# 土壤夯實引致土體內之靜止土壓力

## Earth Pressure At-rest Induced by Soil Compaction

**計劃編號 : NSC 89-2211-E-009-092**
**執行期間 : 89 年 8 月 1 日至 90 年 7 月 31 日**
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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靜止土壓力之影響。本研究利用國立交通大學模型擋土牆設備探討夯實土壤所造成土壓力之變化。試驗採用單位重為** $16.4\ \mathrm{kN/m^3}$**，內摩擦角為** $39.6^o$ **之渥太華砂為夯實回填材料，填土高度分別為** 0.3、0.6、0.9、1.2 **及** 1.5 m。**根據實驗結果，獲得以下各項結論**: (1) **土壤夯實在回填土頂部附近造成高側向壓力，**Jaky **靜止土壓力理論明顯低估側向應力；**(2) **隨著回填土高度的增高，夯實影響區的位置隨之往上方移動；**(3) **夯實影響區下方的土壓力會隨著填土高度的增加，夯實影響區向上移動，而漸漸趨近於** Jaky **所建議的理論值。**

**關鍵詞: 夯實、模型試驗、靜止土壓力、砂**

### 1.2 English Abstract

This research utilizes the NCTU model wall facility to investigate the earth pressure against the rigid wall. The backfill was compacted by a vibrator compactor. Ottawa sand was used as a backfill material with unit weight of $16.4\ \mathrm{kN/m^3}$ and internal friction angle of $39.6^o$. Earth pressure experiments with various thickness of backfill, H, were conducted and the test results were compared with the well-known Jaky theory. Based on this study, the following conclusions can be drawn: (1) Soil compaction will induce high lateral pressure near the top of the backfill；(2)With the rise of the surface of the compacted fill, location of the compaction influenced zone moved upward；(3)The lateral pressures below the compaction influenced zone tend to converge to Jaky's solution.

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

## 2. Introduction

Civil engineers build retaining structures to resist the earth pressure. In most specifications for earth work, the contractor is required to compact the backfill to 90% ~ 95% of its maximum dry unit weight based on Standard Proctor Test. Due to the rigidity of the base slabs and floor slabs of the building, the earth pressure acting on the basement wall would be nearly the earth pressure at-rest. Traditionally, civil engineers calculate the earth pressure at-rest against a retaining wall following Jaky's formula $K_o = 1 - \sin\phi$. It is postulated that the earth pressure distribution is linear, and the location of total thrust is located at one third of the wall height above the wall base. However, when soil is compacted in layers by rollers, vibrating plates, or rammers, the stress condition within soil mass is quit different. Rowe (1954), Sherif et al. (1984), Duncan and Seed (1986) reported that extra lateral pressure would be induced near the top of backfill due to soil compaction. The horizontal earth pressure within the compacted soil mass would increase. Based on the test results and field studies, compaction would significantly increase the stress level within soil mass, and it is not possible to accurately analyze the problem with existing theories.

This research utilizes the NCTU model wall facility to investigate the earth pressure at-rest induced by soil compaction. Earth pressure experiments with various thickness of backfill, H, were conducted and the test results were compared with the well-known Jaky theory.

## 3. NCTU Model Retaining Wall Facility

To investigate the earth pressure at-rest against retaining structures, the instrumented non-yielding retaining-wall facility was developed at National Chiao Tung University. All of the experiments mentioned in the paper were conducted in this model wall facility. The entire facility consists of three components, namely, model wall, soil bin, and data acquisition system. The model wall shown in Fig. 1 is 1.5 m-wide, 1.6 m-high, and 45 mm-thick. The wall is a solid steel plate with a Young's modulus of 210 GPa. To achieve an at-rest condition, the major factor considered in choosing the wall material is rigidity. As indicated in Fig. 1, the model wall is actually the front-side of the reinforced steel box. Outside the box, twenty-four 20 mm-thick steel columns were welded vertically on the sides to confined the lateral deformation of the box. 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, soil pressure transducers (SPT) were attached to the model wall. Sixteen strain-gage-type transducers (Kyowa PGM-02KG, capacity = 19.6 kN/m$^2$) were arranged within the central zone of the wall. Another three transducers mounted between the central zone and sidewall could be used to investigate the variation of the sidewall effect. To eliminate the soil-arching effect, all soil-pressure transducers were made quite stiff, and were installed flush with the wall.

The soil bin was fabricated of steel plates with inside dimensions of 1.5 m × 1.5 m × 1.6 m as illustrated in Fig. 1. The end-wall and sidewalls of the soil bin were made of 35 mm-thick steel plates. Outside the steel walls, vertical steel columns and horizontal steel beams were used to confine the lateral movement of the end-wall and sidewalls. The bottom of the soil bin was covered with a layer of SAFETY WALK to provide adequate friction between the soil and the base of the bin. Due to the considerable amount of data collected by the soil pressure transducers, a data acquisition system was used. The analog signals from the sensors were filtered and amplified by the dynamic strain amplifiers, then digitized by an analog-to-digital converter. The digital data were stored and processed by a personal computer.

To achieve backfills with different densities, a vibratory soil compactor had been used. An acentric motor (KJ75-2P) manufactured made by Mikasa Company had been selected to be the source of vibration. A photograph of the soil compactor is shown in Fig. 2. The compactor frame is composed of a flat pan and the handle. The size of the flat pan is 0.33 m ✕0.33 m, and the height of the handle is 1.0 m. The total mass of the compactor is 12.1 kg.

## 4. Backfill and Interface Characteristics

Ottawa silica sand (ASTM C-778) 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 $\gamma$ and its internal friction angle $\phi$, direct shear tests were conducted. A unique relationship between $\gamma$ and $\phi$ can be obtained for Ottawa sand, the relationship is expressed as follows:

$$\phi = 7.25\gamma - 79.5 \tag{1}$$

where $\gamma$ is unit weight of backfill in kN/m$^3$. In this study, the unit weight $\gamma$ of the compacted dense is 16.4 kN/m$^3$, and the corresponding friction angle $\phi$ is 39.6$^o$.

To simulate field conditions, dense backfill was achieved for all experiments in this study. To obtain a dense condition, the loose backfill was densified with the soil compactor. Ottawa sand was shoveled from the soil storage into the soil hopper and pluviated into the soil bin for a thickness of about 0.35m. The surface of the first layer backfill was carefully leveled to form a flat surface. The loose backfill was divided into 6 lanes and compacted as illustrated in Fig. 3. Each lane was densified with the soil compactor for a pass of 70 seconds. The thickness of the compacted lift is about 0.3 m. Repeat the above procedures for the second, third, forth and fifth lift, until the height of backfill accumulated up to 1.5m.

## 5. Experimental Results

In this section, experimental findings associated with earth pressure at-rest are presented and compared with Jaky's solution. Fig. 4 shows that horizontal earth pressure distribution for a 1.5 m-high backfill. It is obvious that the pressure distribution is nonlinear. Extra-high lateral pressure was observed near the top of the backfill. The horizontal earth pressures increased substantially from 0 to 0.75 m below soil surface, and the peak value was reached at 0.35 m below soil surface. This high pressure zone developed due to compaction is defined as "compaction influenced zone". Duncan et al. (1991) developed charts to estimate the compaction-induced earth pressure quickly and reliably. In this study, the peak earth pressure induced by compaction was about 10 kN/m$^2$. It was much larger than Jaky's solution. However, below the compaction-influenced zone, lateral earth pressure distributions was in fairly good agreement with Jaky's solution.

During the experiment, test data were taken as the backfill thickness of H = 0.3 m, 0.6 m, 0.9 m, 1.2 m, and 1.5 m. Fig. 5 and Fig. 6 show the horizontal earth pressure distributions obtained at different backfill thickness. When backfill was 0.9 m-high, the peak earth pressure was developed about 10.5 kN/m$^2$. With increasing backfill thickness, location of the compaction influenced zone would move upward with the rising of compaction surface. Fig. 6 shows that, as H = 1.2 m, the lateral presures below the compaction influenced zone had a tendency to converge with Jaky's solution. In Fig. 4, the tendency was more obvious when backfill was 1.5-m thick.

As illustrated in Fig. 7, the horizontal earth pressure coefficient $K_h$ decreased with increasing backfill thickness. The coefficient $K_h$ is defined as the ratio of the horizontal total thrust $P_h$ to $\gamma H^2 / 2$. If the wall is non-yielding, $K_h$ would be the earth pressure at-rest $K_0$. The at-rest thrust $P_h$ is calculated by summing the earth pressure acting on the wall, for comparsion purposed, the at-rest earth-pressure coefficient $K_0$ determined from Jaky's formula was also demonstrated in Fig. 7. The coefficient of earth pressure at-rest against the wall can be expressed as :

$$K_o = K_{oj} + K_{oc} \qquad (2)$$

where $K_{oj}$ = at-rest pressure coefficient by Jaky's formula

$K_{oc}$= at-rest pressure coefficient induced by compaction

It is obvious in Fig. 4 through Fig. 6 that compaction-induced pressure only exist near the surface of backfill. That is the reason why $K_{oc}$ decreases with increasing backfill thickness. In Fig. 7, $K_o$ decreases from 1.58 to 0.51, as the backfill thickness increases from 0.3 m to 1.5 m. Duncan et al. (1991) reported that the magnitude of pressure induced by compaction is influenced by the type and weight of compactor used.

## 6. Conclusions

This paper studies the earth pressure at-rest induced by soil compaction. Based on the experimental results, the following conclusions can be made.

1. Soil compaction induces high lateral pressure near the top of the backfill. With the rise of the surface of the compacted fill, location of the compaction influenced zone moved upward.
2. As the compactor removed, lateral pressures below the compaction influenced zone tend to converge with Jaky's solution.

## 7. References

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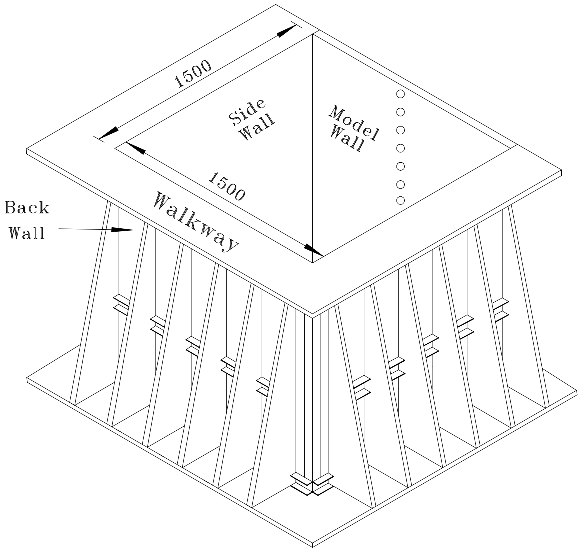
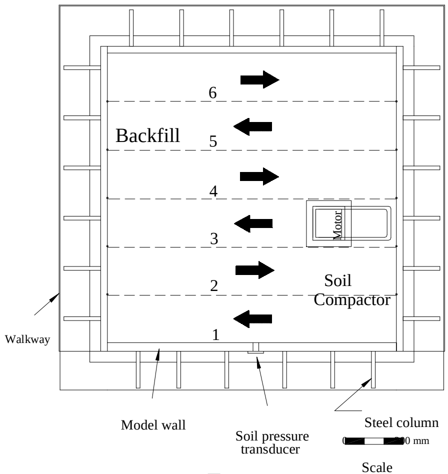


Unit : mm

Fig. 1. NCTU Non-Yielding Retaining Wall.

Fig. 2. Vibratory Soil Compactor



Top - view

Fig. 3. Soil Compaction Procedure

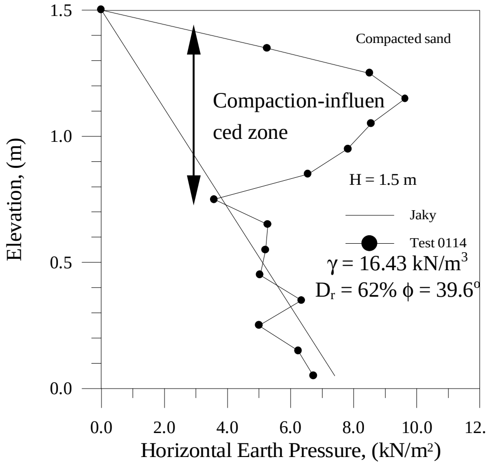


Fig. 4. Distribution of Lateral Pressure(H=1.5m)

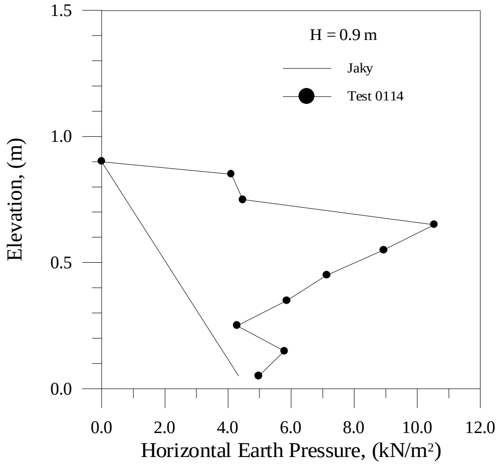


Fig. 5. Distribution of Lateral Pressure(H=0.9m)

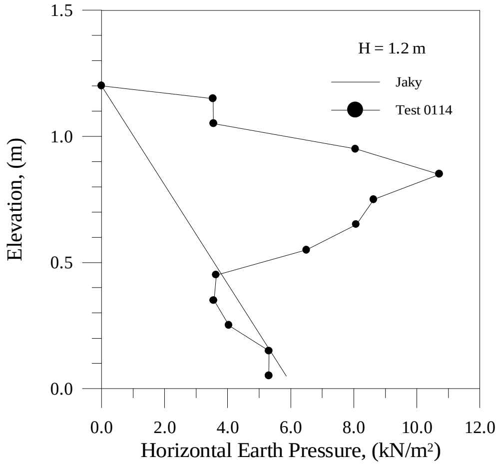


Fig. 6. Distribution of Lateral Pressure(H=1.2m)

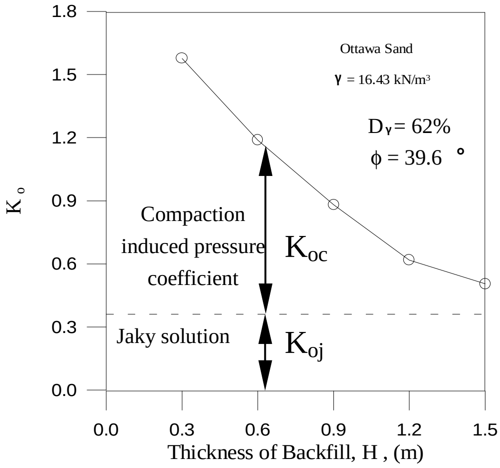


Fig.7. Variation of $K_h$ with Different Backfill Thickness