



Week 11
Concrete (1)

457.308 Construction Methods and Equipment
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Introduction

- The Assyrians in 690 _{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)

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 | (5) Consolidating (다짐) |
| (2) Mixing | (6) Finishing (표면처리) |
| (3) Transporting | (7) Curing (양생) |
| (4) Placing (타설) | |

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, 다양산출 가능, 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**

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

- 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**

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

- 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

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

Batching Concrete Materials

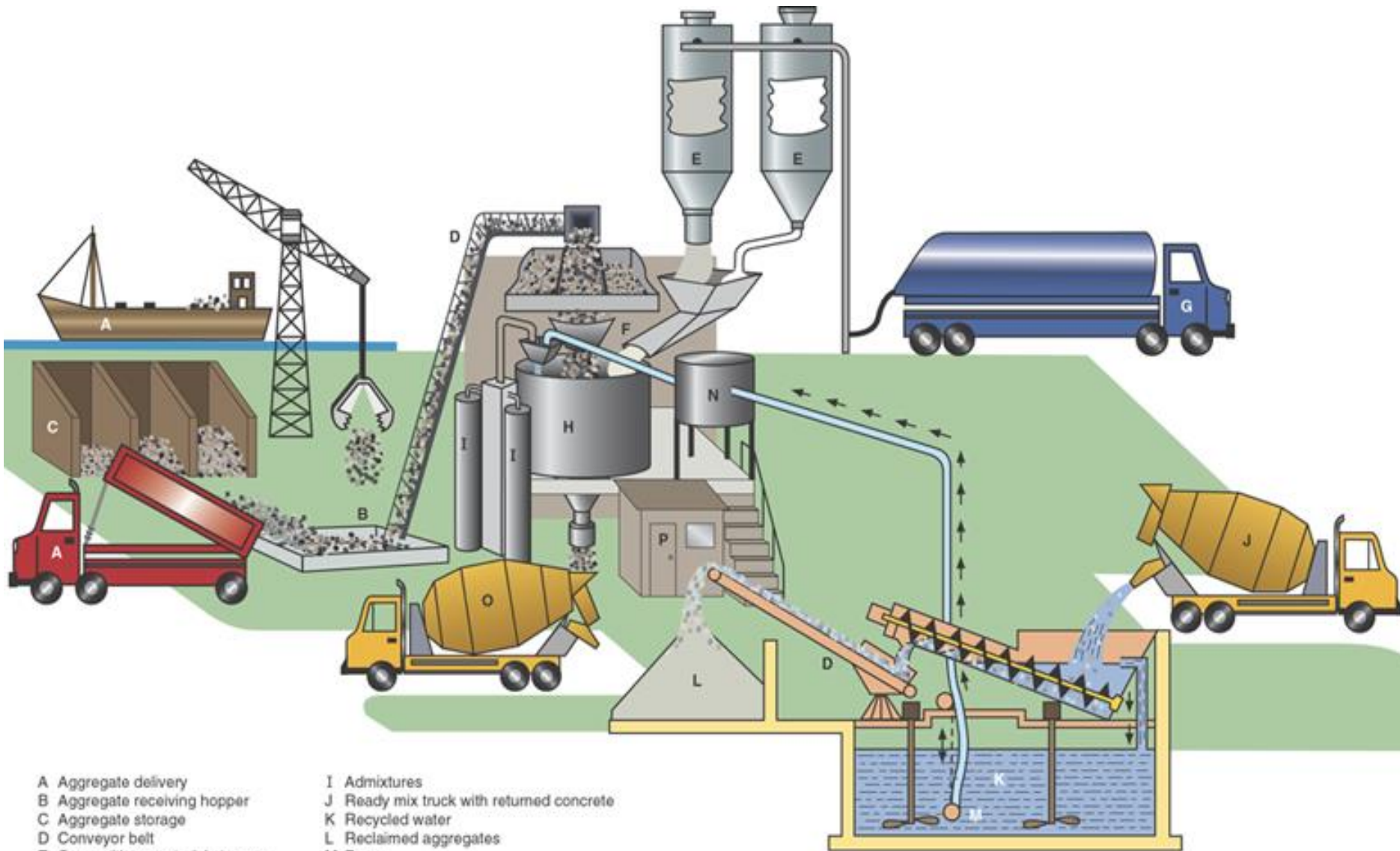
- Determine the quantities(weight) of materials required per cubic yard to create a concrete mix. The specifications require a maximum size aggregate of 1.5 in., a minimum cement content of 6 sacks per cy, and a maximum water-cement ratio of 0.65. 6% air voids, 35% fine aggregates.

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



- A Aggregate delivery
- B Aggregate receiving hopper
- C Aggregate storage
- D Conveyor belt
- E Cementitious material storage
- F Weigh hopper
- G Cement delivery
- H Mixer

- I Admixtures
- J Ready mix truck with returned concrete
- K Recycled water
- L Reclaimed aggregates
- M Pump
- N Water storage
- O Concrete loaded in ready-mix truck
- P Control room

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

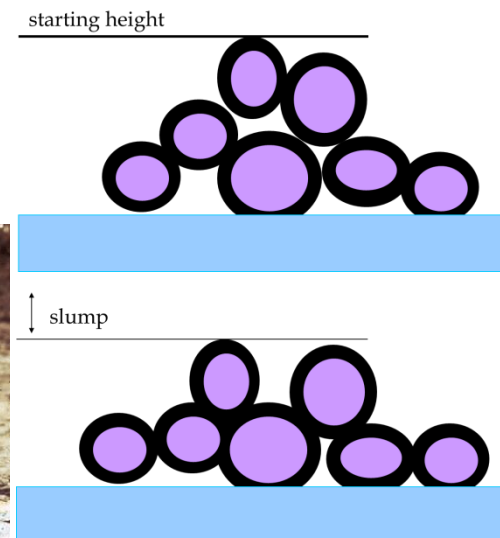
Workability: It is desirable that freshly mixed concrete be relatively easy to transport, place, compact and finish w/o harmful segregation. A concrete mix satisfying these conditions is said to be workable.

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

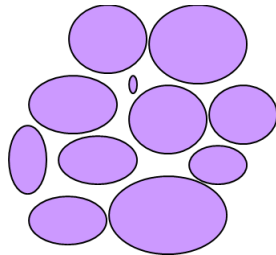
Entrained air: surface chemical reaction by AE(air entraining) agent produces entrained air bubbles into the concrete

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

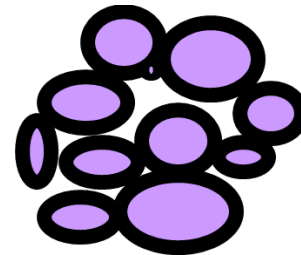
Mixing Concrete

• Factors Affecting Workability

- Method and duration of transportation
- Quantity and characteristics of cementing materials



*Low paste content
Harsh mix*



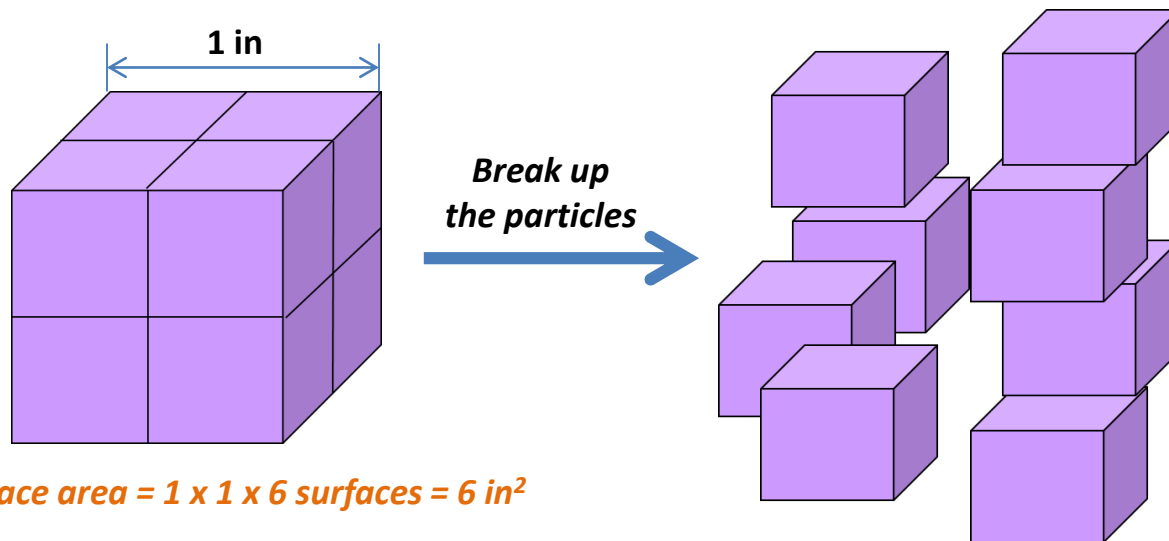
*High paste content
Rich mix*

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

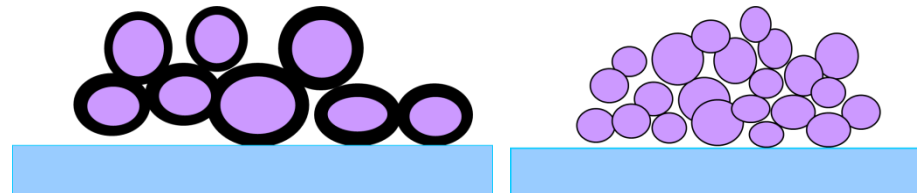
Mixing Concrete

- **Factors Affecting Workability**

- Aggregate grading, shape and surface texture



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



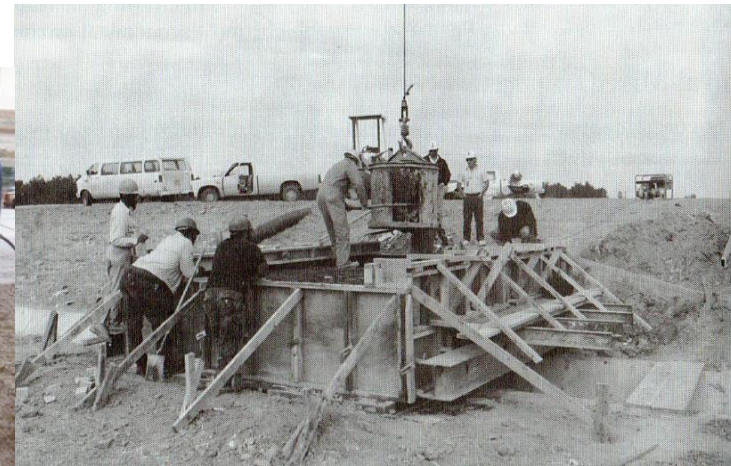
Placing Concrete

- **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.

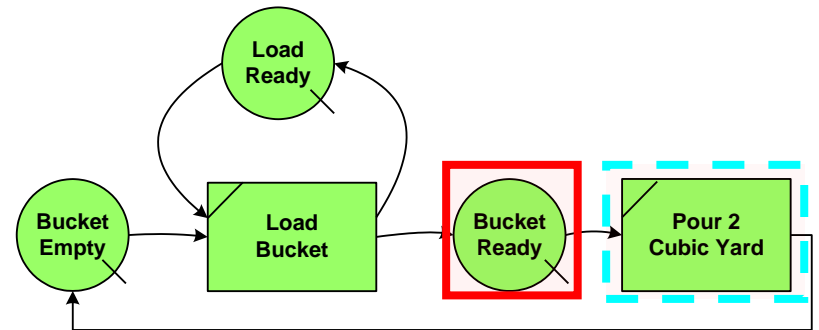
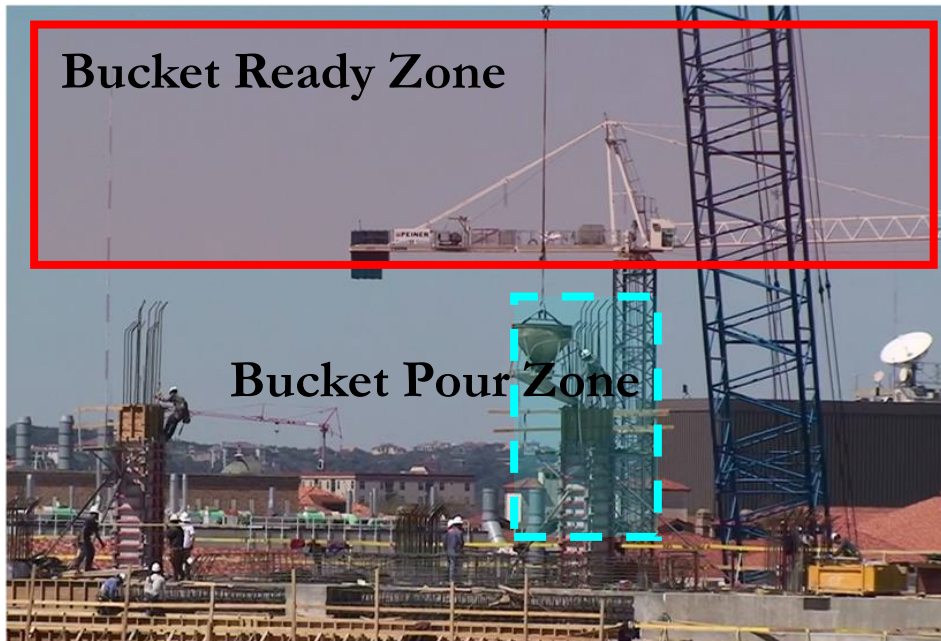
- **Hand Buggies/Wheelborrows**

- 2 wheels vs 1 wheel
- 4 to 9 cf of concrete
- Distance less than 200 ft



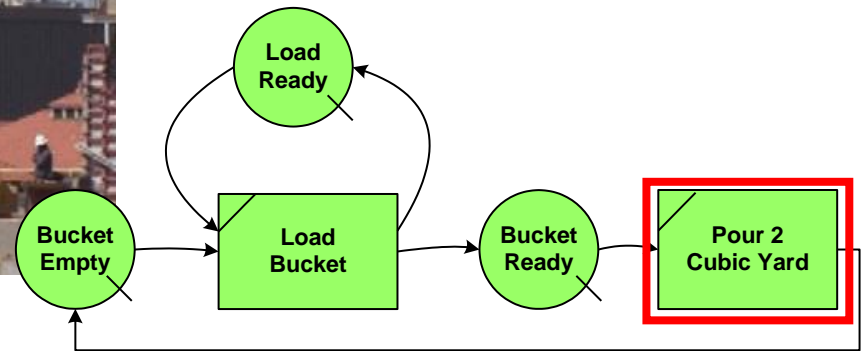
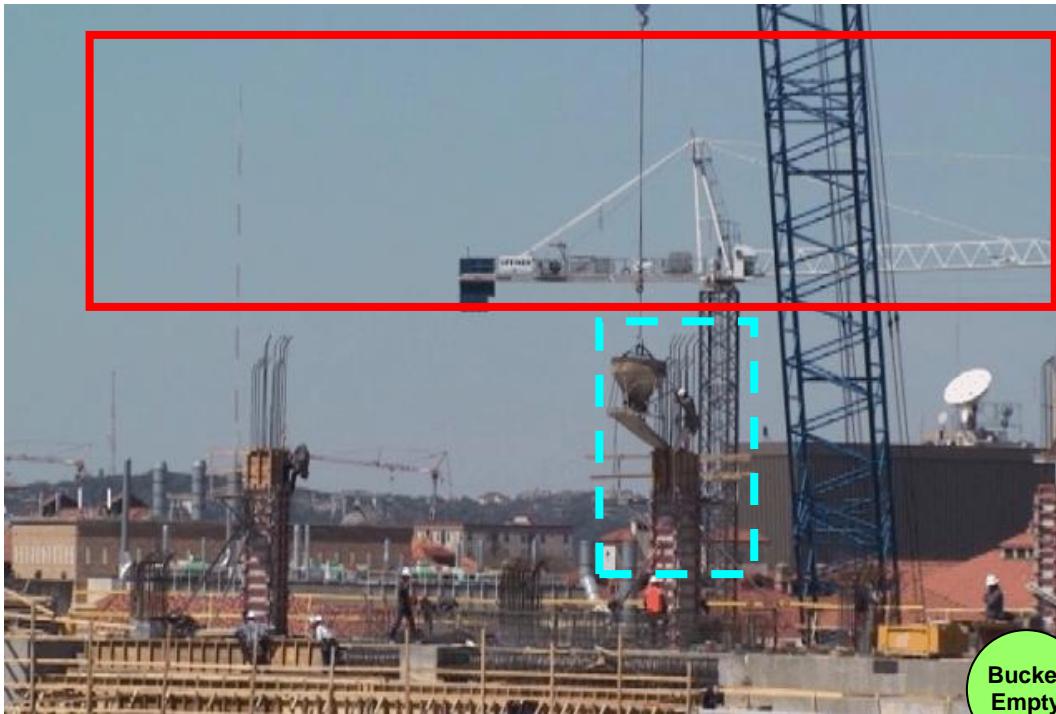
Placing Concrete

- 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

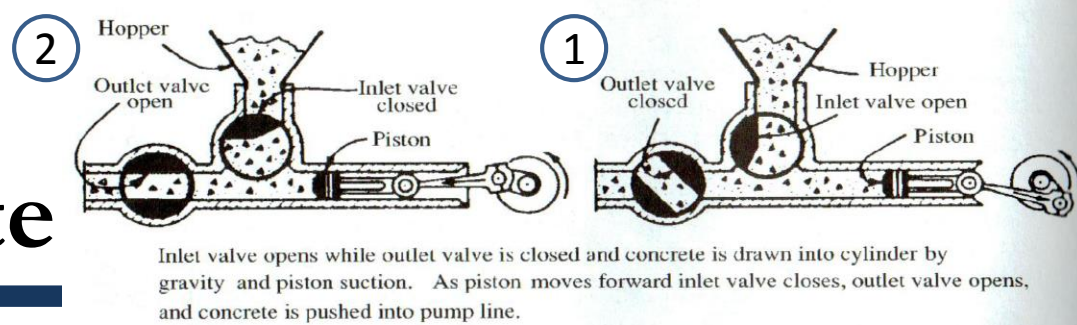


A belt conveyor to place roller-compacted concrete

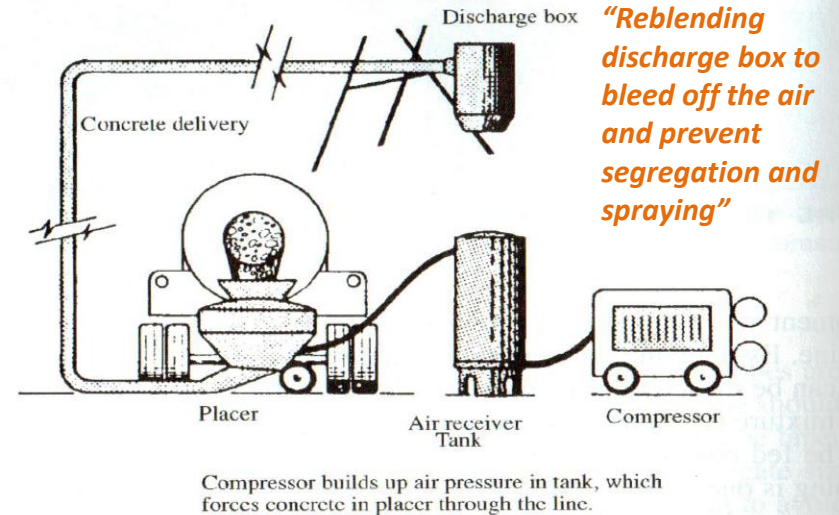
Placing Concrete

• 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

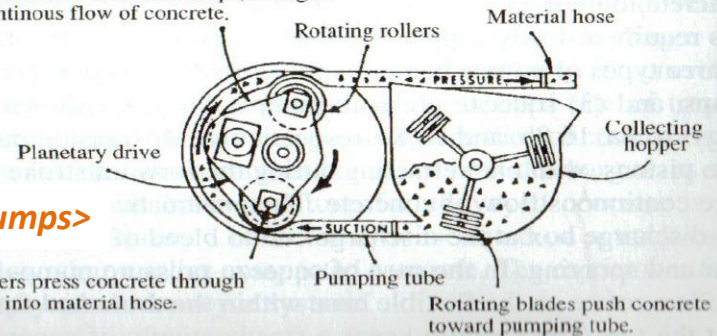


<Piston Pumps>



<Pneumatic Pumps>

Vacuum maintained in pumping chamber returns tube to normal shape, aiding in continuous flow of concrete.



<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

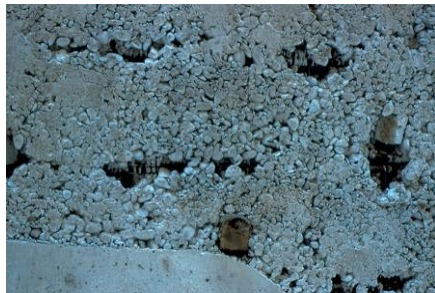
- **Remove the entrapped air void when placed**
 - Concrete, a heterogeneous mixture of water and solid particles in a stiff condition, will normally contain a large quantity of voids when placed
 - Entrapped air can render the concrete totally unsatisfactory
 - Normally achieved through the use of mechanical 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**
 - **Honeycomb**: 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
 - **Bugholes**: excessive amount of entrapped air voids
 - **Sand streaks**: condition in which some of the Portland cement has been washed out leaving exposed fine aggregate in the surface, resulted from excessive bleeding
 - **Placement lines (cold joints)**: during continuous concrete placement unplanned joints are created between the concrete placed earlier and the later one.

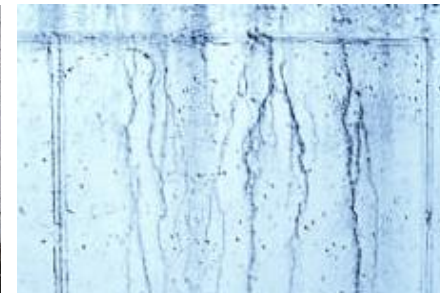
Honeycomb



Bughole



Sand Streak



Cold Joint



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

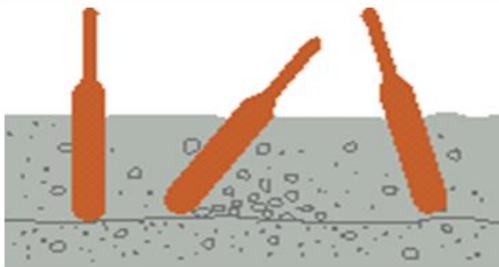
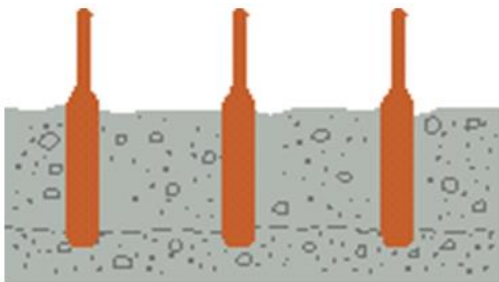
Consolidating Concrete

- **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°C
- 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°C to 32 °C, 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°C for 3 days or not less than 10°C 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