Chapter 5

BACKFILL AND INTERFACE CHARACTERISTICS

This chapter reports the properties of the backfill and characteristics between the backfill and sidewall, model wall, and interface plate. The control of soil density distribution is also introduced in this chapter.

5.1 Backfill Properties

Ottawa silica sand (ASTM C-778) was used for the model wall experiments. All tests were conducted under air-dry condition. Physical properties of Ottawa sand are listed in Table 5.1. Grain-size distribution of the backfill is shown in Fig. 5.1.

Major factors considered in choosing the backfill material (Ottawa sand) are summarized as follows.

1. Its round shape, which avoids effect of angularity of soil grains.
2. Its uniform distribution of grain size (coefficient of uniformity $C_u = 1.48$), 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 γ and its internal friction angle ϕ, direct shear tests were conducted. The shear box used has a square (60 mm × 60 mm) cross-section, and its arrangement is shown in Fig. 5.2. Before shearing, for loose sand, Ottawa sand was air-pluviated into the shear box to the desired density. For dense sand the soil compactor was used to compact the soil to the desired density. The technique to control soil density is discussed in section 5.5.

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, an empirical relationship between soil unit weight γ and ϕ angle is formulated as follows:

$$\phi = 6.43\ \gamma - 68.99 \tag{5.1}$$

where

ϕ = internal friction angle of soil (degree)

γ = unit weight of soil (kN/m^3)

Eq. 5.1 is applicable for γ = 15.45 ~ 17.4 kN/m^3 only. For compacted backfill, an empirical relationship was proposed as follows:

$$\phi = 7.25\ \gamma - 79.5 \tag{5.2}$$

where

ϕ = internal friction angle of soil (degree)

γ = unit weight of soil (kN/m^3)

Eq. 5.2 is applicable for γ = 15.8 ~ 17.05 kN/m^3 only.

5.2 Model Wall Friction

To evaluate the wall friction angle δ_w between the backfill and model wall, special direct shear tests have been 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, as shown in Fig. 5.4.

To establish the wall friction angles developed between the steel plate and sand, soil specimens with different unit weights were tested. Compaction and air-pluviation methods were used to achieve different soil densities, and the test result is shown in Fig. 5.5. For the air-pluviated backfill, Ho (1999) suggested that wall friction angle vs. density relationship can be expressed as follows:

$$\delta_w = 3.41 \quad \gamma - 43.69 \tag{5.3}$$

where

δ_w = wall friction angle (degree)

γ = unit weight of soil (kN/m^3)

Eq. 5.3 is applicable for γ = 15.6 ~ 16.3 kN/m^3 only. For compacted backfill, an empirical relationship between soil unit weight γ and δ_w angle can be formulated as follows:

$$\delta_w = 3.08 \quad \gamma - 37.54 \tag{5.4}$$

where

δ_w = wall friction angle (degree)

γ = unit weight of soil (kN/m^3)

Eq. 5.4 is applicable only γ = 16.0 ~ 17.0 kN/m^3 only.

5.3 Side Wall Friction

To constitute the 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 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 (see Fig. 5.6) before the backfill was deposited.

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 photograph of sliding block test proposed by Fang et al. (2004) is illustrated in Fig. 5.7 and Fig. 5.8. The friction angle by sliding block test is determined using basic principles of physics. Fig. 5.9 shows the variation of friction angle δ_p with normal stress σ for plastic sheet method used in this study. The measured friction angle with this method is about $\delta_p = 7.5°$. It should be noted that with the plastic – sheet lubrication method, the side-wall friction angle is nearly independent of the applied normal stress.

5.4 Interface Plate Friction

To evaluate the friction angle between the backfill and steel interface plate, special direct shear tests were conducted. A steel plate covered with the anti-slip material Safety-Walk 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. 5.10. The vertical stress σ_n used in these tests is 4.60 kN/m^2. It is the earth pressure at-rest calculated with Jaky's formula (K_o = 1-sinϕ) in dense sand (γ = 16.5 kN/m^3 and ϕ = 40.1°) at the mid-height (Z = 0.75 m) of the retaining wall.

To establish the friction angle developed between the backfill and the steel plate, soil specimens with different unit weights were tested. The soil compactor was used to achieve different soil densities for direct shear tests. Fig. 5.11 illustrates the relationship between the unit weight of backfill γ and interface plate angle δ_i. For the air-pluviated backfill, the relationship can be expressed as follows:

$$\delta_i = 2.7\gamma - 21.39 \tag{5.5}$$

where

δ_i = interface plate friction angle (degree)

γ = unit weight of soil (kN/m^3)

Eq. 5.5 is applicable for γ = 15.18 ~ 16.36 kN/m^3 only. For compacted backfill, an empirical relationship between soil unit weight γ and δ_i angle can be formulated as follows:

$$\delta_i = 1.97\gamma - 8.9 \tag{5.6}$$

where

δ_i = interface plate friction angle (degree)

γ = unit weight of soil (kN/m^3)

Eq. 5.6 is applicable only for γ = 16.4 ~ 18.8 kN/m^3 only. The ϕ, δ_w, δ_p, and δ_i angles obtained in section 5.1, 5.2, 5.3, and 5.4 are used for calculation of earth pressure based on Jaky, Janssen, Reimbert and Reimbert, Spangler and Handy, and Rankine theories.

Fig. 5.12 illustrates the relationship between unit weight γ and friction angle for different types of interfaces. From Fig. 5.12, it can be observed that $\phi > \delta_i > \delta_w > \delta_p$.

5.5 Control of Soil Density

5.5.1 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 to achieve the desired loose states. The 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. 5.13, the soil hopper that lets the sand pass through a calibrated slot opening at the lower end was used for the spreading of sand. A picture of the pluviating process is shown in Fig. 5.14.

Das (1994) suggested that relative density 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 experiments in this study.

5.5.2 Compaction of Backfill

To simulate field conditions, dense backfill was achieved for experiments in this study. To a dense condition, the loose backfill was densified with a strip soil compactor (90 mm Ｘ 500 mm). To determine the effective thickness of compaction, a 0.5 m-thick loose soil layer was compacted with the strip compactor as shown in Fig. 5.15. Density cups were buried in the 0.5 m-thick soil layer and the variation of relative density with depth is plotted in Fig. 5.15. In Fig. 5.15, it can be found that effective thickness of compaction (to achieve $D_r \geq 70\%$) for this strip compactor is about 0.1m. For prepare a backfill specimen, air-dry Ottawa sand was shoveled from the soil storage into the soil hopper, then pluviated into the soil bin for a thickness of about 0.12 m. The surface of the top layer was carefully leveled to form a flat surface, and then compacted with the compactor (Fig. 5.16). As illustrated in Fig. 5.17, the thickness of the compacted lift is about 0.1 m. Fig. 5.18 shows that, each layer was divided into 10 lanes. Each lane was densified with the soil compactor for a pass of 70 seconds. Repeat the above procedures for the second, third, through fifteenth lift, until the height of backfill accumulated up to 1.5 m.

The magnitude of compaction force is ocntrolled by number of acentric plates attached to the motor on the soil compactor. For this study, the number of acentric plates attached to the central rotating axis of the acentric motor was 8 + 8. It means that 8 pieces of acentric plates are attached to the front-end of the rotating axis, while another 8 pieces are attached to the rear-end of the axis.

5.5.3 Distribution of Soil Density

To investigate the possible scattering of density in the soil mass, soil density cups illustrated in Fig. 5.19 were used to monitor the soil density at different locations. As shown in Fig. 5.20, the cylindrical density cup was made of acrylic with an inner-diameter of 40 mm and a height of 30 mm. With the soil placement process, soil density cups were buried in the soil mass at different depths and locations as shown in Fig. 5.17 and Fig. 5.21. After the soil had been filled and compacted up to 1.5 m from the bottom of the soil bin, soil density cups were dug out from the soil mass carefully. The density of soil was determined by dividing the mass of soil in the cup by the inside volume of the cup. The procedure of soil density control test is shown in Fig. 5.22.

The distributions of relative density of loose and compacted sand measured at different elevations are shown in Fig. 5.23. It may be observed from these data that the soil density is approximately uniform with depth. For loose sand, the mean unit weight γ is 15.6 kN/m^3, and the corresponding mean relative density $D_{r,mean}$ is 35%, with a standard deviation of 3.1%. For dense sand, the mean unit weight γ is 16.5 kN/m^3 and the mean relative density is 72% with a standard deviation of 2.8%. Results of soil density tests appear to satisfy the suggestion of Das (1994) that 15% ≤

$D_r \le 50\%$ is defined as loose sand, while $70\% \le D_r \le 85\%$ is defined as dense sand.