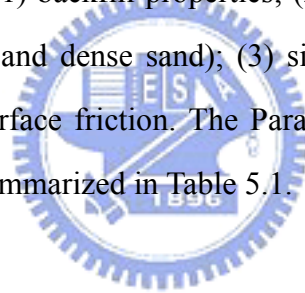


Chapter 5

BACKFILL AND INTERFACE CHARACTERISTICS

This chapter introduces the properties of backfill and the distribution of soil density in the soil bin. The interface characteristics between the backfill and the sidewalls of soil bin, the model wall, and the interface plate will be discussed. The following sections included: (1) backfill properties; (2) distribution of soil density in the soil bin (including loose and dense sand); (3) sidewall friction; (4) model wall friction; and (5) inclined interface friction. The Parameters of loose and compacted sand used for this study are summarized in Table 5.1.



5.1 Backfill Properties

Air-dry Ottawa silica sand (ASTM C-778) was used as backfill. Physical properties of Ottawa sand are listed in Table 5.2. Grain-size distribution of the backfill is shown in Fig. 5.1. Major factors considered in choosing Ottawa sand as backfill material are summarized as follows.

1. Its round shape, which avoids the effect of angularity of soil grains.
2. Its uniform distribution of grain size (coefficient of uniformity $C_u = 1.52$), which avoids the effects due to soil gradation.
3. High rigidity of solid grains, which reduces possible disintegration of soil particles under loading.
4. Its high permeability, which allows fast drainage and therefore reduces water

pressure behind the wall.

To establish the relationship between unit weight of backfill and its internal friction angle ϕ , direct shear tests have been conducted. The shear box used has a square (60 mm \times 60 mm) cross-section, and its arrangement is shown in Fig. 5.2. Before shearing, Ottawa sand was air-pluviated into the shear box and then compacted to the desired density. Details of the technique to control soil density are discussed in section 5.2.1.

Chang (2000) established the relationship between the internal friction angle ϕ and unit weight γ of Ottawa sand as shown in Fig. 5.3. It is obvious from the figure that soil strength increases with increasing soil density. For the air-pluviated backfill, the empirical relationship between soil unit weight and ϕ angle can be formulated as follows

$$\phi = 6.43 \gamma - 68.99 \quad (5.1)$$

where

ϕ = angle of internal friction of soil (degree)

γ = unit weight of soil (kN/m³)

Eq. (5.1) is applicable for $\gamma = 15.45 \sim 17.4$ kN/m³ only.

For compacted backfill, the following relationship can be formulated.

$$\phi = 2.75 \gamma - 79.55 \quad (5.2)$$

Eq. (5.2) is applicable for $\gamma = 15.8 \sim 17.05$ kN/m³ only.

5.2 Control of Soil Density

5.2.1 Air Pluviation of Backfill

To achieve a uniform soil density in the backfill, Ottawa sand was deposited by air-pluviation method into the soil bin. The air-pluviation method had been widely

used for a long period of time to reconstitute laboratory sand specimens. Rad and Tumay (1987) reported that pluviation is the method that provides reasonably homogeneous specimens with desired relative density. Lo Presti et al. (1992) reported that the pluviation method could be performed for greater specimens in less time. As indicated in Fig. 5.4, the soil hopper that lets the sand pass through a calibrated slot opening at the lower end was used for the spreading of sand. Air-pluviation of the Ottawa sand into soil bin is shown in Fig. 5.5.

Das (1994) suggested that relative densities of 15~50%, and 70~85% are defined as loose and dense condition, respectively. To achieve loose backfill ($D_r = 32\%$), Chen (2002) adopted the drop height of 1.0 m and hopper slot opening of 15 mm. However, for this study, since the steel interface plate is placed into the soil bin, the spacing between model wall and the interface plate may not be sufficient to accommodate the sand hopper. As a result, the drop height of 1.5 m and hopper slot-opening of 18 mm are selected to achieve the loose backfill ($D_r = 35\%$) for testing in this study.

5.2.2 Compaction of Backfill

To obtain a dense condition to simulate field conditions, the loose backfill was densified with the vibratory compactor. Air-dry Ottawa sand was shoveled from the soil storage into the soil hopper, then air-pluviated into the soil bin as shown in Fig. 5.5.

As shown in Fig. 5.6, for the backfill compacted with the 0.225 m × 0.225 m square compactor, each compacted lift is 0.3 m. In Fig. 5.7, it is illustrated that for the backfill compacted with 0.09 m × 0.5 m strip compactor, each compacted lift is 0.1 m. The surface of the top lift was carefully leveled to form a horizontal soil surface.

For the interface inclination angle $= 0^\circ$ (Fig. 5.8), the surface of air-pluviation backfill was divided into 6 lanes, and compacted with square compactor (Fig. 3.7). Fig. 5.9 shows, the surface of the loose backfill for $= 0^\circ$ was divided into 15 lanes and densified with the strip compactor. Each lane was densified with the vibratory

compactor for a pass of 70 seconds. Repeat the compaction procedures for next lift until the height of backfill accumulated up to 1.5 m.

Chang (2002) reported that the soil density achieved by compaction is affected by number of acentric plates attached to the motor on the soil compactor. For the compactors used, the numbers of the acentric plate could vary from 1 +1 to 10 + 10. The relative densities obtained range from 38 % to about 95 %. For this study, the number of acentric plates attached to the motor was 8 + 8. It means that 8 pieces of acentric plates are attached to the front-end of number the motor axis, while another 8 pieces are attached to the rear-end of motor axis.

5.2.3 Uniformity of Soil Density

To observe the distribution of soil density in the soil bin, soil density measurement was made. The soil density control cup made of acrylic is illustrated in Fig. 5.10 and Fig. 5.11. Density cups were buried in the soil mass at different elevations and different locations in the backfill as shown in Fig. 5.12 and Fig. 5.13. The distribution of soil density for loose sand at $\alpha = 45^\circ$ is shown in Fig. 5.14. The mean relative density is $D_r = 35.1\%$ with the standard deviation of 3.9%. The soil densities reported by Chen (2002). The test results are in fairly good agreement with Chen's data. The backfill achieved is obviously loose, $D_r = 15\sim 50\%$ as suggested by Das (1994).

Fig. 5.15 shows the compaction of backfill with the square compactor. After compaction, the buried soil density cups were carefully dug out of the soil mass. Soil density in the cup can be determined by dividing the mass of soil in the cup by inside volume of the cup. The distribution of soil density measured at different elevations is shown in Fig. 5.16. Excluding the 2 data points in the top 0.15 m, the mean relative density is $D_r = 72.3\%$ with the standard deviation of 2.3 %. The test results are in fairly good agreement with Chin's data. The compacted backfill obtained is clearly dense, $D_r = 70\sim 85\%$ as suggested by Das.

Fig. 5.17 shows the compaction of backfill by the strip compactor at the backfill height $H = 1.1$ m under the interface inclination angle $= 70^\circ$. The distribution of soil density for a single 0.5-m-thick soil layer compacted with the strip compactor is shown in Fig. 5.18. Since the compacted plate is only 0.09 m-wide, the relative density exceeds 70% at elevation 0.4 m to 0.5 m. The relative density was not uniform for the lower 0.4 m of fill. It is clear that effective depth is only approximately 0.1 m below the surface. Fig. 5.19 shows the distribution of relative density for a fill compacted in five 0.1 m thick. It can be observed that the relative densities are approximately uniform and $D_r > 70\%$ at different elevations. The mean relative density is 72 % with a standard deviation of 3.64 %. The distribution of relative density for soil compacted with the strip compactor is compared with test data reported by Chen (2002) in Fig. 5.20. It may be seen in Fig. 5.20 that the soil density near the surface of fill are not as dense as expected. D'Appolonia et al. (1969) reported that, due to the lack of confining pressure, the soil near the surface may not be dense even after compaction in Fig. 5.21.



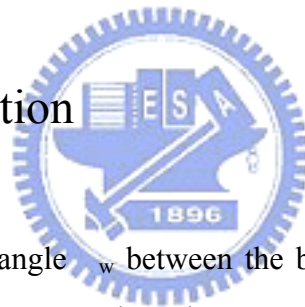
5.3 Side Wall Friction

To constitute a plane strain condition for model wall tests, the shear stress between the backfill and sidewall should be minimized to nearly frictionless. To reduce the friction between sidewall and backfill, a lubrication fabricated layer with plastic sheets was furnished for all model wall experiments. Two types of plastic sheeting, one thick and two thin plastic sheets, were adopted to reduce the interface friction. All plastic sheets will be hung vertically on each sidewall before the backfill was deposited as shown in Fig. 5.22.

Multiple layers of thin plastic sheets (without any lubricant) were used by McElroy (1997) for shaking table tests of geosynthetic reinforced soil (GRS) slopes.

Burgess (1999) used three thin plastic sheets to reduce side wall friction in full-scale GRS wall tests. The wall friction angle was approximately 15° as determined by the shear box tests. In this study, two thin and one thick plastic sheet were adopted for the earth pressure experiments. The friction angle developed between the plastic sheets and steel sidewall could be determined by the sliding block test. A schematic diagram and a photograph of the sliding block test proposed by Fang et al. (2004) are illustrated in Fig. 5.23 and Fig. 5.24. The sidewall friction angle δ_{sw} for the sliding block test is determined using basic principles of physics. Fig. 5.25 shows the variation of friction angle δ with normal stress σ for the plastic sheet method (1 thick + 2 thin sheeting) used in this study. The measured friction angle with this method is about 7.5° . It should be noted that with the plastic – sheet lubrication method, the interface friction angle is nearly independent of the applied normal stress.

5.4 Model Wall Friction



To evaluate the friction angle δ_w between the backfill and model wall, special direct shear tests (Fig. 5.26) were conducted. A 88 mm × 88 mm × 25 mm smooth steel plate, made of the same material as the model wall, was used to replace the lower shear box. Ottawa sand was placed into the upper shear box and vertical load was applied on the soil specimen. The arrangement of this test and detail of the lower steel plate are shown in Fig.5.26.

Ho (1999) established the wall friction angles developed between the steel plate and Ottawa sand. Soil specimens with different unit weights were tested. The soil compactor is used to obtain different soil densities for direct shear tests and the normal stress σ_n applied was 79.8 kN/m^2 . Fig. 5.27 illustrates the relationship between the unit weight of the backfill γ and wall friction angle (δ_w). For air-pluviation Ottawa sand, the relationship can be expressed as follow

$$\delta_w = 3.41 \gamma - 43.69 \quad (5.3)$$

where

δ_w = wall friction angle (degree)

γ = unit weight of backfill (kN/m³)

Eqn. (5.3) is applicable for $\gamma = 15.6 \sim 16.3$ kN/m³ only. For backfill prepared with compaction method.

$$\delta_w = 3.08 - 37.54 \quad (5.4)$$

where

δ_w = wall friction angle (degree)

γ = unit weight of backfill (kN/m³)

Eqn. (5.4) is applicable for $\gamma = 16.0 \sim 17.0$ kN/m³ only.

5.5 Inclined Interface Friction

To evaluate the friction angle between the interface plate and model wall, direct shear tests were shown in Fig. 5.28. A 80 mm × 80 mm × 15 mm steel plate was covered with the anti-slip material Safety-Walk to simulate the surface the interface behavior between the sand stone rock-face and sandy fill. Ottawa sand was placed into the upper shear box and vertical stress was applied on the soil specimen. Assuming the internal friction angle of soil $\phi = 40.1^\circ$, and the unit weight of soil is 16.5 kN/m³. The normal stress acting at mid-height of the wall $\sigma_o = K_o \cdot z = (1 - \sin 40.1^\circ) \times (16.5) (7.5) = 4.40$ kN/m². The normal stress applied direct shear for all test was 4.6 kN/m².

Fig. 5.29 illustrates the relationship between the unit weight of the backfill γ and interface friction angle δ_i . For the backfill prepared with air-pluviation method.

$$\delta_i = 2.7 - 21.39 \quad (5.5)$$

where

δ_i = interface-plate friction angle (degree)

γ = unit weight of backfill (kN/m³)

Eqn. (5.5) is applicable for $\gamma = 15.18 \sim 16.36$ kN/m³ only.

For Ottawa sand densified with compaction, the δ_i vs γ relationship can be expressed as:

$$\delta_i = 1.97 \gamma - 8.9 \quad (5.6)$$

where

δ_i = interface-plate friction angle (degree)

γ = unit weight of backfill (kN/m^3)

Eqn. (5.6) is applicable for $\gamma = 16.4 \sim 18.8 \text{ kN/m}^3$ only.

The relationship between backfill unit weight γ and different friction angles is illustrated in Fig. 5.30. The internal friction angle of sand ϕ , model wall friction angle δ_w , Inclined interface angle δ_i , and sidewall friction angle δ_{sw} are compared for air-pluviated and compacted sand. It is clear in Fig. 5.30 that, with the same unit weight, the order of 4 different friction angles is $\phi > \delta_i > \delta_w > \delta_{sw}$.

