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地表載重對擋土結構物造成之側向土壓力(III)

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地表載重對擋土結構物造成之側向土壓力(III) –
子題三：鄰近岩石界面傾角對靜止土壓力之影響
Lateral Earth Pressure on Retaining Structures Due to Surcharge (III) – Effects of Adjacent Rock Face Inclination on Earth Pressure At-Rest

計 劃 編 號 : NSC 93-2211-E-009-012
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1. Abstracts

1.1 中文摘要

本研究利用國立交通大學模型擋土牆設備，探討不同岩石界面傾角 α 對擋土牆靜止土壓力的影響。本研究以氣乾渥太華砂作為回填土，回填土高 1.5 m，量測於鬆砂(D_r = 35%)與緊砂(D_r = 72%)狀態下的側向土壓力值。為了模擬堅硬的岩石界面，本研究設計並建造一塊表面鋪上防滑材料的傾斜界面板，及其支撐系統。本研究共包含岩石界面傾角 α = 0°、45°、60°、70°與 80°五種實驗。依據鬆砂實驗結果，獲得以下幾項結論：(1)當岩石界面傾角 α=0°時，側向土壓力稍微低於 Jaky 解，其合力約作用於距擋土牆底部 0.33H 處。當岩石界面傾斜 α 角增加，其側向土壓力係數 K_o 隨之減少。合力作用點則隨 α 角之增加而向上提升;(2)側向土壓力係數 $K_{o,h}$ 與岩石界面傾斜間 α 可建立下列關係式 $K_{o,h,\alpha} = K_{o,h,Jaky} - 0.00462 \times \alpha$，其中 α 值適用於岩石界面傾角介於 0°至 80°間。

關鍵詞: 土壓力、模型試驗、擋土牆、砂、傾斜界面板

1.2 English Abstract

This paper studies the effects of adjacent inclined rock face on earth pressure at-rest. Dry Ottawa sand was used as backfill material. Horizontal earth pressures in loose (D_r = 35%) and compacted (D_r = 72%) soil mass were measured. The height of backfill is 1.5 m. The instrumented model retaining-wall at National Chiao Tung University was used to investigate the lateral earth pressure at different rock face inclination angles α. To simulate an inclined hard rock face, an interface plate covered with Safety-Walk (anti-slip material) and its supporting system were designed and constructed. The interface inclination angles α = 0°, 45°, 60°, 70°, and 80°. Base on the test results for loose sand, the following conclusions can be drawn. (1) Without the interface plate (α= 0°), the coefficient $K_{o,h}$ is slightly less than Jaky solution. The point of application h/H of the at-rest earth pressure is located at about 0.33 H above the base of the wall. The coefficient $K_{o,h}$ decreases with the increase of the rock face inclination. The total soil thrust rises to higher locations with increasing interface inclination angle α. (2) An empirical relationship between the coefficient $K_{o,h}$ and the interface inclination angle α can be established: $K_{o,h,\alpha} = K_{o,h,Jaky} - 0.00462 \times \alpha$. This equation is applicable for loose sand for $0^o \le \alpha \le 80^o$.

Keywords: Earth pressure; Model test; Retaining wall; Sand; Inclined interface

2. Introduction

In this study, the effect of adjacent inclined rock face on earth pressure at-rest is studied. In traditional, earth pressure at-rest behind a non-yielding retaining wall is estimated with Jaky Formula. However, if the retaining wall is constructed adjacent to an inclined rock face, the rock face intrudes the backfill. The inclined rock face is excavated near the bridge abutment, and soil backfill is filled between the abutment and the rock face. Under this condition, Can Jaky formula be used to evaluate the earth pressure at-rest on the abutment and basement walls? Would the distribution of earth pressure at-rest still be linear? The distribution of earth pressure at-rest on retaining structures adjacent to an inclined rock face will be discussed in this study.

3. NCTU Model Retaining Wall Facility

The NCTU model retaining wall facility consists of three parts: (1) model wall; (2) soil bin; and (3) data acquisition system (Chen and Fang, 2002).

The model wall is 1500 mm-wide, 1600 mm-high, and 45 mm- thick as show in Fig. 1. A solid steel plate with a Young's modulus of 210 GPa was chosen as the wall material. The model wall is actually the front-side of the reinforced steel box. To avoid the lateral deformation of the box, twenty-four 20 mm-thick steel columns were welded vertically on the outsides of the box. In addition, twelve C-shaped steel beams were welded horizontally around the box to achieve an at-rest stress condition in the box.

The soil bin is 1500 mm-wide, 1600 mm-high steel plates as illustrated in Fig. 1. The end-wall and sidewalls of the soil bin were made of 35 mm-thick steel plates. Outside the steel walls, vertical steel columns and horizontal steel beams were used to confine the lateral movement of the end-wall and sidewalls. From a practical point of view, the deformation of the sidewalls could be considered negligible.

To investigate the earth pressure distribution, 15 earth pressure transducers (PGM-02KG, capacity = 19.62kN/m^2) were attached to the model wall. The arrangement of the earth pressure cells should be able to closely monitor the variation of the earth pressure of the wall with depth.

4. Inclined Interface Plate and Supporting System

A steel interface plate is designed and constructed to simulate inclined rock face near the retaining structure. As shown in Fig. 2, the plate and its supporting system are developed to fit in the NCTU non-yielding retaining-wall facility. The interface plate consists of two parts: (1) steel plate; and (2) reinforcement steel beams.

The steel plate is 2.100 m-long, 1.497 m-wide, and 45 mm-thick. The unit weight of the steel plate is 76.52 kN/m3 and its total mass is 110.34 kg (1.08 kN). A layer of anti-slip material (Safety-walk, 3M) is attached on the face of the steel plate to simulate the friction that acts between the backfill and rock face.

To simulate the hard rock face, and to increase the rigidity of the thin steel plate, the steel plate is reinforced with 5 Ｘ 8 steel L-beams of longitudinal and transverse directions to the back of steel plate. Section of the steel L-beam (65 mm Ｘ 65 mm Ｘ 8 mm) was chosen as the reinforced material.

To keep the steel interface plate stable, the supporting system was designed. The supporting system consists of the following three parts: (1) top supporting beam; (2) base supporting frame; and (3) fixing plate.

5. Backfill and Interface Characteristics

Air-dry Ottawa silica sand (ASTM C-778) was used as backfill. The compactor is used to obtain different soil densities. For the air-pluviated backfill, the empirical relationship between soil unit weight γ and ϕ angle can be formulated as follows:

$$\phi = 6.43\gamma - 68.99 \quad (1)$$

For compacted backfill, the following relationship can be formulated.

$$\phi = 2.75\gamma - 79.55 \quad (2)$$

where γ is unit weight of soil in kN/m^3, and ϕ is angle of internal friction of soil (degree)

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. To obtain a dense condition to simulate field conditions, the loose backfill was densified with a vibratory compactor.

The internal friction angle of sand, model wall friction angle δ_w, Inclined-interface friction angle δ_i, and sidewall friction angle δ_{sw} are compared for air-pluviated and compacted sand. With the same unit weight, the order of 4 different friction angles is $\phi > \delta_i > \delta_w > \delta_{sw}$.

6. Experimental Results

The distributions of lateral earth pressure for the interface inclined at α = 0°, 45°, 60°, 70° and 80° are illustrated in Fig. 3. In this figure, it is seen that the distribution of lateral earth pressure are not linearly with depth. The measured horizontal pressure is lower than Jaky solution. The magnitude of σ_h decreased with increasing α angle. The measured σ_h is significantly affected by the presence of the nearby rock face. It would be reasonable to expect the resultant soil thrust P_h acting on the wall to decrease with increasing α angle. On the other hand, it may be expected that the point of application of the total soil thrust P_h would rise with increasing α angle.

The variation of horizontal at-rest pressure coefficient $K_{o,h}$ as a function of interface inclination angle α is shown in Fig. 4. The coefficient $K_{o,h}$ is defined as the ratio of the horizontal component of total thrust to $rH^2/2$. The horizontal thrust P_h is calculated by summing the pressure diagram shown in Fig. 3. Without the interface plate (α = 0°), the coefficient $K_{o,h}$ is slightly less than Jaky solution. However, after steel interface plate was placed into soil bin. The coefficient $K_{o,h}$ decreased with increasing rock face inclination angle α. The measured are apparently less than the Jaky solution. Based on the test results, an empirical relationship between the coefficient $K_{o,h}$ and the interface inclination angle α can be established：

$$K_{o,h,\alpha} = K_{o,h,Jaky} - 0.00462 \times \alpha \qquad (3)$$

where $K_{o,h,Jaky} = 1 - \sin\phi$

α = interface inclination angle (degree)

Eq.(3) is applicable for loose sand with $0^o \le \alpha \le 80^o$.

Fig. 5 shows the distribution of lateral stress for the dense backfill compacted with the strip compactor. In this Figure, below the compaction-influenced zone, the measured lateral stresses for α = 45°, 60°, 70°, and 80° are lower than Jaky solution. For α = 70° and 80°, the distribution of lateral stress is similar to that for α = 60°. The depth of compaction-influenced zone decreased with increasing interface inclination angle α. For α = 0°, compaction was compacted from Lane 1 through Lane 15 for the top layer. However, for α = 80°, compaction was carried out only from Lane 13 to Lane 15 for the top layer. The effective compaction depth is significantly influenced by the amount of energy input.

The point of application h/H of the total thrust as a function of the rock face inclination angle α is discussed. Fig. 6 shows, without the interface plate (α = 0°), due to the compaction induced stress near the top of the wall, the point of application of the at-rest soil thrust for compacted sand is located at about 0.49 H to 0.50 H above the base of the wall. As the interface angle α increases, the earth pressure near the base of the wall start to decrease. This change of earth pressure distribution causes the total thrust to rise to higher locations as shown in Fig.6. For α = 80°, the point of application of the total thrust for backfill compacted with strip compactor is located at 0.68 H above the base of the wall. Due to the compacted effect, at the same inclination angle α, the order of h/H for compacted and loose sand is $(h/H)_{strip} > (h/H)_{square} > (h/H)_{loose}$.

7. Conclusions

A. For loose sand

(1) The distributions of lateral earth pressure are not linearly with depth for the interface inclined at α= 0°, 45°, 60°, 70° and 80°. The measured horizontal pressure σ_h is lower than Jaky solution, and σ_h decreased with increasing α angle.

(2) Without the interface plate (α= 0°), the coefficient $K_{o,h}$ is slightly less than Jaky solution. The coefficient $K_{o,h}$ decreased with increasing rock face inclination angle α.

(3) An empirical relationship between the coefficient $K_{o,h}$

and the interface inclination angle α can be established: $K_{o,h,\alpha} = K_{o,h,Jaky} - 0.00462 \times \alpha$. This equation is applicable for loose sand for $0^o \le \alpha \le 80^o$.

(4) Without the interface plate (α = 0°), the point of application h/H of the at-rest earth pressure is located at about 0.33 H above the base of the wall. The total soil thrust rises to higher locations with increasing interface inclination angle α.

B. For dense sand

(1) After compaction, the lateral stress measured near the top of backfill is almost identical to passive earth pressure. Below the compaction-influenced zone for α = 0°, the lateral stresses converge to the earth pressure at-rest based on Jaky equation.

(2) The extra horizontal stress induced by compaction $\Delta\sigma_{h,ci}$ decreases with increasing α angle. Below the compaction-influenced zone, the distributions of lateral earth pressure are lower than Jaky solution.

(3) The point of application h/H of the total thrust rises to a higher location with increasing interface angle. The order of h/H, with the same interface inclination angle α, for compacted and loose sand is (h/H),strip ＞ (h/H),square ＞ (h/H),loose.

8. References

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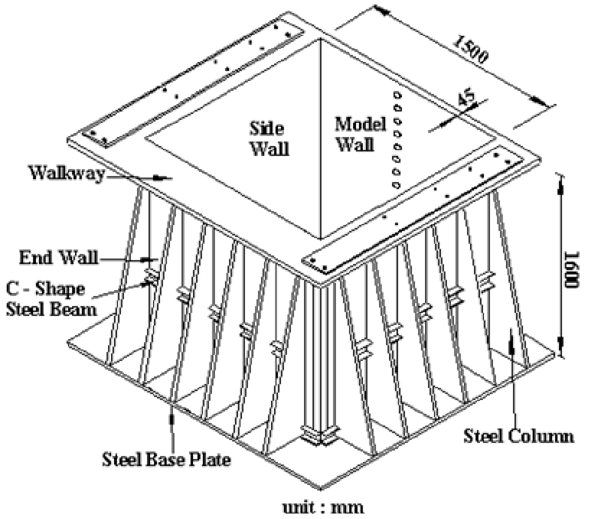

Fig.1. NCTU Non-Yielding Retaining Wall.

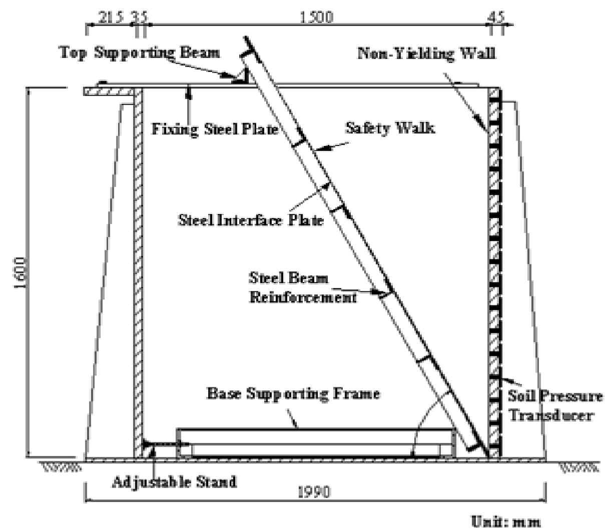

Fig. 2. steel interface plate and supporting system

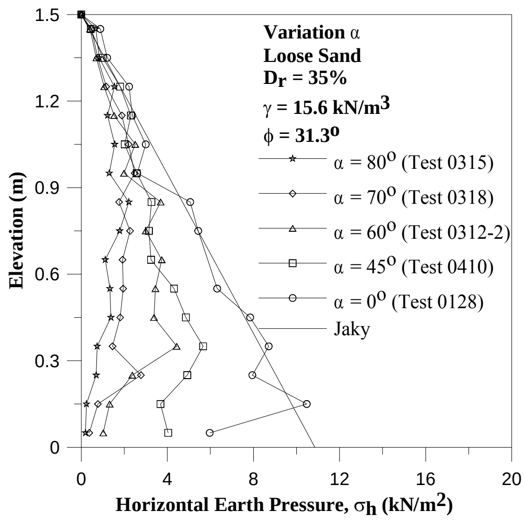

Fig.3. Distribution of lateral earth pressure at various α for loose sand

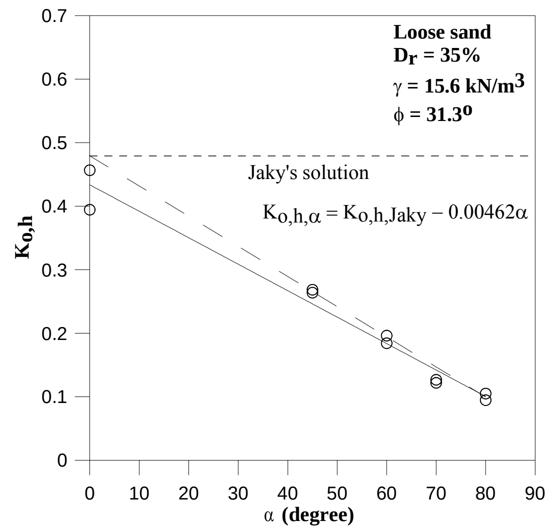

Fig. 4. Variation of $K_{o,h}$ at various α for loose sand

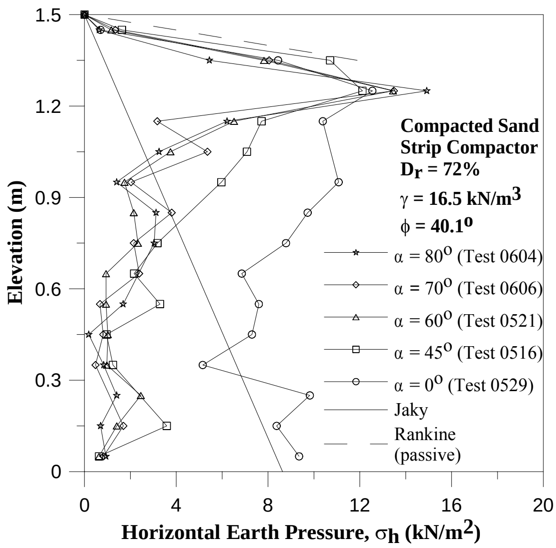

Fig. 5. Distribution of lateral earth pressure at various α for sand compacted with strip compactor

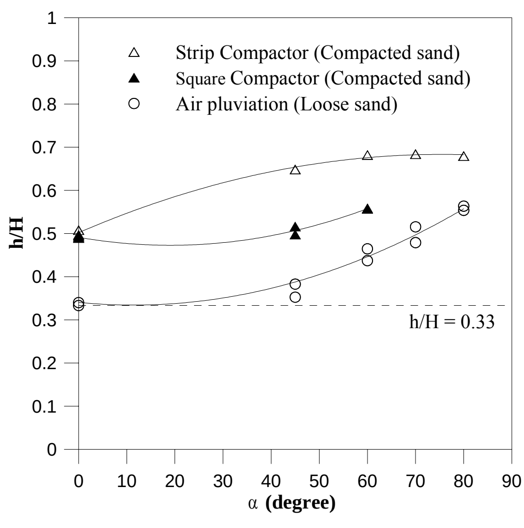

Fig. 6. Point of application of resultant force at various α