以實驗方法探討擋土牆位移型式及回填土傾角對土壓力的影響(IV)-回填土密度對被動土壓力之影響

An Experimental Study of Earth Pressure due to Various Wall Movements and Backfill Inclinations (IV) - Passive Earth Pressure with Various Backfill Densities.

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1. Abstract

1.1 中文摘要

本論文探討不同密度回填土作用在垂直牆面上的被動土壓力。本研究採用 31%，60%，與 84%相對密度之氣乾渥太華砂為回填土，利用國立交通大學模型擋土牆設備探討牆面向著土壤平移所造成土壓力之變化。依據實驗結果，獲得以下結論:無論土壤之初始密度為何，當被動牆位移量達到 0.14 牆高時，被動土壓力就達到一定值，此乃因回填土內沿破壞面上已大量變形達成「臨界狀態」(Critical state)。以下兩種類型之土壓力可視為被動狀態: (1)以「尖峰值」定義被動土壓合力；(2)以臨界狀態定義被動土壓力。實驗結果指出，Coulomb 與 Terzaghi 理論可能高估緊砂造成之被動土壓力。但若將由直接剪力實驗中所得到於臨界狀況下之內摩擦角ϕ_{cr} 與牆摩擦角δ_{cr} 帶入 Coulomb 公式中，理論值與實驗值吻合良好。

關鍵詞: 臨界狀態 、 密度、模型試驗、被動土壓力 、砂

1.2 English Abstract

This paper presents experimental data of earth pressure acting against a vertical wall, which moved toward a mass of dry sand with different densities. Backfills with relative density of 31%, 60%, and 84% are tested. The instrumented retaining-wall facility at National Chiao Tung University was used to investigate the variation of earth pressure induced by the translational wall movement. Based on this study, the following conclusions can be drawn. As the passive wall movement S/H exceeds 0.14, the passive soil thrust reaches a constant value regardless of the initial density of the backfill. This is because at this state the soil along the failure surface has deformed significantly and reached the "critical state". Two types of earth pressure can be defined as passive. One group is defined by the peak passive thrust, and the other group is defined by the critical passive thrust. Experimental results indicate that both Coulomb and Terzaghi theories overestimated the passive soil thrust. However, if the ϕ_{cr} and δ_{cr} angles obtained from direct shear tests at its critical state are used in the Coulomb and Terzaghi solution. The theoretical solutions are found to be in good agreement with the experimental data.

Keywords: **Critical state**, **Density**, **Model test**, **Passive earth pressure**, **Sand**

2. Introduction

Traditionally, civil engineers take the passive earth pressure as a force, which could balance the active force against the retaining structures. In most cases, civil engineers calculate the passive earth pressure behind a retaining wall following either Coulomb's or Rankine's theory. In the past, little experimental investigation has been conducted to study the effect of backfill density on the variation of passive earth pressure. However, based on their test data, Mackey and Kirk (1967) concluded that if the backfill is dense, the Coulomb's solution is approximately 100% higher than the experimental results. An overestimation of passive pressure would result in an overestimation of factor of safety against sliding, which makes the design unsafe.

This research utilizes the NCTU model wall facility to investigate the earth pressure exerted against the rigid wall, which move toward a cohesionless backfill. Earth pressure experiments with different relative densities were conducted and the test results are reported. Relative densities of 31%, 60%, and 84% have been achieved for the backfill. The variation of lateral pressure against the wall as a function of wall movement is measured. These results were compared with the well-known Rankine, Coulomb, and Terzaghi theories. Based on the experimental results, data recorded, a more rational design approach is suggested.

3. NCTU Model Retaining Wall Facility

To find the distribution of earth pressure under translational wall movement with different backfill densities, the National Chiao Tung University (NCTU) model retaining wall facility was used. The entire system can be divided into following main parts: (1) soil bin; (2) model retaining wall; (3) driving system; and (4) data acquisition system. The soil bin is 2000 mm in length, 1000 mm in width and 1000 mm in depth 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 backfill can be observed. To constitute a plane strain condition, the soil bin is built very rigid so that lateral deformations of the side walls will be negligible. The friction between the backfill and the side walls is to be minimized to nearly frictionless. This is accomplished by creating a lubrication layer between the side walls and the soil. The lubrication layer consists of a 0.2-mm thick rubber membrane and a thin layer of silicone grease (Shin-Etsu KS-63W).

Fig.1 shows the movable model retaining wall and driving system. The retaining wall is 1000-mm-wide, 550-mm-high, and 120-mm-thick, and is made of steel. Two separately controlled wall-driving mechanisms, one at the upper level and the other at the lower level, provide various kinds of lateral wall movement.

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. To investigate the earth pressure distribution, 9 earth pressure transducers are attached to model retaining wall. Earth pressure transducers (Kyowa BE-2KRS17, 196.2 kN/m^2 capacity, and PGM-0.2KG, 19.62 kN/m^2 capacity) have been arranged within a narrow central zone to avoid the friction that might exist near the side walls of the soil bin. To achieve the translational mode wall movement, two sets of driving rods are attached to the model wall. By setting the same motor speed for the upper and lower driving rods, a translation mode can be achieved for the model wall. Due to the considerable amount of data collected, all the signals generated by the earth pressure transducers and displacement transducers are processed by a data acquisition system.

4. Backfill and Interface Characteristics

Ottawa silica sand is used for the model wall experiments, and the tests are to be conducted under an air-dry condition. To establish the relationship between unit weight of backfill γ and its internal friction angle ϕ, direct shear tests have been conducted. A unique relationship between γ and ϕ can be obtained for the Ottawa sand used, the relationship can be expressed as follows:

$$\phi = 7.37\,\gamma - 85.2 \tag{1}$$

where γ is unit weight of backfill in kN/m^3. To evaluate the friction angle between the backfill and model wall, special direct shear tests have been conducted. A smooth steel plate, made of the same material as the model wall, was used as the lower shear box. Ottawa sand was placed into the upper shear box and vertical load was applied on the soil specimen. For the Ottawa sand used the relationship can be expressed as follows:

$$\delta = 2.33\,\gamma - 17.8 \tag{2}$$

5. Experimental Results

A loose backfill was made by pouring dry Ottawa sand from the hopper into the soil bin with a drop height of 1 m and the slot opening of 15 mm. The actual relative density achieved was 31.5% ± 1.5%. After recording the earth pressure at-rest, the model wall was slowly moved as a solid block toward the soil mass at a constant speed of 0.24 mm/sec. The horizontal earth pressure increases with increasing wall movement until a maximum value is reached. The earth pressure coefficient, K_h defined as $P_h/0.5\gamma H^2$, increases with increasing wall movement until a maximum value is reached, then K_h value remains approximately a constant. This ultimate value of K_h is defined as the passive earth pressure coefficient $K_{p,h}$. It should be mentioned that P_h is calculated by summing the pressure diagram and that P_h is only the horizontal component of the total soil thrust.

The medium dense backfill is assigned to have the relative density of 60%. However, the desired density could not be produced precisely by the air-pluviation method. The actual relative density achieved is 60%± 3%. The dense backfill is defined to have the relative density of 80%. It is not an easy task to control the slot opening of sand hopper to obtain a backfill with exactly Dr = 80%. During backfill preparation, the slot opening of 7 mm was selected. Densities achieved were 84%± 1%.

5.1 Effects of Soil Density

Fig.2 shows the variation of experimental earth pressure coefficient K_h with wall movement for loose, medium dense and dense backfill. It is clear for the dense sand, that initially K_h increases with increasing wall movement, then drops down until a constant value is reached. For the loose backfill, K_h increases till a stable value is reached. The wall movement needed for K_h to reach a peak value for dense sand is shorter than that for a medium dense backfill. It implies that the dense backfill will lose its strength faster than the medium dense soil does. When the passive wall movement S/H is greater than 0.14, it appears that K_h reaches to a constant value regardless of the initial density of the backfill. It is clear that at this state the soil along the failure surface has reached the "critical state" K_h. (Casagrande, 1936)

Fig.3 shows the theoretical and experimental passive earth pressure coefficient $K_{p,h}$ versus soil density. It may be observed that two groups of experimental K_p are plotted on the graph. One group defined by the peak passive thrust and the other group defined by the residual passive thrust at critical state. It is apparent that the classic Coulomb and Terzaghi theories significantly overestimated the passive soil thrust. However, if the ϕ_{cr} and δ_{cr} angles obtained from direct shear tests at its critical state are used in the Coulomb and Terzaghi solution. The theoretical solutions are found to be in good agreement with the experimental results. It is of critical importance that the concept of critical state should be included by geotechnical engineers during the design of retaining structure.

6. Conclusions

In this study, the traditional earth-pressure theories have been modified by introducing the progressive failure and the critical state concepts. Based on this study, the following conclusions can be drawn. (1) For dense sand, the experimental earth pressure initially increases with increasing wall movement, then drops down until a constant value is reached. However, in the loose backfill, horizontal earth pressure increases till a stable value is reached. (2) As the passive wall movement S/H exceeds 0.14, the passive soil thrust reaches a constant value regardless of the initial density of the backfill. This is because at this state the soil along the failure surface has deformed significantly and reached the "critical state". (3) Two types of earth pressure can be defined as passive. One group defined by the peak passive thrust and the other group defined by the critical passive thrust. Experimental results indicate that both Coulomb and Terzaghi theories overestimated the passive soil thrust. However, if the ϕ_{cr} and δ_{cr} angles obtained from direct shear tests at its critical state are used in the Coulomb and Terzaghi solution, the theoretical solutions are found to be in good agreement with the experimental data.

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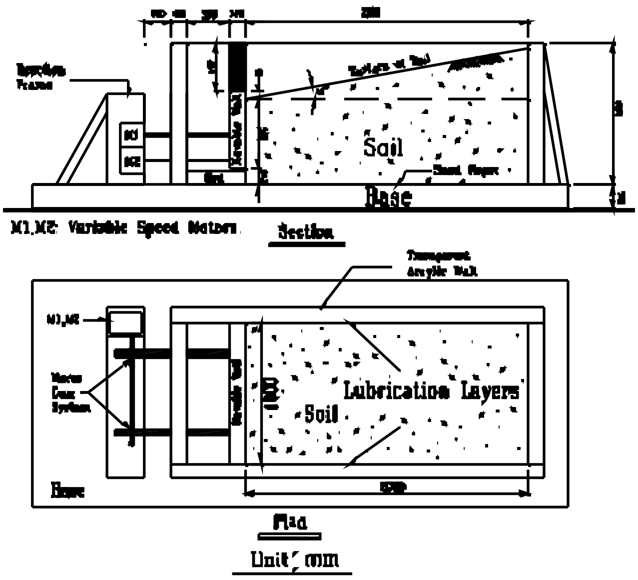

Fig.1 Movable Retaining Wall Model

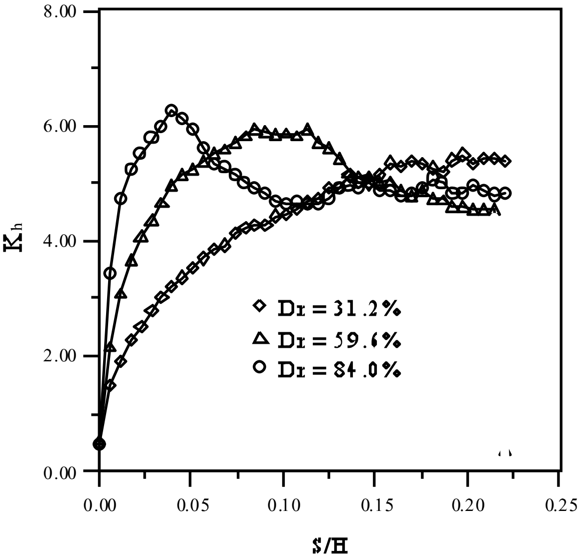

Fig.2 Variation of K_h for Different Relative Densities

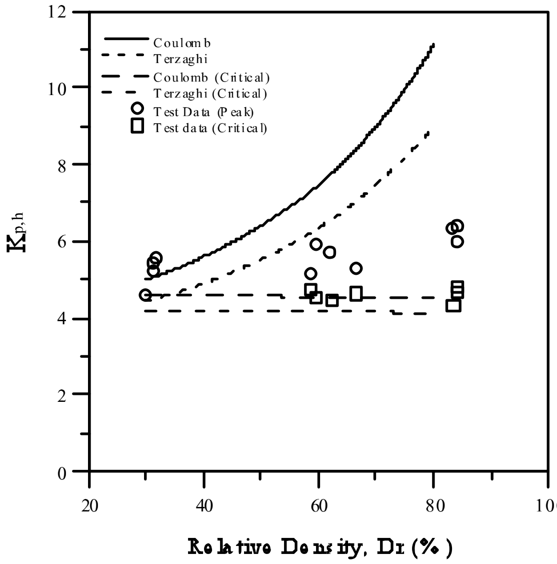

Fig.3 Variation of $K_{p,h}$ for Different Relative Density