

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(V) - 臨界狀態觀念與被動土壓力

An Experimental Study of Earth Pressure due to Various Wall Movements and Backfill Inclinations (V) - Critical State Concept and Passive Earth Pressure

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1. Abstract

1.1 中文摘要

本論文探討回填土夯實對作用於擋土牆被動土壓力之影響。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38%、63%與80%相對密度之渥太華砂為回填材料。根據實驗結果,獲得以下各項結論:(1)對緊砂而言,土壓力係數 K_h 隨牆移動而增加,當土壓力係數達到尖峰後, K_h 逐漸下降,最後達到一極限值。Coulomb及Terzaghi理論利用尖峰摩擦角 ϕ_{peak} 估計之土壓力係數會比實驗所獲得之尖峰 K_h 值及極限 K_h 值為高。在大量的牆位移(如 $S/H = 0.12$)之下, K_h 的極限值可將土壤殘餘強度 ϕ_r 引入Terzaghi理論加以推估。(2)無論回填土之初始密度為何,當牆位移量 S/H 超過0.12後,土壓力係數 K_h 會到一固定值。這是因為在破壞土楔內之土壤都已達到臨界狀態,其剪力強度應利用土壤的殘餘抗剪角 ϕ_r 估計。(3)在計算緊密狀態下回填土之被動土壓力時,必須考慮破壞土壤之膨脹及強度折減現象。將土壤之殘餘強度引用在Coulomb及Terzaghi理論可合理估計在牆發生大位移時的被動土壓力。依此保守的設計,擋土牆將可確保維持在安全的狀態。

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 compacted at different densities. Ottawa sand with relative densities of 38%, 63%, and 80% 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: (1) For dense sand, the horizontal earth pressure coefficient K_h increases with the increasing wall movement. After reaching a peak value, K_h decreases and finally remained an ultimate value. Coulomb and Terzaghi solutions calculated with a peak ϕ angle are greater than the experimental peak and ultimate passive thrusts. At a large wall movement, the ultimate K_h could be properly estimates by introducing the critical state concept into the Terzaghi theory. (2) When the passive wall movement S/H is greater than 0.12, the passive soil thrust K_h reaches to a constant value regardless of its initial density. It may be deduced that, the soil along the failure surface has reached the "critical state", and the shearing strength on the surface could be estimated with the residual ϕ_r angle. (3) When calculate the passive earth pressure in dense backfill, it is recommended to consider the dilation and the strength reduction of soil along the failure surface. The passive earth pressure under a large wall deformation could be successfully approximated by introducing the residual soil strength into Coulomb and Terzaghi's theories. The conservative design will keep the retaining wall always on the safe side.

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 most specifications for earth work, the contractor is required that the backfill behind the wall be compacted to 90 % ~ 95 % of its maximum dry unit weight determined by Standard Proctor Test. Therefore, in most case, the backfill encountered in the field would be dense soil. Casagrande (1936) indicated that, during the shearing process for dense sands, shear stress would increase with increasing shear deformation to a peak value, then decrease and finally reach an ultimate value. For loose sand, shear stress increases with increasing shear strain to an ultimate value and remains a constant. The volume of the dense sand initially decreases with shear deformation, then increases, finally reach a constant volume. For loose sand, the volume of specimen decreases, then approaches as an ultimate value. Lambe and Whitman (1969) states that, after considerable straining of the soil, both the shear resistance and the void ratio achieve values that are independent of the initial void ratio. At this condition, the sand strains without further volume change. This condition referred to as the ultimate (or constant volume, or critical, or residual) condition. The friction angle at this condition is defined as ϕ_r , where r stands for residual. When the backfill reaches the passive state, wall movement could be very large. The soil along the failure surface could dilate and the friction angle decreases from the peak value (ϕ_{peak}) to the residual value (ϕ_r). It is reasonable to apply the critical state concept in the passive earth pressure theory when the wall movement is large.

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 38%, 63%, 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 sidewalls 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 sidewalls will be negligible. The friction between the backfill and the sidewalls is to be minimized to nearly frictionless. This is accomplished by creating a lubrication layer between the sidewalls 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/m² capacity) have been arranged within a narrow central zone to avoid the friction that might exist near the sidewalls 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. The soil compactor is used to obtain different density samples. To establish the relationship between unit weight of backfill γ and its internal friction

angle ϕ_{peak} , direct shear tests have been conducted. A unique relationship between γ and ϕ_{peak} can be obtained for the Ottawa sand used, the relationship can be expressed as follows:

$$\phi_{peak} = 8.31 \gamma - 97.05 \quad (1)$$

where γ is unit weight of backfill in kN/m^3 . The residual friction angle ϕ_r is 31.5° in this investigation. 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 densified with soil compactor:

$$\delta = 3.41 \gamma - 43.69 \quad (2)$$

For Ottawa sand prepared with air-pluviation method:

$$\delta = 3.08 \gamma - 37.54 \quad (3)$$

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 38.4%. 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.

To obtain the expected medium dense and dense backfill conditions, the loose backfill is densified with the soil compactor. Ottawa sand is pluviated into the soil bin for a thickness of about 0.14 m. The surface of the backfill is carefully leveled to form a plane surface. The area to be compacted is divided into 4 lanes. Each lane is densified with the soil compactor for a pass of 90 seconds. The soil was compacted layer by layer up to 0.61 m from the wall base. For medium dense and dense

sand, the relative densities obtained are 63% and 80%, respectively.

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. In dense backfill, the soil thrust initially increases rapidly with small amount of passive movement. After reaching a peak value, the coefficient k_h drops down until a constant value is reached. For loose backfill, k_h increases with increasing wall deformation until a steady state is reached. For medium dense backfill, the earth pressure value varies between that for loose backfill and dense sand. Its peak K_h value is greater than that for loose sand but less than that for dense sand. The wall movement needed for K_h to reach a peak value is about 0.015 S/H for dense sand, and about 0.03 S/H for medium dense backfill. It should be noted that when the passive wall movement S/H is greater than 0.12, that the passive soil thrust K_h reaches to a constant value, regardless of its initial density. It may be deduced that, the soil along the failure surface has reached the "critical state", and the shearing strength on the surface could be estimated with the critical ϕ angle.

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 $K_{p,h}$ are plotted on this figure. One group indicates the peak thrust, and the other indicates the critical passive thrust at a large wall displacement. The classic Coulomb and Terzaghi's theories are also plotted in this figure. It is apparent that for loose backfill, Coulomb and Terzaghi's theories slightly underestimate the passive thrust. For medium dense and dense backfill the peak experimental results are in good agreement with Terzaghi's solution calculated with ϕ_{peak} . If the residual ϕ_r angle obtained from the direct shear tests is used in the Coulomb and Terzaghi's formula, the theoretical solutions are found to be in good agreement with the experimental passive thrust at a large wall movement. It is 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 horizontal earth pressure coefficient K_h increases with the increasing wall movement. After reaching a peak value, K_h decreases and finally remained an ultimate value. Coulomb and Terzaghi solutions calculated with a peak angle ϕ_{peak} are greater than the experimental peak and ultimate passive thrusts. At a large wall movement, the ultimate K_h could be properly estimates by introducing the critical state concept into the Terzaghi theory. (2) When the passive wall movement S/H is greater than 0.12, the passive soil thrust K_h reaches to a constant value regardless of its initial density. It may be deduced that, the soil along the failure surface has reached the “critical state”, and the shearing strength on the surface could be estimated with the residual angle ϕ_r . (3) When calculation the passive earth pressure in dense backfill, it is recommended to consider the dilation and the strength reduction of soil along the failure surface. The passive earth pressure under a large wall deformation could be successfully approximated by introducing the residual soil strength into Coulomb and Terzaghi’s theories. The conservative design will keep the retaining wall always on the safe side.

7. References

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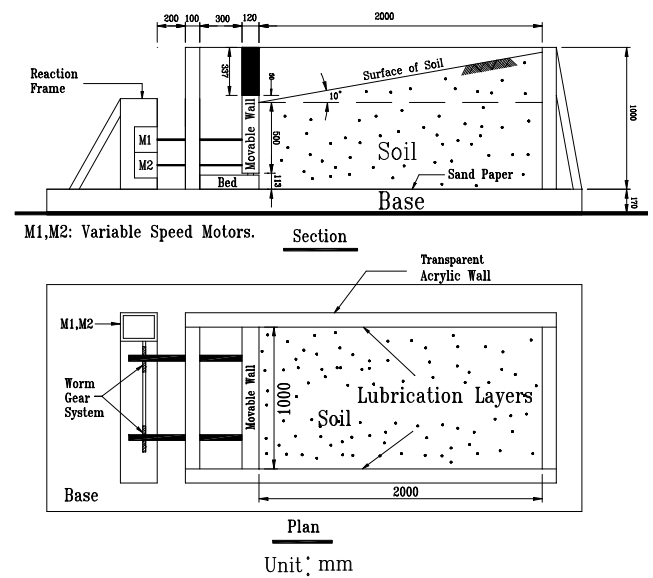


Fig.1 Movable Retaining Wall Model

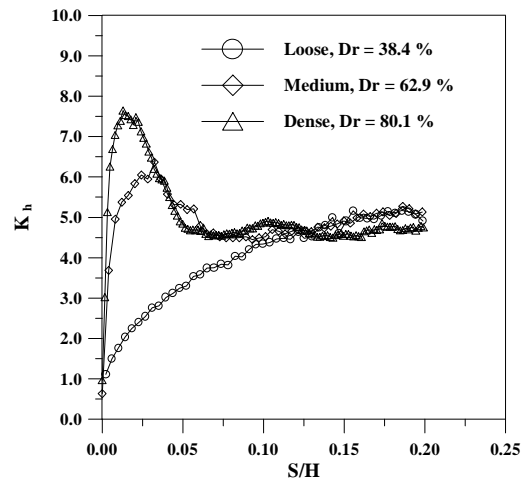


Fig.2 Variation of K_h for Different Relative Densities

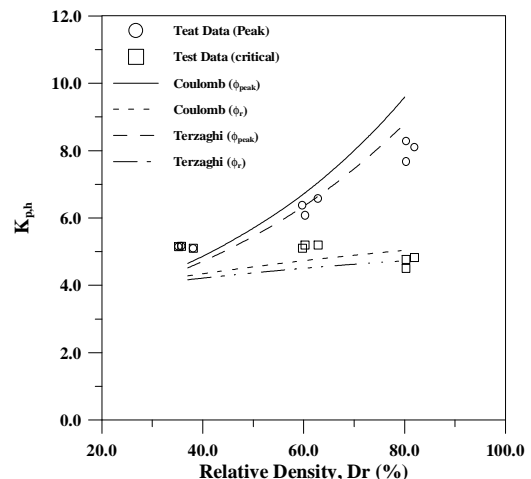


Fig.3 Variation of $K_{p,h}$ for Different Relative Densities