Week 11

Concrete

457.308 Construction Methods and Equipment

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Introduction

- The Assyrians in 690 $_{\text{B.C.}}$ used a mixture of lime, sand, and limestone aggregate to create a crude concrete used in building the Bavian canal.
- In 1824 Joseph Aspdin took out a patent in England on "Portland" cement. This manufactured cement consists of limestone and clay burned at temperatures in excess of 2,700°F
- "Concrete" consists of Portland cement, water, and aggregate that have been mixed together, placed, consolidated, and allowed to solidify and harden.
  – **Paste**: water + Portland cement (ratio b/w 0.4 & 0.7 by weight), acts as the glue or binder
  – **Mortar**: with fine aggregate sizes b/w No. 200 mesh sieve and No. 4 sieve
  – **Concrete**: with both fine and coarse aggregate sizes larger than the No. 4 sieve (3/4 aggregate + 1/4 paste by volume)

*No. 4: 4.75mm, No. 200: 0.075mm

Introduction

- **Proportioning Concrete Mixture**
  - Higher the water-cement ratio → Lower strength and durability
  - More water → Higher slump
  - More aggregate → Lower cost of the concrete
  - More fresh concrete → Stronger and more durable
  - The surface abrasion resistance of the concrete is almost entirely a function of the properties of the fine aggregate
- **Operations**

(1) Batching the materials
(2) Mixing
(3) Transporting
(4) Placing (타설)
(5) Consolidating (다짐)
(6) Finishing (표면처리)
(7) Curing (양생)

Batching Concrete Materials

- Most concrete batches, although designed on the basis of absolute volumes of the ingredients, are ultimately controlled in the batching process on the basis of weight → weigh first then consider the weight-volume relationship
- **Cement**
  - For most large projects, the cement is supplied in bulk quantities from cement transport trucks (25 tons or more / each) or from railroad cars
  - Unloaded by air pressure and stored in overhead silos or bins
  - Paper bags (1 cf, 94 lb): store in dry place on pallets
- **Water**
  - Cleanliness, freedom from organic material, alkalies, acids, and oils

Batching Concrete Materials

- **Type of Portland Cement by ASTM (American Society of Testing and Materials)**

	Classification	Applications
Type I	General purpose (보통)	General construction (most buildings, bridges, pavements, precast units, etc.) 90% 이상, 품질 우수, 가격 저렴
Type II	Moderate sulfate resistance (중용열)	수화열을 중용열로 억제 → 적은 건조수축, 장기강도 발현, 댐 등의 두꺼운 콘크리트 공사나 도로포장 및 지하 구조물 또는 원자로 차폐용 콘크리트 등에 활용
Type III	High early strength (조강)	급경성 → 조기강도 발현, 조기 고강도 공사, 공기를 서두르는 공사, 동기공사, 수중공사 등에 활용
Type IV	Low heat of hydration (slow reacting) (저열)	중용열보다 더 수화열이 적게 나오도록 한 시멘트, 중용열과 마찬가지로 댐 등의 두꺼운 콘크리트 공사 및 더운 지역 공사에 활용
Type V	High sulfate resistance (내황산염)	Structure exposed to high levels of sulfate ions (해수), 원자력발전소, 항만구조물, 장대교량 등
White	White color	Decorative (otherwise has properties similar to Type I)

Batching Concrete Materials

- **Designing a Concrete Mix**
  - Mix design is the process of selecting suitable ingredients of concrete and determining their relative quantities with the objective of producing as economically as possible concrete of certain minimum properties such as workability, strength, and durability.
  - So, basic considerations in a mix design is cost and minimum properties
  - The requirements of concrete in hardened state are specified by the structural engineer.
  - The requirements of fresh concrete such as workability, setting time are specified by the construction engineer (type of construction, placing methods, compacting techniques and transportation).

Batching Concrete Materials

- **Water-Cement Ratio**
  - w/c = weight of water / weight of cement
  - Example
    - Weight of water mixed at the plant: 292 lbs
    - Weight of cement: 685 lbs/cy
    - w/c = 292/685 = 0.43

    - If you add 10 gallons of water per cy at job site, then
    - Extra water = 10 gallons/cy X 8.33 lbs/gallon = 83.3 lbs
    - w/c = 375.3/685 = 0.55 > 0.43

Batching Concrete Materials

- **Aggregates**
  - Clean, hard, strong, durable, and round or cubical in shape
  - Resistant to abrasion from weathering and wear
- **Mix Proportions**

$$Volume(cf) = \frac{Weight\ of\ the\ ingredient(lb)}{Specific\ gravity\ of\ the\ ingredient \times 62.4lb/cf}$$

  - Maximum size aggregate
  - Minimum cement content
  - Maximum water-cement ratio
  - The average specific gravity (비중) of cement: 3.15
  - The average specific gravity of coarse or fine aggregate: 2.65
  - Water weight: 62.4 lb/cf
  - 1 cf of water = 7.48 U.S. gallons
  - 1 gallon of water: 8.33 lb
  - Fine aggregates: 25-45% of total aggregate volume

$$Volume(cf) = \frac{Weight\ of\ the\ ingredient(lb)}{Specific\ gravity\ of\ the\ ingredient \times 62.4lb/cf}$$

Batching Concrete Materials

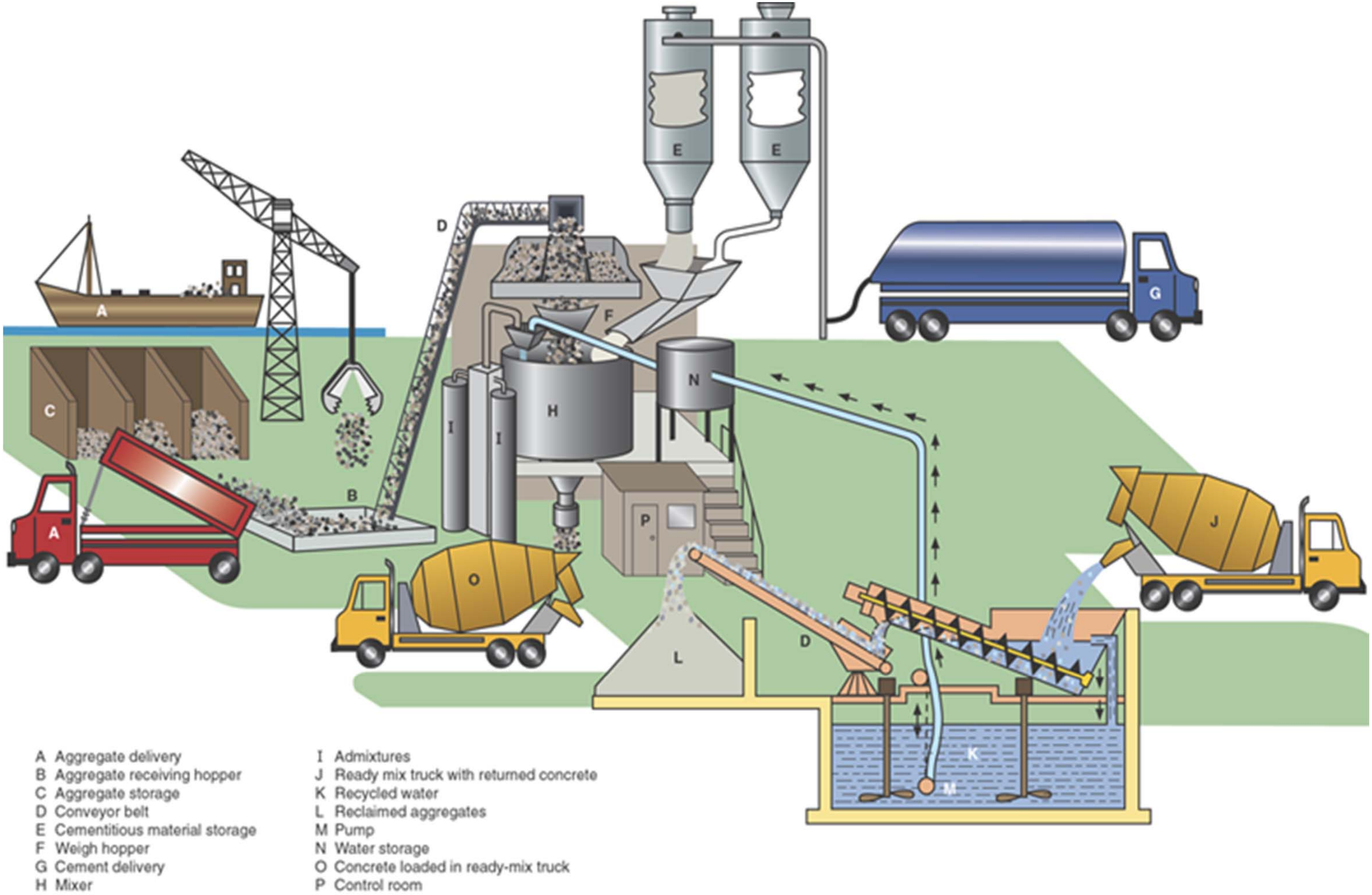
- Determine the quantities(weight) of materials required per cubic yard to create a concrete mix. The specifications require a maximum size aggregate of 1.5 in., a minimum cement content of 6 sacks per cy, and a maximum water-cement ratio of 0.65. 6% air voids, 35% fine aggregates.

Mixing Concrete

- Unless the project is in a remote location or is relatively large, the concrete is batched in a central batch plant and transported to the job site in transit-mix trucks often referred to as ready-mixed concrete trucks.
- Ready-mixed concrete must be available within a reasonable distance from the project. At remote locations and locations requiring large quantities of concrete, generally concrete plants are set up on site.
- Most popular ready-mixed concrete trucks:

  8 cy
- Result in stiffening the mixture and allow the addition of water at the job site to restore the slump, followed by remixing with additional revolutions

Mixing Concrete



Mixing Concrete

- **Order of Ready-Mixed Concrete**
  - **Recipe batch**: the purchaser assumes responsibility for proportioning the concrete mixture, including specifying the cement content, the maximum allowable water content, percentage air, the admixtures required. The purchaser may also specify the amounts and type of coarse and fine aggregate. The purchaser assumes full responsibility for the resulting strength and durability of the mixture.
  - **Performance batch**: the purchaser specifies the requirements for the strength of the concrete, and the manufacturer assumes full responsibility for the proportions of the various ingredients that go into the batch.
  - **Part performance and part recipe**: the purchaser generally specifies a minimum cement content, the required admixtures, and the strength requirement, allowing the producer to proportion the concrete mixture within the constraints imposed. ***MOSTLY USED: ensure min. durability + allowing the supplier some flexibility for the most economical mixture.***

Mixing Concrete

- **Mixing at Site**

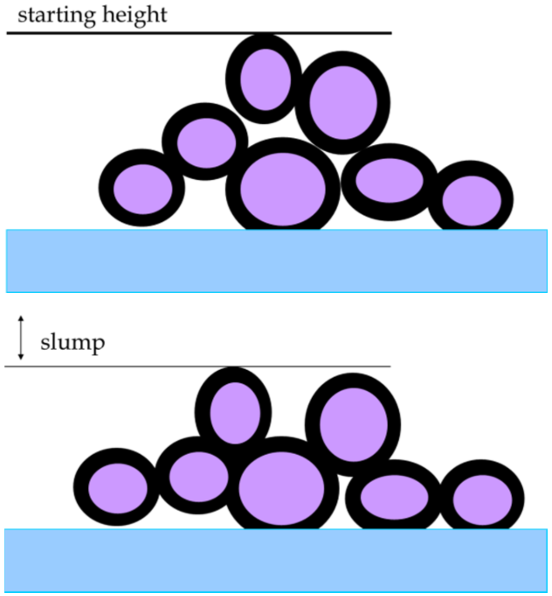
- Mixing time should be sufficient to produce a uniform concrete. The time of mixing depends on the type of mixer and also to some properties of fresh concrete
  - Under-mixing: non-homogeneity
  - Over-mixing: danger of water loss, breakage of aggregate particles

Workability: It is desirable that freshly mixed concrete be relatively easy to transport, place, compact and finish w/o harmful segregation. A concrete mix satisfying these conditions is said to be workable.

Mixing Concrete

- ## Slump Test
  - Measure of workability, pseudo measurable value based on an American Society for Testing and Materials standard test (ASTM C143)
  - Fresh concrete is placed into a hollow frustrum of a cone (top: 4 in in diameter, bottom: 8 in, high: 12 in)
  - After filling, the cone is raised from the concrete, allowing the fresh concrete to "slump" down

Types of Construction	Slump (in)	
	Max	Min
Reinforced foundation walls and footing	3	1
Plain footings, caissons, and substructure walls	3	1
Beams and reinforced walls	4	1
Building columns	4	1
Pavements and slabs	3	1
Mass concrete	2	1

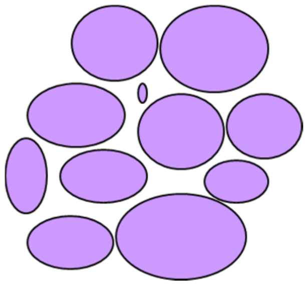


Entrapped air: *air (1-2%) naturally entrapped into the concrete*
Entrained air: *surface chemical reaction by AE(air entraining) agent produces entrained air bubbles into the concrete*

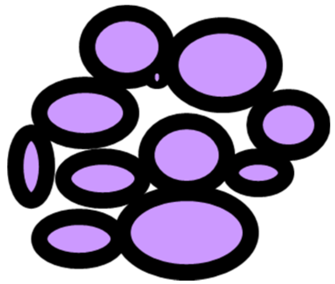
AE제: 기포를 발생시켜 쿠션역할을 하여 균열방지 및 내구성 증가, 유동성을 좋게 하여 부어넣기작업을 용이하게 함.

Mixing Concrete

- **Factors Affecting Workability**
  - Method and duration of transportation
  - Quantity and characteristics of cementing materials



Low paste content
Harsh mix

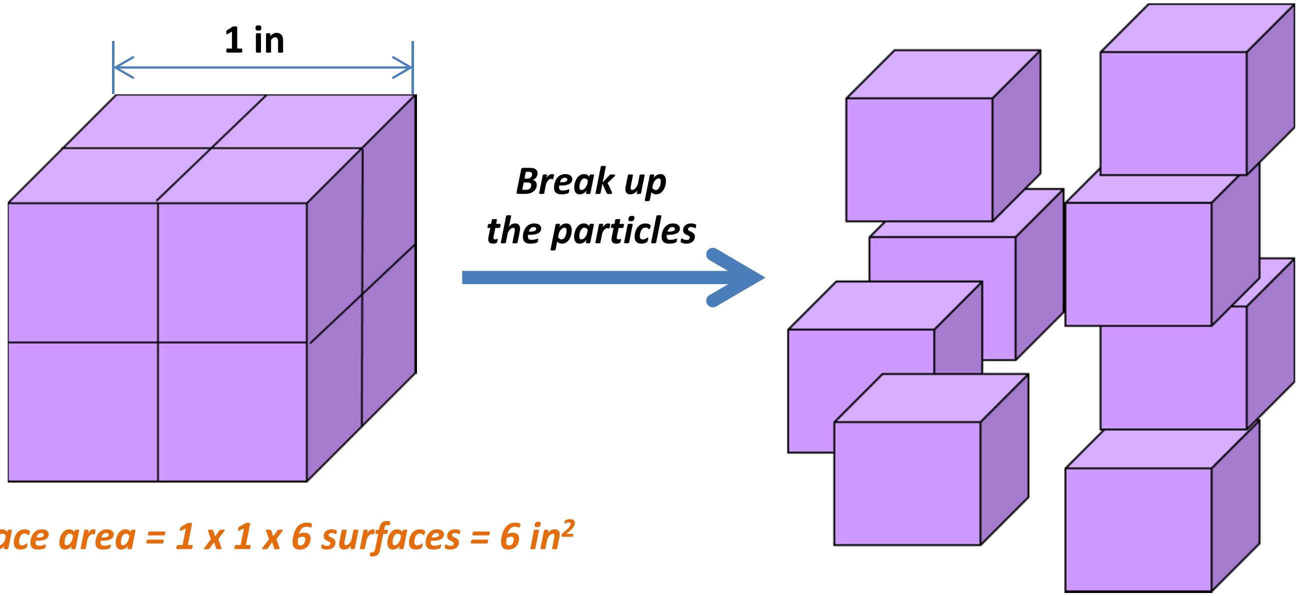


High paste content
Rich mix

  - Amount of water
  - Amount of entrained air
  - Concrete and ambient air temperature
  - Quantity and characteristics of chemical admixtures

Mixing Concrete

- **Factors Affecting Workability**
  - Aggregate grading, shape and surface texture



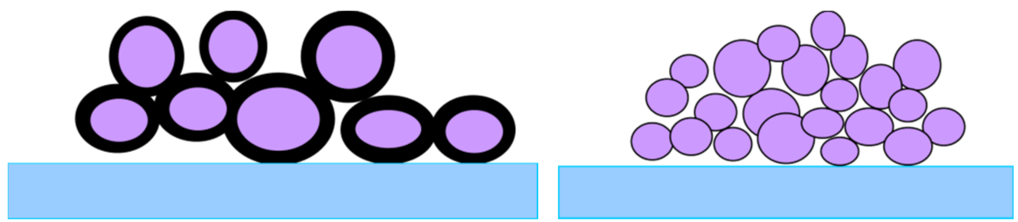
Surface area = 1 x 1 x 6 surfaces = 6 in^2

Surface area
= 0.5 x 0.5 x 6 surfaces x 8
= 12 in^2

If breaking it up further,
Surface area
= 0.25 x 0.25 x 6 x 8 x 8
= 24 in^2

Larger particles, less surface area, thicker coating, easy sliding of particles → higher slump

Smaller particles, more surface area, thinner coating, interlocking of particles → lower slump

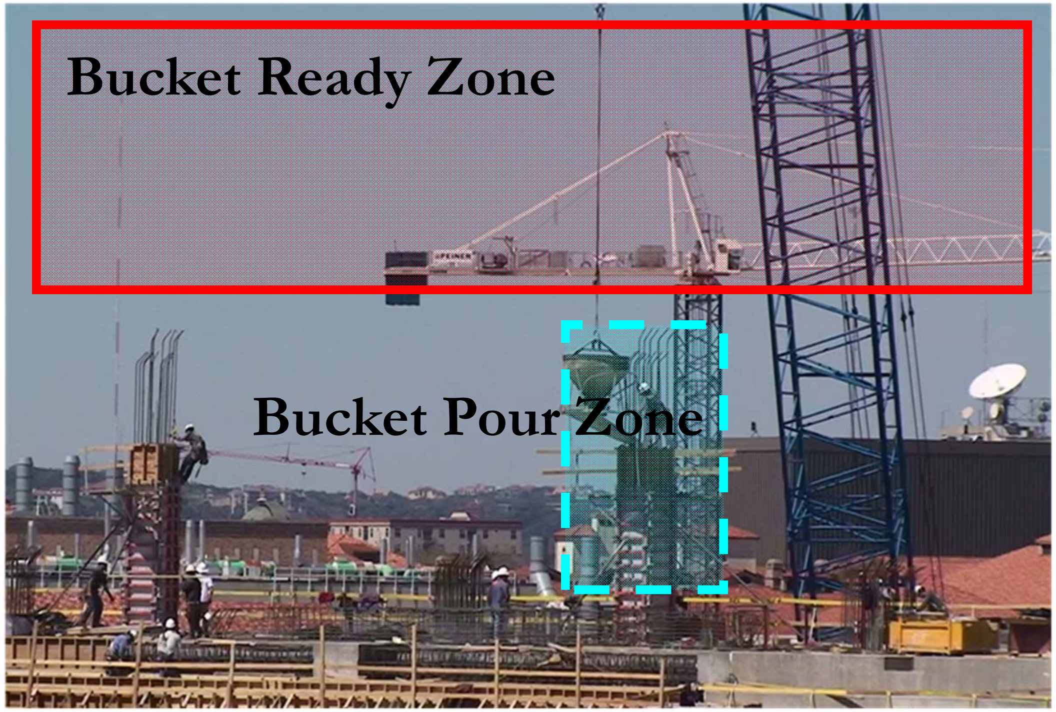


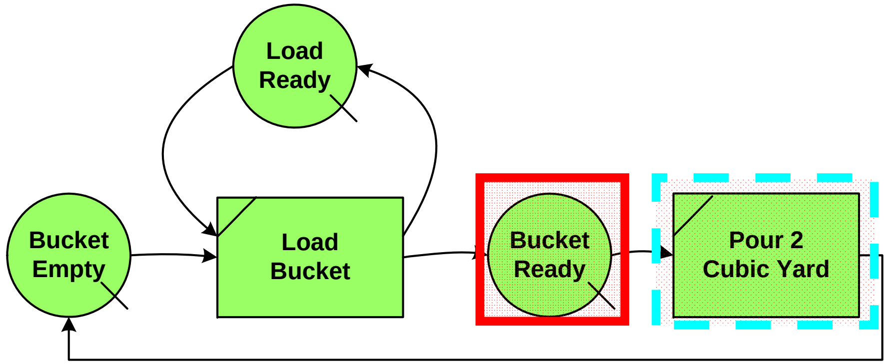
Placing Concrete

- **Buckets**
  - Properly designed bottom-dump buckets permit concrete placement at the lowest practical slump. Gates should be designed so that they can be opened and closed at any time during the concrete discharge.
  - Care should be exercised to prevent the concrete from segregating as a result of discharging from too high above the surface or allowing the fresh concrete to fall past obstructions.
- **Hand Buggies/Wheelborrows**
  - 2 wheels vs 1 wheel
  - 4 to 9 cf of concrete
  - Distance less than 200 ft

Placing Concrete

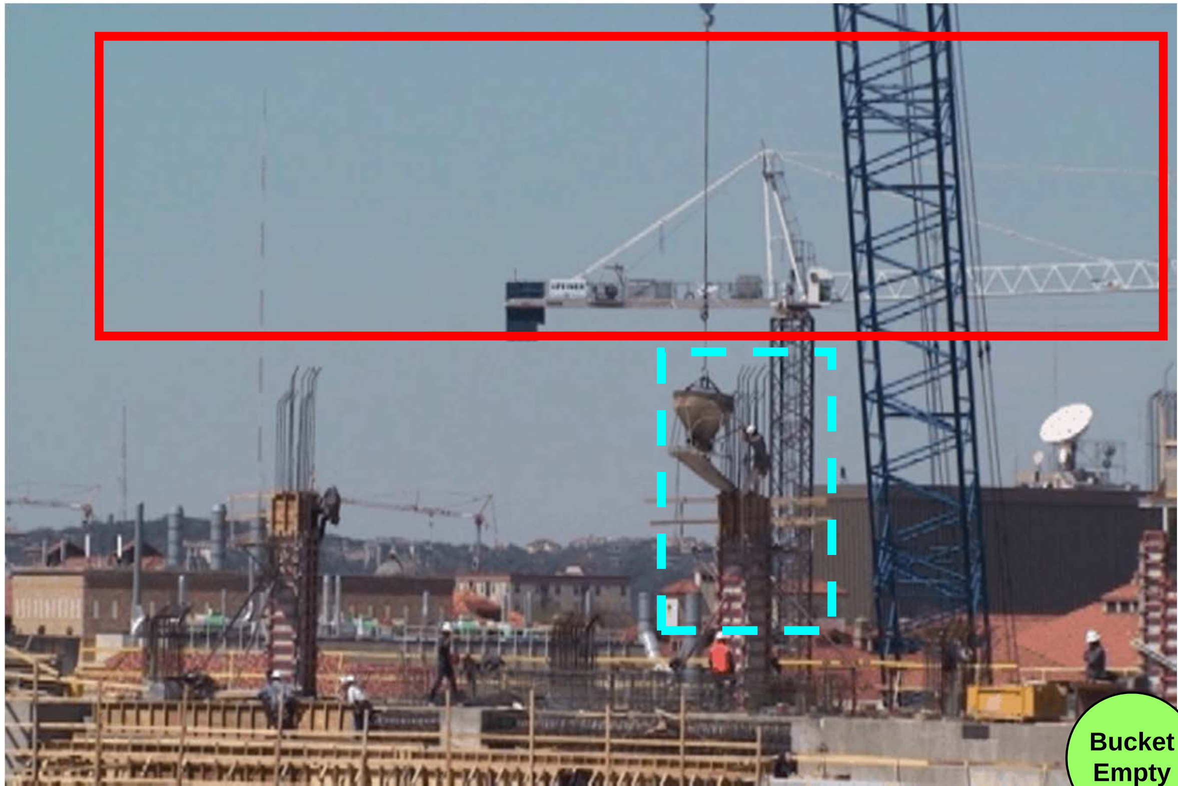
- Rapid Productivity Analysis of Concrete Placement

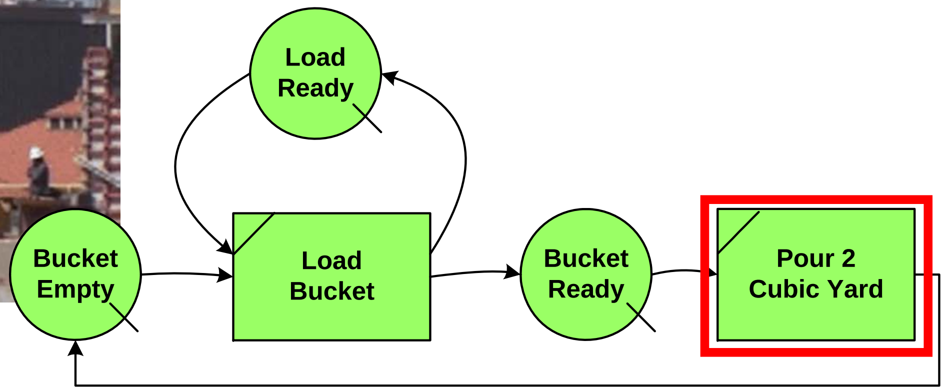




Placing Concrete

- Rapid Productivity Analysis of Concrete Placement





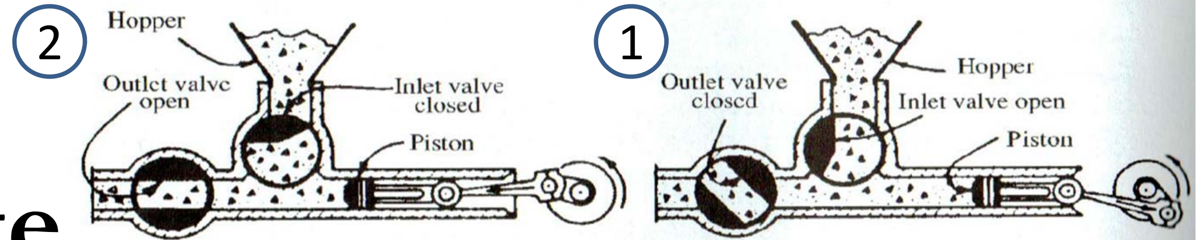
Placing Concrete

- **Chutes**
  - Transfer concrete from a higher elevation to a lower elevation
  - Round bottom, slope steep enough for the concrete to flow continuously without segregation
- **Belt Conveyors**
  - Provide for the rapid movement of fresh concrete but must have proper belt size and speed to achieve the desired rate of transportation
  - Attention given to the points where the concrete leaves one conveyor and either continues on another conveyor or is discharged, as segregation can occur.
  - Optimum slump: 2.5 to 3 in

A belt conveyor to place roller-compacted concrete

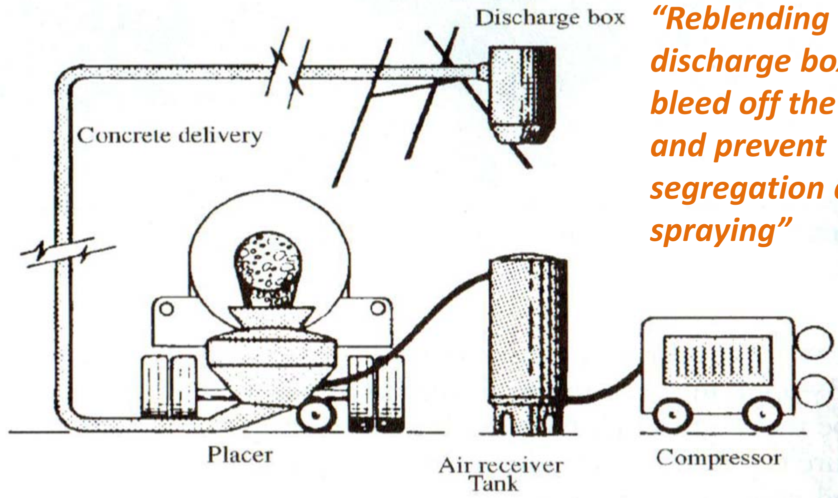
Placing Concrete

- **Concrete Pumps**
  - By applying pressure to a column of a fresh concrete in a pipe, the concrete can be moved through the pipe if a lubricating outer layer is provided and if the mixture is properly proportioned for pumping.
  - Need uniform workability and consistency



Inlet valve opens while outlet valve is closed and concrete is drawn into cylinder by gravity and piston suction. As piston moves forward inlet valve closes, outlet valve opens, and concrete is pushed into pump line.

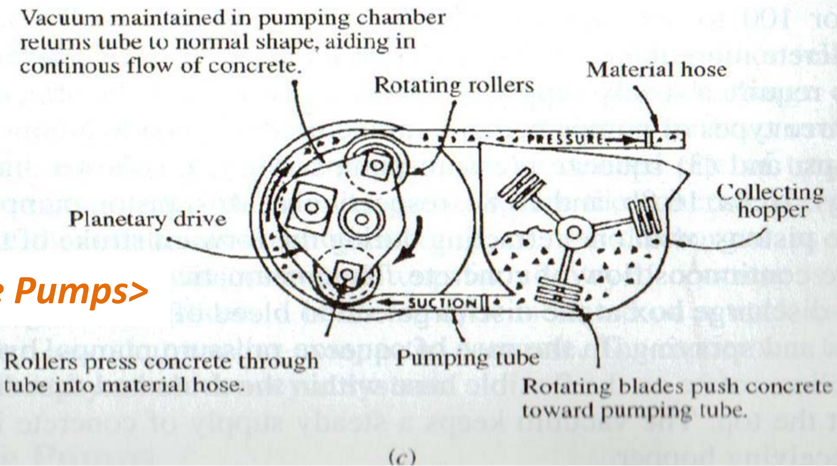
<Piston Pumps>



"Reblending discharge box to bleed off the air and prevent segregation and spraying"

Compressor builds up air pressure in tank, which forces concrete in placer through the line.

<Pneumatic Pumps>



<Squeeze Pressure Pumps>

Placing Concrete

- Can be mounted on trucks, trailers, or skids
- Truck-mounted pump & boom combination: efficient and cost-effective in saving labor and eliminating the need for pipelines to transport the concrete.

Placing Concrete

- Rules
  - Use a minimum cement factor of 517 lb(5.5 sacks) of cement/cy of concrete
  - Use a minimum pipe diameter of 5 in
  - Always lubricate the line with cement paste or mortar before beginning the pumping operating
  - Ensure a steady, uniform supply of concrete, with a slump of between 2 and 5 in as it enters the pump
  - Always presoak the aggregates before mixing them in the concrete to prevent their soaking up mix water under the imposed pressure
  - Never use aluminum lines. Aluminum particles will be scraped from the inside of the pipe as the concrete moves through and will become part of the concrete. They react each other liberating hydrogen gas that can rupture the concrete.
  - Avoid the use of reducers at the discharge end

Consolidating Concrete

- **Remove the entrapped air void when placed**
  - Concrete, a heterogeneous mixture of water and solid particles in a stiff condition, will normally contain a large quantity of voids when placed
  - Entrapped air can render the concrete totally unsatisfactory
  - Normally achieved through the use of mechanical vibrators

- **Internal**: have a vibrating casing or head that is immersed into the concrete and vibrate at a high frequency against the concrete

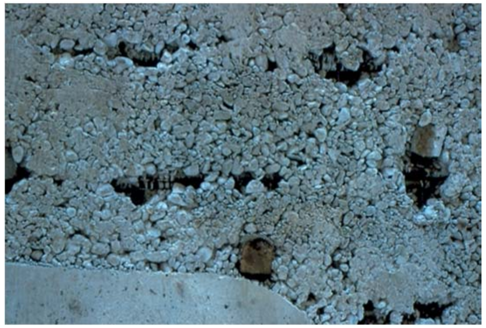
- **Surface**: exert their effects at the top surface and consolidate the concrete from the top down, used mainly in slab construction

- **Form**: external vibrators attached to the outside of the form or mold, vibrate the form that in turn vibrates the concrete, used in large precast concrete plants

Consolidating Concrete

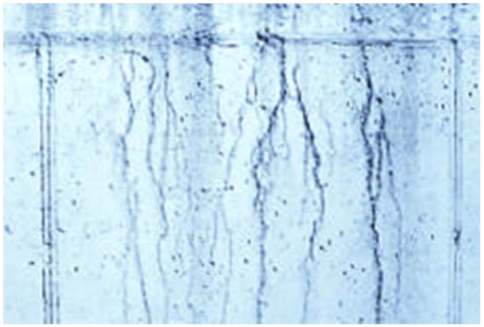
- **Inadequate consolidation can result in**
  - **<u>Honeycomb</u>**: voids left in concrete due to the dry mix that was not properly consolidated and failure of the mortar to effectively fill the spaces among coarse aggregate particles
  - **<u>Bugholes</u>**: excessive amount of entrapped air voids
  - **<u>Sand streaks</u>**: condition in which some of the Portland cement has been washed out leaving exposed fine aggregate in the surface, resulted from excessive bleeding
  - **<u>Placement lines (cold joints)</u>**: during continuous concrete placement unplanned joints are created between the concrete placed earlier and the later one.

Honeycomb



Bughole

Sand Streak

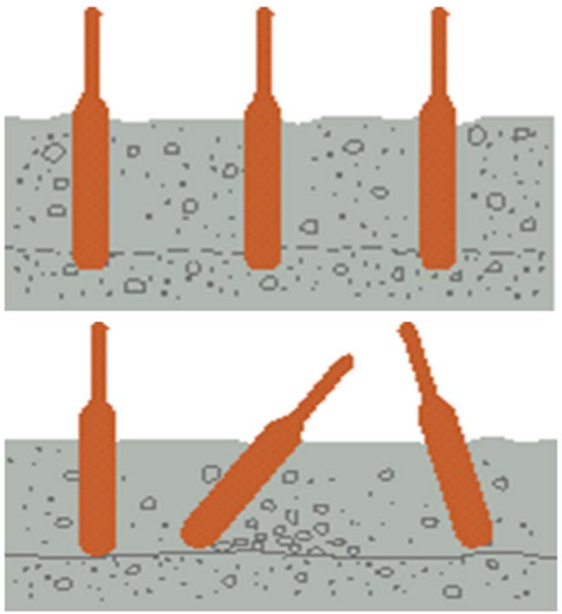


Consolidating Concrete

- **Vibration**
  - First it slumps the concrete, removing a large portion of air that is entrapped when the concrete is deposited. Then continued vibration consolidates the concrete, removing most of the remaining entrapped air.
  - The operator should note that the presence of air bubbles escaping to the concrete surface as the vibrator is inserted or placed. When these bubbles cease, vibration is generally complete and the vibrator should be withdrawn.
  - Vibration improves the bond between the reinforcing steel and the concrete, and thus is desirable. But avoid to damage to the vibrator and possible movement of the steel from its intended position

Consolidating Concrete

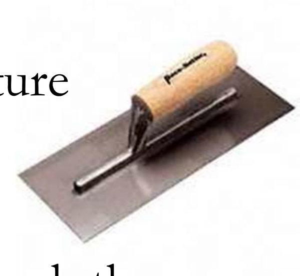
- **Correct Vibration**
  - Vertical penetration a few inches into previous lift (which should not yet be rigid) of systematic regular intervals will give adequate consolidation
- **Incorrect Vibration**
  - Haphazard random penetration of the vibrator at all angles and spacings without sufficient depth will not assure intimate combination of the two layers



Diameter of head (mm)	Recommended frequency (vib/min)	Approximate radius of action (mm)	Rate of placement (m^3/h)	Application
20-40	9000-15,000	80-150	0.8-4	Plastic and flowing concrete in thin members. Also used for lab test specimens.
30-60	8500-12,500	130-250	2.3-8	Plastic concrete in thin walls, columns, beams, precast piles, thin slabs, and along construction joints.
50-90	8000-12,000	180-360	4.6-15	Stiff plastic concrete (less than 80-mm slump) in general construction.

Finishing Concrete

- Any work done to a concrete surface after it has been consolidated will weaken the surface
- On a floor slab, sidewalk, or pavement the surface strength is very important!
  - Only the absolute minimum finishing necessary to impart the desired texture should be permitted
  - Each step in finishing operation from first floating to the final floating or troweling should be delayed as long as possible to allow the concrete to reach the desired grade and surface smoothness while it can still be worked



Curing Concrete

- Properties of concrete can improve with age as long as conditions are favorable for the continued hydration of cement. These improvements are rapid at early ages and continues slowly for an indefinite period of time.
- Curing is the procedures used for promoting the hydration of cement and consists of a control of temperature and the moisture movement from and into the concrete
- The primary objective of curing is to keep concrete saturated or as nearly saturated as possible: hydration reactions can take place in only saturated water filled with capillaries
  - Normally 14 days (reach to 40% compressive strength), 28 days (70%) with the optimum temperature b/w 5 and 27℃
- Proper curing reduces the detrimental effects of cracking and develops the intended strength of the concrete

Curing Concrete

- **Methods to supply additional water to prevent concrete drying**
  - Ponding with water (for slabs, 수중양생)
  - Covering with wet covers (습포양생)
  - Sprinkling (살수양생)
- **Methods to prevent loss of moisture by sealing the surface**
  - Water proof plastics (시트양생)
  - Spraying liquid membrane-forming compounds (피막양생)
  - Forms left in place
- **Accelerate strength gain by supplying heat and moisture**
  - Steam curing (증기양생), Heating coils (전열양생)

Wet covering

Sprinkling

Water proof plastic

Compound Spraying

Pipe-cooling: *use cold water or cold air flow through the pre-installed pipe inside of the concrete for cooling the concrete*

Placing Concrete in Different Weather

- ## Hot Weather
  - **Rapid hydration → early setting → rapid loss of workability**
  - When the temperature exceeds around 30℃ to 32 ℃, the resulting strength and durability of the concrete can be reduced
  - Extra problems due to low humidity, wind, excessive evaporation, direct sunlight
  - Solutions
    - The ingredients should be cooled before mixing: using ice instead of water in the mix, cooling the aggregate with liquid nitrogen
    - Windbreaks
    - Water ponding
    - Reflective coatings or coverings
    - Type IV Portland cement (low heat of hydration)

Placing Concrete in Different Weather

- **Cold Weather**
  - Need to keep the concrete above freezing during the first few days after placement (The concrete be kept at not less than 21℃ for 3 days or not less than 10℃ for 5 days after placement)
  - Solutions
    - Preheating the water
    - Heated enclosures, insulation
    - It is good to add 1% $CaCl_2$
    - Avoid to use ice or snow entrained aggregates
    - Clean mixers before mixing to remove any ice and snows
    - Important to use windbreaker during curing
    - Type III Portland cement (high early strength)

Shotcreting

- **Characteristics**
  - Mortar or concrete conveyed through a hose and pneumatically projected at high velocity onto a surface
  - The force of the concrete impacting on the surface compacts the mixture
  - A relatively dry mixture is used and thus it is able to support itself without sagging or sloughing even for vertical and overhead applications (accelerating agent)
  - Repair work, thin layers or fiber-reinforced layers

Shotcreting

- **Process** (5-10% loss by rebounding)
  - **Dry-mix process**
    - Placing the dry ingredients (cement and sand) into a hopper and then conveying them pneumatically through a hose to the nozzle
    - The water and the dry mixture is not completely mixed, but is completed as the mixture hits the receiving surface
    - **Advantage**: The water content can be adjusted instantaneously by the nozzleman, allowing more effective placement in overhead and vertical applications without using accelerators
    - The dry mix process is useful in repair applications when it is necessary to stop frequently, as the dry material is easily discharged from the hose
  - **Wet-mix process**
    - Pumping of a previously prepared concrete, typically ready-mixed concrete, to the nozzle
    - Compressed air is introduced at the nozzle to impel the mixture onto the receiving surface
    - **Advantage**: Larger volumes can be placed in less time

Fly Ash

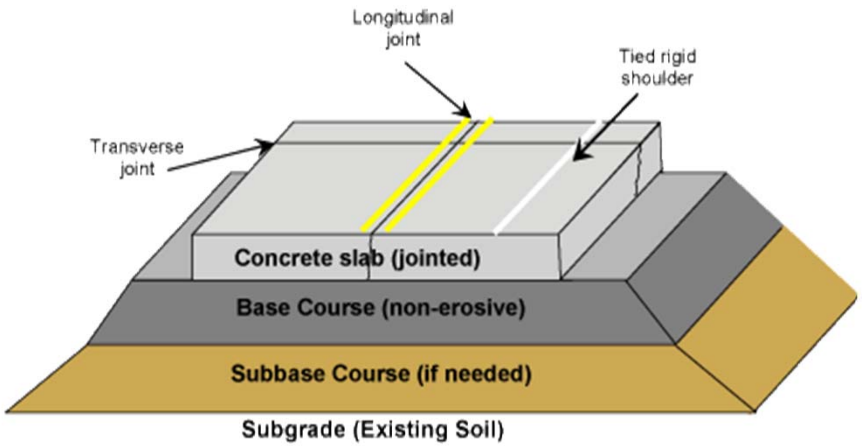
- **Characteristics**
  - By-product from the burning of coal
  - Portland cement, when it combines with water, releases calcium hydroxide. It does not contribute to strength or durability. By introducing fly ash, the calcium hydroxide and fly ash chemically combine in a process called pozzolanic action. Curing takes a relatively long time but the resulting concrete is stronger, less permeable and more durable than before.
  - It improves the workability of concrete and the pumpability of concrete mixes, and it is easier to finish
- **Problems**
  - QA/QC: Difficult to ensure high-quality fly ash is used (difficult production and produced by different plants)
  - The chances for a mistake being made in the batching are increased, making it desirable to increase the quality control efforts

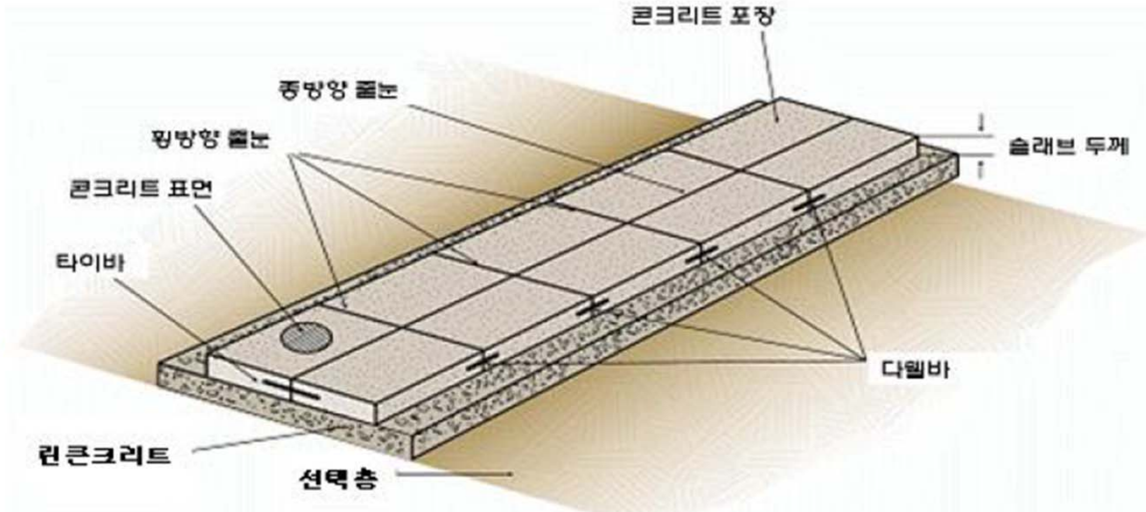
Slipform Paving

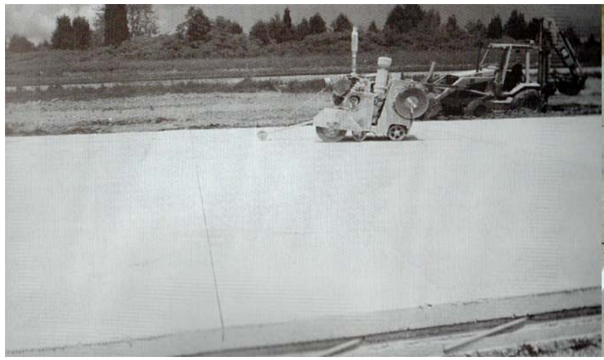
- **Slipform Paver**
  - Perform the functions of spreading, vibrating, striking off, consolidating, and finishing the concrete pavement with a minimum of handwork

Slipform Paving

- **Pavement Joint (줄눈)**
  - Joints are the discontinuities in the concrete pavement slab, and help to release stresses due to temperature variation, subgrade moisture variation, shrinkage of concrete, etc.







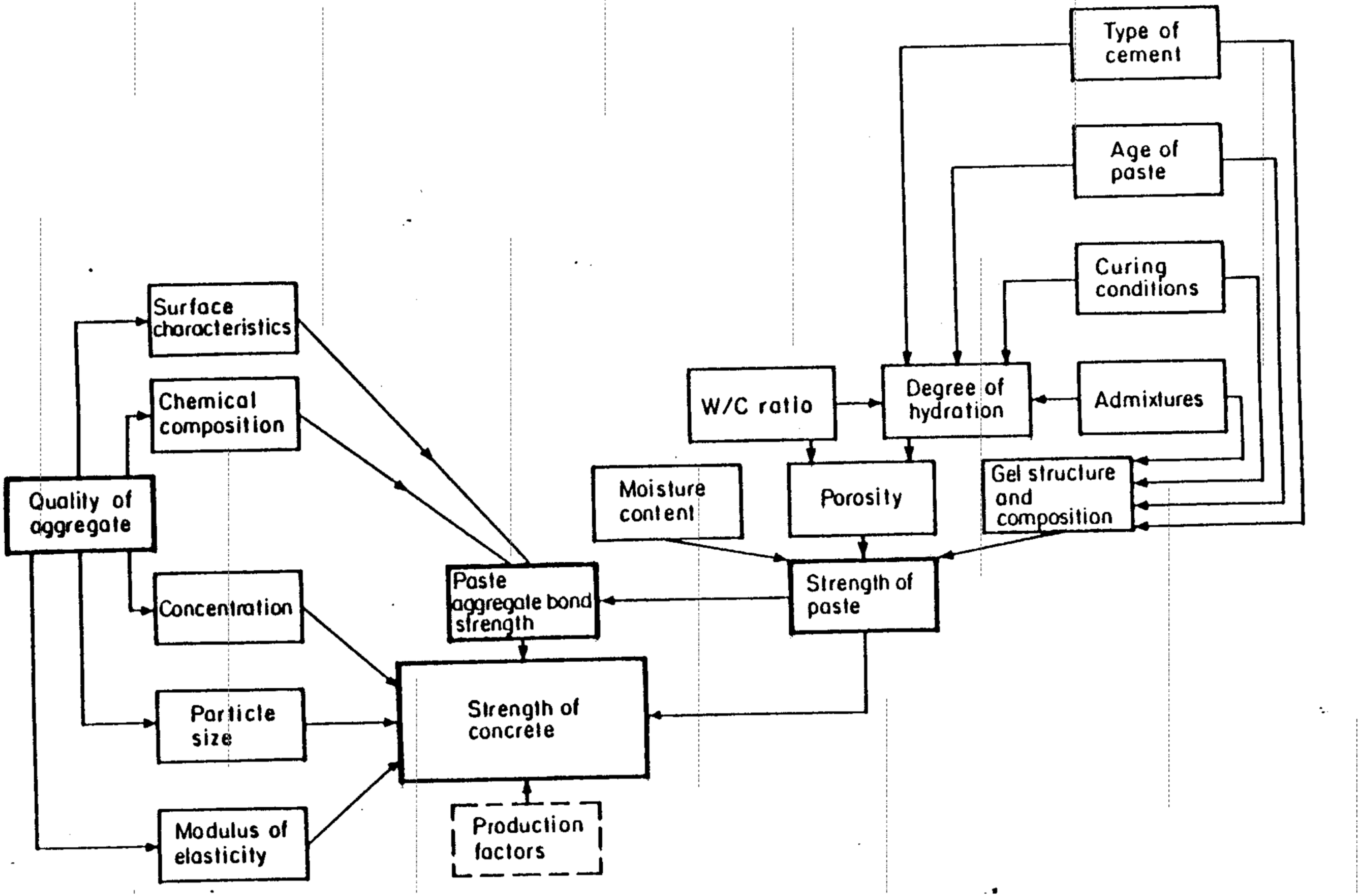
Diamond-bladed saw for cutting pavement joint

Concrete

- **Advantages**
  - Economical: Cheap
  - Ability to be cast: Flexible to any sizes and shapes
  - Good durability, fireproof, waterproof
  - Good to protect steels used for reinforcement

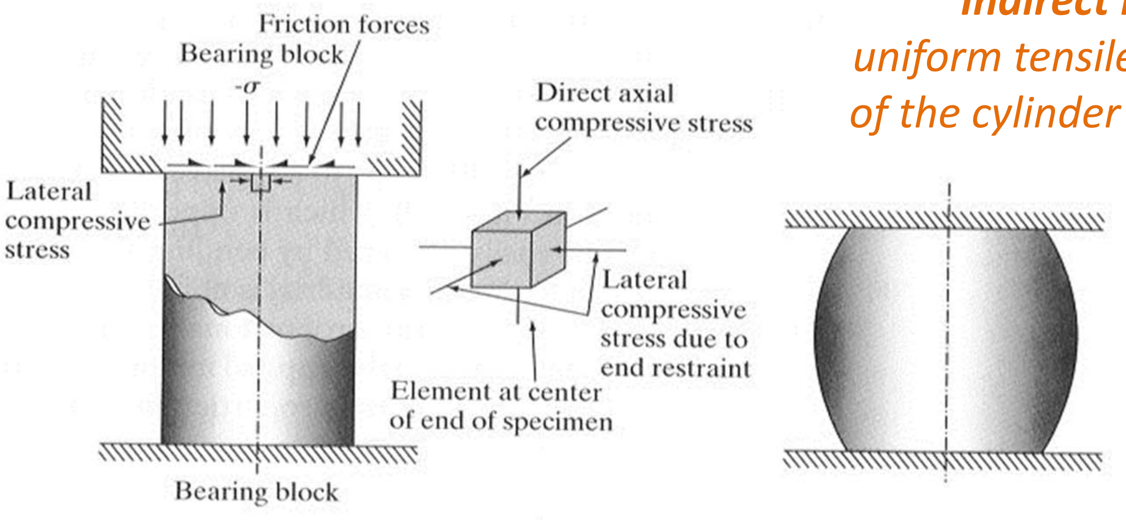
- **Disadvantages**
  - Heavy
  - Compare to compression, weak ductility and tensile strength: cracks
  - Deformation with continuous loading: creep
  - Possible drying shrinkage

What Affects Concrete Strength

- 

Strength Test

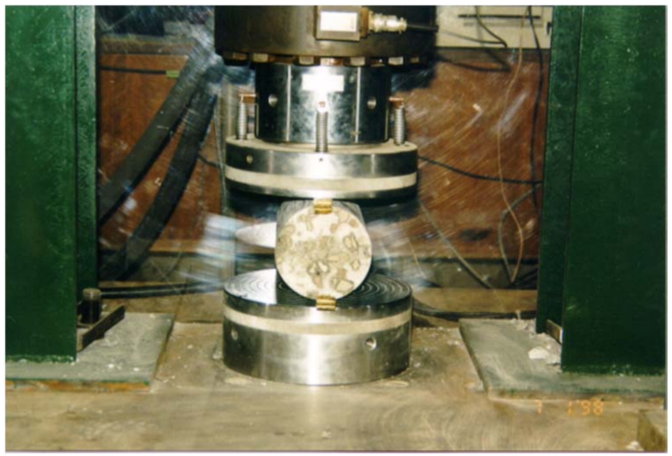
- **Compressive strength** is determined by loading properly prepared and cured specimens under compression.
- **Tensile strength** can be tested either by direct methods or indirect methods. The direct methods suffer from a number of difficulties related to holding the specimen properly in the testing machine w/o introducing stress concentration and to the application of load w/o eccentricity.



(a) End restraint in compression

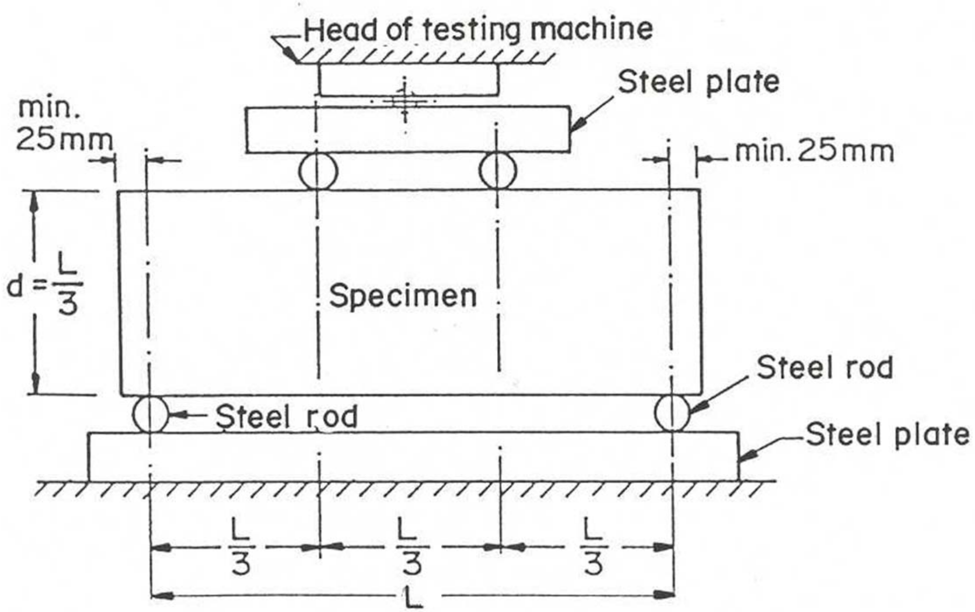
(b) Barrel-shaped specimen resulting from end restraint

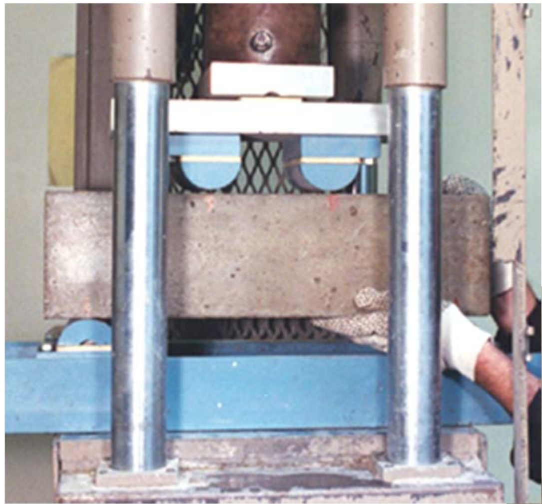
Indirect Method: *Due to applied compression load a fairly uniform tensile stress is induced over nearly 2/3 of the diameter of the cylinder perpendicular to the direction of load application*

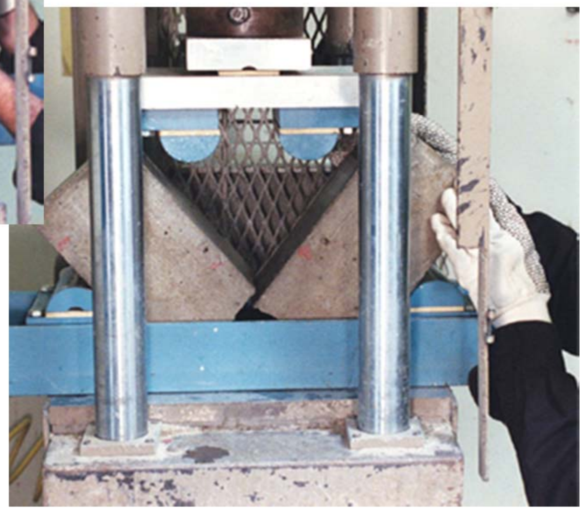


Strength Test

- **Flexural tensile strength** (휨강도) at failure or **the modulus of rupture** (파열) is determined by loading a prismatic (각기둥) concrete beam specimen. The results obtained are useful because concrete is subjected to flexural loads more often than it is subjected to tensile loads.







Segregation (재료분리)

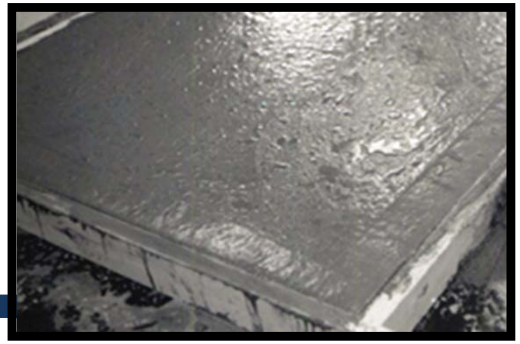
- Refers to a separation of the components of fresh concrete, resulting in a non-uniform mix
- The primary causes of segregation are differences in specific gravity and size of constituents of concrete. Moreover, improper mixing, improper placing and improper consolidation also lead to segregation.

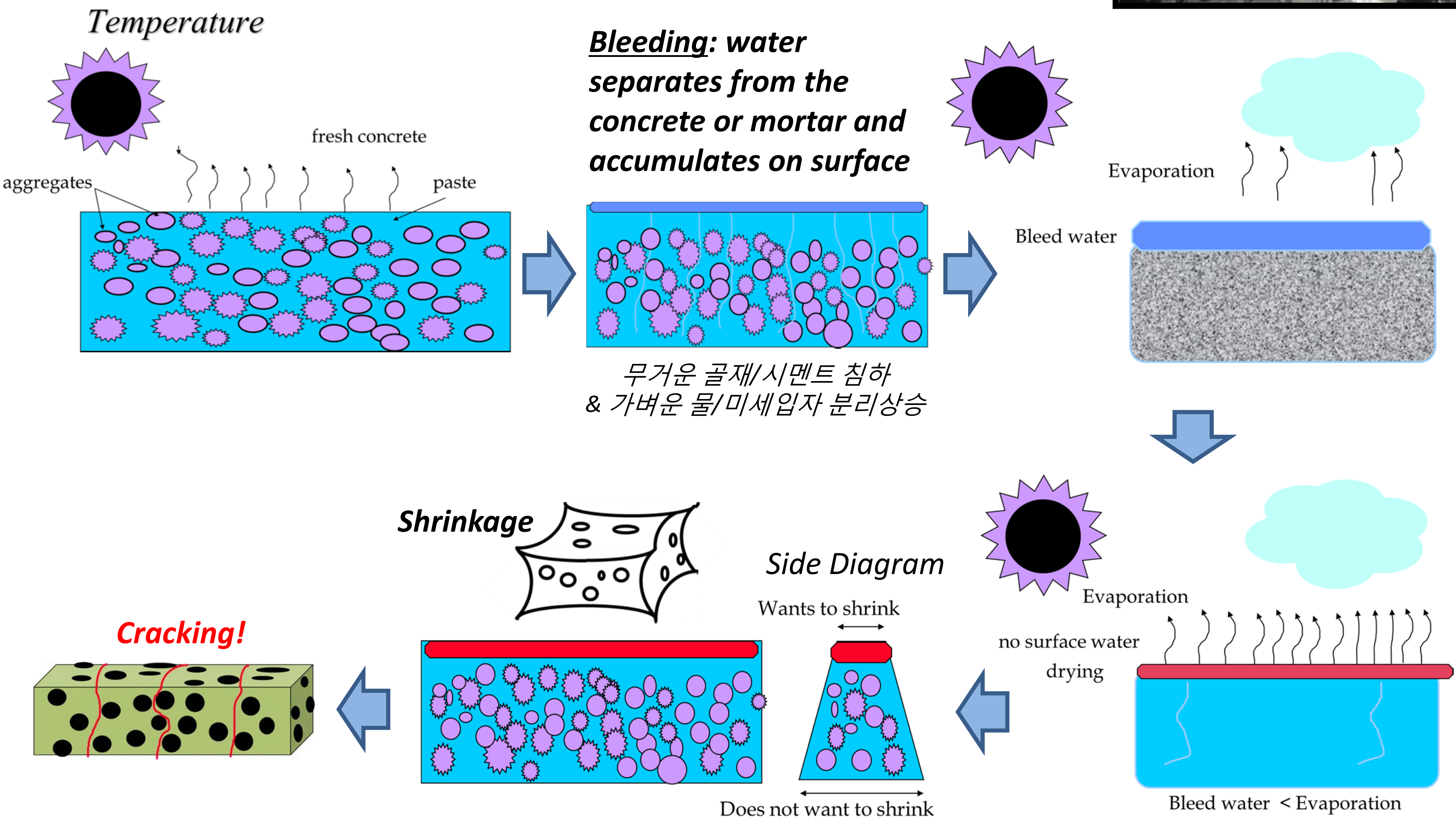
- **Factors**
  - Larger maximum particle size (25mm) and proportion of the larger particles
  - High specific gravity of coarse aggregate
  - Decrease in the amount of fine particles or cement
  - Particle shape and texture
  - W/C ratio
  - Improper mixing or transportation time
  - High placing heights and fast placing

Cracking

방지책

(1) 분말도 높은 시멘트 사용
(2) 단위수량이 적은 강자갈 사용
(3) 혼화재를 통한 수화속도 증진
(4) 낮은 콘크리트 타설 높이
(5) 적정한 타설속도 유지





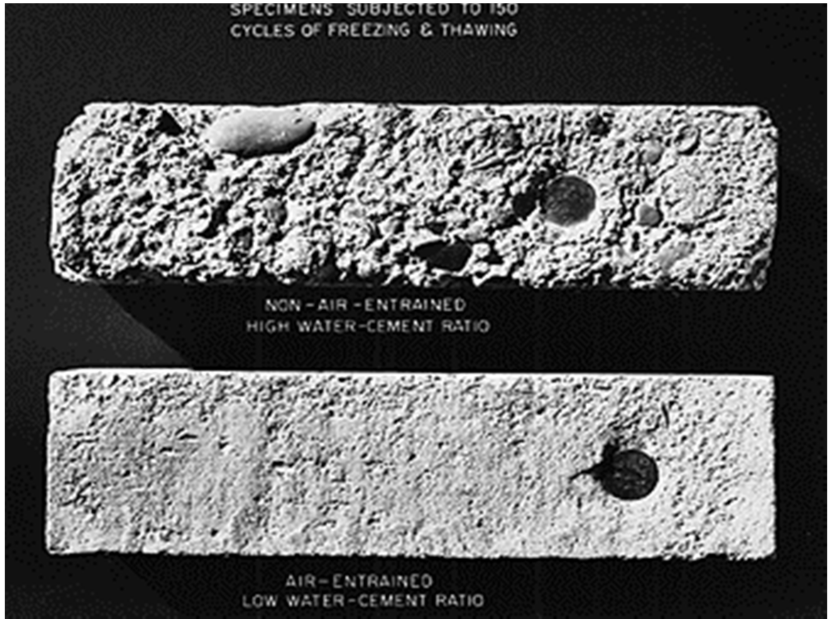
Efflorescence (백태) & Sulfate Attack

- **Efflorescence**
  - When water penetrates into concrete, it dissolves the non-hydraulic CH (and various salts, sulfates and carbonates of Na, K, Ca)
  - This alkali reaction with water takes salts outside of concrete and leaves a salt deposit.
- **Sulfate Attack**
  - Ground water in clay soils containing alkali sulfates. These solutions attack CH to produce gypsum. Later, gypsum and calcium alumina sulfates together with water react to form "ettringite".
  - Formation of ettringite is hardened cement paste or concrete leads to volume expansion thus cracking.

Corrosion / Freezing & Thawing

- **Corrosion**
  - Electrochemical reactions in the steel rebars of a reinforced concrete structure results in corrosion products which have larger volumes than original steel.
  - Thus this volume expansion causes cracks in reinforced concrete. In fact, steel is protected by a thin film provided by concrete against corrosion. However, that shield is broken by CO_2 of air or the Cl^- ions.

- **Freezing and Thawing**
  - Water when freezes expands in volume will cause internal hydration pressure and cracks the concrete.
  - To prevent the concrete from this distress air-entraining admixtures are used to produce air-entrained concrete.



Procedure for Mix Design

(1) Required concrete strength

(2) Choice of W/C ratio

(3) Choice of slump value (workability)

(4) Choice of maximum aggregate size

(5) Choice of entrapped air % (공기량)

(6) Choice of fine aggregate content (S/a, 잔골재율) with known volumes of coarse aggregate, water, cement and air & Unit water mass

(7) Estimation of unit volume of cements, fine aggregates, and coarse aggregates

(8) Adjustment for field mix (현장배합) *cf. specified mix (시방배합)*

Procedure for Mix Design

- **Specified Mix**
  - Mix based on the mixing design specifications
  - All fine aggregates pass No. 4 sieve
  - All coarse aggregates remain in No. 4 sieve
  - Does not consider aggregates' surface water: saturated aggregates with dried surface

- **Field Mix**
  - Consider aggregates' surface water
  - Consider % of fine aggregates remained in No. 4 sieve
  - Consider % of coarse aggregates passed No. 4 sieve

Mix design is first calculated based on specified mix specification and then adjusted meeting to the field mix design!

Procedure for Mix Design

- Example
  - **Design conditions**
    - Design strength (설계기준강도) $\sigma_{ck} = 240\ \text{kg/cm}^2$
    - Slump: 8cm
    - Variation factor (공사의 변동계수): 15%
  - **Material test results**
    - Specific gravity: cement (3.15), fine aggregate (2.60), coarse aggregate (2.65)
    - Maximum size of coarse aggregates: 25mm
    - Fineness modulus of fine aggregates (조립률): 2.90
  - **Condition of field aggregates**
    - Surface water mass: fine aggregate (4%), coarse aggregate (1%)
    - No.4 sieve: remaining fine agg. (4%), passed coarse agg. (3%)

Procedure for Mix Design

(1) Required concrete strength (σ_r, 배합강도)

- $\boldsymbol{\sigma_r = \sigma_{ck} \times \alpha = -210 + 215 \cdot \frac{C}{W}}$
    - σ_{ck}: design strength at 28 days of curing
    - α: incremental factor (required strength > design strength), determined by variation factor of the project
    - w/c: water-cement ratio

Variation Factor 변동 계수(%)	α 증가 계수	Constr. Condition 시공 관리 상태	
5	1.05	아주 좋다.	Good
10	1.07	아주 좋다.	
15	1.11	좋다.	
18	1.15	보통이다.	
20	1.19	나쁘다.	
25	1.35	나쁘다.	Bad

(2) Choice of w/c ratio

Procedure for Mix Design

(3) Choice of slump value: 8cm

(4) Choice of maximum aggregate size: 25mm

(5) Choice of entrapped air %: 1.5%

Max. Coarse Agg. Size 굵은 골재의 최대 치수 (mm)	Vol. Coarse Agg. Size 단위 굵은 골재 용적 (%)	Normal Concrete AE 제를 사용하지 않는 콘크리트		
		Air 갇힌 공기 (%)	Fine Agg. 잔 골재율 S/a (%)	Water 단위 수량 W (kg)
15	53	2.5	49	190
19	61	2.0	45	185
25	66	1.5	41	175
40	72	1.2	36	165
50	75	1.0	33	155
80	81	0.5	31	140

Procedure for Mix Design

(6) Choice of fine aggregate content (S/a) & Unit water mass

Max. Coarse Agg. Size 굵은 골재의 최대 치수 (mm)	Vol. Coarse Agg. Size 단위 굵은 골재 용적 (%)	Normal Concrete AE 제를 사용하지 않는 콘크리트		
		Air 갇힌 공기 (%)	Fine Agg. 잔 골재율 S/a (%)	Water 단위 수량 W (kg)
15	53	2.5	49	190
19	61	2.0	45	185
25	66	1.5	41	175
40	72	1.2	36	165
50	75	1.0	33	155
80	81	0.5	31	140

It is based on **2.80 fineness modulus of fine aggregates, 0.55 w/c ratio and 8cm slump concrete. If it is different, correction factors need to be applied.*

*(1) To increase **0.1 of fineness modulus**, increase **0.5 fine aggregate content***

*(2) To increase **0.05 w/c ratio**, increase **1 fine aggregate content***

*(3) To increase **1cm slump**, increase **1.2% of unit water mass***

Procedure for Mix Design

(7) Estimation of unit volume of cements and aggregates

1) Unit mass of cement (kg) = Unit mass of water / w/c
2) Unit volume of aggregates (m^3) =

$$1-\left(\frac{Unit\ Weight\ of\ Water(kg)}{1000}+\frac{Unit\ Weight\ of\ Cement(kg)}{Specific\ Gravity\ of\ Cement\times 1000}+\frac{Entrapped\ Air(\%)}{100}\right)$$

3) Unit volume of fine aggregates (m^3) = Unit volume of aggregates × S/a
4) Unit mass of fine aggregates (kg) = Unit volume of fine aggregates × Specific gravity of fine aggregates × 1000
5) Unit volume of coarse aggregates (m^3) = Unit volume of aggregates – Unit volume of fine aggregates
6) Unit mass of coarse aggregates (kg) = Unit volume of coarse aggregates × Specific gravity of coarse aggregates × 1000

Procedure for Mix Design

(7) Estimation of unit volume of cements and aggregates

1) Unit mass of cement (kg)
2) Unit volume of aggregates (m^3)

3) Unit volume of fine aggregates (m^3)
4) Unit mass of fine aggregates (kg)
5) Unit volume of coarse aggregates (m^3)
6) Unit mass of coarse aggregates (kg)

Max. Coarse Agg. Size

굵은골재 최대치수 (mm)	Slump (cm)	W/C (%)	잔골재율 S/a (%)	Unit Mass (kg/m^3)			
				Water (W)	Cement (C)	Fine Agg. (S)	Coarse Agg. (G)
25	8	45	39.5	175	389	705	1101

Procedure for Mix Design

(8) Adjustment for field mix

- Adjustment based on the sieve test
  - ***fine aggregates mass (X) + coarse aggregates mass (Y) = Calculated unit mass of aggregates***
  - Remaining fine aggregates at No. 4 sieve A (%)
  - Passed coarse aggregates at No. 4 sieve B (%)
  - ***X • A/100 + (1 – B/100) • Y = Calculated mass of coarse aggregates***
- Adjustment based on the surface water volume
  - X' = X x Surface water volume % (fine aggregates)
  - Y' = Y x Surface water volume % (coarse aggregates)

***Surface water needs to be subtracted from the water volume in mix and added into the aggregate mass**

- Amounts at field
  - Cement at field mix = Same as specified mix
  - Water at field mix = Specified mix – X' – Y'
  - Fine aggregates at field mix = X + X'
  - Coarse aggregates at field mix = Y + Y'

Procedure for Mix Design

(8) Adjustment for field mix

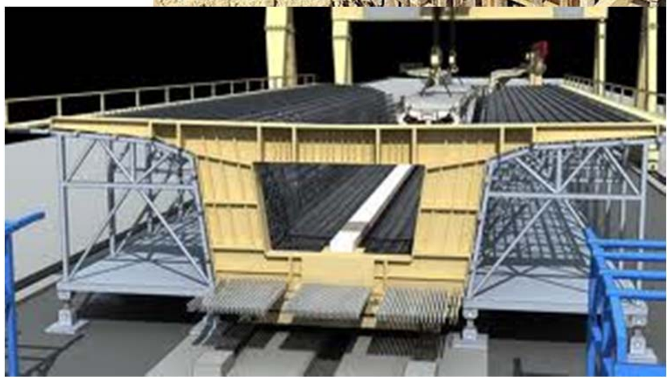
– Adjustment based on the sieve test

– Adjustment based on the surface water volume

– Amounts at field mix

Formwork (거푸집)

- Temporary structures to allow placed concrete to reach to designed shapes and strengths
- **Requirement**
  - Accurately designed
  - Enough bearing capacity to support concrete structures
  - Easy to install, assemble/disassemble
  - Possible reuse
- **Types**
  - Traditional timber formwork
  - Metal formwork
    - Easy to reuse, good supporting strength, clean finish of concrete, easy assembly
    - Expensive, possible rust during curing, affected by temperature



Formwork

- **Sliding Formwork**
  - Moveable molds that are lifted by hydraulic jacks, continuous process fitting reinforcement cables and placing concrete. Good for bridge columns, silos, LNG tanks, etc.

Supports (동바리)

- Temporary structure to support formworks and other scaffolding or material handling structures
- **Requirements**
  - Should distribute loads evenly and avoid foundation settlement where the supports are installed
  - Should thoroughly inspect supporting structures before concrete placement
- **Loads on Supports and Formwork**
  - Vertical
  - Horizontal by wind, water, earthquake, vibration
  - Internal stress by concrete