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地表載重對擋土結構物造成之側向土壓力(I)

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計畫主持人：方永壽

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地表載重對擋土結構物造成之側向土壓力(I)

Lateral Earth Pressure on Retaining Structures Due to Surcharge (I)

計 劃 編 號 : NSC 91-2211-E-009-022
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1. Abstracts

1.1 中文摘要

本論文探討回填土伴隨地表條型載重對作用於擋土牆主動土壓力之影響。本研究利用國立交通大學模型擋土牆設備探討平移模式牆位移所造成土壓力之變化。試驗採用相對密度 35%之氣乾渥太華砂為回填材料，其單位重為 15.6 kN/m^3，內摩擦角為 31.6°。根據實驗結果，本研究獲得以下各項結論：(1) 以空中霣降法所製作之鬆砂土體，其靜止土壓力係數 K_o 與 Jaky 建議的公式互相吻合； (2) Coulomb 理論能準確預測在水平牆移動模式下的水平主動土壓力；(3) 當地表載重作用於背填土上方，實驗量測之側向土壓力分佈介於 DM-7.2 所建議的 $\Delta\sigma_h$ 與 1.6 $\Delta\sigma_h$ 之間； (4) 檔土牆發生額外主動移動量時，實驗的側向主動合力增量與 Terzaghi and Peck 的預測值相吻合，Steenfelt and Hansen 理論計算明顯高估地表載重作用與牆移動造成的側向土壓力。

關鍵詞: 條型載重、靜止土壓力、砂、擋土牆

1.2 English Abstract

This paper presents experimental data of earth pressure. The backfill carries a surcharge load acting against a vertical rigid wall which moves away from a mass of dry sand. Ottawa sand is prepared at the relative density of 35% with air-pluviation method. The instrumented retaining-wall at National Chiao Tung University was used to investigate the variation of lateral earth pressure due to strip surcharge, and that induced by translational wall movement. For all tests, the soil unit weight is 15.6 kN/m^3, and its internal friction angle is 31.6°. Base on this study, the following conclusions can be drawn. (1) For the loose soil placed with the air-pluviation method, the coefficient of earth pressure at-rest K_o calculated with Jaky's formula is in good agreement with experimental values. (2) Coulomb's theory provides a good evaluation of the active thrust as a result of the translational wall movement. (3) As the surcharge is applied on backfill, the distribution of lateral pressure increment could be reasonably described with $\Delta\sigma_h$ and 1.6 $\Delta\sigma_h$ suggested by the Navy Design Manuel DM-7.2. (4) Steenfelt and Hansen's theory overestimates the lateral earth pressure due to the surcharge and that due to further active wall movement.

Keywords: Strip footing, Earth pressure at-rest, Sand, Retaining wall

2. Introduction

Traditionally, civil engineers build retaining structures to resist the earth pressure. If no wall movement is allowed, the filling of soil behind the wall will induce an at-rest earth pressure on the retaining structure. However, with the rise of fill, the wall was gradually pushed away from the backfill and active pressure will act against the wall. The surcharge loading induces an extra pressure on the wall. Further active wall movement may cause another lateral stress adjustment, under the new equilibrium condition.

The earth pressure distribution behind the wall has a great influence on the safety of the retaining structure. It influences not only the stress within the body, but also the structure safety as a whole. Therefore, the distribution of lateral earth pressure on the retaining wall should be carefully considered. It would be interesting to know how the earth pressure changes as a result of filling of soil, active wall movement, surcharge loadings, and further active wall movements.

This research utilizes the NCTU model wall facility to investigate the changes of earth pressure due to surcharge loading. The theories to estimate the earth pressure induced by surcharge, and experimental finding associated with lateral stress induced by surcharge loading are summarized.

3. NCTU Model Retaining Wall Facility

To study the earth pressure behind retaining structures, the National Chiao Tung University (NCTU) built a model retaining wall system which can simulate different kinds of wall movement. All of the investigations described in the thesis were conducted in this model wall. The entire system consists of the following components: soil bin; model retaining wall; driving system; and surcharge loading system.

The soil bin is 2,000 mm-long, 1,000 mm-wide and 1,000 mm-deep as shown in Fig. 1. Both side walls of the soil bin are made of 30 mm-thick transparent acrylic plates, through which the behavior of the backfill can be observed. Outside the acrylic plates, steel beams and columns are used to confine the side walls to ensure a plane strain condition.

The retaining wall is 1000 mm-wide, 550 mm-high, and 120 mm-thick, and is made of solid steel. The retaining wall is vertically supported by two unidirectional rollers , and lateral supported by the steel frame through the driving system. Two separately controlled wall driving mechanism, one at the upper level, and the other at the lower level, provide various kinds of lateral wall movements.

Each wall driving system is powered by a variable-speed motor. The motors turn the worm driving rods which cause the driving rods to move the wall back and forth. Two displacement transducers (Kyowa DT-20D) are installed at the back of retaining wall and their sensors are attached to the movable wall. Such an arrangement of displacement transducers would be effective in describing the wall translation and rotation.

To investigate the earth pressure distribution, 9 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.

The soil pressure transducers were arranged within a narrow central zone to avoid the friction that might exist near the side walls of the soil bin. To eliminate the soil arching effect, all soil pressure transducers are built quite stiff, and their measuring surfaces are flush with the face of the wall. They provide closely spaced data points for determining variation of the earth pressure distribution with depth.

The surcharge loading system consists of four parts：(1) reaction frame；(2) vertical-force loading system；(3) strip footing ；and (4) settlement measuring system.

4. Backfill Properties

Ottawa silica sand (ASTM C-109) was used for the model wall experiments. All tests have been conducted under an air-dry condition. The compactor is used to obtain different soil densities. To establish the relationship between unit weight of backfill γ and its internal friction angle ϕ, direct shear tests were conducted. A unique relationship between γ and ϕ can be obtained for Ottawa sand as follows:

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

where γ is unit weight of backfill in kN/m^3. In this study, the unit weight γ of the compacted dense is 15.6 kN/m^3, and the corresponding friction angle ϕ is 31.6^o.

Air-dry Ottawa sand is sucked from storage bin to the sand hopper, weighted on the electric scale, then pluviated into the soil bin. Das (1994) suggested that the granular soil with a relative density of 15% ~ 50% is defined as loose. In this study, the drop height of 1.0 m and the slot opening of 15 mm were selected to achieve the loose backfill with a relative density of 35%.

5. Experimental Results

Step 1 - Earth Pressure At-Rest

Fig. 2 shows the experimental earth pressure at-rest (S/H = 0). The test data are compared with Jaky's equation. Mayne and Kulhawy (1982), Mesri and Hayat (1993) reported that Jaky's equation is suitable for backfill in its loosest state.

Step 2 - Active Earth Pressure

For the active earth pressure experiments, the model wall was slowly moved as a solid block away from the soil mass at a constant speed of 0.01 mm/sec. Fig. 3 shows typical variations of the earth pressure distribution at various wall movements, the movement is almost linear.

The earth pressure coefficient, K_h decreases with increasing wall movement until it reaches a constant value.

Step 3 - Lateral pressure Due to Strip Surcharge

In Fig. 4, the experimental $\Delta\sigma_h$ distribution with depth is compared with theoretical values calculated by the method of images and values suggested by the Navy Design Manuel DM-7.2. The earth pressure distribution due to the strip surcharge could be reasonably described with $\Delta\sigma_h$ and 1.6 $\Delta\sigma_h$ curves suggested by the Manuel DM-7.2.

Step 4 - Pressure Change Due to Further Active Wall Movement

Fig. 5 shows the soil thrust decreases with increasing active wall movement. The experiment data are much lower than the Steenfelt and Hansen solution. The lateral force increment $\Delta P_{h.y}$ as a result of both surcharge and further active wall movement is suggested by Terzaghi and Peck (1967).

$$\Delta K_{h.y} = \Delta P_{h.,y} / 0.5\gamma H^2 \quad (2)$$

The variation of $\Delta K_{h.y}$ as a function of wall movement in Fig. 5 shows $\Delta K_{h.y}$ decreases with increasing wall movement. It may be observed in the figure that Terzaghi and Peck (1967) provide a suitable prediction.

6. Conclusions

This paper studies the effect of intensity and position of surcharges on active earth pressure due to extra wall movement. Based on this study, the following conclusions can be made：

(1) For the loose soil placed with the air-pluviation method, the coefficient of earth pressure at-rest K_o calculated with Jaky's formula is in good agreement with experimental values.

(2) Coulomb's theory provides a good evaluation of the active thrust as a result of the translational wall movement.

(3) As the surcharge is applied on backfill, the distribution of lateral pressure increment could be reasonably described with $\Delta\sigma_h$ and 1.6 $\Delta\sigma_h$ suggested by the Navy Design Manuel DM-7.2.

(4) Steenfelt and Hansen's theory overestimates the lateral earth pressure due to the surcharge and that due to further active wall movement.

7. References

1. Bowles, J. E., (1988),"Foundation Analysis and Design," 4^{th} Edition, McGraw-Hill Book Co., pp. 474.
2. Das, B. M., (1994), "Principles of Geotechnical Engineering," PWS Publishing Company, Boston.
3. Fang, Y. S., and Ishibashi, I., (1986), "Static Earth Pressures with Various Wall Movements," Journal of Geotechnical Engineering, ASCE, Vol. 112, No. 3, Mar., pp. 317-333.
4. Jaky, J., (1944),"The Coefficient of Earth Pressure at Rest," Journal for Society of Hungarian Architects and engineers, Budapest, Hungary, Oct., pp. 355-358.
5. Steenfelt, J. S., and Hansen, B. (1983), "Total Lateral Surcharge Pressure Due to Strip Load," Journal of the Geotechnical Engineering Division, ASCE, pp.271-273
6. Terzaghi, K., Peck, R. B., (1967), Soil Mechanics n Engineering Practice, 2^{th} ed. John Wiley, New York.
7. US NAVY, (1982), Foundation and Earth Structures, *NAVFAC Design Manual DM-7.2*, Naval Facilities Engineering Command, U.S. Government Printing Officer, Washington, D. C.

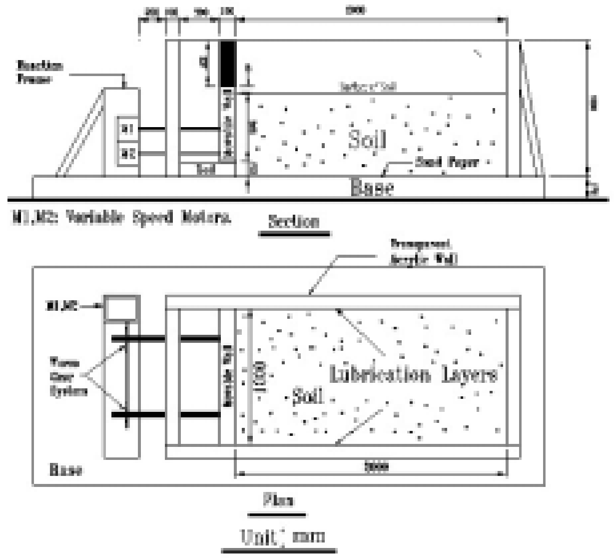

Fig .1 NCTU Model Retaining Wall

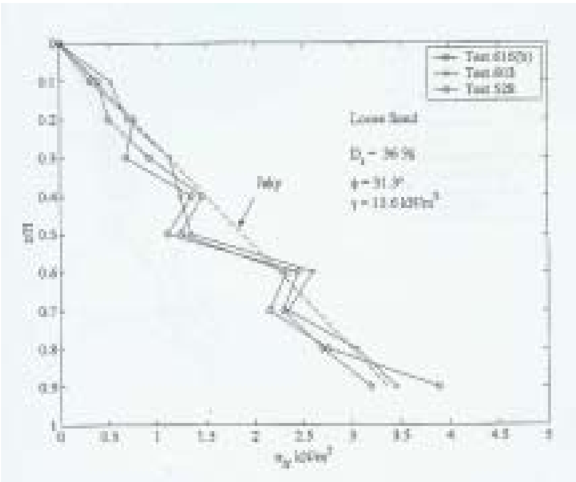

Fig .2 Earth Pressure at-Rest

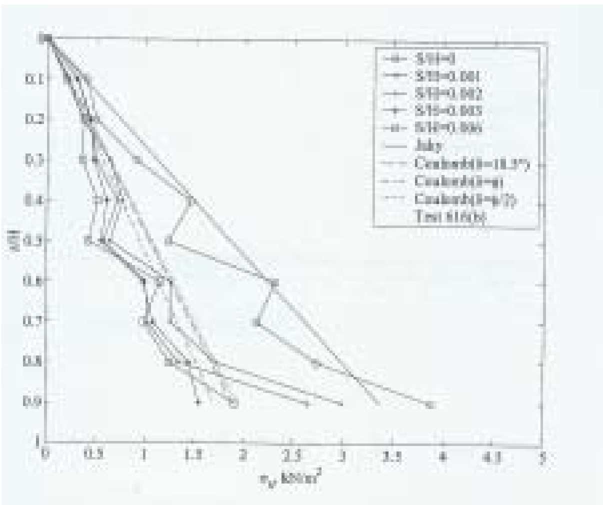

Fig .3 Distribution of Horizontal Earth Pressure

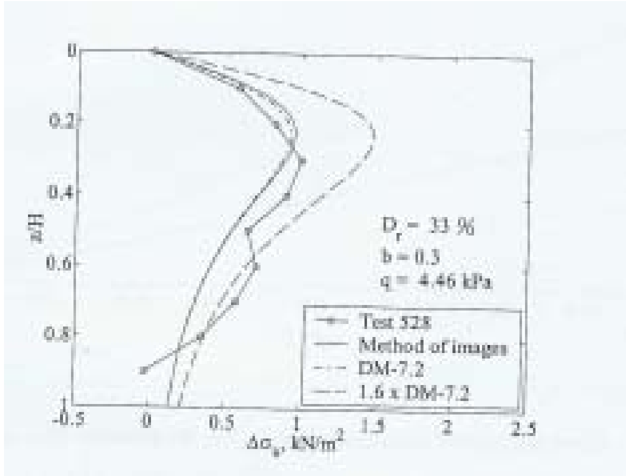

Fig .4 Lateral Earth Pressure Due to Strip Surcharge

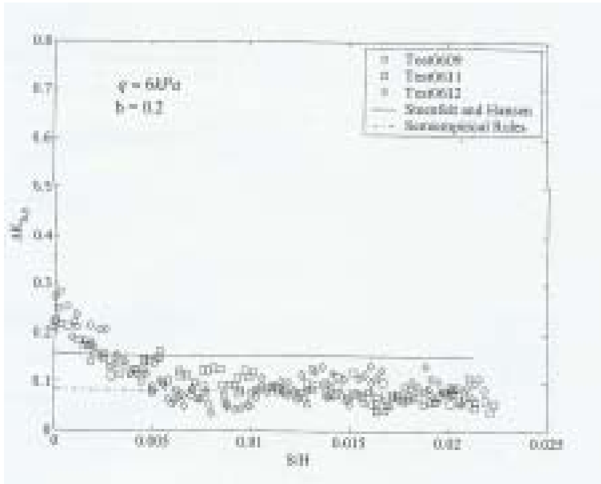

Fig .5 Variation of $\Delta K_{h.y}$ with Further Wall Movement