行政院國家科學委員會專題研究計畫　期中進度報告

堅硬土層侵入回填土對擋土牆靜止主動及被動土壓力之影響(1/3)

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計畫主持人： 方永壽

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中　華　民　國 95 年 5 月 30 日

堅硬土層侵入回填土對擋土牆靜止主動及被動土壓力之影響(1/3)

摘要

本研究探討鄰近岩石界面傾角對靜止土壓力之影響。 在實驗中，本研究以氣乾之渥太華砂作為回填土，回填土高 1.5 公尺。量測於鬆砂(D_r = 35%)狀態下的側向靜止土壓力。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 對靜止土壓力的影響。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。本研究包含岩石界面傾角 α= 0^o、45^o、60^o、70^o 與 80^o 五種實驗。依據鬆砂實驗結果，獲得以下兩項結論。(1) 在岩石界面傾角 45^o、60^o、70^o 與 80^o 狀況下，側向土壓力隨深度呈非線性分布，所測得的靜止土壓力低於 Jaky 解，側向土壓力隨界面傾角的增加而降低。(2) 當岩石界面傾角 α=0^o 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，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。

關鍵詞：土壓力;模型試驗;擋土牆;砂;堅硬土層

Earth Pressure on Retaining Walls with Intrusion of a Stiff Interface into Backfill (1/3)

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^o, 45^o, 60^o, 70^o, and 80^o. Base on the test results for loose sand, the following conclusions can be drawn. (1) The distributions of lateral earth pressure are not linearly with depth for the interface inclined at α= 0^o, 45^o, 60^o, 70^0 and 80^o. The measured horizontal pressure σ_h is lower than Jaky's solution, and σ_h decreased with increasing α angle. (2) Without the interface plate (α= 0^o), 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.

Keywords: Earth Pressure; Model Test; Retaining Wall; Sand; Stiff Soil

1. INTRODUCTION

In this study, the effects 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's Formula. However, if the retaining wall is constructed adjacent to inclined rock face as shown in Fig. 1.1, the rock face intrudes the backfill. In this figure, 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's 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.

1.1 Objective of Study

The NCTU model retaining wall was used to study the effects of adjacent inclined rock face on earth pressure at-rest. A steel interface plate was designed and constructed to the inclined rock face. Air-dry Ottawa sand was air-pluviation into the soil bin to achieve a D_r = 35% loose backfill. The rock face inclination angles α = 0°, 45°, 60°, 70° and 80° as shown in Fig.1.2. The height of the model wall H = 1.5m. The distribution of lateral earth pressure is measured with the soil pressure transducers on the model wall. Based on experimental results, the distribution of earth pressure adjacent inclined rock face will be obtained. Test results are compared with Jaky's theory.

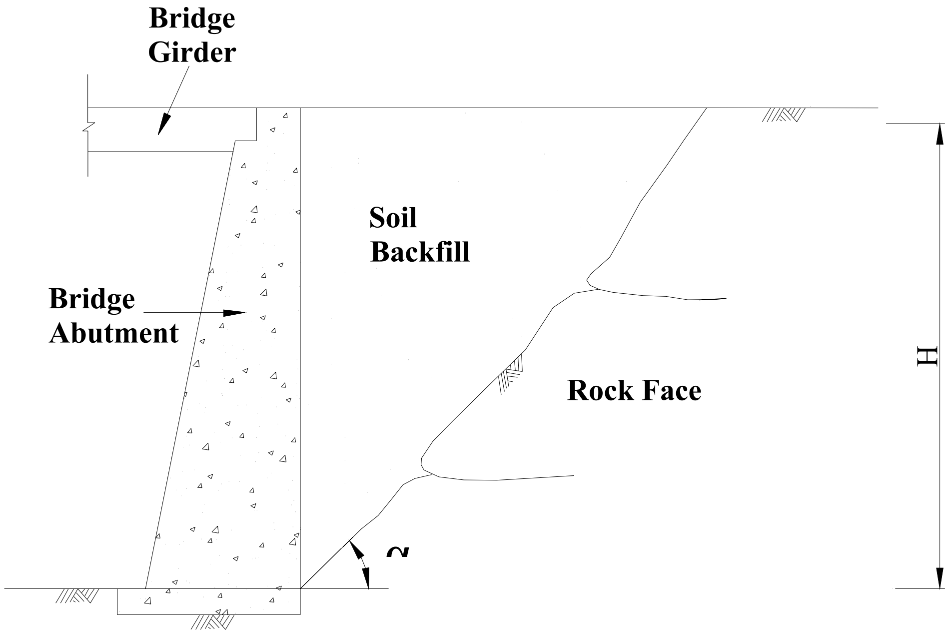

Fig. 1.1. Bridge abutment near an inclined rock face

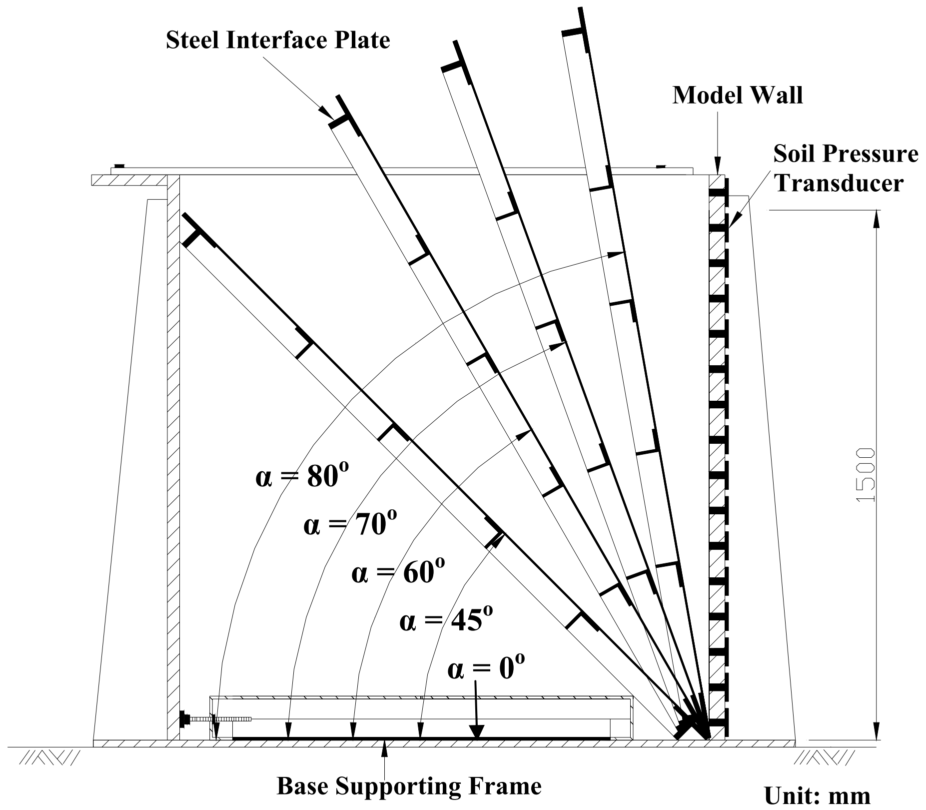

Fig. 1.2. Different interface inclinations

2. LITERATURE REVIEW

Jaky's formula was often used to calculate the earth pressure at-rest behind a retaining wall. However, the theory to estimate the lateral earth pressure on retaining wall near an inclined rock face has received very little attention in the literature. Theoretical and empirical relationship to estimate the lateral earth pressure adjacent to a vertical rock face has been reported by Janssen (1895), Reimbert and Reimbert (1976), and Spangler and Handy (1984).

3. EEPERIMENTAL APPARATUS

To investigate effects of inclined rock face on earth pressure at-rest, the instrumented model retaining wall facility at National Chiao Tung University (NCTU) was used. 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).

3.1 Model Wall

The model wall shown in Fig. 3.1 is 1500 mm-wide, 1600 mm-high, and 45 mm-thick. To achieve an at-rest condition, the wall material should be nearly rigid. With the application of earth pressure, the deformation of the wall could be neglected. As indicated in Fig. 3.1, the model wall is actually the front-side of the reinforced steel box. To reduce avoid the lateral deformation of the box, twenty-four 20 mm-thick steel columns were welded vertically on the outsides of the box (Fig. 3.1). In addition, twelve C-shaped steel beams were welded horizontally around the box to achieve an at-rest stress condition in the box.

To investigate the distribution of earth pressure behind retaining wall, fifteen soil pressure transducers (SPT) were attached in the central zone of the model wall as illustrated in Fig. 3.2. The soil pressure transducers are strain-gage-type transducers (Kyowa PGM-02KG, capacity = 19.6 kN/m^2). To eliminate the soil-arching effect, all soil-pressure transducers were quite stiff and were installed flush with the wall.

3.2 Soil Bin

To constitute a plane strain condition for model test, the soil bin is designed to minimize the lateral deflection of sidewalls and the friction between the backfill and sidewalls. In Fig. 3.1, the sidewalls were fabricated of 1500 mm-wide, 1600 mm-high steel plates. The end-wall and sidewalls of the soil bin were made of 35 mm-thick steel plates. From a practical point of view, the deformation of the sidewalls could be considered negligible.

To reduce the friction between backfill and sidewalls, a lubrication layer consists of plastic sheets (Fang et al., 2004) was furnished for all model wall experiments. The lubrication layer consists of one thick and two thin plastic sheets were hung vertically on each sidewall of the soil bin before the backfill was deposited. The thick sheet was placed next to the soil particles. It is expected that the thick sheet would help to smooth out the rough interface as a result of plastic-sheet penetration under normal stress. Two thin sheets were placed next to the steel sidewall to provide possible sliding planes.

3.3 Data Acquisition System

The Data acquisition system used for this study composed of the following four parts: (1) dynamic strain amplifiers (Kyowa: DPM601A and DPM711B); (2) NI card; (3) AD/DA card; and (4) PC. The analog obtained signals from the sensors are filtered and amplified by dynamic strain amplifiers. Analog Experimental data are converted digital data by the A/D – D/A card. The LabVIEW program is used to acquire experimental data finally. Experimental data are storage and analysis with the Pentium 4 personal computer.

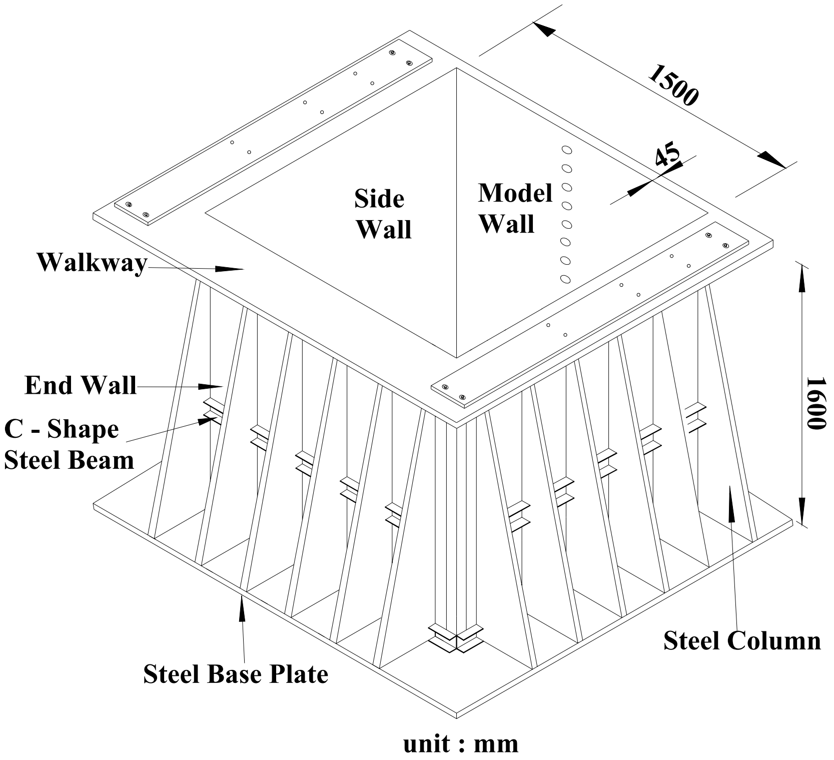

Fig. 3.1. NCTU non-yielding retaining wall

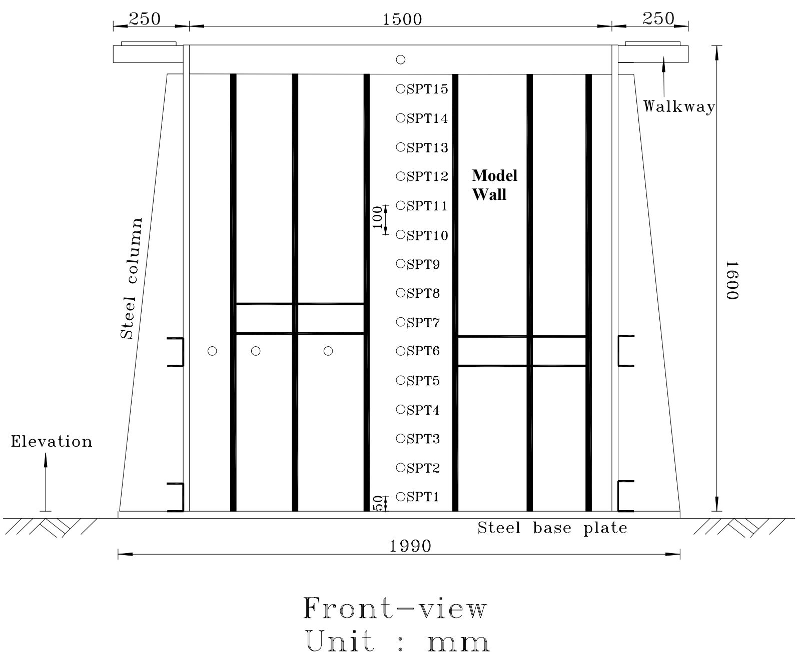

Fig. 3.2. Location of soil pressure transducer mounted on the model wall (after Chen and Fang, 2002)

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. 4.1, 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 supporting system consists of the following three parts: (1) top supporting beam; (2) base supporting frame; and (3) fixing plate.

4.1 Inclined Interface Plate

A steel plate is 2.10 m-long, 1.497 m-wide, and 0.0045 m-thick. The unit weight of the steel plate is 76.52 kN/m^3 and its total mass is 110.34 kg (1.08 kN). A layer of anti-slip material (Safety-walk, 3M) is attached on 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 ╳ 8 steel L-beams of longitudinal and transverse directions to the back of steel plate.

4.2 Supporting System

To keep the steel interface plate stable, the supporting system was designed and constructed. The supporting system was composed of the following three parts: (1) base supporting frame; (2) top supporting beam; (3) fixing steel plate. Top view of the model wall and steel interface plate is shown in Fig. 4.2.

4.3 Different Interface Inclinations

Different interface inclinations associated with this investigation are shown in Fig. 1.2. Ottawa sand was pluviated into the soil bin with the arrangement of interface plate angles for $\alpha = 45^o, 60^o, 70^o$ and 80^o.

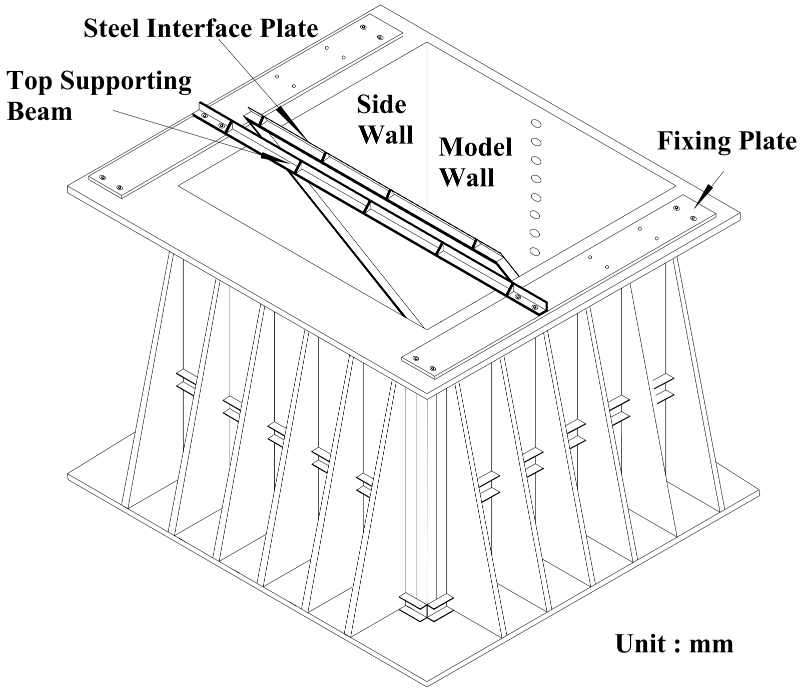

Fig. 4.1. Steel interface plate and non-yielding wall

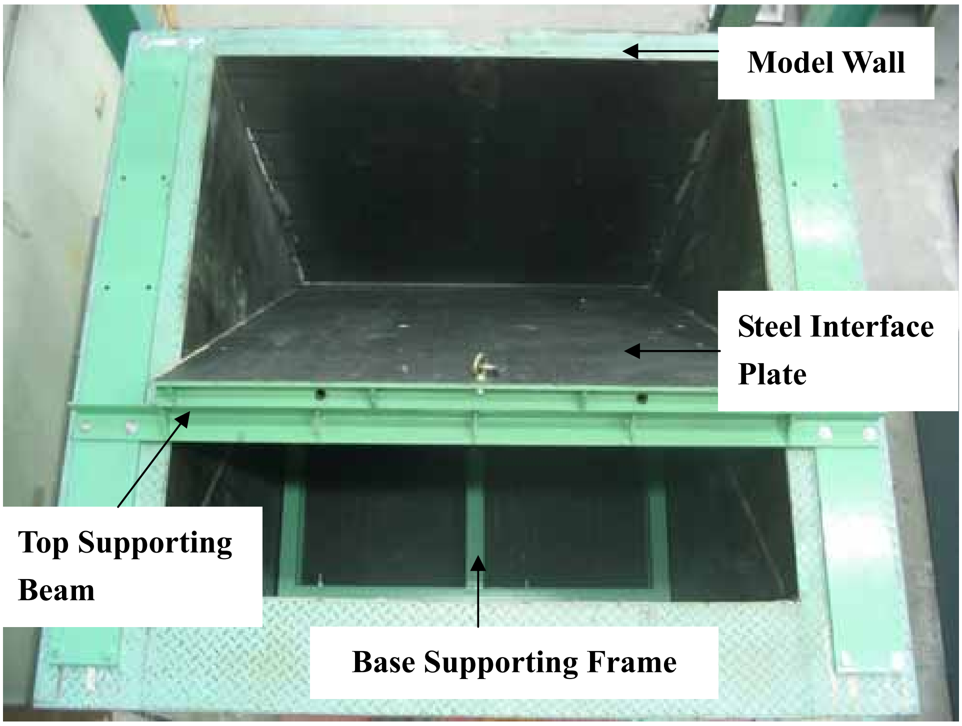

Fig. 4.2. Non-yielding wall and steel interface plate

5. BACKFILL AND INTERFACE CHARACTERISTICS

5.1 Backfill Properties

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

$$\phi = 6.43\,\gamma - 68.99 \qquad (5.1)$$

Where ϕ = angle of internal friction of soil (degree); and γ = unit weight of soil (kN/m^3). Equation (5.1) is applicable for $\gamma = 15.45 \sim 17.4$ kN/m^3 only.

5.2 Control of Soil Density

To achieve a uniform soil density in the backfill, Ottawa sand was deposited by air-pluviation method into the soil bin. 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. 5.1.

5.3 Side Wall Friction

To reduce the friction between sidewall and backfill, a lubrication fabricated layer with plastic sheets was furnished for all model wall experiments. 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^o.

5.4 Model Wall Friction

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 relationship between γ and wall friction angle δ_w For air-pluviation Ottawa sand can be expressed as follows

$$\delta_w = 3.41\,\gamma - 43.69 \qquad (5.2)$$

Where δ_w = wall friction angle (degree), and γ = unit weight of backfill (kN/m^3).

5.5 Inclined Interface Friction

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 sandstone rock-face and sandy fill. For the backfill prepared with air-pluviation method.

$$\delta_i = 2.7\gamma - 21.39 \qquad (5.3)$$

Where δ_i = interface-plate friction angle (degree), and γ = unit weight of soil (kN/m^3).

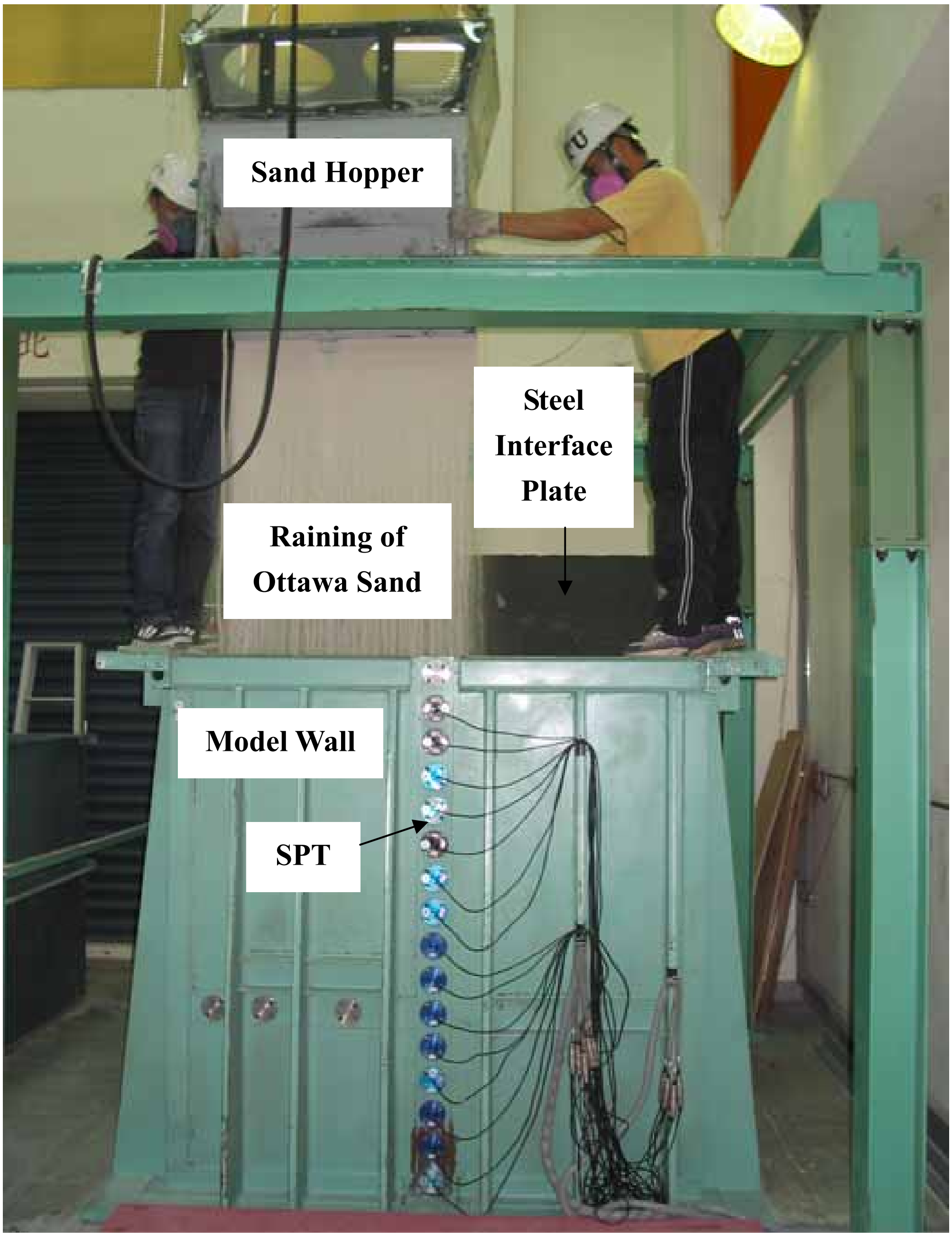

Fig. 5.1 Pluviation of the Ottawa sand into soil bin

6. EXPERIMENTAL RESULTS

This section reports the experimental results regarding effects of adjacent inclined rock face on earth pressure at-rest for loose sand.

6.1 Distribution of Earth Pressure At-Rest

The distribution of lateral earth pressure for the interface inclined at $\alpha = 0^o$, 45^o, 60^o, 70^0 and 80^o illustrated in Fig. 6.1. 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's solution. The magnitude of σ_h decreased with increasing α angle. In Fig. 6.1, the measure σ_h is significantly affected by the presence of the nearby rock face. It would be reasonable to expect the resultant soil thrust acting P_h 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.

6.2 At-Rest Soil Thrust

The variation of horizontal at-rest pressure coefficient $K_{o,h}$ as a function of interface inclination angle α is shown in Fig. 6.2. 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. 6.1. Without the interface plate ($\alpha = 0^o$), 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 $K_{o,h}$ are apparently less than the Jaky's solution. Based on the test results, an empirical relationship between the coefficient $K_{o,h}$ and the interface inclination angle α can be established:

$$K_{o,h,\alpha} = K_{o,h,Jaky} - 0.00462 \times \alpha \qquad (6.1)$$

Where $K_{o,h} = 1 - \sin\phi$, α = interface inclination angle (degree). Equation (6.1) is applicable for loose sand with $0^o \le \alpha \le 80^o$.

6.3 Point of Application of At-Rest Soil Thrust

The point of application h/H of the total thrust as a function of the α angle is Shown in Fig. 6.3 Without the interface plate ($\alpha = 0^o$), 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. As the interface angle α increase, the earth pressure start to decrease near the base of the wall as seen in Fig. 6.1. This change of earth pressure distribution causes the total thrust to rise to higher locations as shown in Fig. 6.3. For $\alpha = 80^o$, the point of application of the total thrust is located at 0.65 H above the base of the wall.

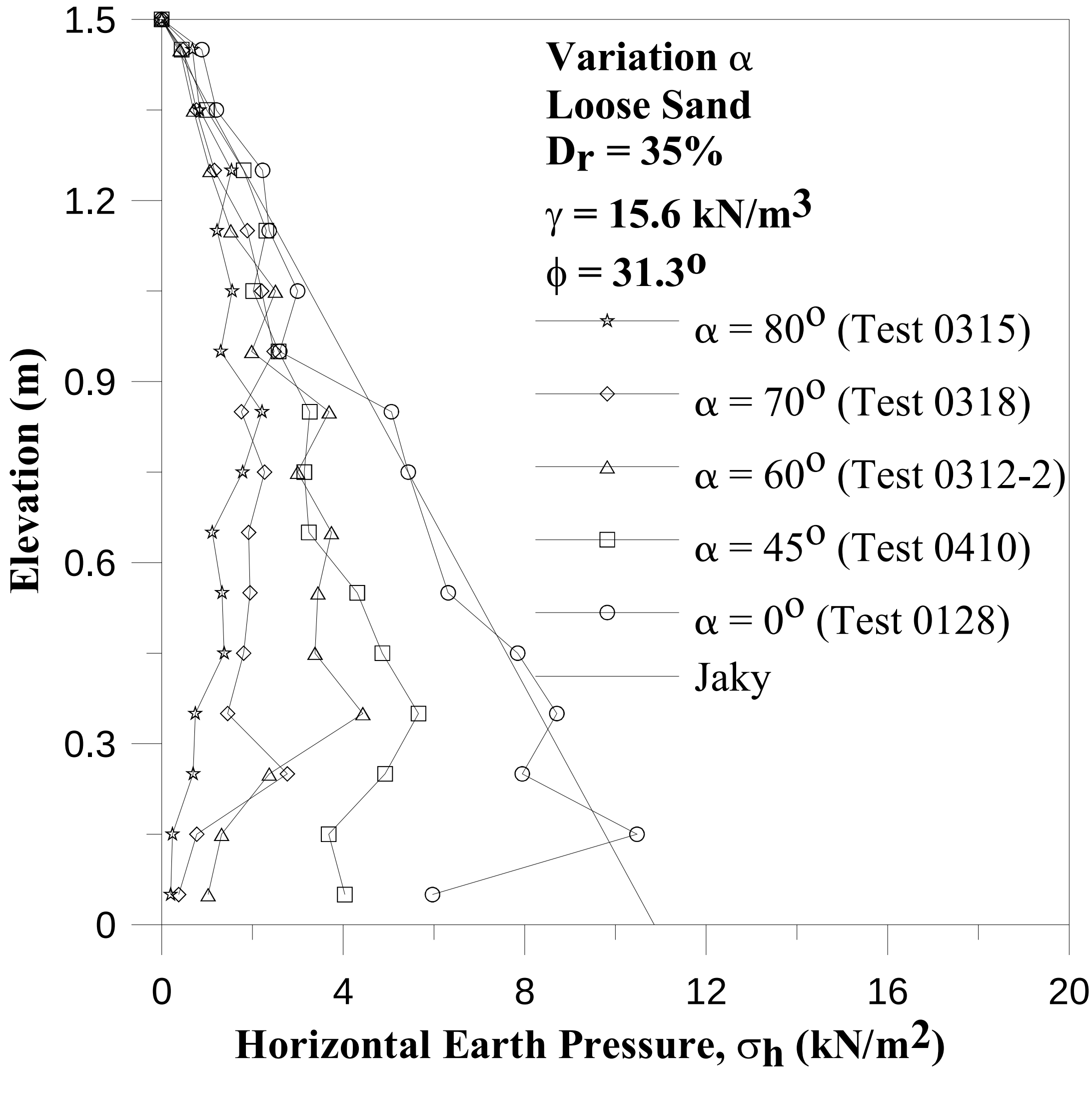

Fig. 6.1. Distribution of lateral earth pressure at various α for loose sand

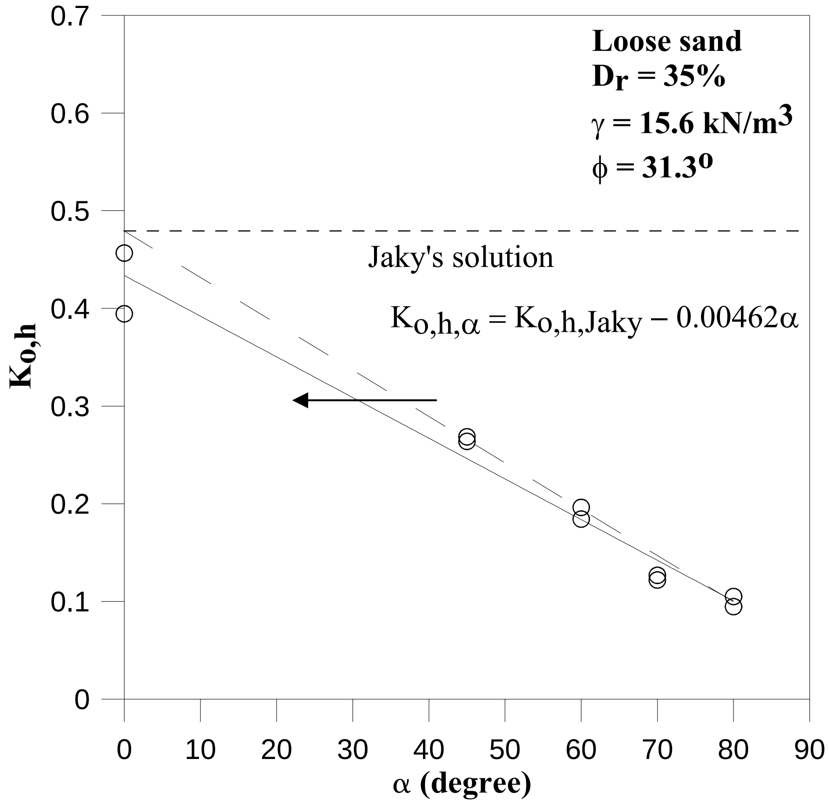

Fig. 6.2. Variation of $K_{o,h}$ at various α for loose sand

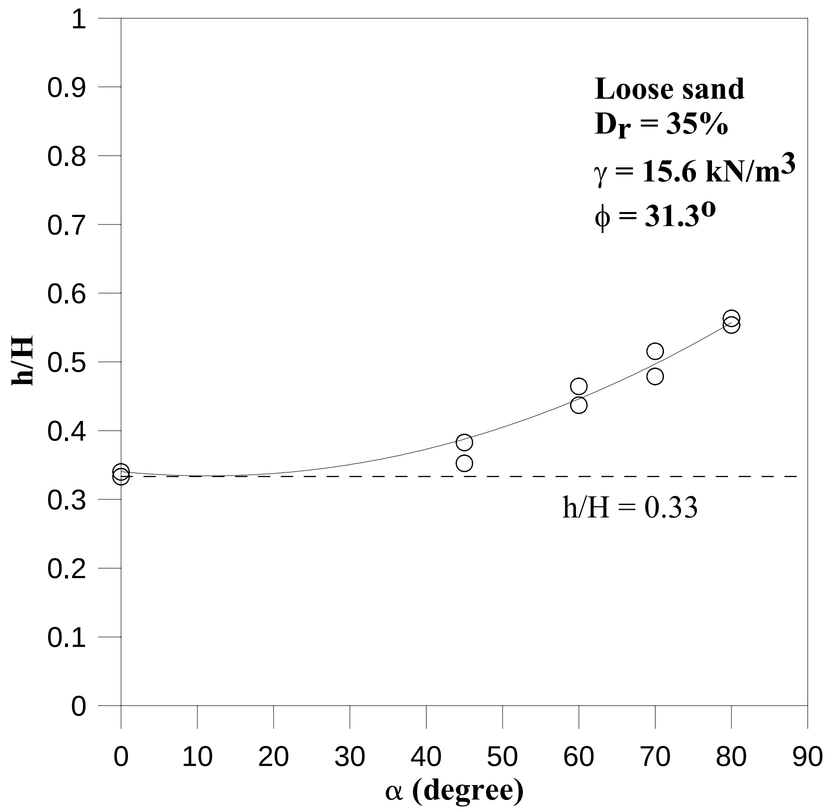

Fig. 6.3. Point of application of resultant force at various α for loose sand

7. CONCLUSIONS

In this study, the effects of adjacent inclined rock face on earth pressure at-rest for loose sand are studied. Base on the test results, the following conclusions can be drawn.

1. The distributions of lateral earth pressure are not linearly with depth for the interface inclined at $\alpha = 0^o$, 45^o, 60^o, 70^0 and 80^o. The measured horizontal pressure σ_h is lower than Jaky's solution, and σ_h decreased with increasing α angle.
2. Without the interface plate ($\alpha = 0^o$), 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 ($\alpha = 0^o$), 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.

8. REFERENCES

1. Broms, B., and Ingleson, I. (1971). "Earth pressures against abutment of a rigid frame bridge." *Geotechnique*, 21(1), 15-28.
2. Burgess, G. P. (1999). "Performance of two full-scale model geosynthetic reinforced segmental retaining walls," MS thesis, Royal Military College of Canada, Kingston, Ontario, 207.
3. Chen (2002). "Earth pressure due to vibratory compaction." Ph.D. dissertation, Department of Civil Engineering, National Chiao Tung University, Hsinchu, Taiwan.
4. Chen, T. J. and Fang, Y. S. (2002). "A new facility for measurement of earth pressure at rest". *Geotechnical Engineering Journal*, SEAGES, Vol. 33. No. 3, December, pp.153-159.
5. Fang, Y. S., Chen, J. M., and Chen, C. Y. (1997). "Earth pressures with sloping backfill." *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, 123(3), March, 250-259.
6. Fang, Y. S., Chen, T. J., and Wu, B. F. (1994). "Passive earth pressures with various wall movements." *Journal of Geotechnical Engineering*, ASCE, 120(8),

1307-1323.
7. Frydman, S., and Keissar, I. (1987). "Earth pressure on retaining walls near Rock Faces." *Journal of Geotechnical Engineering*, ASCE, 113(6), 586-599.
8. Jaky, J. (1944). "The coefficient of earth pressure at rest." *Journal for Society of Hungarian Architects and Engineers*, Budapest, Hungary, Oct., 355-358.
9. Mackey, R. D., and Kirk, D. P. (1967). "At rest, active and passive earth pressures." *Proc., South East Asian Conference on Soil Mechanics and Foundation Engineering*, Bangkok, 187-199.
10. Matteotti, G. (1970). "Some results of quay-wall model tests on earth pressure." *Proceeding, Institution of Civil Engineers,* 47, 185-204.
11. Mesri, G., and Hayat, T. M. (1993). "The coefficient of earth pressure at rest." *Canadian Geotechnical Journal*, 30(4), 647-666.
12. Rad, N. S., and Tumay, M. T. (1987). "Factors affecting sand specimen preparation by raining."*Geotechnical Testing Journal*, ASTM, 10(1), 31-37.
13. Reimbert, M., and Reimbert, A. (1976). Silos - *theory and practice*, Trans Tech Publications, 1st ed., Clausthal, Germany.
14. Safarian, S.S., and Harris, E.C. (1985). "Design and construction of silos and bunkers. " *Methods of computing static pressures due to granular material*, 10-14.
15. Spangler, M. G., and Handy, R. L. (1984), *Soil Engineering*, Harper and Row, New York, N.Y. 572-573.

9. 計劃成果自評

本研究在國立交通大學基礎模型試驗室內，自行建造大型靜止土壓模型擋土牆、鋼製界面板、及其支撐系統，探討鄰近岩石界面傾角對靜止土壓力之影響。 在實驗中，本研究以氣乾之渥太華砂作為回填土，回填土高 1.5 公尺。量測於鬆砂(D_r = 35%)狀態下的側向土壓力值。本研究利用實驗方法來探討不同岩石界面傾角 α 對側向土壓力造成的影響。研究內容與計劃書完全相符。

本研究獲得數項創新且具有實用性的之研究成果，充分達成預期之目標，將於近期內投稿至國際知名期刊。參與研究的碩士班研究生藉此機會，學習大型基礎模型實驗及資料擷取系統之操作，習得嚴謹的實驗方法及獲得獨立解決問題的能力，獲益良多。

附件二

可供推廣之研發成果資料表

☐ 可申請專利　☐ 可技術移轉　日期：95 年 5 月 31 日

國科會補助計畫	計畫名稱：堅硬土層侵入回填土對擋土牆靜止主動及被動土壓力之影響(1/3) 計畫主持人：方永壽 教授 計畫編號：NSC 94-2211-E-009-042 學門領域：土木水利工程
技術/創作名稱	
發明人/創作人	
技術說明	中文： 本研究屬於基礎學術性研究，目前尚處於初步建構階段，三年計畫完成後，所獲結果將有助於擋土結構物的設計。 （100~500 字）
	英文：
可利用之產業及可開發之產品	

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