Earthmoving and Equipment (1)

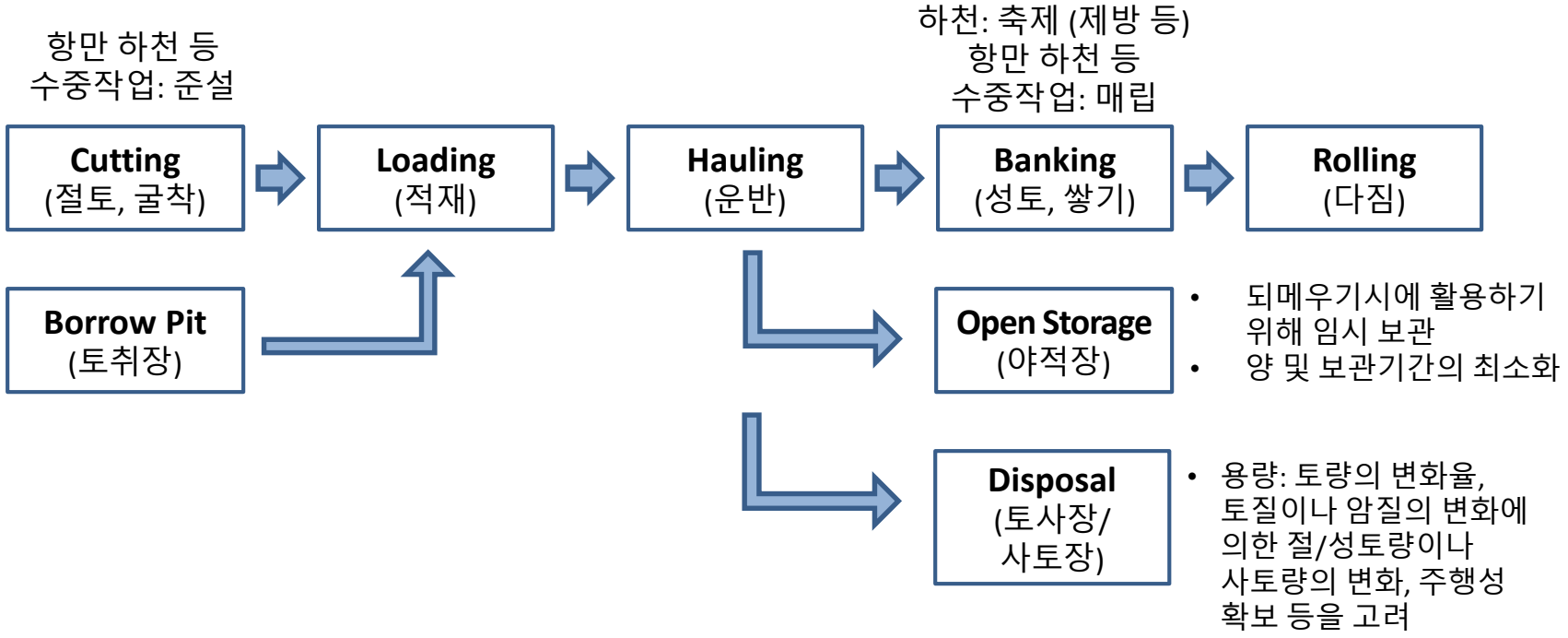
457.308 Construction Methods and Equipment

Department of Civil and Environmental Engineering
Seoul National University

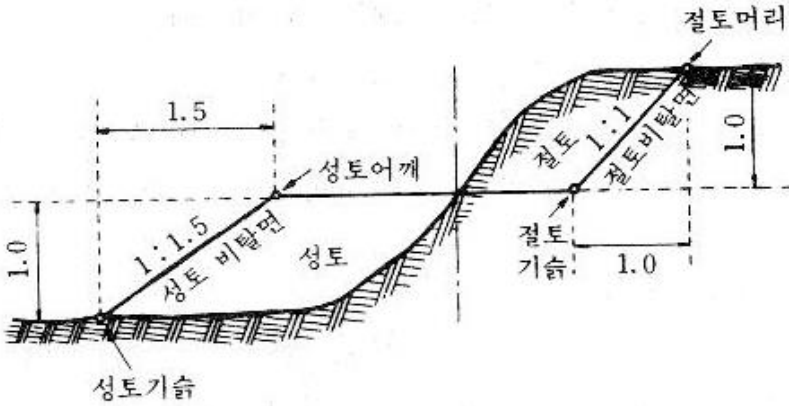
Prof. Seokho Chi
shchi@snu.ac.kr
건설환경공학부 35동 304호

Earthmoving (토공)

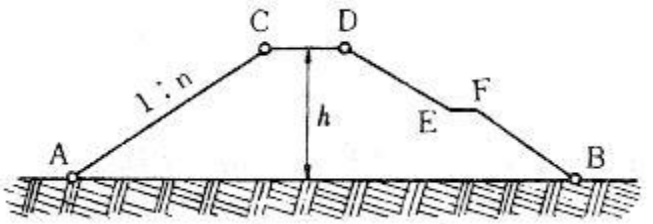
- 토목공사를 할 때 공사계획면보다 높은 곳을 낮추고 낮은 곳은 높여 계획면에 맞도록 하는 것으로, 높은 곳을 낮추는 것을 **절토(cutting)**라 하고, 낮은 곳을 높이는 것을 **성토(filling)**라 하여 일반적으로 절토공사와 성토공사로 대별
- 시공기면(formation level): 지반계획고인 최종 끝손질면



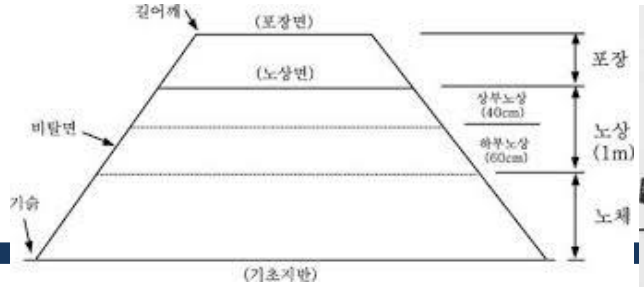
Earthmoving

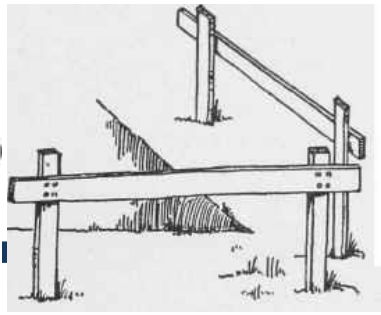


- **Other Terminologies**
  - Side Slope(비탈, 사면): AC, DE, FB
  - Top of Slope(비탈머리): C, D
  - Toe of Slope(비탈기슭): A, B
  - Levee Crown(뚝마루, 천단): CD
  - Berm(소단, 턱):
    - EF부분과 같이 사면 중간에 만든 폭 1-2m를 말하며 절토나 성토 높이 5-10m마다 소정의 소단을 만들어 사면의 안정에 도움이 되도록 시공
    - 비탈면의 점검통로와 배수로 구실도 함으로 중요함
  - Slope(사면경사, 비탈면): vertical:horizontal → 1:1, 1:1.5 (1:n)

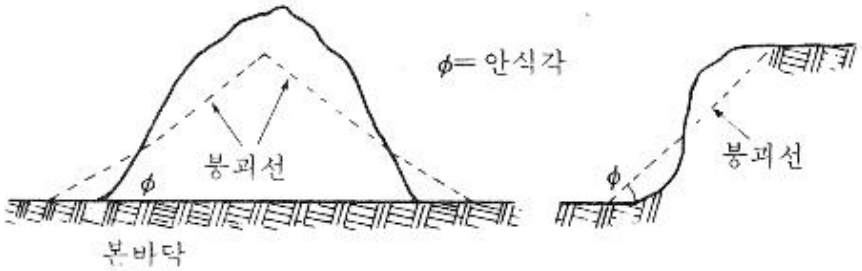


Earthmoving





- **Other Terminologies**
  - 규준틀
    - 토공작업에 있어서 비탈면의 위치, 구배, 노체(맨 바닥의 땅), 노상(노체위의 1m)의 완성고 등을 나타내기 위해서 현장에 설치하는 가설물
  - 여성토 (더돋기)
    - 다짐이 중요하지 않은 성토나 연약지반의 침하촉진을 위하여 소정의 높이보다 추가로 성토하는 것
    - 소정의 침하가 이루어지면 여성토 부분을 걷어내고 다음 작업을 시행
  - 안식각 (자연구배)
    - 자연 상태에서 급 경사면은 스스로 붕괴하여 안정된 사면을 형성하게 되는데, 이러한 붕괴사면과 수평면이 이루는 각. 일반토사의 경우 30-35도(1:1 – 1:0.7)
    - 자체 자중 + 뒷면에서 주는 흙의 하중 = 흙 입자 사이의 응집력, 마찰력



Earthmoving

- **Other Terminologies**
  - 벌개제근
    - 토공의 굴착 또는 흙쌓기의 시공에 앞서 절취부, 토취부, 흙쌓기부에서 풀이나 나무뿌리를 제거하는 표토깍기 및 이들의 처리
    - 흙쌓기 중에 혼입된 초목, 나무뿌리 등의 유기물은 점차 부식하여 부등침하나 처짐을 일으키는 원인이 될 수 있으므로 완전히 제거 필요
  - 표토제거
    - 지표면의 유기물(잡초, 이물질 등)을 제거하는 행위로 논이나 밭구간의 토공작업과 토취장에서 흙을 채취하기 시작 전에 반드시 시행
  - 되메우기
    - 작업에 소요되는 여유공간 확보를 위한 터파기 흙을 작업 완료전에 다시 메우는 토공사
  - 산마루 측구
    - 표면수 흐름을 유도하여 절토 비탈면의 안정을 확보하기 위해 비탈면 끝에 설치한 측구
    - 재료: 토사, 콘크리트, PVC 등

Type of Geotechnical Materials

- **Five types of soils (ASTM, 미국시험재료협회)**
  - Gravel(자갈): rounded or semi-rounded particles of rock (2.0 mm to 3 in)
  - Sand(모래): disintegrated rock (0.074 to 2.0 mm), coarse or fine
  - Silt(실트): material finer than sand (0.005 to 0.074 mm)
  - Clay(점토): cohesive material (less than 0.005 mm)
  - Organic matter(유기질흙): partly decomposed vegetable matter, spongy and unstable structure

TABLE 4.1 | Unified soil classification system

Symbol	Primary	Secondary	Supplementary
GW	Coarse-grained soils	Well-graded gravels, gravel-sand mixtures, little or no fines	Wide range of grain size
GP	Coarse-grained soils	Poorly graded gravels, gravel-sand mixtures, little or no fines	Predominantly one size or a range of intermediate sizes missing
GM	Gravel mixed with fines	Silty gravels and gravel-sand-silt mixtures—may be poorly graded	Predominantly one size or a range of intermediate sizes missing
GC	Gravel mixed with fines	Clayey gravels, gravel-sand-clay mixtures, which may be poorly graded	Plastic fines
SW	Clean sands	Well-graded sands, gravelly sands, little or no fines	Wide range in grain sizes
SP	Clean sands	Poorly graded sands, gravelly sands, little or no fines	Predominantly one size or a range of sizes with some intermediate sizes missing
SM	Sands with fines	Silty sands and sand-silt mixtures, which may be poorly graded	Nonplastic fines or fines of low plasticity
SC	Sands with fines	Clayey sands, sand-clay mixtures, which may be poorly graded	Plastic fines
ML	Fine-grained soils	Inorganic silts, clayey silts, rock flour, silty very fine sands	Plastic fines
CL	Fine-grained soils	Inorganic clays of low to medium plasticity, silty sandy or gravelly clays	Plastic fines
OL	Fine-grained soils	Organic silts and organic silt-clay of low plasticity	
MH	Fine-grained soils	Inorganic silts, clayey silts, elastic silts	
CH	Fine-grained soils	Inorganic clays of high plasticity, fat clays	
OH	Fine-grained soils	Organic clays and silty clays of medium to high plasticity	

입도분포가 좋은 자갈

입도분포가 나쁜 자갈

실트질 자갈

점토질 자갈

입도분포가 좋은 모래

입도분포가 좋은 모래

실트질 모래

점토질 모래

*fine: clay or silt

Symbol classification

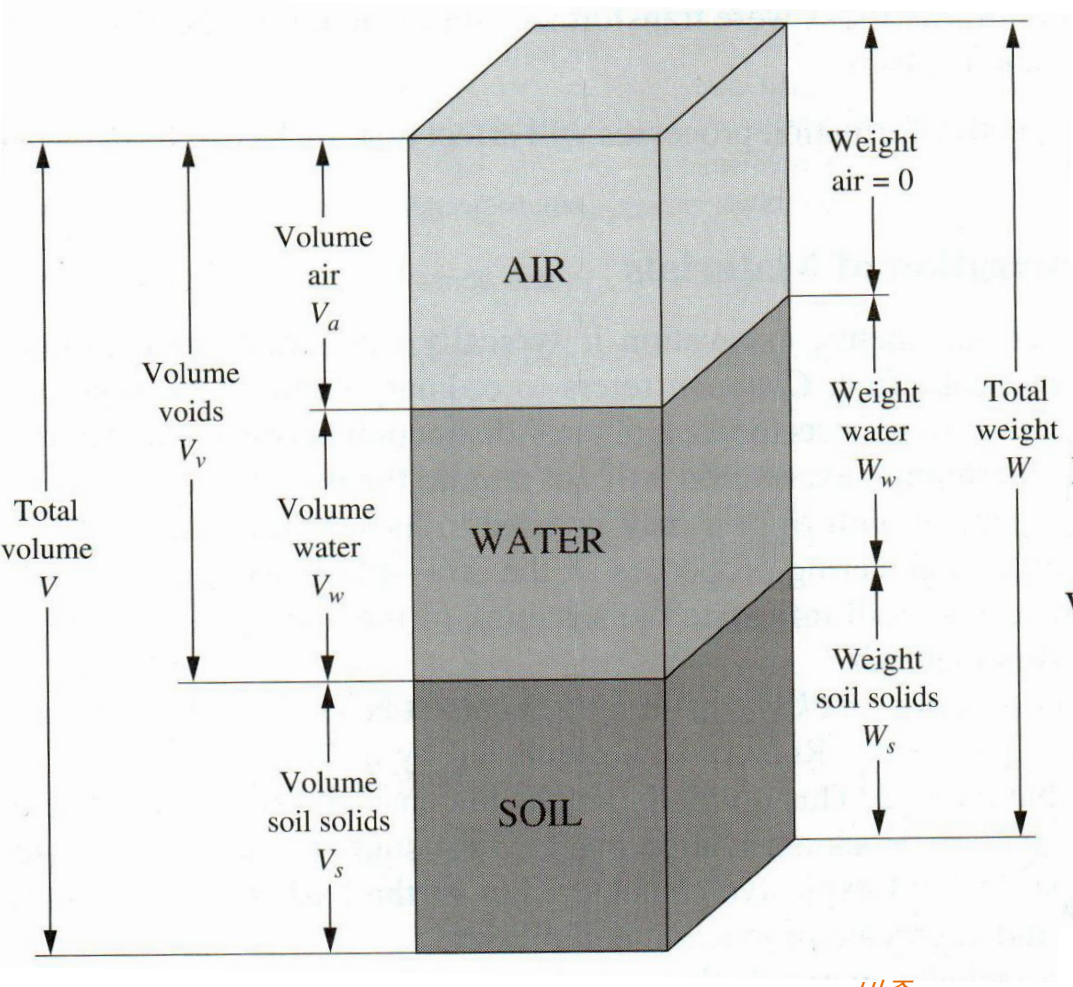
COARSE GRAINED MATERIAL
Symbol
G—Gravel grain size from 3″ to No. 4 sieve size
S—Sand grain size from No. 4 to 200 sieve size

Subdivision
W—Well graded, little or no fines
P—Poorly graded, little or no fines
M—Concentration of silty or nonplastic fines
C—Concentration of clay or plastic fines

FINE GRAINED MATERIAL
Symbol
M—Silt very fine grain size, floury appearance
C—Clay finest grain size, high dry strength—plastic
O—Organic matter partly decomposed, appears fibrous, spongy and dark in color

Subdivision
L—Low plastic material, lean soil
H—High plastic material, fat soil

Soil Weight-Volume Relationship



$$\text{Unit weight } (\gamma) = \frac{\text{total weight of soil}}{\text{total soil volume}} = \frac{W}{V}$$

단위중량

$$\text{Dry unit weight } (\gamma_d) = \frac{\text{weight of soil solids}}{\text{total soil volume}} = \frac{W_s}{V}$$

건조단위중량

$$\text{Water content } (\omega) = \frac{\text{weight of water in soil}}{\text{weight of soil solids}} = \frac{W_w}{W_s}$$

함수비

$$\text{Void ratio } (e) = \frac{\text{volume of voids}}{\text{total soil volume}} = \frac{V_v}{V_s}$$

공극률

Volume of soil solids

$$\text{Porosity } (n) = \frac{\text{volume of voids}}{\text{total soil volume}} = \frac{V_v}{V}$$

투과성

비중

$$\text{Specific Gravity } (G_s) = \frac{\text{weight of soil solids/volume of solids}}{\text{unit weight of water}} = \frac{W_s/V_s}{\gamma_w}$$

Soil Weight-Volume Relationship

- Total soil volume (V) = volume voids (V_v) + volume solids (V_s)
- Weight of solids (W_s) = weight of soil (W) / (1 + water content(ω))

→ $$\gamma_d = \frac{\gamma}{1 + \omega}$$

Soil Limits

- **Certain limits of soil consistency (liquid limit, plastic limit) were developed to differentiate between highly plastic, slightly plastic, and nonplastic materials.**

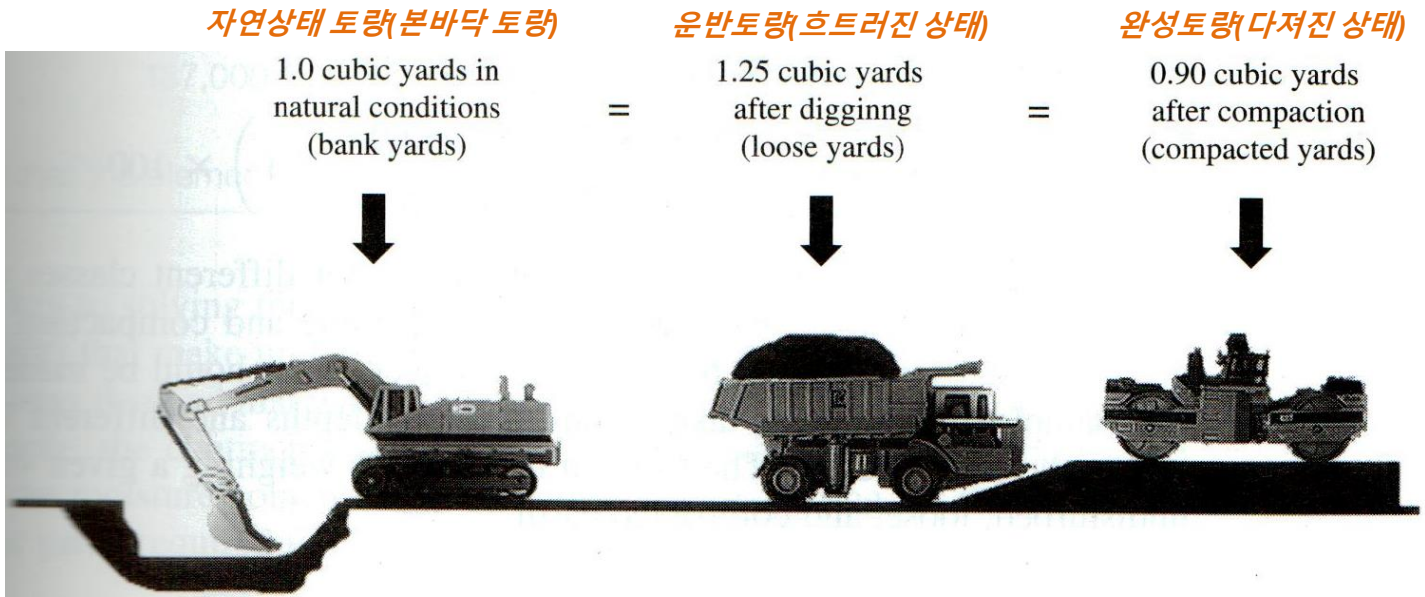
액성한계
- **Liquid Limit (LL)**: 흙이 액성상태에서 소성상태로 변화하는 한계함수비. High LL values are associated with soils of high compressibility. Clays have high LL values and sandy soils have low LL values.

소성한계
- **Plastic Limit (PL)**: 흙이 소성상태에서 반고체상태로 변화하는 한계함수비. The lowest water content at which a soil can be rolled into an 3.2 mm-diameter thread without crumbling.

소성지수
- **Plasticity Index (PI)**: the numerical difference between a soil's liquid limit and its plastic limit is its plasticity index (PI = LL – PL). Soils having high PI values are quite compressible and have high cohesion.

Volumetric Measure

- **Material volume changes caused by processing**
  - **Bank cubic yard (bcy)**: 1 cy of material as it lies in the natural state
  - **Loose cubic yard (lcy)**: 1 cy of material after it has been disturbed by a loading process
  - **Compacted cubic yard (ccy)**: 1 cy of material in the compacted state, also referred to as a net in-place cubic yard



Volumetric Measure

- **Shrinkage factor** = $\frac{\text{compacted dry unit weight}}{\text{bank dry unit weight}}$

  수축률

  **Shrinkage factor > 1.0*
  b/c compacted soils dense more

- **Swell factor** = $\frac{\text{loose dry unit weight}}{\text{bank dry unit weight}}$

  팽창률

  **Swell factor < 1.0*

Example (1)

An earth fill, when completed, will occupy a net volume of 187,000 cy. The borrow material that will be used to construct this fill is a stiff clay. In its "bank" condition, the borrow material has a wet unit weight of 129 lb per cubic foot (cf) (γ), a water content (ω%) of 16.5%, and an in-place void ratio (e) of 0.620. The fill will be constructed in layers of 8-in. depth, loose measure, and compacted to a dry unit weight (γ_d) of 114 lb per cf at a water content of 18.3%. Compute the required volume of borrow pit excavation.

(1 cy = 27 cf)

Example (1)

- To achieve the desired fill density and water content, the contractor will have to add water (moisture content in fill: 18.3%, in borrow: 16.5%). This water must be hauled in by water wagon and is not part of the in-place borrow unit weight. How many gallons of water must be supplied?

Example (2)

The soil borrow material to be used to construct a highway embankment has a mass unit weight of 98.0 lb per cf, a water content of 9%, and the specific gravity of the soil solids is 2.67. The specifications require that the soil be placed in the fill so the dry unit weight is 114 lb per cf and the water content be held to 12%.

a. How many cubic yards of borrow are required to construct an embankment having an 800,000 cy net section volume?

b. How many gallons of water must be added per cubic yard of borrow material assuming no loss evaporation?

c. If the compacted fill becomes saturated at constant volume, what will be the water content and unit weight?

Example (2)

Soil Processing

- **Adding water to soil**
  - If the water content of a soil is below the optimum moisture range (e.g., 12-25% for fine-grained soils, 7-12% well-graded granular soils), water must be added to the soil prior to compaction.
  - Consider
    - Amount of water required
    - Rate of water application
    - Method of application
    - Effects of the climate and weather

Soil Processing

- **Amount of Water Required**
  - Computed in gallons per station (100 ft of length)

$$\text{Gallons} = \text{desired dry density pounds per cf (pcf)} \times \frac{(\text{desired water content \%}) - (\text{water content borrow \%})}{100} \times \frac{\text{compacted vol. of soil (cf)}}{8.33 \text{ lb per gal}}$$

**8.33: Weight of a gallon of water*

Soil Processing

- **Application Rate**
  - Normally calculated in gallons per square yard

$$\text{Gallons per square yard} = \text{desired dry density of soil (pcf)} \times \frac{(\%\ \text{moisture added or removed})}{100} \times \text{lift thickness (ft) (compacted)} \times \frac{9\ \text{sf/sy}}{8.33\ \text{lb/gal}}$$

Soil Processing

Job specifications require placement of the embankment fill soil in 6-in. (compacted) lifts. The desired dry unit weight of the embankment is 120 pcf. The laboratory compaction curve indicates that the optimum water content, sometimes referred to as optimum moisture content, (OMC) of the soil is 12%. Soil tests indicated that the moisture content of the borrow material is 5%. The roadway lift to be placed is 40 ft wide. Compute the amount of water in gallons to add on a per station basis for each lift of material.

Also, determine the required application rate in gallons per square yard.

Soil Processing

- **Application Methods**
  - Important to ensure the proper application rate is achieved and the water is uniformly distributed.
  - **Water distributor**: designed to evenly distribute the correct amount of water over the fill under various pressures or by gravity feed
  - **Ponding**: prewetting borrow materials using a sprinkler system

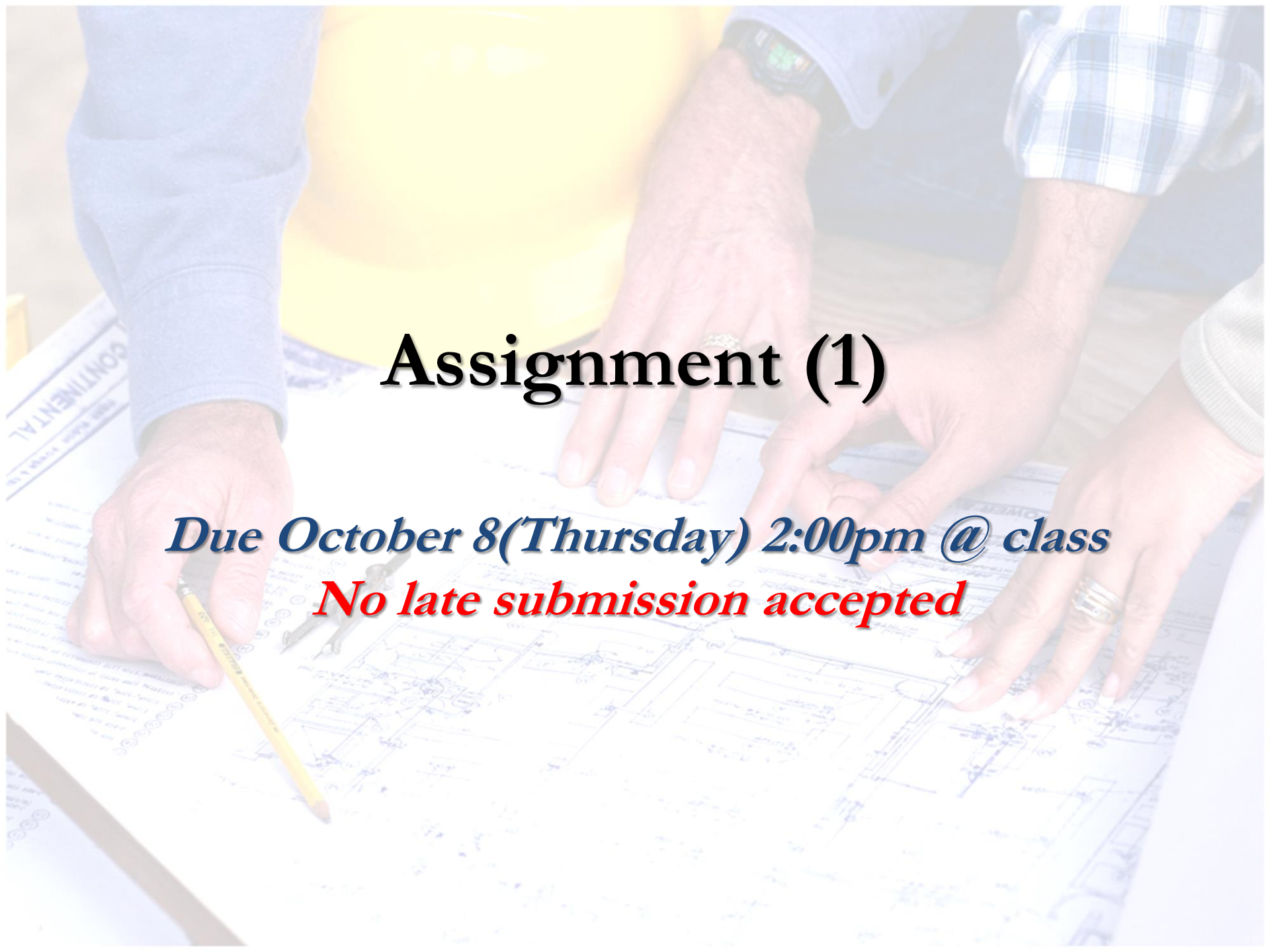
Reducing the moisture content:
(1) Aerating the soil
(2) Adding soil stabilization agent that changes the physical properties of soils (e.g., lime, fly ash for fine grained soils)
Reduce → Scarifying the soil (흙을 고르다) → Compaction

Rear Rippers


Disk Harrow

Soil Processing

- **Effects of Weather**
  - Cold, rainy, cloudy and clam weather → Retain water
  - Hot, dry, sunny, and windy weather → Dry the soil
  - Example, for a desert project, the engineer might have to go as high as 6% above the optimum water content as a target for all water application calculations so that the actual water content will fall very near to the desired content when the material is placed and compacted.
- **Mixing and Blending**
  - Mixing is necessary to ensure a uniform distribution of the existing moisture and accomplished using motor graders, farm disks, or rotary cultivators.



Assignment (1)

Due October 8(Thursday) 2:00pm @ class

No late submission accepted

Assignment Question (1)

The soil borrow material, to be used to construct a highway embankment, has a mass unit weight of 96.0 pcf, a water content of 8%, and the specific gravity of the soil solids is 2.66. The specifications require that the soil be compacted to a dry unit weight of 112 lb per cf, and the water content be held to 13%. (315,000 bcy, 14.4 gal per bcy borrow, 132.3 lb/cf).

a. How many cubic yards of borrow are required to construct an embankment having a 250,000 cy net section volume?

b. How many gallons of water must be added per cubic yard of borrow material assuming no loss by evaporation?

c. If the compacted fill becomes saturated at constant volume, what will be the water content and mass unit weight of the soil?

Assignment Question (2)

Embankment at a 12% water content is to be placed at the rate of 270 ccy per hr. The specified dry weight of the compacted fill is 2,900 lb per cy. How many gallons of water must be supplied each hour to increase the moisture content of the material from 7 to 12% by weight?

$$\text{Dry unit weight } (\gamma_d) = \frac{\text{weight of soil solids}}{\text{total soil volume}} = \frac{W_s}{V}$$

$$\text{Water content } (\omega) = \frac{\text{weight of water in soil}}{\text{weight of soil solids}} = \frac{W_w}{W_s}$$

Assignment Question (3)

The borrow material to construct an embankment has a mass unit weight of 96.5 pcf and a water content of 8%. The specific gravity of the solids is 2.66. The contract specifications require that the soil be placed in the fill at a γ_d of 114 pcf and a water content of 10%.

a. How many cubic yards of borrow are required to construct an embankment having a 455,000-cy net volume?

b. How many gallons of water must be added per cubic yard of borrow material assuming no loss by evaporation?