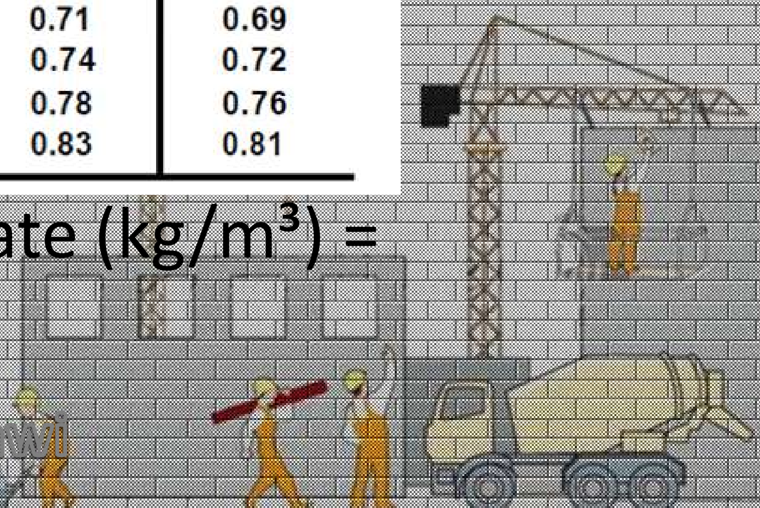


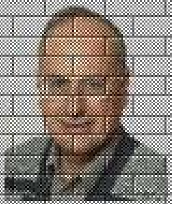
TABLE A1.5.3.6 — VOLUME OF COARSE AGGREGATE PER UNIT OF VOLUME OF CONCRETE (SI)

Nominal maximum size of aggregate, mm	Volume of dry-rodded coarse aggregate* per unit volume of concrete for different fineness moduli† of fine aggregate			
	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
75	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

Amount of coarse dry aggregate (kg/m^3) =
Volume x density= $V \times \rho_{bulk}$



Example



- Assume that the FM of sand is 2.5.
- Then Volume of coarse aggregate = $0.65 m^3$.

- Assume that the dry rodded unit weight is $1400 kg/m^3$
- Then the weight of coarse aggregate is

  $0.65 \times 1400 = 910\ kg/m^3$

Step 9: Fine Aggregate Content

- Apply absolute volume method
- Note that y% air is written as y/100 in the equation. Note that $\rho_W = 1000 kg/m^3$

$$\sum V_{Concrete} = 1 = V_W + V_C + V_{CA} + V_{FA} + V_{AIR}$$

$$V_{FA} = 1 - \left(\frac{M_W}{1 \times 1000} + \frac{M_C}{3.15 \times 1000} + \frac{M_{CA}}{S.G_{CA} \times \rho_W} + AIR\%\right)$$

$$FA = V_{FA} \times S.G_{FA} \times \rho_W$$

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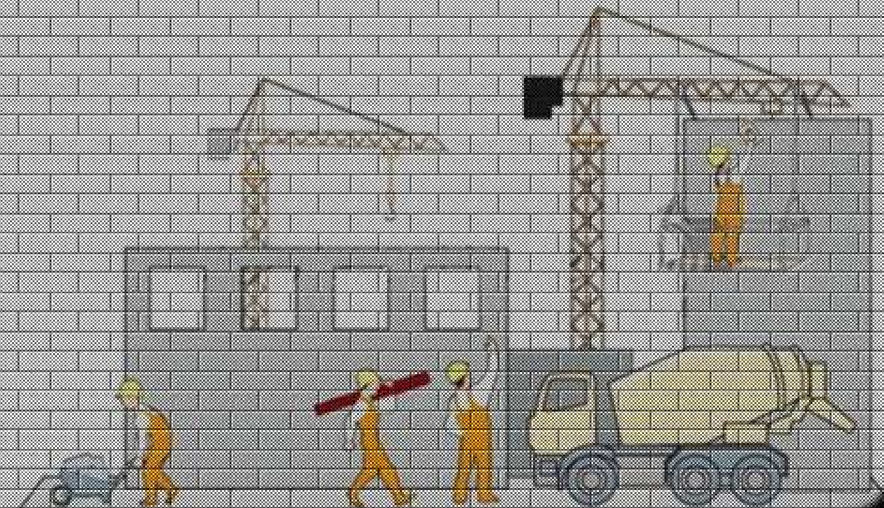
Example

- Assume that the SG of CA is 2.5 and that of FA is 2.8.
- Then

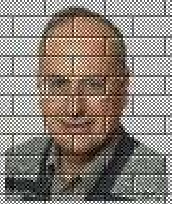
$$\frac{410}{3.15\times1000}+\frac{205}{1\times1000}+\frac{910}{2.5\times1000}+0.02+\frac{W_{FA}}{2.8\times1000}=1$$

- Then

  W_{FA} is 786 kg/m^3.

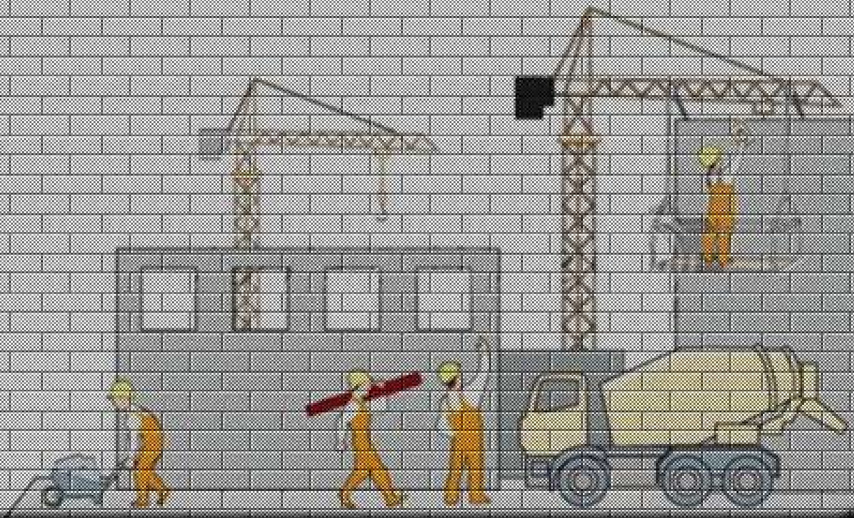


Step 10: Adjustment for absorption

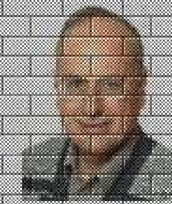


- **Required water= free water+ absorption – moisture**
- **=free Water+(CA×abs$_{CA}$+FA×abs$_{FA}$) - (CA×m$_{CA}$+FA×m$_{FA}$)**

- **Where:**
- **CA: coarse aggregate content**
- **FA: Fine aggregate content**
- **Abs: absorption**
- **m: moisture content**



Example

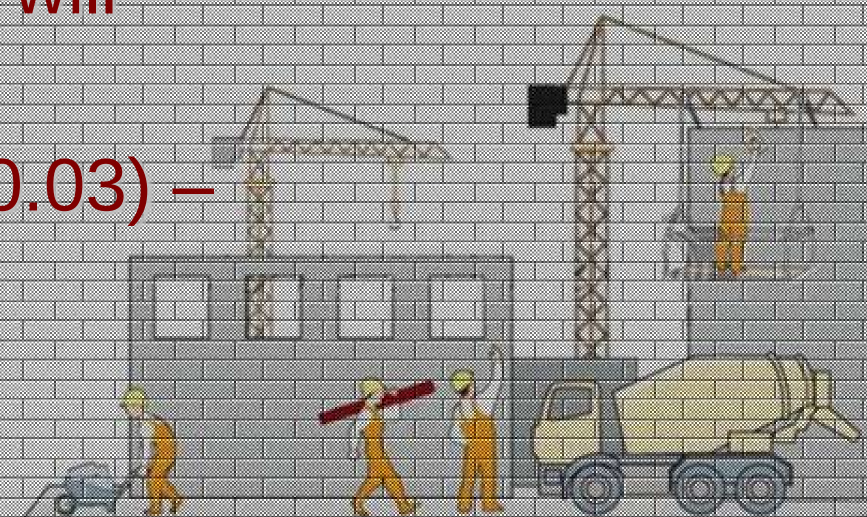


- Assume

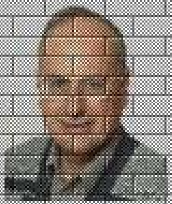
	Absorption	Moisture content
CA	2%	4%
FA	3%	1%

- Then the adjusted water will *approximately* be

205 + (910x0.02 + 786x0.03) – (910x0.04+786x0.01)



Step 11: Adjust for practical values

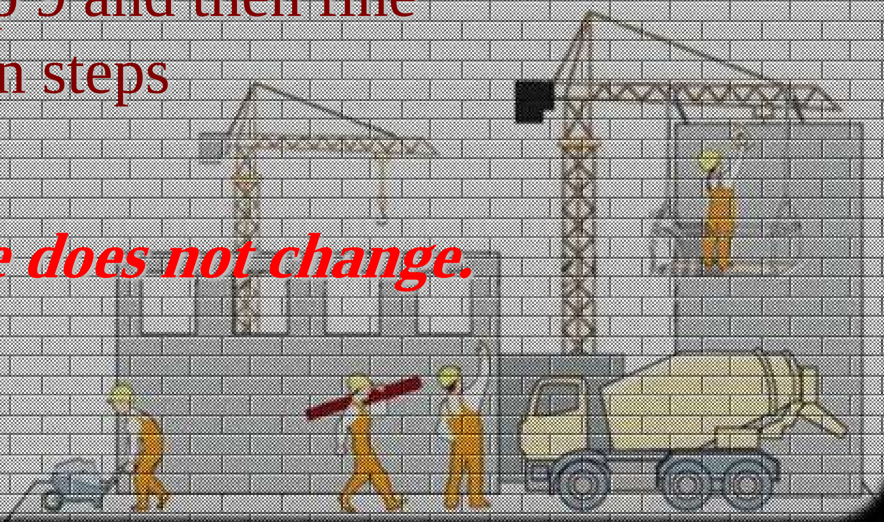


- 1) Add 2 kg of water to increase slump by 1 cm and vice versa
- 2) Add 3 kg of water to reduce air by 1% and vice versa

USE THE HIGHER OF 1 or 2.

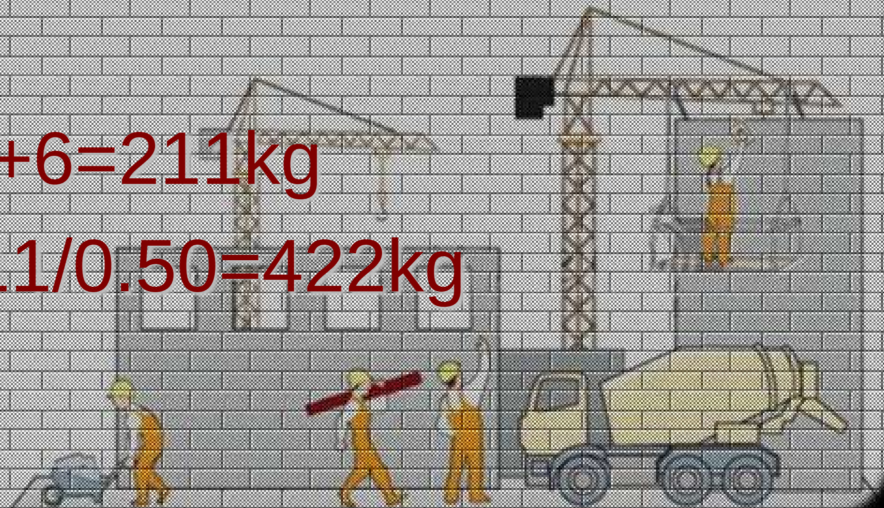
- After adjustment of water you have to recalculate cement content according to step 9 and then fine aggregate content as described in steps

- ***Note that the coarse aggregate does not change.***

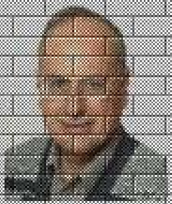


Example

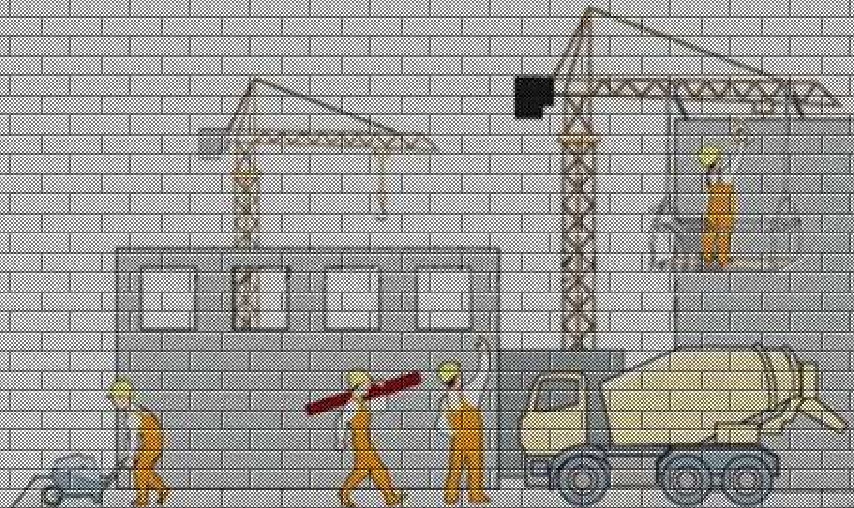
- Assume that slump is 70mm and air content is 3.5%.
- Then
  - For slump, add (10-7)x2 = 6kg
  - For air, add (3.5-2)x3 = 4.5 kg
  - Choose 6 kg.
  - New water will be 205+6=211kg
  - New cement will be 211/0.50=422kg



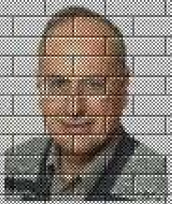
Example



- Also
  - The coarse aggregate will not change (910kg)
  - The fine aggregate will be calculated using the absolute volume method.
    - $\Sigma V = 1\ m^3$



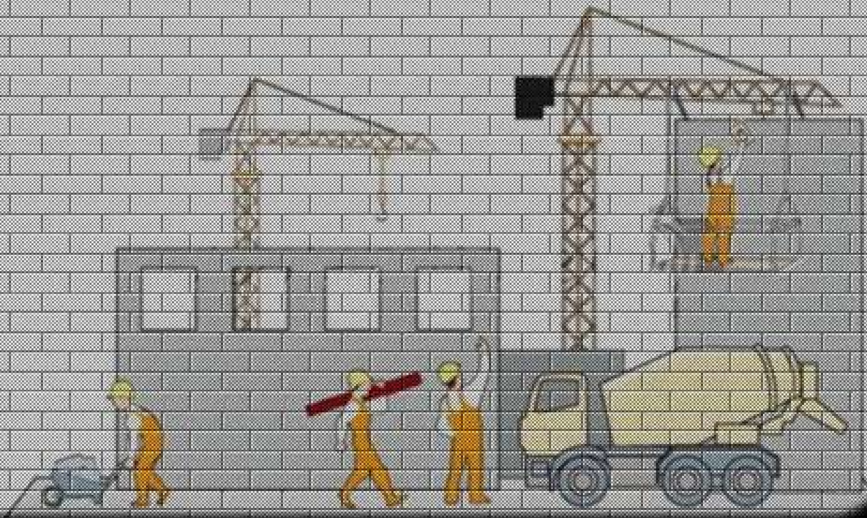
Approximate density of concrete using the amounts per cubic meter of concrete



- Approximate density of the trial mix can be calculated using the relationship

  - Approximate Density =

    $W_w + W_c + W_{coarse} + W_{fine} + W_{\text{any other ingredient}}$



Maturity of Concrete

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Maturity of Concrete

- Reference

- Textbook: Chapter 10

MATURITY OF CONCRETE

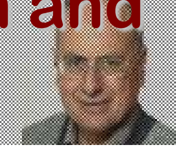
- The maturity method is a technique for approximately predicting concrete strength based on the temperature history of the placed concrete
- Strength increases as cement hydrates.
- Higher curing temperatures accelerates hydration and results in higher strength at early ages.
- Maturity is a measure of how far hydration has progressed.
- Maturity is a time-age relationship
- Important to determine when to strike formwork

- **The simplest common expression for maturity is**

$$M(t) = \sum (T_a - T_0)\Delta t$$

- where:
  - T_a = average concrete temperature during each time interval
  - T_0 = temperature below which cement hydration is ceases (stops): mostly taken (-11 C°) DATUM.
  - Δt = time intervals, days or hours
  - Σ = summation of all the intervals of time multiplied by temperature.

The simple relation between compressive strength and maturity



Strength = A+B log M

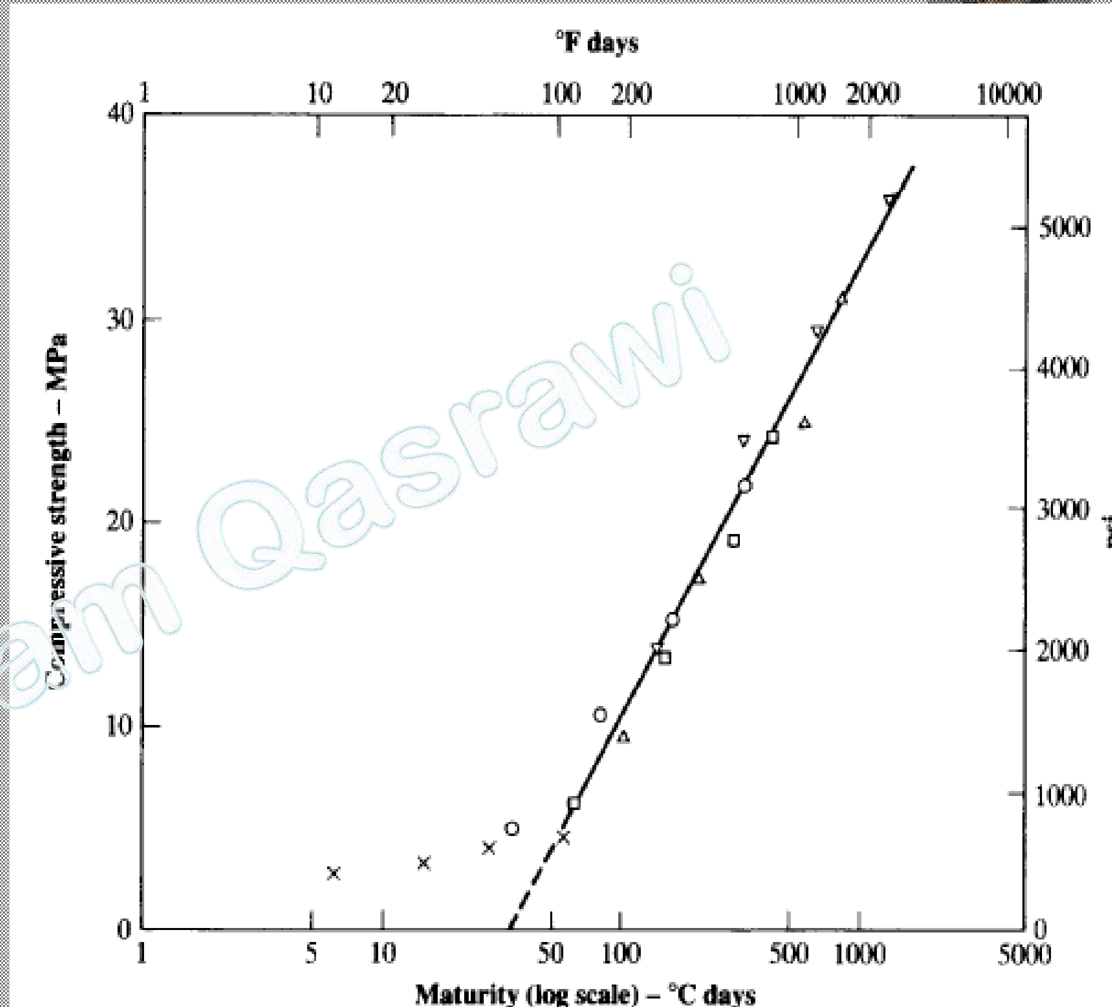
Where:

A: y-intercept,

B: slope,

M: maturity

A and B are constants that value vary according to concrete



Example1:

- A. Assume that the relationship between strength and maturity of concrete is
  $f'_c = -33+21 \log M$

- B. If the concrete is cured at 27°C, calculate the age when strength reaches 17MPa.

- Calculate the standard strength.

- Assume the cement hydration will cease at - -11°C.

Solution:

A. $f'_c = -33+21 \log M$

$17=-33+21 \log_{10} M$

$M=240.4$ °C.days

$M=\sum(Ta-Datum)\Delta t$

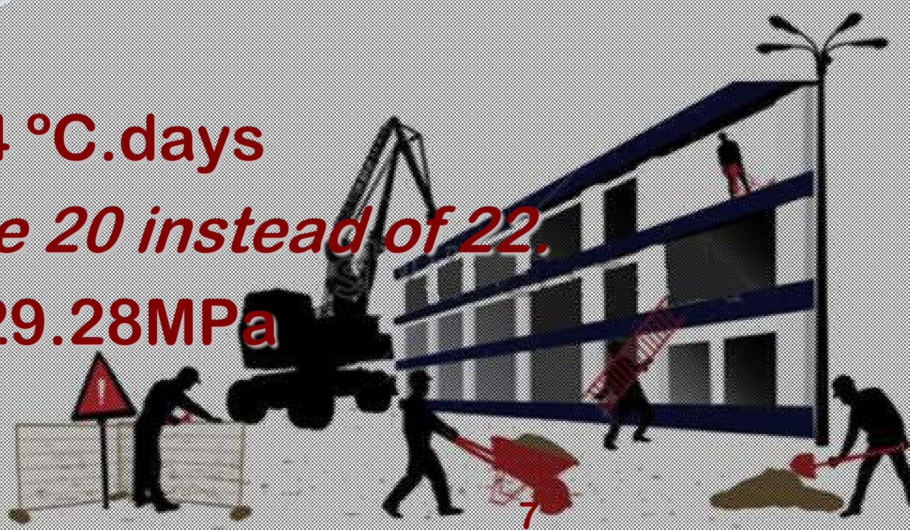
$240.4=(27-(-11))\times\Delta t$

$\Delta t=6.32$ days

B. $M=(22+11)\times(28)= 924$ °C.days

It is acceptable to use 20 instead of 22.

$f'_c = -33+21 \log 924= 29.28$MPa



Example2:

1-Calculate the strength when the concrete is cured at 30°C for 7 days.

2-What temperature is required to reach a strength of 30MPa at 28 days?

$f'_c = -33 + 21 \log M$

Solution:

1-Strength

- $f'_c = -33 + 21 \log_{10} M$
- M=7(30+11) =287 C° days
- $f'_c = -33 + 21 \log_{10} 287 = 18.6$ MPa

2- Temperature

- $f'_c = -33 + 21 \log_{10} M$
- $30 = -33 + 21 \log_{10} M$
- M=1000 C° days
- M=28(Ta+11) =1000 C° days
- Ta=24.7 C° ~25 C°

When to strike formwork?

- In addition to maturity, depends on type of structural element (column, footing, slabs and beams, walls,....etc)
- Unless special recommendations are required, ordinary formwork can be stripped when the following are satisfied:
  - The strength is at least n% of the standard strength.
  - The shrinkage is at least m% of the final shrinkage.

Curing condition	Type of cement	Minimum period of curing and protection (days) for average surface temperature of concrete:	
		between 5 and 10 °C (41 and 50 °F)	any temperature, t* between 10 and 25 °C (50 and 77 °F)
Good: damp and protected (relative humidity > 80 per cent, protected from sun and wind)	All types	No special requirements	
Average: between good and poor	Portland, class 42.5 or 52.5 and Sulfate-resisting Portland, class 42.5	4	$60/(t + 10)$
	All types except those above	6	$80/(t + 10)$
Poor: dry or unprotected (relative humidity < 50 per cent, not protected from sun and wind)	Portland, class 42.5 or 52.5 and Sulfate-resisting Portland, class 42.5	6	$80/(t + 10)$
	All types except those above	10	$140/(t + 10)$

* t = temperature (°C) in the formula to calculate the minimum period of protection in days

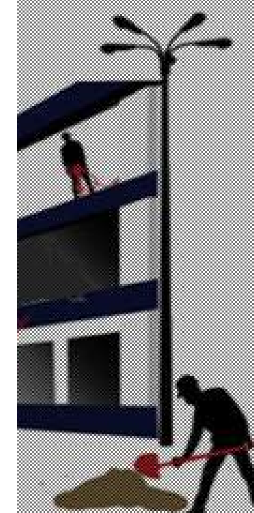


TABLE A1.533 — APPROXIMATE MIXING WATER AND AIR CONTENT REQUIREMENTS FOR DIFFERENT SLUMPS AND NOMINAL MAXIMUM SIZES OF AGGREGATES (SI)

	Water, Kg/m³ of concrete for indicated nominal maximum sizes of aggregate							
Slump, mm	10	12	20	25	40	50	75	150
Non-air-entrained concrete								
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-entrained concrete								
25 to 50	181	175	168	160	150	142	122	107
75 to 100	202	193	184	175	165	157	133	119
150 to 175	216	205	197	184	174	166	154	—
Recommended average§total air content, percent for level of exposure:								
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**††

Table 17.3: **Required increase in strength for specified compressive strength when no tests records are available, according to ACI 318–05**

Specified compressive strength		Required increase in strength	
MPa	psi	MPa	psi
less than 21	less than 3000	7	1000
21 to 35	3000 to 5000	8.5	1200
35 or more	5000 or more	10.0	1400

$F_{MD} = F_{STRUC} + 1.34\ s$ MPa

$F_{MD} = F_{STRUC} + 2.33\ s - 3.5$ MPa

TABLE A1.5.3.4(a) — RELATIONSHIPS BETWEEN WATER-CEMENT RATIO AND COMPRESSIVE STRENGTH OF CONCRETE (SI)

Compressive strength at 28 days, MPa*	Water-cement ratio, by mass: 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 A1.5.3.6 — VOLUME OF COARSE AGGREGATE PER UNIT OF VOLUME OF CONCRETE (SI)

Nominal maximum size of aggregate, mm	Volume of dry-rodded coarse aggregate* per unit volume of concrete for different fineness moduli† of fine aggregate: 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
75	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

NON-DESTRUCTIVE TESTS

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Definition

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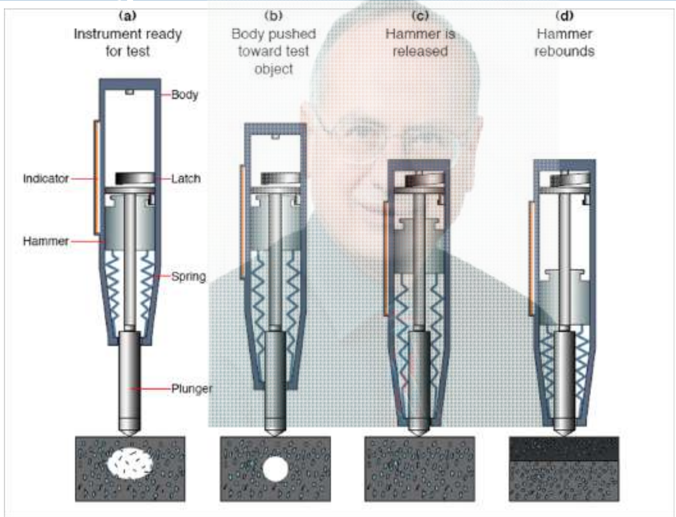
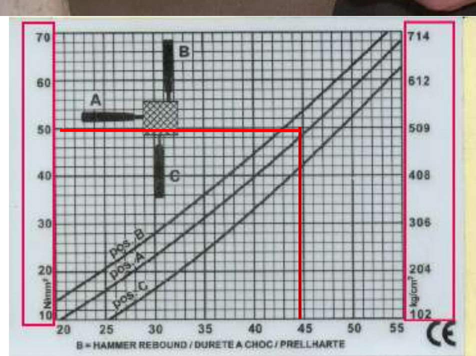
- Nondestructive tests are those tests that are used to measure a property of concrete without destroying it.
- They should not affect the structural behavior and must keep the structure in acceptable to the client
- The most important property is the strength of concrete.

- *Refer to text book pp 311-320*

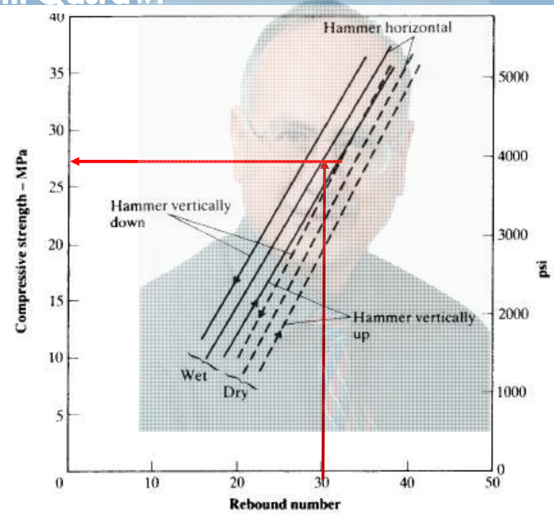
Rebound Hammer (Shcmidt Hammier)

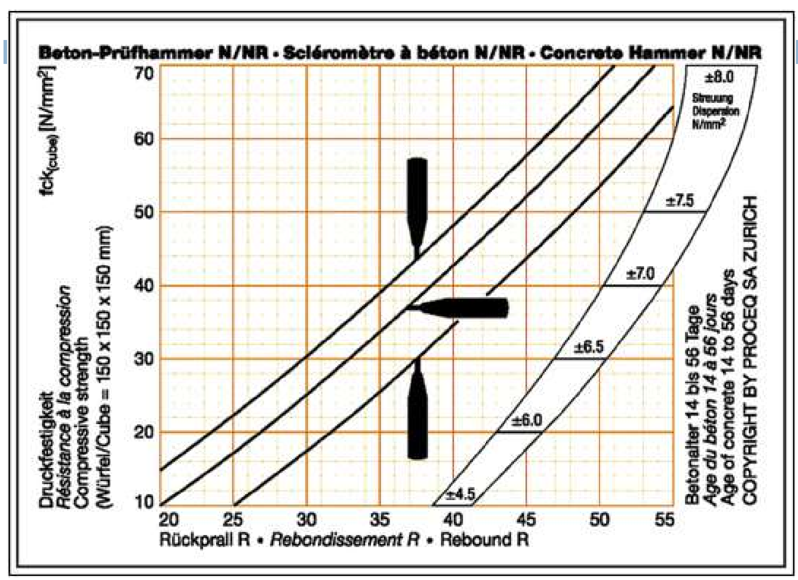


Rebound Hammer



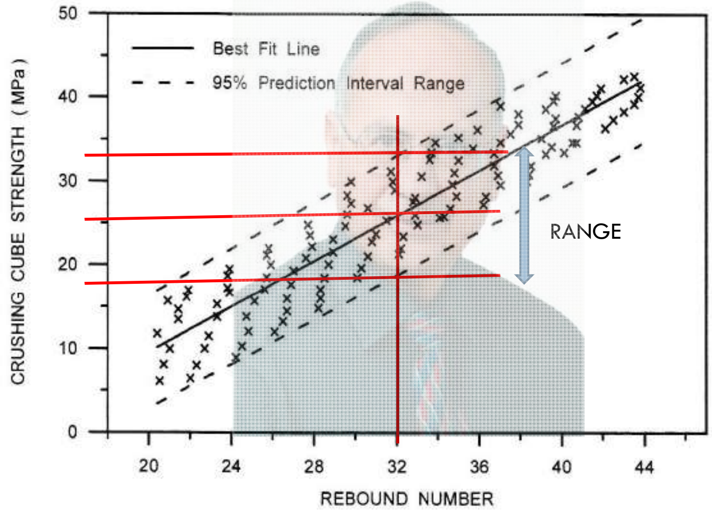
Rebound Hammer





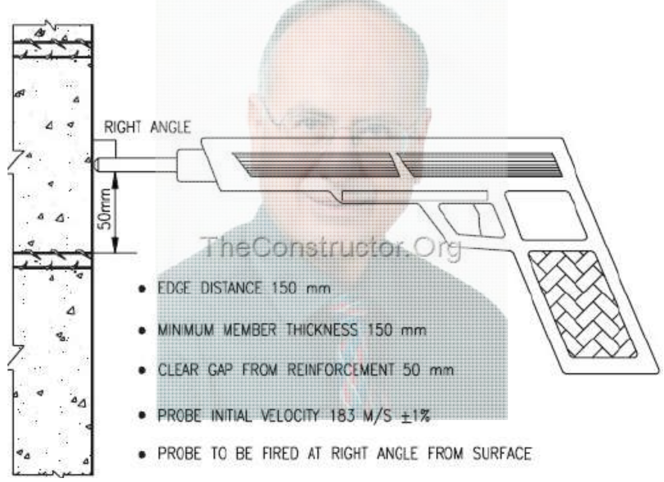
Better approximitation

II.Y. Qasrawi, Cement and Concrete Research, 30 (2000) pp 739- 716



Windsor Probe

Penetration Resistance



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Windsor Probe

Penetration Resistance

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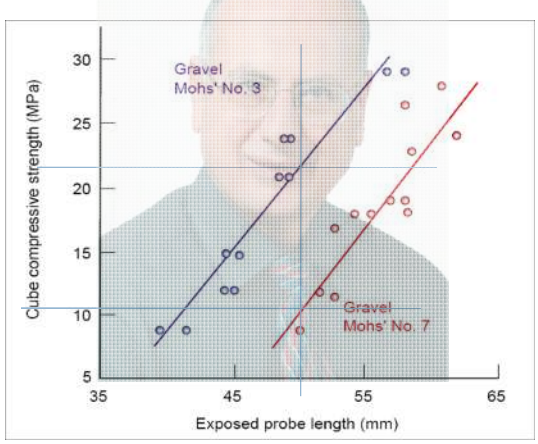
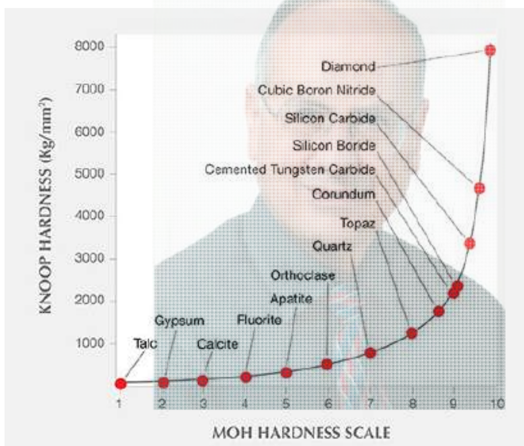
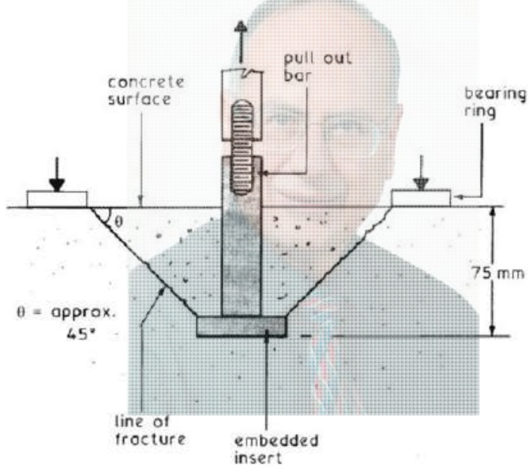


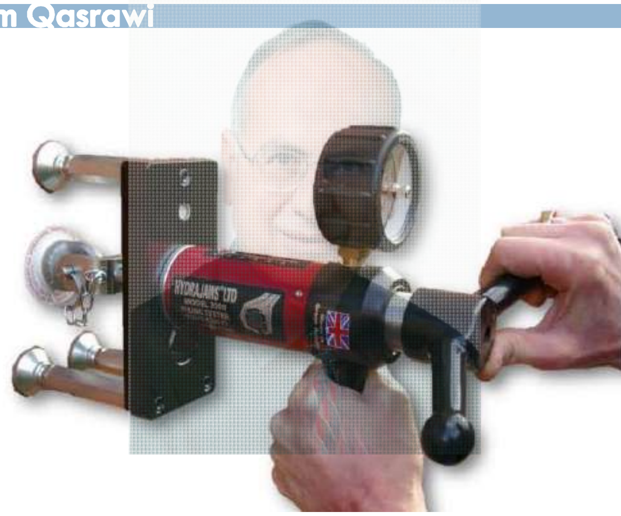
Hardness of materials

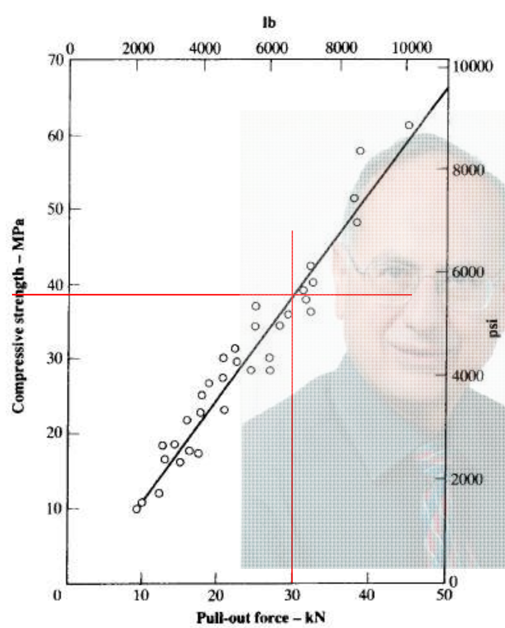


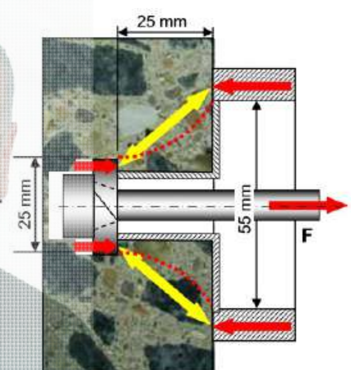
Pull-out Test



Pull-out Test



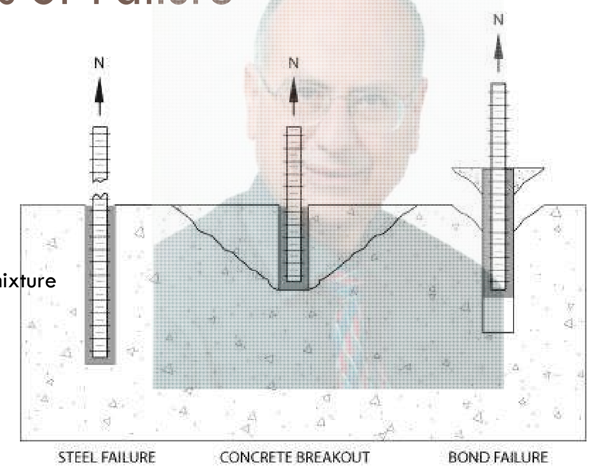




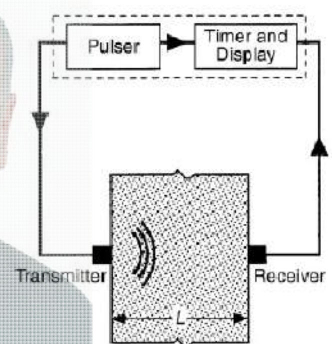
Steel Pull-off Test

Types of Failure

Bonding admixture

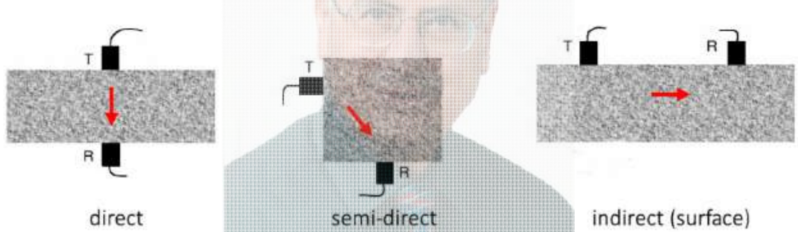


Ultrasonic Pulse Velocity Test

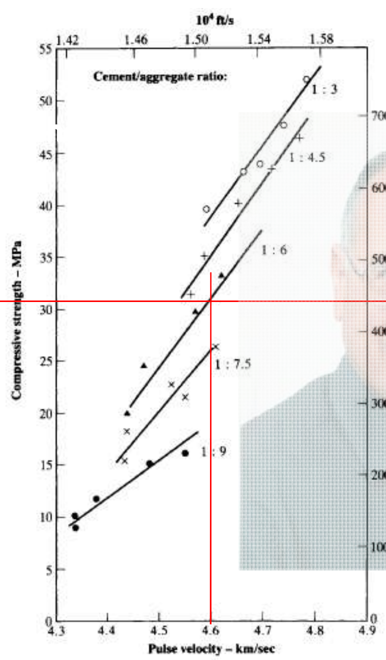


Pluses are transferred through concrete.
The higher the velocity, the denser the material and the higher the strength.

Direction of measurement



Velocity = distance/time (V=L/T)



Example
v = 4.6

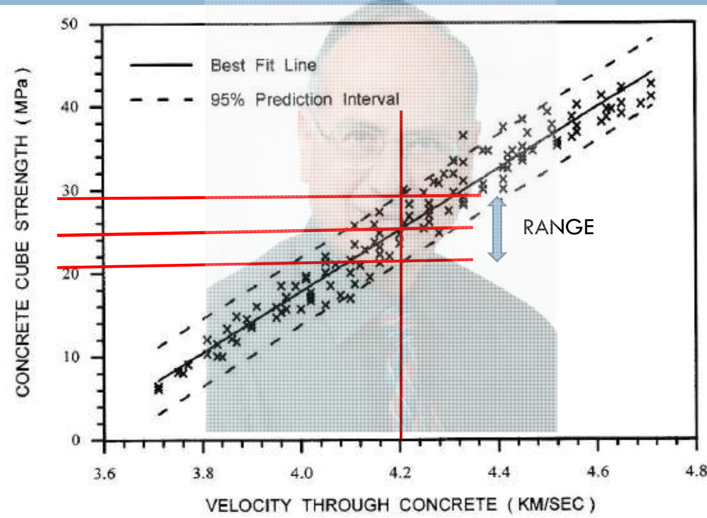
Calculate cement/aggregate ratio as follows:

Example: Mix proportions per cubic meter of concrete are:
Water 180 kg
Cement 300 kg
Coarse aggregate 1000 kg
Fine aggregate 800 kg

cement/aggregate ratio is 300 /(1000+800) = 1/6

Better approximitation

II.Y. Qasrawi, Cement and Concrete Research, 30 (2000) pp 739- 716



Depth of Crack

Depth of crack = d, diagonal = L

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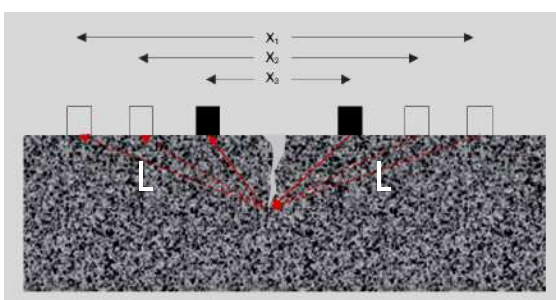

To simplify calculations, the crack is in the middle of the distances x.
If the depth extends to the end of the concrete, no measurement will be recorded.

Determine crack depth (d)

T = tansmitter

R = receiver

x_1, x_2 are measured

$L_1 = \sqrt{d^2+(\frac{x_1}{2})^2}$, $L_2 = \sqrt{d^2+(\frac{x_2}{2})^2}$

Assume that T_1 = Time measured in readings 1 $(x = x_1)$

" " T_2 = " " " " 2 $(x = x_2)$

$V = \frac{\text{Length}}{\text{time}}$

Then $V_1 = \frac{2L_1}{T_1} = \frac{2\sqrt{d^2+(\frac{x_1}{2})^2}}{T_1}$

and $V_2 = \frac{2L_2}{T_2} = \frac{2\sqrt{d^2+(\frac{x_2}{2})^2}}{T_2}$

As concrete is the same in the two measurements, then $V_1 = V_2$

Get d.

Calculations

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$$V = \frac{2L}{T} = \frac{2\sqrt{d^2+(\frac{x}{2})^2}}{T}$$

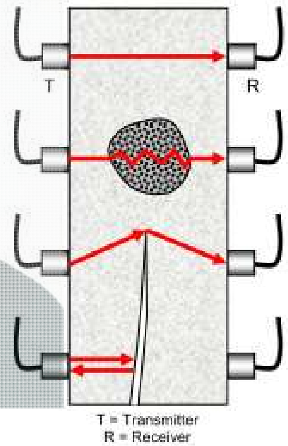
- T in microseconds.
- d is the depth of crack.
- L is the diagonal distance travelled by the waves.
- V is the same in the two measurements.
- You have two equations:

  x = x1 then x = x2 or x3

  Get d.

Check internal voids or cracks.

- Velocity is highest when it passes through solid concrete.
- Internal honeycombing (تعشيش) can be located and repaired.
- If the crack is wide, there will be no measurements.



Questions for Discussion (USPV)

- How are the results of the USPV measurements are affected in each of the following cases:
- 1. Presence of steel bars in the path of waves ?
- 2. Difference in results when the same concrete is measured dry and saturated surface dry ?
- 3. The use of basalt aggregate instead of limestone in the same concrete ?
- 4. Presence of honeycombed areas in the path of waves ?

Cover Meter
Pachometer
R-meter

- MAGNATIC
- Locates the position of steel bars.
- Measures spacing.
- Measures the cover to steel bars.
- Get approximate value for the diameter.

Production of Concrete

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1

Definition of Workability

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- Workability is the easiness to produce concrete.
- Concrete must be workable during all the steps of production.

- *Refer to textbook: Chapter 7*

2

Production Steps

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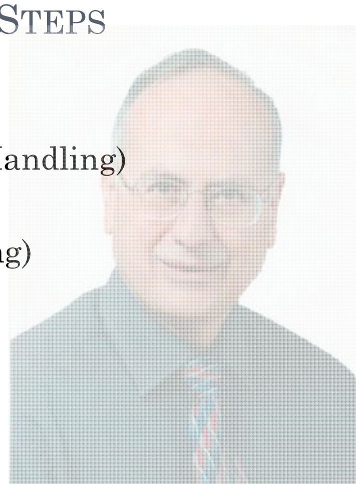

- Batching
- Mixing
- Dispatching (Handling)
- Transporting
- Pouring (casting)
- Compacting
- Finishing
- Curing

3

Concrete Production Batching

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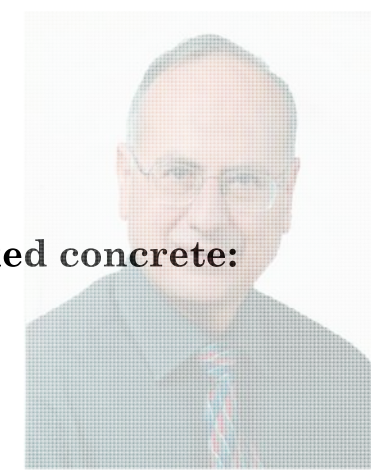
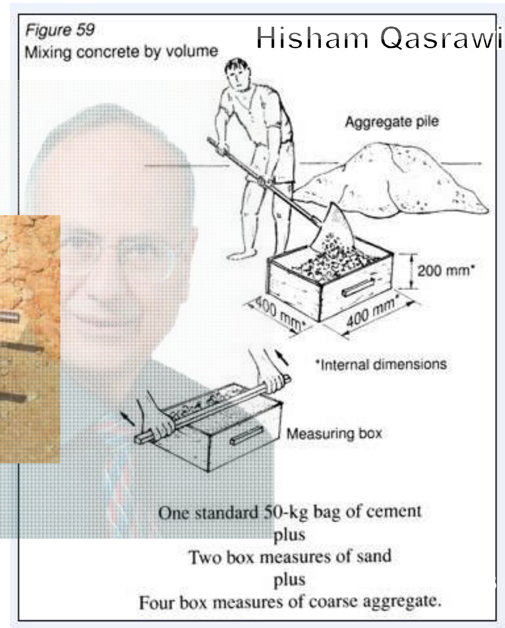


- **At site:**
  - **Weight**
  - **Volume**
- **Ready-mixed concrete:**
  - **Weight**

4

VOLUME BATCHING



LIMITS

- Generally, volume batching should not be allowed in structural concrete, i.e. strength above 25MPa according to Jordanian code for reinforced concrete.
- In Jordan, you can use it only for nonstructural concrete of strength below 20MPa.

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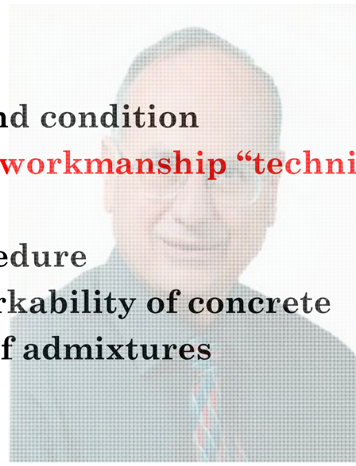
Concrete Production
Mixing



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- Mixer type and condition
- Experienced workmanship “technician”
- Correct time
- Correct procedure
- Type and workability of concrete
- Correct use of admixtures

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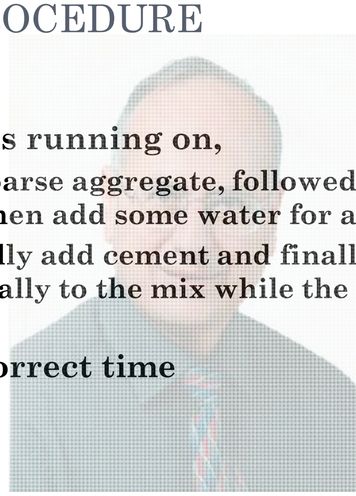
Concrete Production
Mixing: Procedure



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- While mixer is running on,
  - start with coarse aggregate, followed by fine aggregate, then add some water for absorption.
  - then gradually add cement and finally add water gradually to the mix while the mixer is rotating .
- Mix for the correct time

8

Mixing Time

- Standard ideal mixing (ideal for labs and experiments):

  Mix for 3 minutes, stop the mixer and rest for 3 minuets. Start the mixer and continue for 2 minutes.
- In sites, mix until the mix is homogeneous and uniform.

9

Mixing Time
Minimum mixing time

Capacity of mixer		Mixing time, min
m^3	yd^3	
0.8	up to 1	1
1.5	2	$1\frac{1}{4}$
2.3	3	$1\frac{1}{2}$
3.1	4	$1\frac{3}{4}$
3.8	5	2
4.6	6	$2\frac{1}{4}$
7.6	10	$3\frac{1}{4}$

ACI 304R–00 and ASTM C 94–05.

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UNIFORMITY (HOMOGENEITY) OF MIXING

(a) density of concrete: 16 kg/m^3 (1 lb/ft^3)
(b) air content: 1 per cent
(c) Slump: 10mm for low workability, 20mm for medium workability and 30mm for high workability
(d) percentage of aggregate retained on 4.75 mm ($\frac{3}{16}$ in.) sieve: 6 per cent
(e) density of air-free mortar: 1.6 per cent
(f) compressive strength (average 7-day value of 3 cylinders): 7.5 per cent.

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HAND MIXING

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HAND MIXING

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CONCRETE PRODUCTION MIXING: CONVENTIONAL SITE MIXER

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CONCRETE MIXER WITH WEIGHT BATCHER

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CONCRETE PRODUCTION MIXING: CONVENTIONAL SITE MIXER

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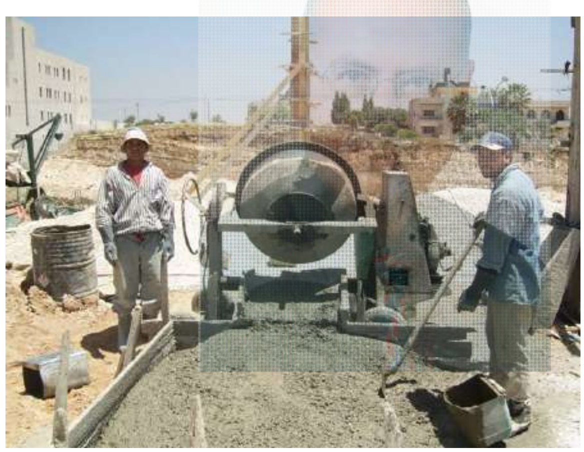

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Concrete Production Mixing: Truck Mixer

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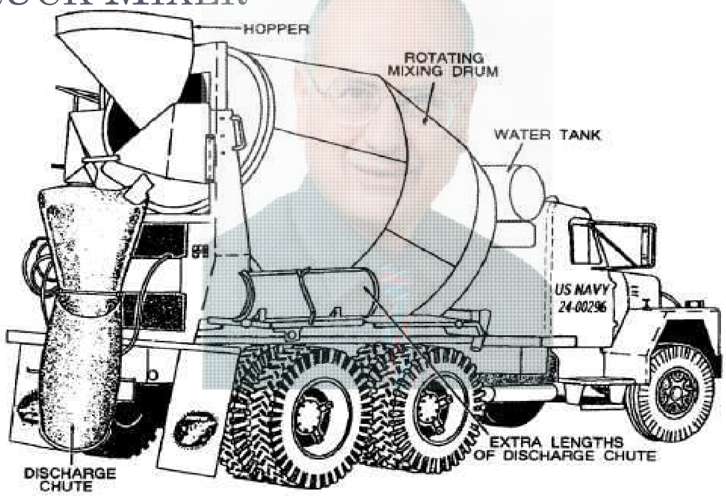

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Dispatching

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- Ensure there is no segregation or bleeding.
- Concrete must not be allowed to drop freely more than 1.20m according to ACI or 1.50 m according to Jordanian.

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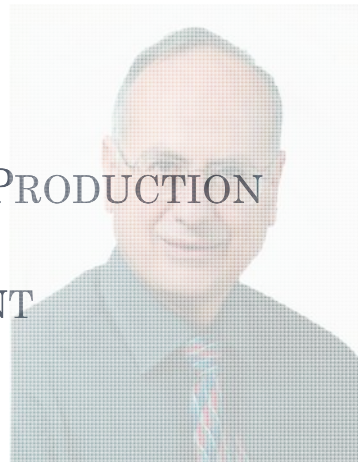

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Concrete Production Mixing: Batch plant

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Batch Plant

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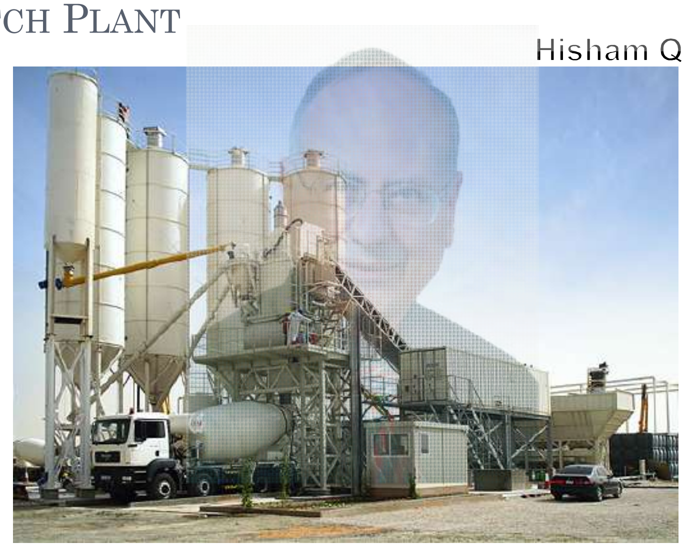

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Concrete Production Transporting

- **The good method**
  - **No segregation or bleeding**
  - **As quick as possible**
- **Use conveyor belts**
- **Pumping**

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Transporting by Hand

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Concrete Production Transporting by Hand

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Buggies

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Chute

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Belt Conveyor

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Type of concrete

- Roller-compacted Concrete

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Concrete Production Pouring

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- **Make sure**
  - **No segregation**
  - **No bleeding**
  - **Layers thickness should be sufficient for compaction**
  - **No cold joints during casting**

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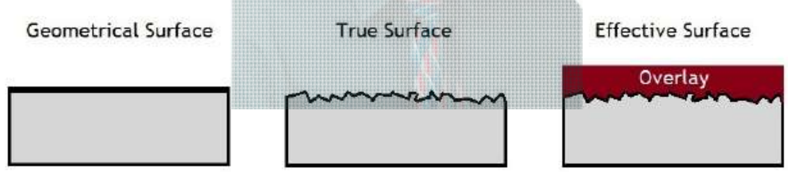
Construction Joint when casting is stopped for a long time

- BEFORE CASTING NEXT LAYER

- Rough surface before setting time occurs
- Bonding admixture on old concrete before casting the new concrete



Example:
in walls and foundations

Concrete Production
Pouring by Hand

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Example
Ready-mixed concrete pouring

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Example: Ready-mixed concrete pouring by Pump

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EXAMPLE: READY-MIXED CONCRETE POURING BY PUMP

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CONCRETE PRODUCTION EXAMPLES

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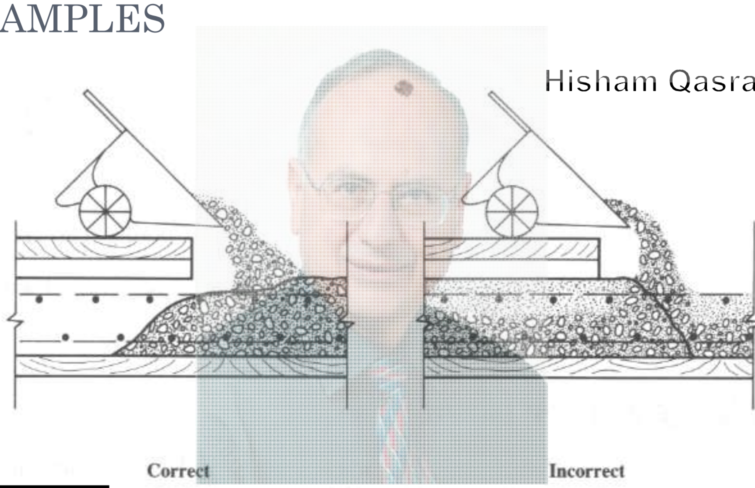
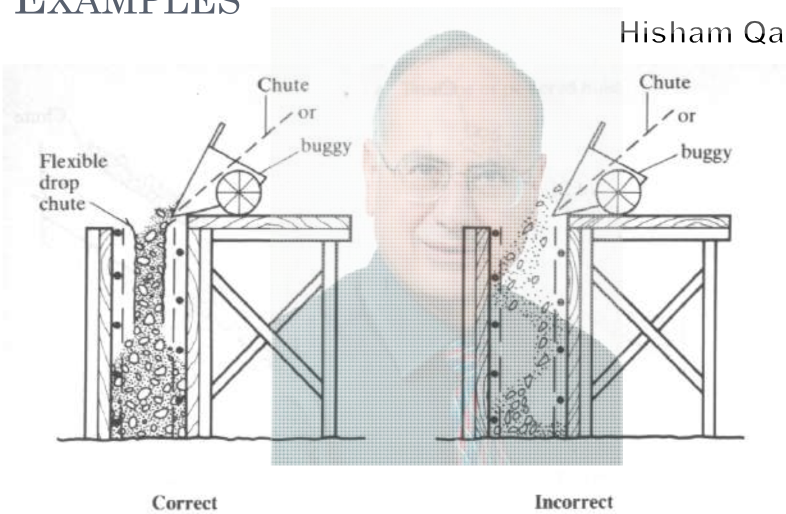


[redacted] Placing concrete from buggies
(Based on *ACI Manual of Concrete Practice*.)

Concrete Production Examples



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Concrete Production Examples

[redacted] Placing concrete in a deep wall
(Based on *ACI Manual of Concrete Practice.*)

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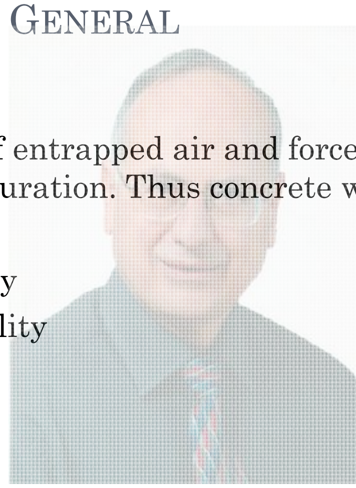
CONCRETE PRODUCTION
COMPACTION: GENERAL



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Used to get rid of entrapped air and force the particles into closer configuration. Thus concrete will have

1- High strength

2- High durability

3- Low permeability

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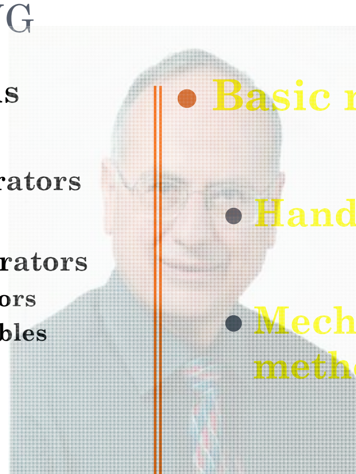
CONCRETE PRODUCTION
COMPACTING



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- Basic methods
  - Internal vibrators
  - External vibrators
    - Form vibrators
    - Vibrating tables

- Basic methods
  - Hand methods
  - Mechanical methods

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Hand compaction

Tampers

Examples for Internal compactors: Poker Vibrator

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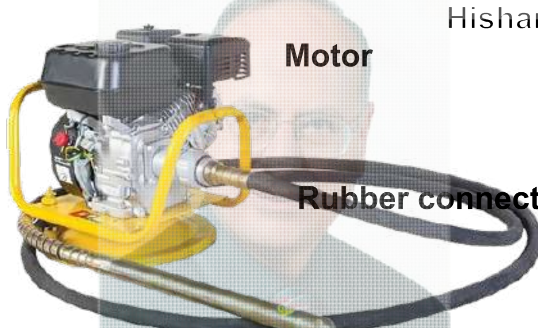
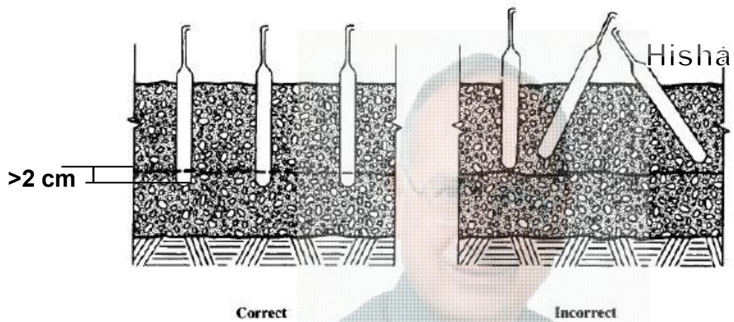
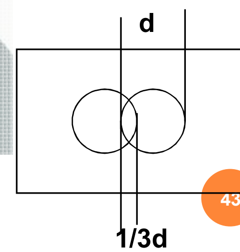




Ensure that compacting time is correct.
Watch air bubbles going out.
Stop once air bubbles stops and water starts to raise up.
Start the new position.
Compaction more than required leads to bleeding and segregation.



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Form vibrators

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Vibrating tables

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Special Types of Concrete Based on Compaction

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- Roller compacted concrete
  - Concrete of very low workability. It is constructed and compacted using pavement construction equipment (

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Special Types of Concrete Based on Compaction

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- Self-compacting concrete
  - Concrete of very high fluidity (mobility) and compactability.
  - Contains very high quality superplasicizers in addition to viscosity modifying admixtures.

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READY-MIXED CONCRETE

DISCUSSION

- What are the advantages of ready-mixed concrete?

Concrete Production
Finishing

- The surface should be as required
- Rough surface if concrete is to be used for further construction.
- If smooth surface where required, do not use dry cement.

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Examples
Hand finish

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Examples
Perfect finish

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TROWEL MACHINE

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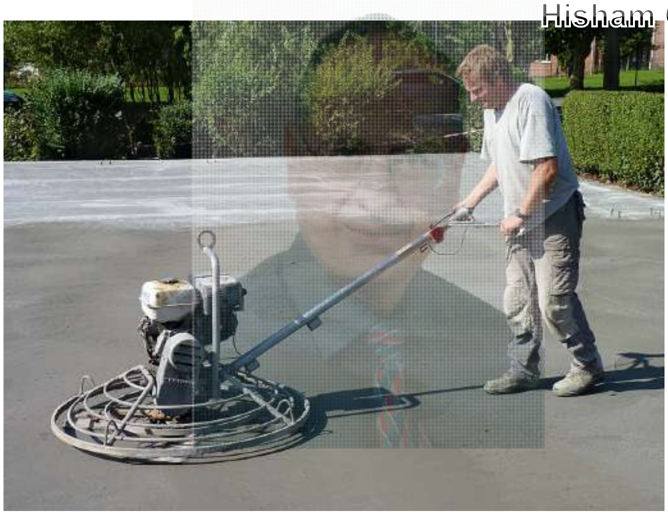

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Brush Finish

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Exposed Aggregate Surface

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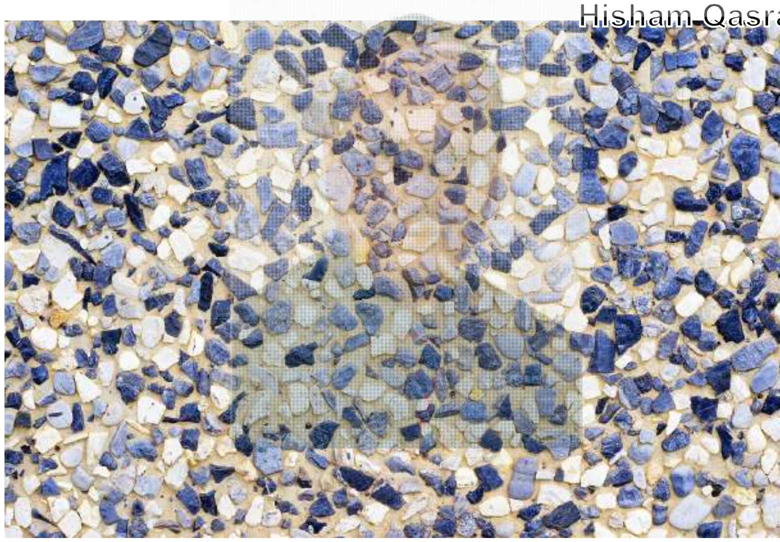

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USING DRY CEMENT LEADS TO CRACKING: *CRAZING*

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PHOTO BY HASHEM MUSTAFA

Strength of Concrete

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General Factors Affecting Measured Compressive Strength

1. ***Rate of loading:** High rates increases strength.*
2. ***Specimen Shape** and size. σ_{cube}=(1.15-1.25) $\sigma_{cylinder}$*
3. ***Water cement ratio** If* w/c ↑ → *then* strength ↓
4. ***Temperature at Testing.** Higher Temperature → lower strength*
5. ***Air content***
6. ***Cement:** Type, chemical composition, temperature of curing, …….as described in Chapter 1.*
7. ***Age of concrete***
9. ***Curing***
8. ***Production of concrete:** Seggregation and bleeding lowers the strength……as described in Chapter 2.*
9. ***Condition at test:** SSD or dry?*

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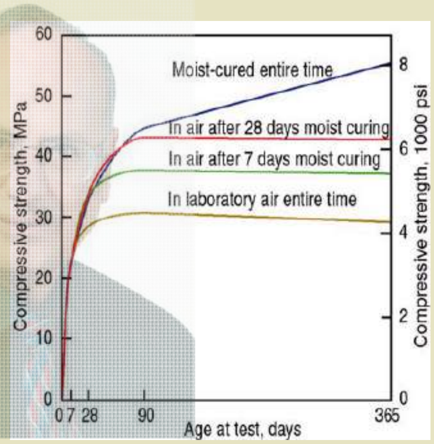
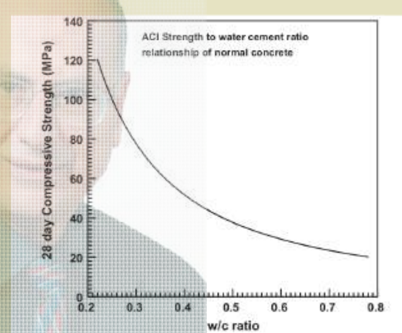
Effect of Age and Curing

- Concrete strength increases with time.
- Once curing stops, concrete strength will not increase.



Effect of w/c ratio

- Strength decreases by the increase in w/c ratio.
- Note that strength sharply increases when w/c<0.50.



Types of Strength

- Compressive strength
- Tensile strength
  - Direct tensile strength
  - Indirect tensile strength (Splitting)
  - Flexural tensile strength

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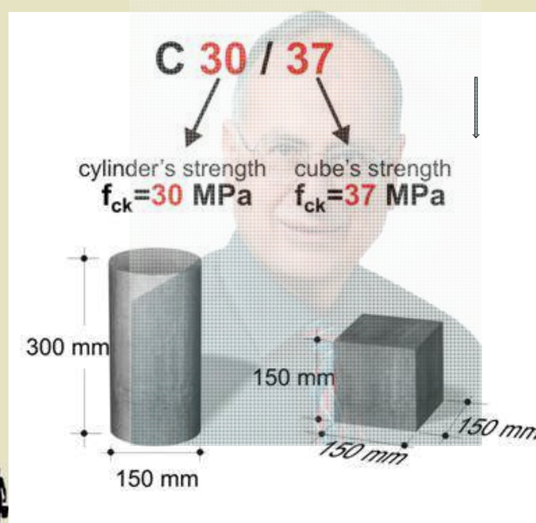
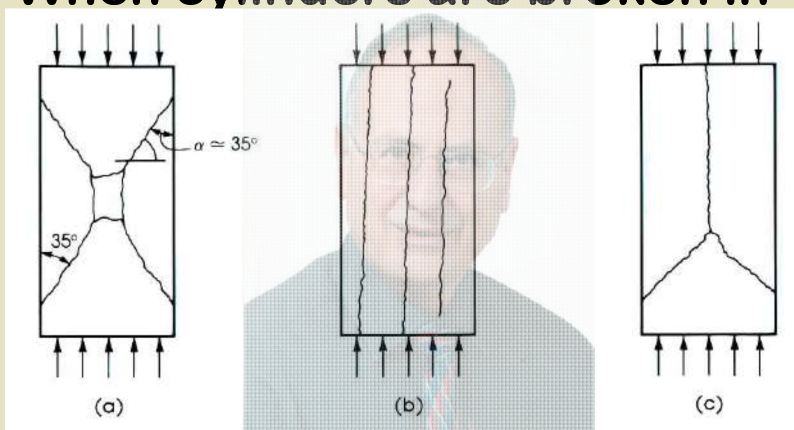
Standard Samples



Types of compression failure When cylinders are broken in



Shear	Splitting	Splitting + Shear

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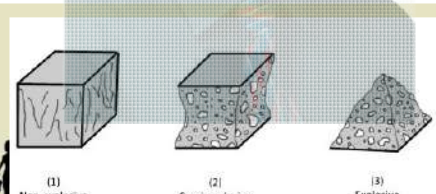
Failure Modes of Compression Testing – 3D



Compressive Strength

Cylinder : ASTM C470

- *Cubes : British standard 150x150x150 mm³*
- *Other sizes:*
  Cylinder: 100 × 200 or 150 × 300 mm
  Cubes: 100 × 100 × 100 mm³ or

$$\sigma_c = \frac{P}{A}$$

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Strength-Age Relationship

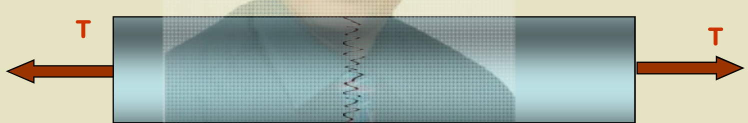
- The standard strength test generally uses a cylindrical or cubical sample.
- It is tested after 28 days to test for strength, f_c.
- The concrete will continue to harden with time and for a normal Portland cement will increase with time as follows

(approximate for OPC only cured under water at standaed temperature

Age	7 days	14 days	28 days	3 months	6 months	1 year	2 years	5 years
Strength ratio	0.67	0.86	1.0	1.17	1.23	1.27	1.31	1.35

Direct Tensile Strength

$$f_{ct} = \frac{Force\ (T)}{Cross\text{-}sectional\ area\ (A)}$$



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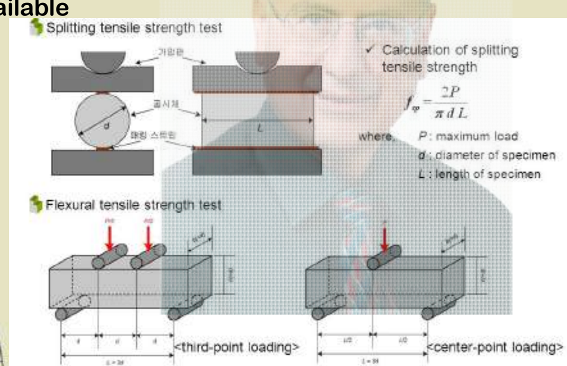
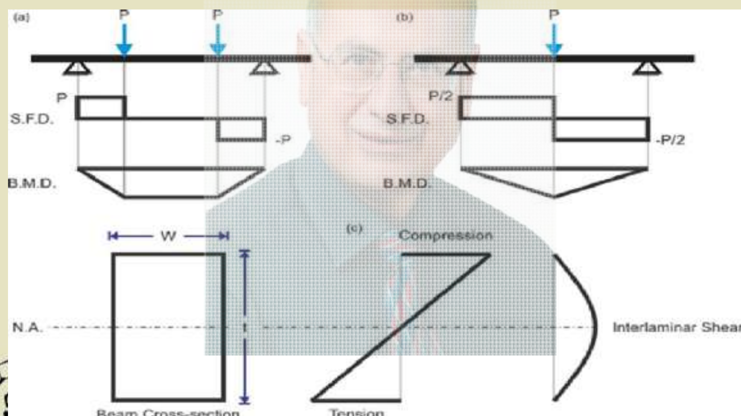
Tensile Strength

The Two point loading (third-point) is more accurate because failure occurs due to pure bending.
Shear in the middle = 0.
One way loading, (centre point) is used only if the other is not available



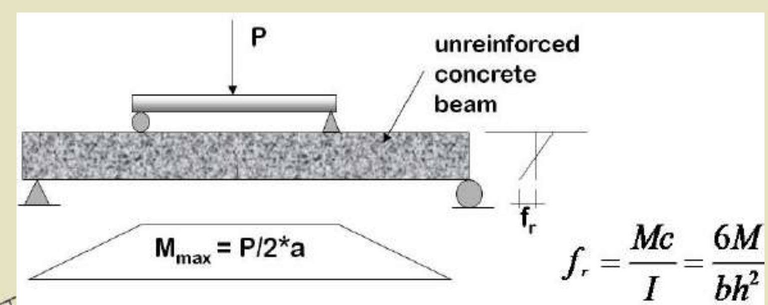
Flexural Tensile Strength
Tow-point loading

Two-point loading and middle-point loading



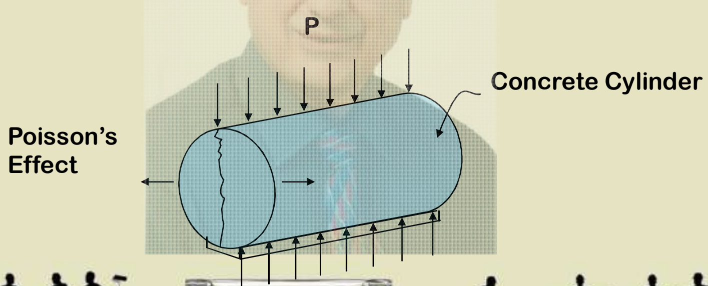
Flexural Tensile Strength
Tow-point loading

- Tensile strength ~ 8% to 15% of f'_c
- Modulus of Rupture is app. 0.5 to 0.6 of the square root of the compressive strength of cylinder



Indirect Tensile Strength (Splitting)

- Splitting Tensile Strength, f_{ct}
- Split Cylinder Test (Brazilian Test)



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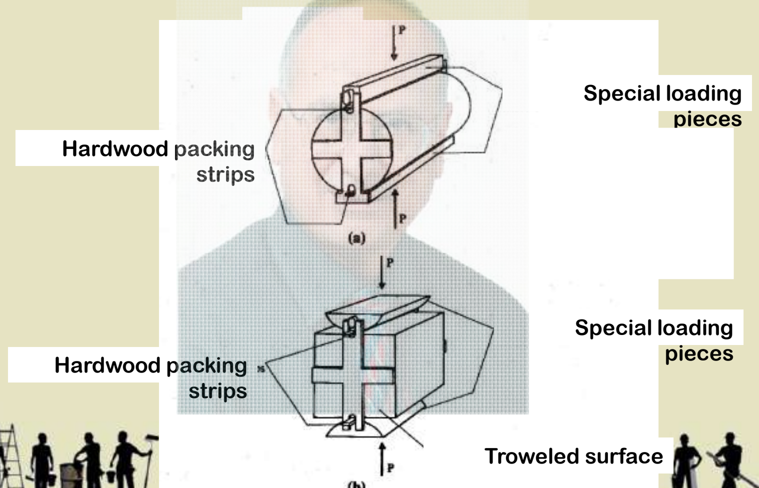
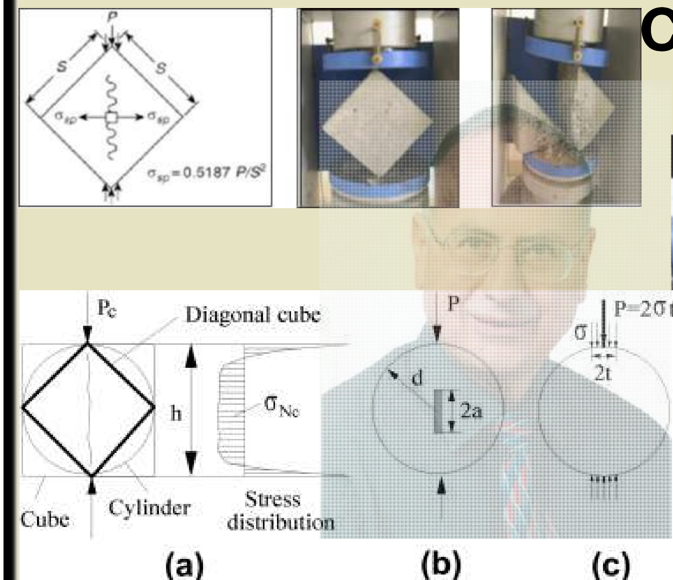
Splitting Tensile Test
Test arrangement



Cube test



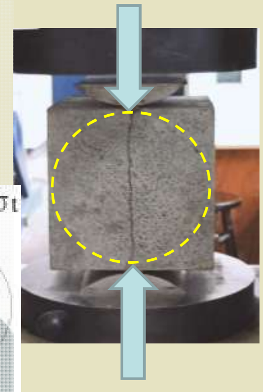


Fig 1

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Cylindrical Splitting Tensile Strength

Failure

$$f_{ct} = \frac{2P}{\pi l d}$$

where, *P* : maximum load
d : diameter of specimen
L : length of specimen

In the case of cube in Fig 1, use d=l= Cube length

The tensile strength of concrete is approximately equal to 10% of its compressive strength.
Generally: Compressive = 7 to 11 of tensile

Indirect (Splitting) ≈ 1.1 Direct
Flexural ≈ (1.15-1.25) Direct

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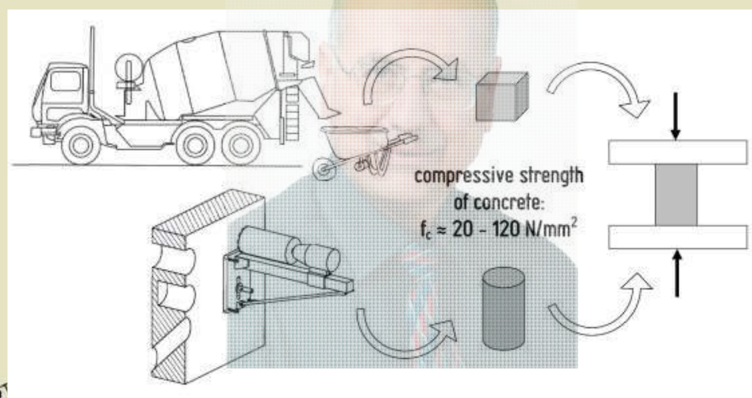
Samples for evaluating concrete strength



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Evaluation of strength

3-Samples ➔ minimum

$$\sigma_{avg} = \frac{\sum \sigma}{n}$$

acceptable?

$$\sigma_{avg} \geq \sigma_{required}$$

$$\frac{\sigma_{min}}{\sigma_{req}} \geq 85\ \%$$

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Example:
Results of testing 3 samples:
σ1=30MPa, σ2=27MPa, σ3=18MPa and σreq=25MPa
Is this concrete accepted?

$$\sigma_{avg} = \frac{30 + 27 + 18}{3} = 25\ MPa$$

$$\sigma_{avg} \geq \sigma_{req}$$

$$\frac{\sigma_{\min}}{\sigma_{req}} = \frac{18}{25} = 72\ \% < 85\ \%$$

- **REJECTED**

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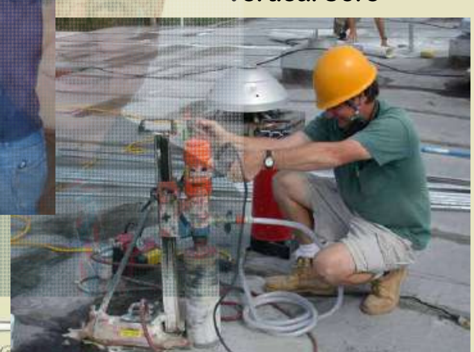
Core Test

Horizontal Core

Vertical Core



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Core

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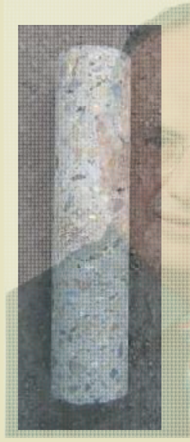
Preparing cores for test by capping or smoothing the surfaces



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Steps of core evaluation

- 1. Prepare the ends of the cores to ensure horizontal smooth surface. Use capping or sawing.
- Calculate the dimensions of the cores (L and d).
- 2. Rupture the cores and record the max loads P.
- 3. Calculate the strength of each core using the A is the area of the circular area.

$$f_{core} = \frac{P}{A}$$

- 4. Calculate equivalent cube strength for each sample.
- 5. Calculate the average.
- 6. Compare with the required.
  - Average > 85% of the required strength
  - Min > 75% of the required.

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Core Strength

$$f_{cube} = \frac{D}{1.5 + \frac{1}{\lambda}} \times f_{core}$$

D=2.3 or 2.5

3-Samples ➔ minimum

$$\sigma_{avg} = \frac{\sum \sigma}{n}$$

$$\sigma_{avg} \geq 0.85 \sigma_{required}$$

$$\frac{\sigma_{min}}{\sigma_{req}} > 75 \%$$

fcore is the tested core strength
fcube is the equivalent cube strength
λ is L/d
D = 2.5 if the core is taken horizontally such as walls
D = 2.3 if the core is taken vertically such as ground slabs

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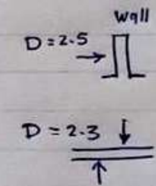
Example

Assume that a core is extracted from a wall.
The length of the core = 150 mm.
The diameter of the core = 100 mm.
The load is 250 kN.
Calculate the equivalant cube strength.



D = 2.5 or 2.3

$$\lambda = \frac{150}{100} = 1.5$$

$$f_{core} = \frac{250 \times 10^3}{\frac{\pi}{4} \times 100^2} = 31.83 \ N/mm^2 \ (MPa)$$

$$f_{cube} = \frac{2.5}{1.5 + \frac{1}{1.5}} \times 31.83 = 36.73 \ MPa$$

Example on acceptance

- After calculating the core strength using P/A equation, the results were calculated using $f_{cube} = \frac{D}{1.5 + \frac{1}{\lambda}} \times f_{core}$
- Required strength = 25 MPa
- Final results are: fcube1 =30 MPa, fcube2=27 MPa, fcube 3=18 MPa

$$fcube_{avg} = \frac{30 + 27 + 18}{3} = 25 \ MPa$$

$$fcube_{avg} \geq 0.85\,\sigma_{req}$$

$$\frac{fcube_{min}}{\sigma_{req}} = \frac{18}{25} = 72\% < 75\%$$

H. Qasrawi

Water for Concrete

Hisham Qasrawi

Uses

- Mixing water
- Curing water

Types of Water

- Municipal (ماء البلدية) water is suitable.
  - Drinking water
    - Ground water
    - Wells water
    - Desalinated water
    - Distilled water

DISCUSSION: Which one is the best for concrete?

Can we use seawater?

ADMIXTURES

Hisham Qasrawi

What are admixtures?

- Materials added to concrete to improve one or more of its properties.

Basic Types of Admixtures

- Retarding admixtures

  delays setting time of concrete.

- Accelerators

  Reduces setting time and accelerates hardening or the development of early strength of concrete

- Water-reducing admixtures

  reduces amount of water for the same workability

- High-range Water-reducing admixtures

  highly reduces amount of water for the same workability

Basic Types of Admixtures

- Plasticizers

  Increases workability for the same water content.

- Super plasticizers

  highly increases workability for the same water content. Collapse slump may be observed..

- Air-entraining agents

  increase resistance to frost. Reduces strength

- Water-proofing agents

  Reduces movement of water through concrete. Some helps to block capillary pores

…Basic Types of Admixtures

- Coloring admixtures
- Bonding agents

  Bonds old concrete to new one. Example plastering.

  Bonds steel bars to concrete.
- Admixtures with combined effect: Examples
  - Plasticizing – retarding
  - Plasticizing – accelerating
  - Plasticizing – air-entraining
  - Plasticizing – waterproofing
  - Plasticizing – waterproofing-retarding
  - Accelerating – air-entraining

...Basic Types of Admixtures

- Viscosity modifying agents

  These are used in self compacting concrete with high quality superplasticizers..

- Bacteria for self-healing concrete

Suitability of Admixtures for Use in Concrete

ASTM

- Ensure that the admixture used satisfies the minimum requirements specified in ASTM C494.

BS

- Ensure that the admixture used satisfies the minimum requirements specified in BS 5075: Part 1.

What to check before use

1- Method of Use

2- Expiry date

3- Dosage

4- Chloride free (don’t use $CaCl_2$ in reinforced concrete)

5- Alkalis ➔ if there is free silica

Should be Alkali-free admixtures.

Mineral Additives

- Pozzolanic materials
- Steel slags
- Silica fume (microsilica)
- Copper slags

Silica fume

- Silica fume is a byproduct of producing silicon metal or ferrosilicon alloys.
- Silica fume consists primarily of amorphous (non-crystalline) silicon dioxide (SiO_2).
- The individual particles are extremely small, approximately 1/100th the size of an average cement particle.
- It is used in concrete in 5% to 25%. Most common dosage 7.5% to 15 % of weight of cement.
- Important in high strength and high performance concrete.
- The quality of silica fume is specified by ASTM C 1240 and AASHTO M 307.

Conventional Building Materials
Normal Aggregate

Hisham Qasrawi

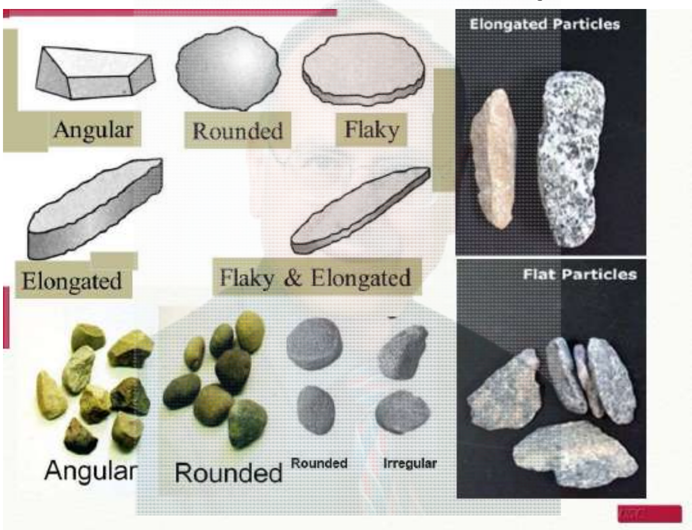
Classification of Aggregate

- According to size
  – Coarse aggregate:
  Size >= 5 mm (ASTM #4)
  – Fine aggregate:
  Size < 5 mm (ASTM #4)
- According to source
  – Natural (Uncrushed)
  – Artificial (Crushed)
  – Manufactured. Some lightweight aggregate.

Shape Classification

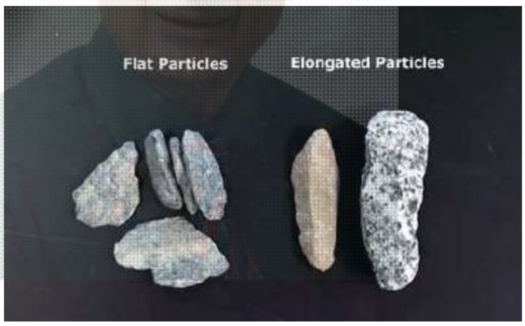
Classification	Effect on properties of concrete
Rounded	Higher workability, low cohesion, low abrasion resistance
Irregular	Medium workability, medium cohesion, medium abrasion resistance
Angular	Low workability, high cohesion, higher abrasion resistance
Flaky	Usually not used
Elongated	Usually not used
Flaky & Elongated	Usually not used

C;assification: Examples



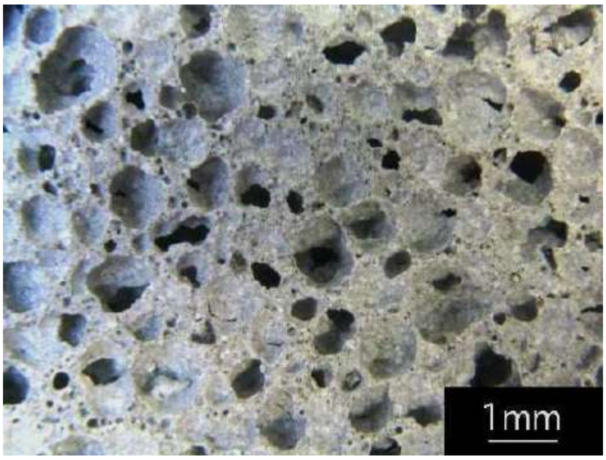
Flaky and Elongated Particles

- Should not exceed 15% for low quality concrete
- Should not exceed 10% for high quality concrete

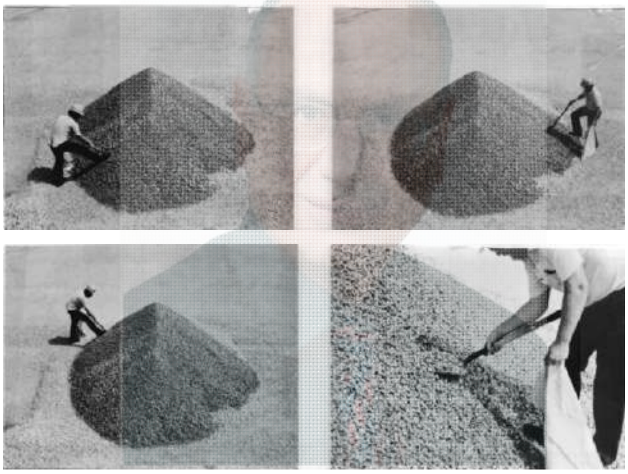


Crystalline Aggregate

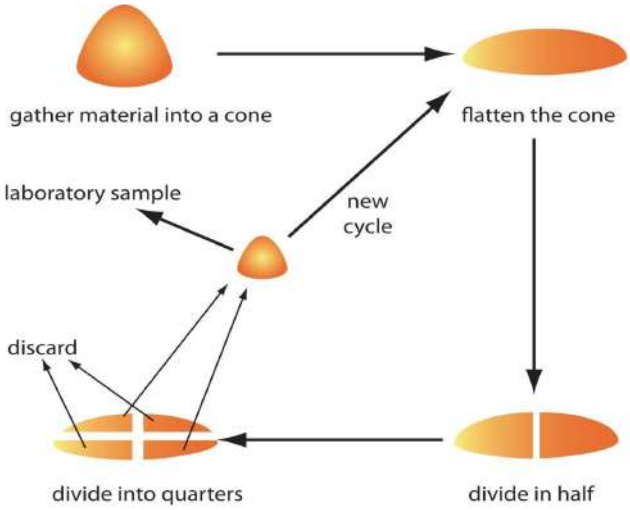
Honeycombed Aggregate



Representative Sample of Aggregate: Quartering Process



Representative Sample of Aggregate Quartering Process



HISHAM QASRAWI 9

Representative Sample of Aggregate Quartering Process

HISHAM QASRAWI 10

Representative Sample of Aggregate Quartering Process

General Properties of Good Normal Aggregate

- Strong: Stronger than concrete by 2 to 3 times
- Good bond with cement paste
- Hard: Has relatively low LA abrasion value
- Tough: Resists impact and dynamic loads
- Has medium specific gravity (2.40 to 2.80)
- Nonporous: Has low absorption (<5%)
- Sound: Stable in volume when subjected to aggressive environments.
- Does not contain free silica
- Well-graded
- Does not contain deleterious materials

Basic standard sieves

IS Sieve (mm)	ASTM (inches)	Comments
150	6	Largest acceptable size for concrete works
75	3	
40	1.5	
20	¾	
\`0	3/8	
5	3/16 (#4)	End of coarse aggregate
2.4	# 8	
1.2	# 16	
0.6	# 30	
9,3	# 50	
0,15	# 100	Smallest acceptacle size for concrete works

Example: sieve #4

Tests on Aggregates
Sieve Analysis

Example on grading of fine aggregate
Sieve Analysis

Sieve	Weight retained	Percent retained	Cumulative % retained	Cumulative % passing
10 mm	0	0	0	100
5 mm	50	5	5	100 - 5 = 95
2.4 mm	80	8	13	87
1.2 mm	100	10	23	77
0.6 mm	320	32	55	45
0.3 mm	350	35	90	10
0.15 mm	50	5	95	5
0.075 (# 200)	30	3	98	2
Pan	20	2	100	0
Total	1000	100		

Example on grading of fine aggregate

Sieve	ASTM	BS Overall	BS C	Cumulative % passing
10 mm	100	100	–	100
5 mm	95–100	89–100	–	100 - 5 = 95
2.4 mm	80–100	60–100	60–100	87
1.2 mm	50–85	30–100	30–90	77
0,6 mm	25–60	15–100	15–54	45
0.3 mm	10–30	5–70	5–40	10
0.15 mm	2–10	0–15†	–	5
0.075 (# 200)				2
The aggregate is accepted according to ASTM				
The aggregate is accepted according BS. It is classified as C.				

Example on grading of fine aggregate

- The fineness modulus is the summation of cumulative retained on all standard main sieves divided by 100.
- = (0+5+13+23+55+90+95) / 100 = 2.81

Sieve	Cumulative % retained
10 mm	0
5 mm	5
2.4 mm	13
1.2 mm	23
0.6 mm	55
0.3 mm	90
0.15 mm	95
0.075 (# 200)	98
Pan	100
Total	

Example on grading of fine aggregate

- According to fineness modulus:
  - Sand is classified as:
    - Fine if FN is less than 2
    - Medium if FM is between 2.2 and 2.8
    - Coarse if FM is above 3.
- Maximum size of aggregate is 10mm
- Nominal maximum size of aggregate (NMSA) is 2.4 mm.

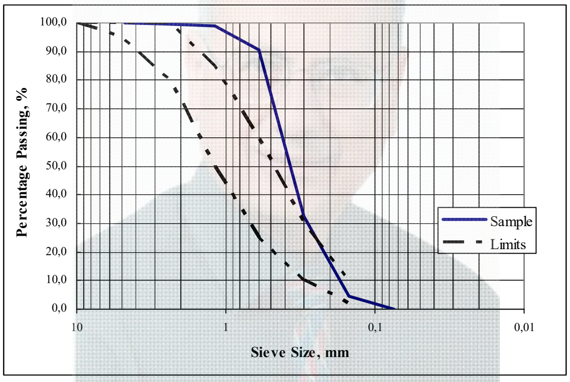
Example on grading limits ASTM & BS for fine aggregate

BS and ASTM grading requirements for fine aggregate

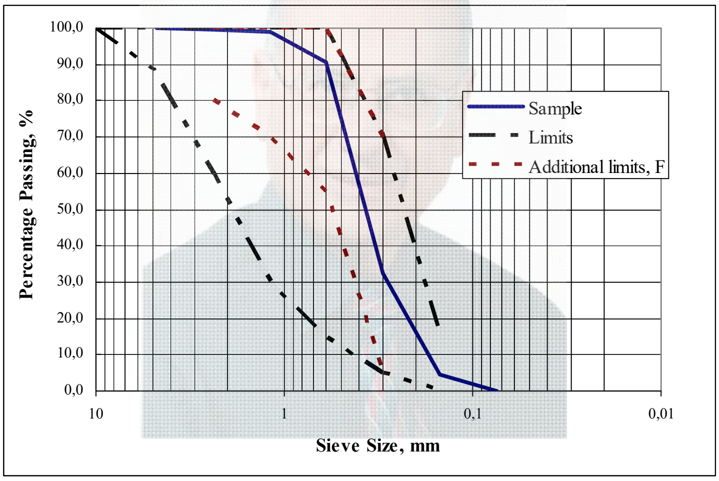
Sieve size		Percentage by mass passing sieve				
		BS 882: 1992				ASTM C 33–92a
BS	ASTM No.	Overall limits	Additional limits*			
			C	M	F	
10 mm	$\frac{3}{8}$ in.	100	–	–	–	100
5 mm	$\frac{3}{16}$ in.	89–100	–	–	–	95–100
2.36 mm	8	60–100	60–100	65–100	80–100	80–100
1.18 mm	16	30–100	30–90	45–100	70–100	50–85
600 μm	30	15–100	15–54	25–80	55–100	25–60
300 μm	50	5–70	5–40	5–48	5–70	10–30
150 μm	100	0–15†	–	–	–	2–10

* C = coarse; M = medium; F = fine.
† For crushed rock sands the permissible limit is increased to 20 per cent, except when used for heavy duty floors.

Example:
Aggregate in not accepted by ASTM



Example:
The same aggregate in accepted by BS and classified as F



Example on grading of coarse aggregate

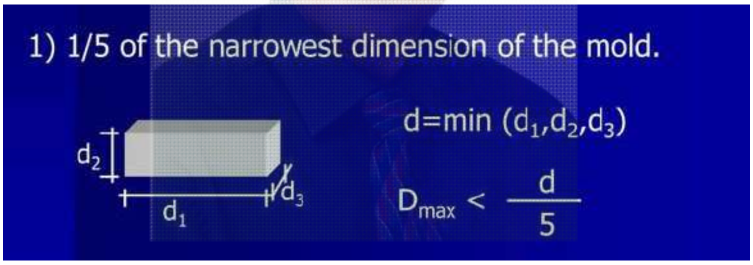
Sieve	Weight retained	Percent retained	Cumulative % retained	Cumulative % passing
40 mm (1.5”)	0	0	0	100-0=100
25 mm (1”)	50	5	5	100 - 5 = 95
20 mm (3/4”)	350	35	40	60
10 mm (3/8”)	460	46	86	14
5 mm (#4)	50	5	91	9
2.4 mm (#8)	40	4	95	5
0.075 (# 200)	30	3	98	2
Pan	20	2	100	0
Total	1000	100		

Maximum size and Nominal Maximum Size of Aggregates

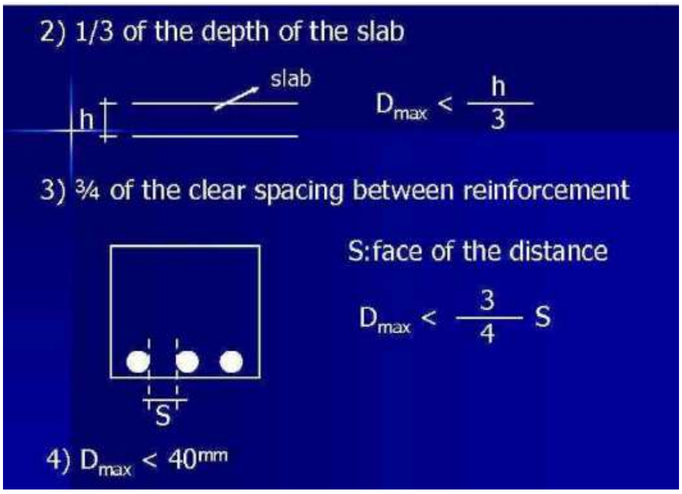
- The maximum size is the minimum size that the whole aggregate passes.
  - In the example: 40mm
- The NMSA is the minimum standard size that the allows a minimum of 85% of the aggregates to pass through. Depends on the standards used: (ASTM, BS or JS)
  - In the example: 40mm or 25mm

How to choose maximum and nominal maximum size of aggregate before construction

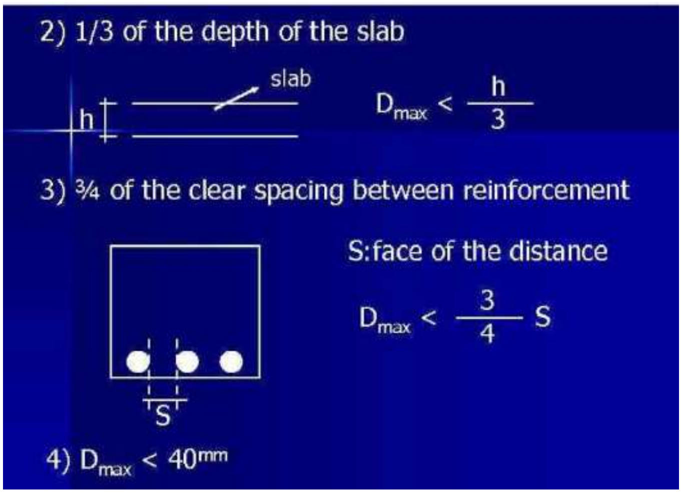
- The concrete mix must be easily cast and constructed.



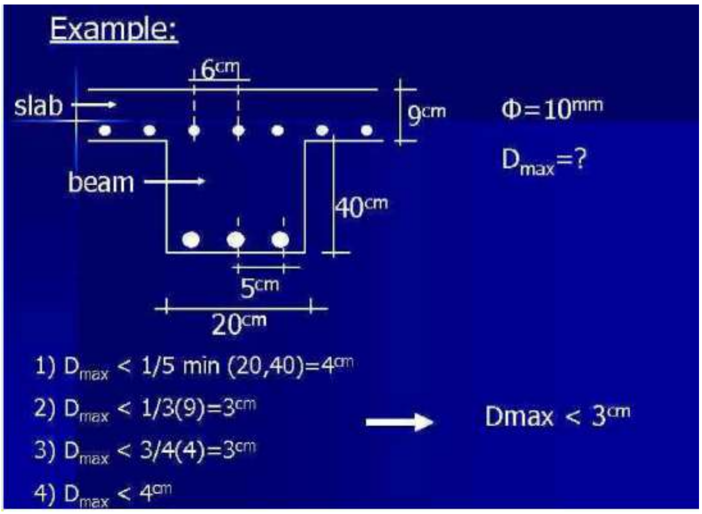
Maximum size of aggregate



Maximum size of aggregate



Maximum size of aggregate



Coarse Aggregate Grading Limits

Table 3.9: Grading requirements for coarse aggregate according to BS 882: 1992

Sieve size		Percentage by mass passing BS sieve							
		Nominal size of graded aggregate			Nominal size of single-sized aggregate				
mm	in.	40 to 5 mm (1½ in. to 3/16 in.)	20 to 5 mm (3/4 in. to 3/16 in.)	14 to 5 mm (1/2 in. to 3/16 in.)	40 mm (1½ in.)	20 mm (3/4 in.)	14 mm (1/2 in.)	10 mm (3/8 in.)	5 mm (3/16 in.)
50.0	2	100			100				
37.5	1½	90–100	100		85–100	100			
20.0	3/4	35–70	90–100	100	0–25	85–100	100		
14.0	1/2			90–100	–	–	85–100	100	–
10.0	3/8	10–40	30–60	50–85	0–5	0–25	0–50	85–100	100
5.00	3/16	0–5	0–10	0–10	–	0–5	0–10	0–25	50–100
2.36	No. 7	–						0–5	0–30

Example on grading of fine aggregate

- The fineness modulus is the summation on cumulative retained on all standard main sieves divided by 100.
- FM = (approximately)
- (0+40+86+91+95+4*100) / 100 = 7.12

Or/ FM (min)

=(0+40+86+91+95)+4*98/ 100 = 7.04

Sieve	Cumulative % retained
40 mm (1.5”)	0
25 mm (1”)	5
20 mm (3/4”)	40
10 mm (3/8”)	86
5 mm (#4)	91
2.4 mm (#8)	95
0.075 (# 200)	98
Pan	100

Compare with BS

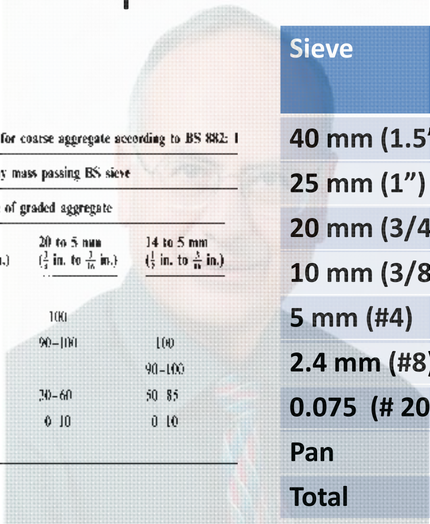


Table 3.9: Grading requirements for coarse aggregate according to BS 882: 1

Sieve size		Percentage by mass passing BS sieve		
		Nominal size of graded aggregate		
mm	in.	40 to 5 mm ($1\frac{1}{2}$ in. to $\frac{3}{16}$ in.)	20 to 5 mm ($\frac{3}{4}$ in. to $\frac{3}{16}$ in.)	14 to 5 mm ($\frac{1}{2}$ in. to $\frac{3}{16}$ in.)
50.0	2	100		
37.5	$1\frac{1}{2}$	90-100	100	
20.0	$\frac{3}{4}$	35–70	90–100	100
14.0	$\frac{1}{2}$			90–100
10.0	$\frac{3}{8}$	10–40	30–60	50 85
5.00	$\frac{3}{16}$	0 5	0 10	0 10
2.36	No. 7	-		

Sieve	Cumulative % passing
40 mm (1.5”)	100
25 mm (1”)	100 - 5 = 95
20 mm (3/4”)	60
10 mm (3/8”)	14
5 mm (#4)	9
2.4 mm (#8)	5
0.075 (# 200)	2
Pan	0
Total	

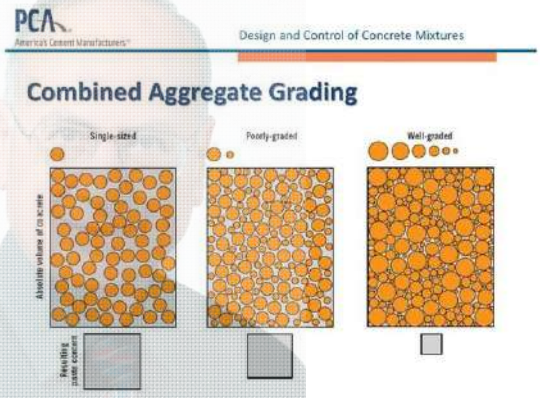
Coarse Aggregate Grading Limits

Table 3.10: Some of the grading requirements for coarse aggregate according to ASTM C 33–03

Sieve size		Percentage by mass passing sieve				
		Nominal size of graded aggregate			Nominal size of single-sized aggregate	
mm	in.	37.5 to 4.75 mm ($1\frac{1}{2}$ to $\frac{3}{16}$ in.)	19.0 to 4.75 mm ($\frac{3}{4}$ to $\frac{3}{16}$ in.)	12.5 to 4.75 mm ($\frac{1}{2}$ to $\frac{3}{16}$ in.)	63 mm ($2\frac{1}{2}$ in.)	37.5 mm ($1\frac{1}{2}$ in.)
75	3			..	100	
63.0	$2\frac{1}{2}$		.	–	90 100	–
50.0	2	100			35 70	100
38.1	$1\frac{1}{2}$	95 100			0 15	90–100
25.0	1		100			20 55
19.0	$\frac{3}{4}$	35 70	90 100	100	0 5	0-15
12.5	$\frac{1}{2}$			90 100	–	
9.5	$\frac{3}{8}$	10 30	20–55	40 70	–	0 5
4.75	$\frac{3}{16}$	0 5	0 10	0 15		–
2.36	No. 8	–	0 5	0 5		

Classification of Grading

- 1. Well-graded
- 2. Single-sized
- 3. Poor-graded
- 4. Gap-graded
- 5. Open-graded



Properties of Good Normal Aggregate Thermal Properties

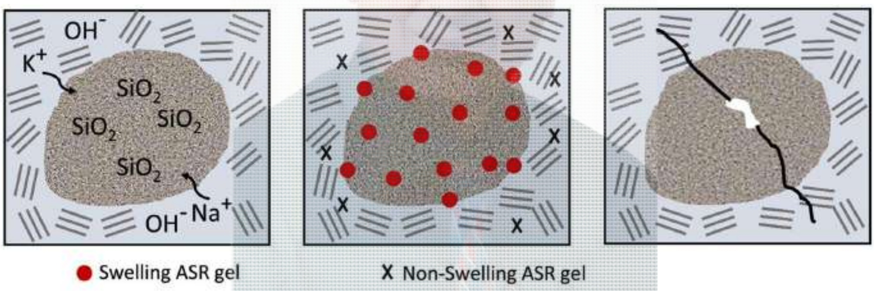
- Stable under thermal effects (The coefficient of thermal expansion is as close as that of paste.
  - (α paste = $11\text{x}10^{-6} - 16\text{x}10^{-6}$ per deg C)
  - (α concrete = $10\text{x}10^{-6} - 12\ \text{x}10^{-6}$per deg C)
  - (α for most common normal aggregate = $6\ \text{x}10^{-6}$ – $13\text{x}10^{6}$per deg C)
- For use in concrete
  - Preferably, α for aggregate = α concrete $\pm\ 5\text{x}10^{-6}$

Properties of Good Normal Aggregate

- Contains approximately no deleterious substances:
  - Organic impurities
  - Salts (basically chlorides and sulfates)
  - Free reactive silica
  - High amounts of fine material (like clay)
  - Unsound particles
  - Clay lumps
  - Shells

Alkali Aggregate Reaction (AAR)
Alkali Silicate Reaction (ASR)

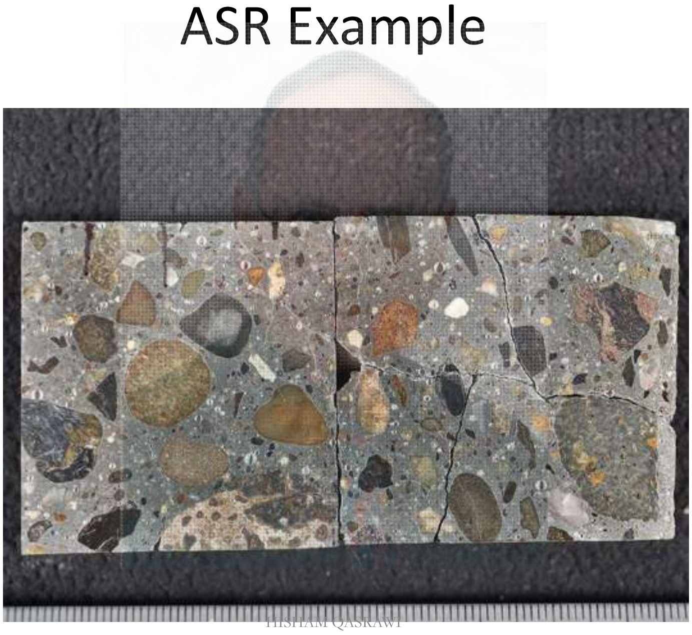
- Alkalis from cement + free silica from aggregate + water gives alkali silicate hydrate gel



(a) (b) (c)

ASR Example
Concrete Cancer

ASR Example

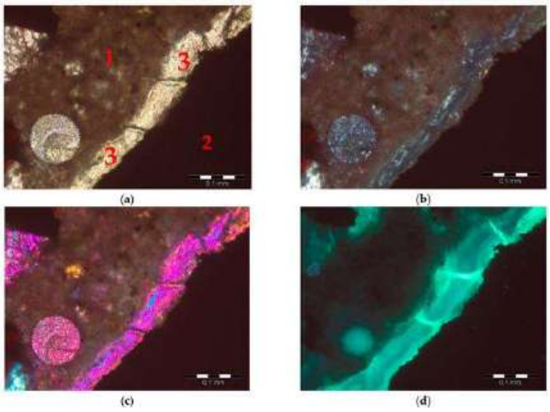


How to reduce ASR Discussion

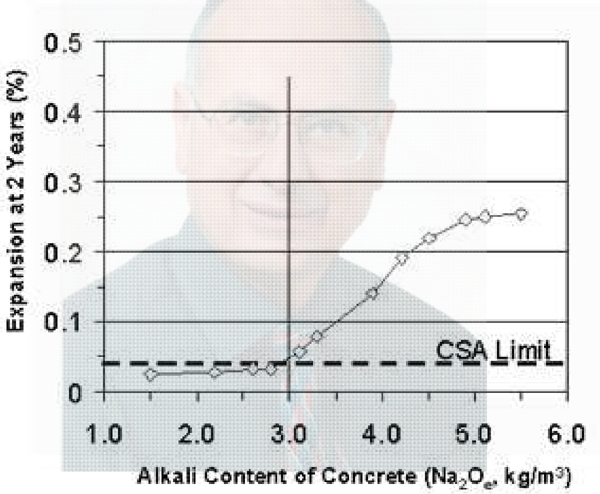
- 1. Cement
  - Use low alkali cement $Na_2O + \frac{2}{3}k_2O \leq 1\%$
- 2. Do not use aggregate with free silica.
  - Check by petrography or by the mortar bar test.
- 3. Keep water away from concrete
- 4. Limit total alkalis in concrete to les than 3kg/m3
- 5. Use Lithium salts

Check free silica by petrographic examination 1-cement matrix, 2-hematite, 3-alkali-silica gel; scale bar = 100 µm.

Alkali-silica gel in the matrix in mortars with hematite aggregate:
(a) plane-polarized light (PPL);
(b) cross-polarized light (XPL);
(c) cross-polarized light (XPL) with λ plate;
(d) ultraviolet light (UV);



Alkalis must be less than 3kg/m3



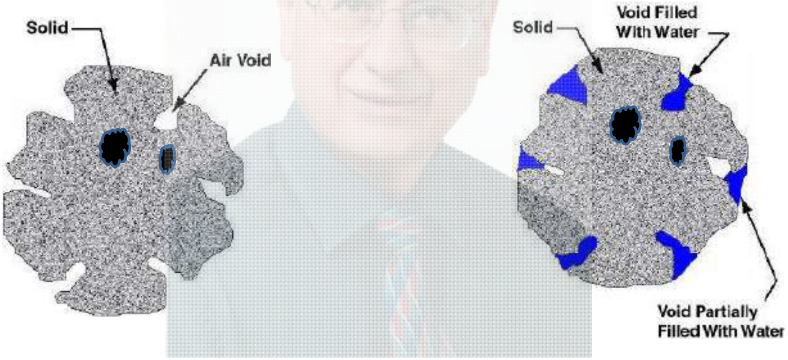
Specific Gravity
General

$$SG = \frac{\text{Weight of a certain volume of material}}{\text{Weight of the same volume of water}}$$

$$= \frac{\gamma_{mat} \times V}{\gamma_{wat} \times V} = \frac{\gamma_{mat}}{\gamma_{wat}} = \frac{\rho_{mat}}{\rho_{wat}}$$

Voids in aggregate

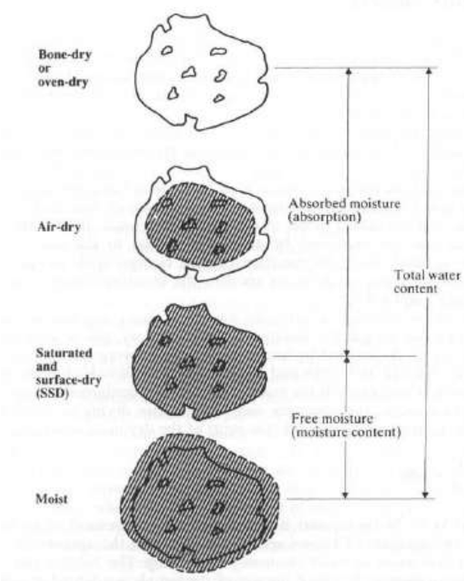
- Note that there are capillary and non capillary pores



Specific Gravity of Aggregate

Moisture in aggregates

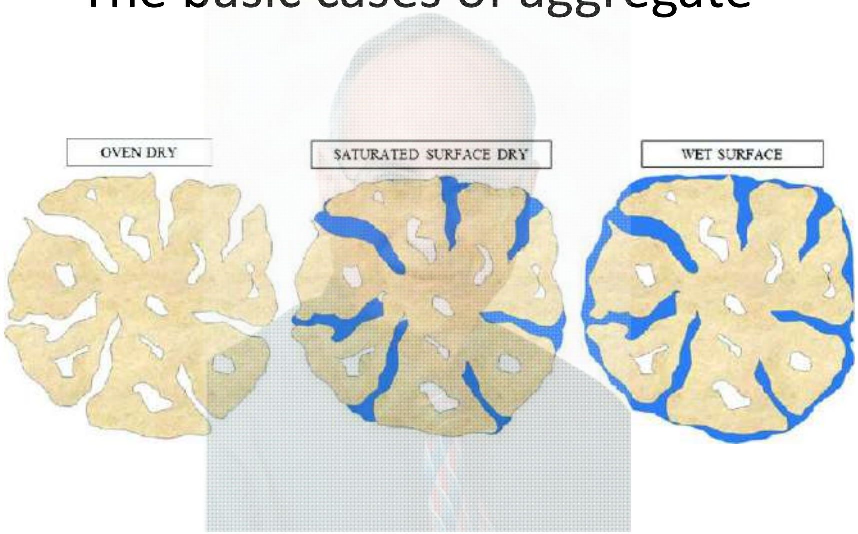
1. True (actual) S.G.
2. Apparent S.G
3. Bulk S.G.



3.1: Schematic representation of moisture in aggregate

Tests on Aggregates
Specific Gravity & Absorption of Coarse Aggregate

The basic cases of aggregate



Calculations

- Weight of SSD sample = B
- Weight of oven-dried sample = A
- Weight of sample in water = C

- Bulk SG = B/(B-C)
- Apparent SG = A/(A-C)
- Absorption (%) = {(B-A)/A }*100%

Moisture content

- Moisture content = {(Wair-Woven)/Woven}x100%
- In real life, moisture content can have any value depending on weather conditions.
- In site, weigh the heated material until you get a constant weight

Importance of determining absorption and moisture content

- Example:
- Assume that the following are the mix proportions for 1.0m3 of concrete:
- Calculate the water that must be added to the mixer as per 1.0m3.

Cement	Water	Coarse aggregate	Fine aggregate	Others
400	**200**	**1000** **Moisture = 3%** **Absorption 2.5%**	**800** **Moisture = 2%** **Absorption 4%**	**None**

Water to be added = Free water + absorption – moisture

= (approximately) 200 + [1000*0.025+800*0.04] – [1000*0.03+800*0.02] = 200+57-46=211 kg/m3 of concrete

Tests on Aggregates
Specific Gravity & Absorption of Fine Aggregate Using Pycnometer

Dry, Wet and SSD sand

Procedure

Pycnometer filled with Water to calibration mark = B

Pycnometer filled with Water and sample to calibration mark = C

Calculations

- B = the weight of pycnometer with water to its calibration mark.
- C = weight of the pycnometer, sample, and water to calibration mark

$$\text{Bulk specific gravity (SSD)} = \frac{W_{SSD}}{W_{SSD} + B - C}$$

$$\text{Apparant specific gravity} = \frac{W_{OD}}{W_{OD} + B - C}$$

$$\text{Absorption (\%)} = \frac{W_{SSD} - W_{OD}}{W_{OD}} \times 100\%$$

Classifications of aggregates

Type of aggregate	Specific gravity
Lightweight	< 2.0
Medium weight (Normal)	2.20 to 2.80
Heaveyweight	> 3.0

Hardness of Aggregate

- Hardness: Resistance to wear and abrasion
- Common methods of testing:
  - Los Angeles abrasion value (LA) – ASTM
  - Aggregator abrasion value (AAV) – BS
  - Polished stone value (PSV) – BS EN

- The common and acceptable test in Jordan is LA value test
- The test is an Indirect measure of strength

Tests on Aggregates
LA Abrasion

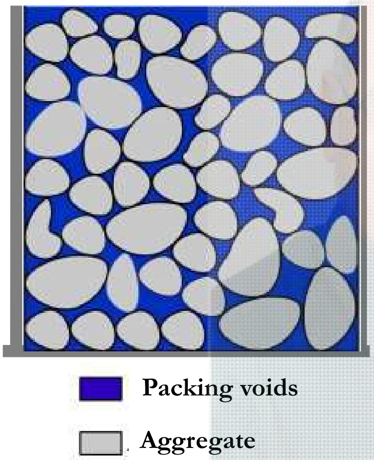
Calculations

$$LA(\%) = \frac{\text{Weight of the material that passed the sieve after test}}{\text{Original weight of material after sieving and before testing}} x100\%$$

Generally, for concrete structures

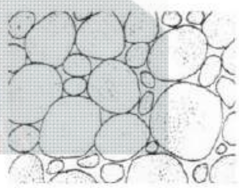
Value	Quality of concrete	Strength (MPa)
> 45	- Do not use	-
35 to 45	Low	<20
25 to 35	Medium	25 to 40
15 to 25	High	45 to 65
< 15	Very and ultra high	> 70

Bulk density (unit weight) of aggregate



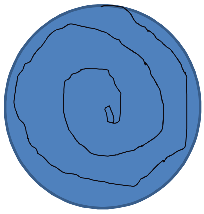
- It is the density of aggregate taking into consideration the packing voids.
- = Weight/total volume

- Total volume = volume of aggregates + volume of voids



Types of unit weight

- Loose unit weight
- Compacted (rodded) unit weight



Calculations

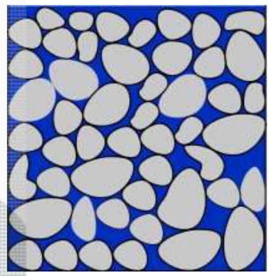
$$\text{Unit weight } (\gamma) = \frac{\text{Weight of aggregate (W)}}{\text{Bulk volume of the aggregate (V)}}$$

Bulk volume = Volume of the mold

$$\text{Voids ratio} = \frac{V_v}{V} = \frac{V - V_s}{V} = [1 - \frac{V_s}{V}]$$

$$V_s = \frac{W}{SG_s \; x \; \gamma_{water}}$$

$$\text{Voids ratio (\%)} = [1 - \frac{\gamma}{SG_s \; x \; \gamma_{water}}] x 100\%$$



Packing voids

Aggregate

Volume of the mold

- The volume of the mold is calculated in one of two methods:
  - 1. Measure accurately the dimensions of the mold and then obtain the volume.
  - 2. Fill the mold with water, Obtain the volume as

$$\text{V of mold} = \frac{\text{Weight of water filling the mold}}{\gamma_{water}}$$

Angularity

$$\text{Angularity number (AN)} = 67 - \frac{\gamma_{agg}}{SG_s \ x \ g_{water}} x100\%$$

- BS standards
- AN must be <= 11 % for the aggregate that is used in concrete construction.

Toughness

- Toughness is the resistance of aggregate for dynamic loads.
- It is measured by the modulus of toughness (MT)
- MT is defined as the energy absorbed by the unit volume of material before failure.

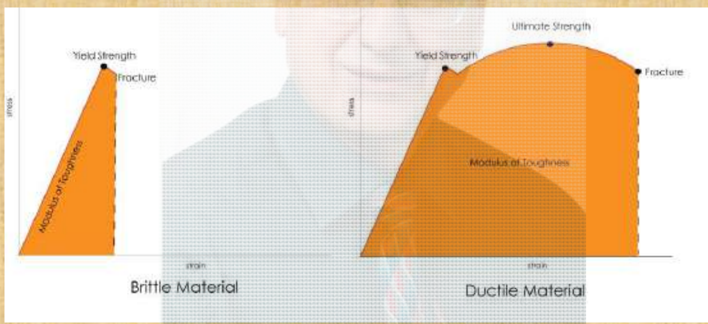
$$MT = \frac{\text{Area under the load - deflection curve}}{\text{Volume of the specimen (V)}}$$

- Load deformation means P Δ curve
- Volume = A x L

- MT = P Δ curve / A L
- = Area in the Stress Strain curve

Modulus of toughness

- Then, MT will be the area under the stress-strain curve



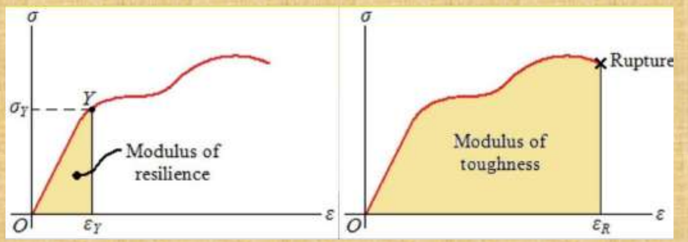
Reselience

- Resilience is the resistance of material for dynamic loads in the elastic range.
- It is measured by the modulus of reselience (MR)
- MR is defined as the energy absorbed by the unit volume of material in the elastic range.

$$MR = \frac{\text{Area under the load - deflection curve in the elastic range}}{\text{Volume of the specimen (V)}}$$

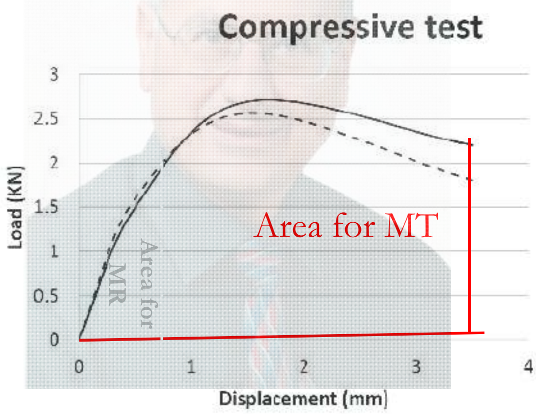
Modulus of reselience

- Then, MR will be the area under the stress-strain curve in the elastic range



Example
The figure shows the load deflection curve of two rock materials. Assume that the specimen diameter is (d) and its length is (l), calculate the modulus of toughness and the modulus of resilience in terms of d and l.

- .



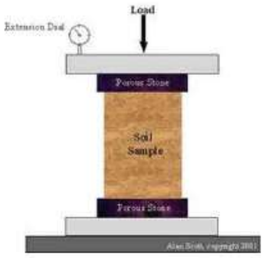
Strength of Aggregate
A rock sample is available

Compressive strength

6_c = P/A

P= Load

A= Area of x-section



It is the resistance to failure, when the applied stress is normal / perpendicular to the area of X-section.

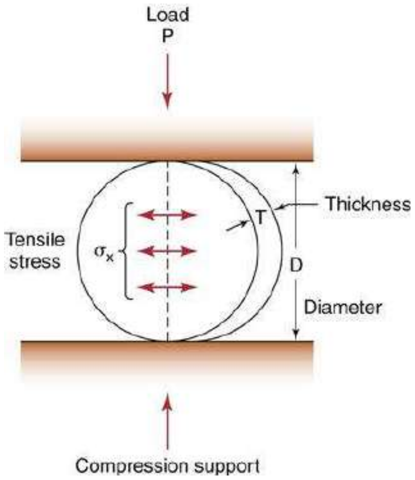
Tests on Aggregates
Rock sample is not available
Aggregate Crushing Value (ACV)

- Aggregate passing a 12.5mm and retained on a 10mm.
- 3 equal layers of aggregate and each layer is tamped 25 strokes
- Apply a load of 40 tones in 10 minutes.
- Aggregate is removed from the cup and sieved on 2.4mm
- Aggregate crushing Value
  ACV =$(W_{fines}/W_{original}) \times 100\%$

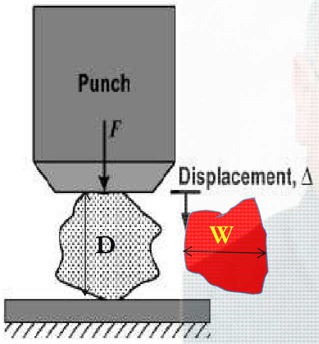
Must be ≤ 35%

Indirect tensile strength Splitting Test (Brazilian Test)

- σ = 2P/πDL



Practical and Idealization of Single Particle Test



$$\sigma_t = \frac{F_b}{D_e^2}$$

$$D_e = \sqrt{\frac{4A_c}{\pi}}$$

$$\sigma_t = \frac{0.9F_b}{D^2}$$

$$A_c = W \times D$$

Clay and Fine Materials in Aggregates

- These are materials that pass sieve 0.075mm (ASTM #200)

- For high quality concrete, these should be ≤ 3%
- In Jordan specifications, these should be ≤ 5%
- In ASTM, these should be ≤ 10% for passing sieve #100.

Some Harmful materials (substances) (deleterious) in Aggregate

- Salts, mainly Sulphates and Chlorides.
- Friable materials.
- Oil-contaminated aggregates at sites.
- Organic impurities.

Soundness of Aggregate

- Sound aggregate is that aggregate that resists volume changes due to environmental effects
  - Freeze and thaw (frost action)
  - Wetting and drying
  - Temperature changes
  - Exposure to deleterious (harmful) materials

Unsound Aggregate

- Can cause volume changes leading to
  - Cracking in concrete
  - Loss of integrity of concrete
  - Disintegration in parts of the structure
  - Scaling

Soundness of Aggregate

To detect unsound particles, aggs are treated with Na_2SO_4 or $MgSO_4$ solutions.

- 18 hours of immersion
- Dry at 105°C+5°C to constant weight
- After 5 cycles determine the loss in weight of the agg.

Determine the loss in weight for each specific sieve size and compute a weighted average percent loss for the entire sample.

The maximum loss values typically range from 10 – 20 percent for every five cycles.

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Soundness of Aggregate

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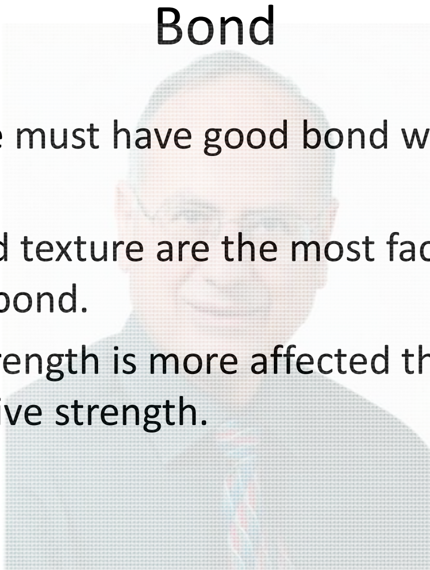
Bond



- Aggregate must have good bond with concrete.
- Shape and texture are the most factors affecting bond.
- Tensile strength is more affected than compressive strength.

Example on grading of fine aggregate

Sieve	ASTM	BS Overall	Cumulative % passing	
10 mm	100	100	0	100
5 mm	95–100	89–100	5	95
2.4 mm	80–100	60–100	20	80
1.2 mm	50–85	30–100	20	80
0,6 mm	25–60	15–100	20	80
0.3 mm	10–30	5–70	90	10
0.15 mm	2–10	0–15†	95	5
0.075 (# 200)			98	2