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(Ⅲ)-回填土密度及傾角對土壓力之影響

An Experimental Study of Earth Pressure Due to Various Wall Movements and Backfill Inclinations (Ⅲ) - Earth Pressure at-rest with Different Soil Densities and Backfill Inclinations.

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計畫主持人：方永壽 國立交通大學土木工程研究所 教授

1. 中文摘要

本研究探討回填土的相對密度及傾角對作用於擋土牆靜止土壓力之影響。本研究利用國立交通大學剛性模型擋土牆設備進行試驗，所使用之回填土爲氣乾之渥太華砂(ASTM C-109)。採用空中隕落法填築回填土，實驗採用之回填土傾角由-20°改變至+20°；回填土相對密度由 21.9%增加到 85.2%。依據試驗結果，獲得以下幾點結論：(1) 不同密度水平填土所造成之靜止土壓力接近線性分佈。(2) 靜止土壓力係數 K_0 隨回填土相對密度之增加而降低。(3) 回填土填築的方法對靜止土壓力係數造成強烈的影響。(4) 靜止土壓力係數隨著回填土傾斜角之增加而升高。(5) 靜止土壓力係數的增量△K_0，隨著回填土傾斜角之增加而升高。

關鍵詞: 密度、傾角、模型試驗、靜止土壓力、砂

英文摘要

This study investigates the earth pressure at-rest against a non-yielding wall with different backfill densities and inclinations. A non-yielding model wall was established at the National Chiao Tung University (NCTU) for this study. Air-dry Ottawa sand (ASTM C-109) is used as backfill for all experiments, and air-pluviation method was adopted for soil placement. For the tests, backfill inclination ranged from -20° to +20° and its relative density varied from 21.9% to 85.2%. Based on the test results, the following conclusions can be drawn. (1) The distributions of earth pressure at-rest with depth are nearly linear for a horizontal backfill. (2) Coefficient of earth pressure at-rest K_0 decreases with increasing soil density. (3) The method used for soil placement has a strong influence on K_0 values. (4) The coefficient of earth pressure at-rest increases with increasing sloping angle i of the backfill. (5) The pressure coefficient increment ΔK_0 increases with increasing slope angle i of the backfill.

Keywords: **Density, Inclination, Model test, Earth pressure at-rest, Sand**

2. Introduction

Earth pressure distribution should be carefully estimated when designing retaining structures, especially when the building is to be constructed on a slope. After the slope is cut, a flat area is created. When construction of the building is completed, soils are backfilled and usually compacted outside of the basement wall. Lateral movements of basement walls are prevented by the lateral support of the basement slab and floor slabs. As a result, the lateral stress against the basement wall would be similar to the earth pressure at-rest.

Conventionally, civil engineers calculate the earth pressure at-rest against a retaining wall following Jaky's formula ($K_0=1-\sin\phi$). However, Jaky presented the equation only for condition of horizontal backfill. When the backfill is sloped at an angle i with the horizontal, it is expected that a +i soil slope would increase the pressure, and a -i would decrease the at-rest pressure against the wall. The earth pressures at-rest is also affected by several variables, such as the properties of the backfill material and the methods of soil placement. Unfortunately, little information has been reported in the literature regarding the earth pressure at-rest against a non-yielding wall with inclined backfill and various backfill densities.

To a better understand the earth pressure at-rest behind a retaining wall, the research group at NCTU has designed and constructed a new 1.5m-high non-yielding model retaining wall. All of the earth-pressure experiments described in this thesis were conducted in non-yielding retaining wall facility, With the soil pressure transducers (SPT) mounted on the model wall, measurements are made for the normal stresses against the wall. Earth pressure experiments with inclined backfills and various densities were conducted. For the tests with an inclined backfill, the inclination angle ranged from -20° to $+20^\circ$. Typical relative densities of the sandy backfill used for the tests were 21.9%, 51.5%, and 85.2%

3. NCTU Non-yielding Retaining-wall Facility

The entire system consists of the following components: (1) soil bin; (2) non-yielding model wall; and (3) data acquisition system. The soil bin is made of steel with inside dimensions of 1.5 m-long, 1.5 m-wide and 1.6 m-deep, as shown in Fig. 1. The major factor considered in choosing the construction material is rigidity. The end wall that sits opposite to the model retaining wall, and side-walls of the soil bin are made of 35 mm-thick steel plates. 20 mm-thick steel columns and horizontal beams are used to confine the model wall and side-walls to ensure an at-rest condition. The bottom of the soil bin is covered with a layer of Safety-Walk to provide adequate friction between the soil and the base of the bin. To constitute a plane strain condition, a lubrication layer is provided between the side wall and the soil. The lubrication layer consists of a 0.2 mm-thick rubber membrane and a thin layer of a silicon grease (Shin-Etsu KS-63G). The retaining wall shown in Fig. 1 is 1,500 mm-wide, 1,600 mm-high, and 45mm-thick, and is made of a solid steel plate.

To investigate the earth pressure distribution with depth, 19 soil pressure transducers (SPT) are attached to the model wall. For experiments discussed in this paper, 7 extremely sensitive earth pressure transducers (Kyowa PGM-02KG, 19.6 kN/m^2 capacity), have been used. The transducers are arranged along the center-line of the wall to avoid the friction effect that might exist near on the side walls of the soil bin. 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 (ASTM C-109) is used for the model wall experiments, and the tests have been conducted under air-dried 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 (kN/m^3) and ϕ (degree) is found for the C-109 Ottawa sand as follows,

$$\phi = 4.83\gamma - 43.1 \quad (1)$$

To evaluate the friction angle between the backfill and model wall, special direct shear tests have been conducted. A 60 mm × 60 mm × 20 mm smooth steel plate, made of the same material as the model wall, was put into the lower shear box, then Ottawa sand was placed into the upper shear box. It is found that there is a unique relationship between γ (kN/m^3) and δ (degree) for the Ottawa sand used.

$$\delta = 1.73\gamma - 7.27 \quad (2)$$

5. Experimental Results

5.1 Horizontal Backfill

Relative densities for the loose, medium dense, and dense backfill are 21.9%, 51.5%, and 85.2%, respectively. It may be observed from the test data that the distributions of the earth pressure at-rest are essentially nearly linear. The earth pressure at-rest for loose backfill was in fairly good agreement with Jaky and Hendron's predictions. Experimental data indicate that since the distribution of earth pressure at-rest is essentially linear, therefore the at-rest thrusts are located at about 0.34H~0.35H above the wall base. Total thrust P_h is calculated by summing the earth pressure acting on the wall. In Fig. 2, the experimental $K_{0,h}$ values are plotted against the void ratio of soil. It may be seen from Fig. 2, that $K_{0,h}$ value decreases with increasing soil density (decreasing void ratio). Jaky's formula tends to overestimate the at-rest earth pressure against a non-yielding wall backfilled with air-pluviated method. Although the data is quite scattered, Hendron's equation would provide a fairly good estimation for K_0 value.

Okochi and Tatsuoka (1984) estimated the K_0-values of the Toyoura sand with the double cell triaxial apparatus. Based on their test data, the relationship recommended between the K_0-values and the initial void ratio e_i under the effective confining pressure σ'_r = 19.6 kN/m^2 was K_0=0.52 e_i for air-pluviated samples. In Fig. 2, it appears that empirical relationship proposed by Okochi and Tatsuoka would be an effective method to estimate K_0 value for an air-pluviated sandy backfill.

The experimental data reported by Sherif et al. (1984) is also indicated in Fig. 2. It was suggested that K_0 value increases with increasing soil density (decreasing void ratio), which is totally contrary to Jaky's formula, and the experimental data in this study. It should be mentioned that Sherif et al. obtained their conclusions from a backfill prepared with vibratory compaction. As a result of vibration, the stresses locked-in between soil particles increased the soil-structure interaction. It is obvious that the method employed for backfill placement has a significant influence on the earth pressure at-rest.

5.2 Sloping Backfill

Fig. 3 show the coefficient of horizontal earth pressure $K_{0,h}$ versus backfill inclination i for a loose backfill. It is obvious that the coefficient $K_{0,h}$ increases with increasing sloping angle i of the backfill. The $K_{0,h}$ values based on elastic solutions are also plotted in the figures. It can be observed that neither the "Jaky + elastic solution" nor the "Hendron + elastic solution" could predict a reliable K_0 value.

It should be noted that the value of $K_{0,h}$ represent the total at-rest earth pressure developed against the wall. For many purposes, it is convenient to separate this pressure into two components -- the initial K_0 due to a horizontal backfill, and the pressure increment associated with the inclination angle i. Thus, for practical purposes it may be written as:

$$K_{0,h} = K_0 + \Delta K_0 \quad (3)$$

For a loose backfill, Values of ΔK_0 for different values of inclination angle i are plotted in Fig. 4. It can be observed from the figure that, ΔK_0 is in agreement with the elastic solution for positive backfill inclinations.

6. Conclusions

Based on the experimental data obtained, major findings of this study are summarized as follows. (1) For a wall with horizontal backfill; the distributions of earth pressures at-rest with depth are nearly linear. (2) For a backfill air-pluviated at different densities, K_0 value decreases with increasing soil density. (3) The method used for soil placement has a strong influence on K_0 values. (4) For a wall with sloping backfill; the coefficient of earth pressure at-rest K_0 increases with increasing sloping angle i of the backfill. (5) The pressure coefficient increment ΔK_0 increases with increasing slope angle i of the backfill.

7. References

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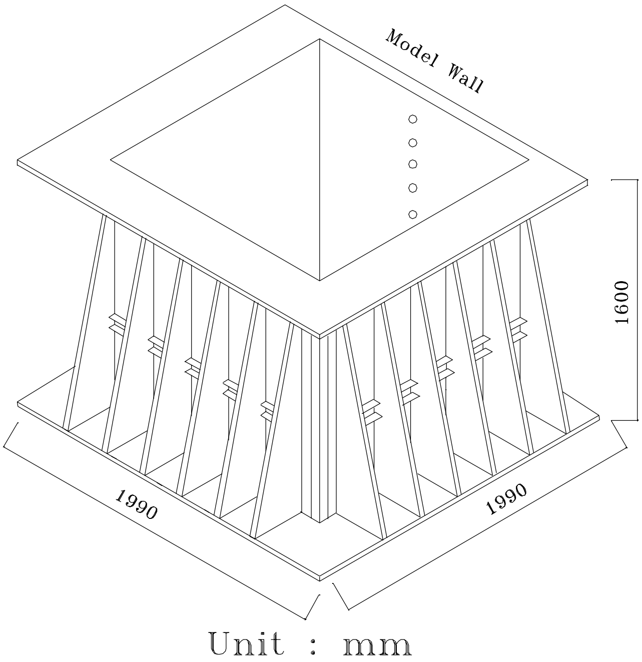

Fig. 1. Schematic Diagram of NCTU Non-Yielding Model Wall

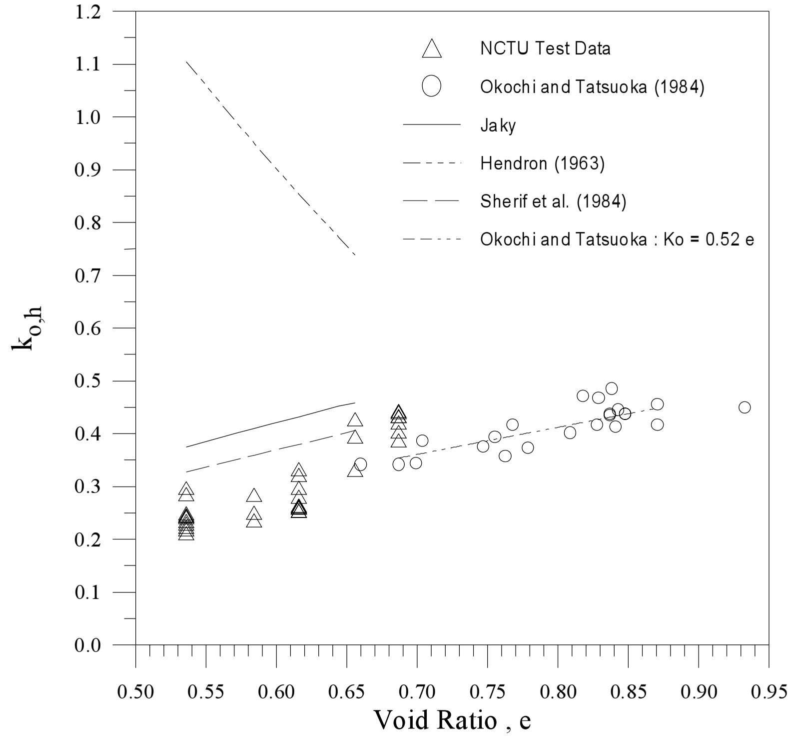

Fig. 2. Variation of Coefficient $K_{0,h}$ for Various Void Ratio

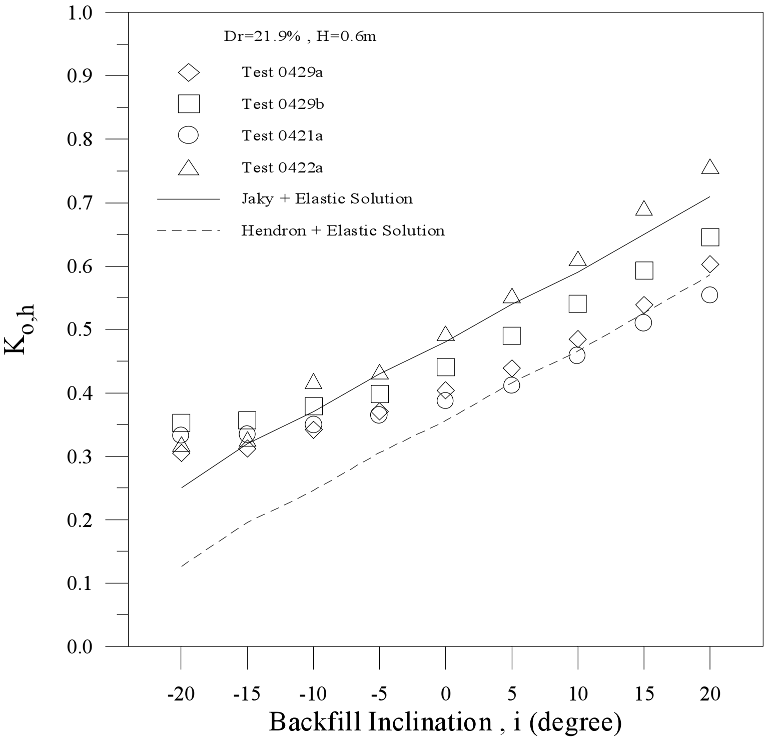

Fig. 3. Variation of Coefficient $K_{0,h}$ as a Function of Backfill Inclination

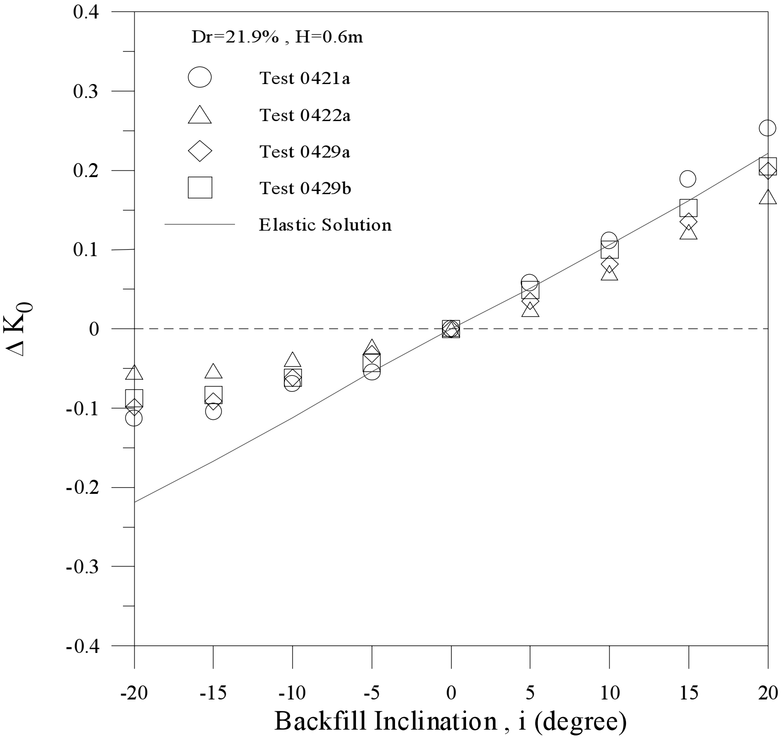

Fig. 4. Variation of $\triangle K_0$ as a Function of Backfill Inclination