Soil Arching on Multi-excavation Type for Large Tunnels

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1. INTRODUCTION

Arching in soil created in ground mass due to single excavation stage for a tunnel has been known as a consideration point to predict vertical pressure on the tunnel's roof. In a case of multi-excavation stages for constructing a large tunnel, loads will move away from ground is being excavated to both non-excavated and preceding excavated ground. It forms earth pressure-loosened zones and earth pressure-concentrated zones in the ground. Therefore, the magnitude vertical pressures acting on the large tunnel are influenced by active arching and passive arching of soil.

2. MODEL EXPERIMENT

A simple model to describe loads transferred phenomena has been done using a laboratory model. A represented ground was aluminum rods mass with a condition as listed in Table 1.

The aluminum rods mass was set up horizontally on the multi-trap door apparatus with height of layer of 500 mm. A trap door of 150 mm in wide was moved continuously towards up and down.

Table 1. Material Properties

Diameter	1.6 mm and 3.0 mm
Mix of Ratio	3 : 2
Length	100 mm
Unit weight (γ)	2.15 kgf/cm^3
Internal friction angle (ϕ)	30^o
Cohesion (c)	0 kgf/cm^2

3. RESULT

An illustration of the attempt can be seen in Figure 1. The model of a hysteretic behavior of the given represented ground is shown in Figure 2. Active arching condition and passive arching condition happen on the cohesive ground produced by multi-excavation. Arrows facing down denotes the loosened earth pressures, i.e. active soil arching, while arrows facing up represents the retaining earth pressures, i.e. passive soil arching created. Decreasing in height of trap door from datum (from zero to minus number, -δ) is the vertical distance from datum when the trap door was moved downward, while positive sign of δ denotes the trap door was moved upward. On the right-hand side of the axis where the active arching state is illustrated, the slope of curves are remain constant. However, in condition of passive arching (refer to the left-hand side of the axis), the slope is steeper around the centre of axis while it decreases regularly as it moves away. Furthermore, observation reveals that, as the slope decreases, i.e. the height increases from datum, the tendency of closing hysteresis curve increases. Therefore a condition of steady state for both condition will not occurred at the same point.

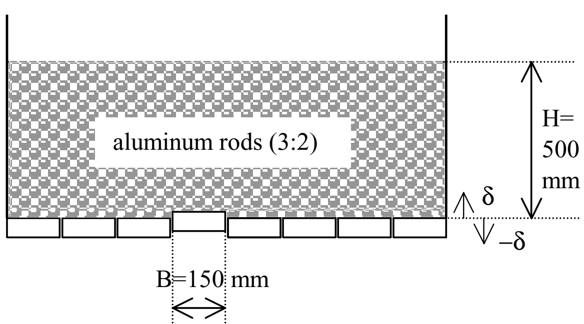

Figure 1. Scheme of Test

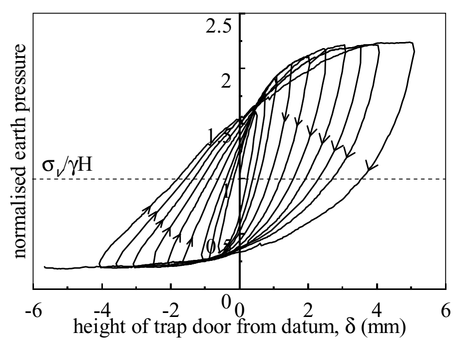

Figure 2. Hysteresis Loop

Experimental result of lowering five trap doors one after another, (Maulidya, 1999) with different sequential lowering will be simplified using the hysteresis loop in Figure 2. The loosened earth pressure is theoretically calculated by Terzaghi's formula as:

$$\frac{\sigma_v}{\gamma H} = \left\{ 1 - \exp(-2\tan\phi K \frac{H}{B}) \right\} \tag{1.1}$$

Where H is depth of the tunnel and B is considered as the tunnel's span. The value of the ratio K, which accepted in this study

Keywords: arching, hysteresis, tunnels

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condition was 1.5. The loosened pressure by Terzaghi's formula will be achieved when the trap door is let downwards until great value of δ.

When a trap door is lowered, the loosened pressure zone occurs above the trap door. The pressure decreases by an amount are equal to total amount of transferred pressure where move away to both disturbed ($\beta n*\gamma H$) and undisturbed-neighbourhood areas ($\alpha n*\gamma H$). The undisturbed zones receive an increment of earth pressure, $\Delta\sigma_{v\alpha n}=\alpha n*\gamma H$, whereupon the pressure equal a summation of the weight of overburden and the increment. While the disturbed zones have an increment as $\Delta\sigma_{v\beta v}=\beta n*\gamma H$. Constant αn is the amount of pressures, i.e. shown in ratio, that transferred from the lowered trap door to the zones above trap doors which have not been lowered. Symbol βn reflects the amount of pressures that leave to the zones above preceding lowered trap doors. The letter of n indicate the n^{th} neighbour on the left-hand and right-hand side of the lowered trap door.

As a sample, the sequential lowering of ABCDE, H=500 mm, and a given δ will be plotted on the curve of Figure 2. As the trap door A lowered, the pressure immediately above the trap door A decreases about $\Delta\sigma 1$ to level of $\Delta 1$. There is an increment of pressure on trap door B, which equalled to $\alpha 1*\gamma H$, at the same time is $\alpha 2*\gamma H$ for an increment on trap door C. Trap door has an increment of $\alpha 3*\gamma H$, while trap door E has none. Total increment pressures on both left-hand and right-hand side of the lowered trap door is $\Delta\sigma 1$. The value of vertical pressures during each lowering are approached by equations shown in Table 2. The letter r represented that the results are considered in ratio of overburden pressure. An illustration of stress distribution in the ground as a result of a lowering of single trap door is shown in Figure 3.

Table 2. Stress History

	Trap Door A	Trap Door B	Trap Door C	Trap Door D	Trap Door E
A	***1–Δr1=Δrσ1***	1+α1	1+α2	1+α3	1+α4
B	Δrσ1+β1	***1+α1-Δr2=Δrσ2***	1+α1+α2	1+α2+α3	1+α3+α4
C	Δrσ1+β1+β2	Δrσ2+β1	***1+α1+α2-Δr3=Δrσ3***	1+α1+α2+α3	1+α2+α3+α4
D	Δrσ1+β1+β2+β3	Δrσ2+β1+β2	Δrσ3+β1	***1+α1+α2+α3-Δr4=Δrσ4***	1+α1+α2+α3+α4
E	Δrσ1+β1+β2+β3+β4	Δrσ2+β1+β2+β3	Δrσ3+β1+β2	Δrσ4+β1	***1+α1+α2+α3+α4-Δr5=Δrσ5***

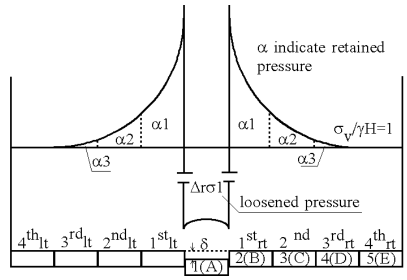

Figure 3. Illustration of Stress Distribution

Refer to Figure 2, the change in pressure will follow the flow of change in pressure according to the hysteresis curve, with $(0,1)$ as a starting point. When the first trap door is lowered, with a given δ, the pressure will change from the starting point to a point of $(-\delta,\Delta r1)$, then the trap door will receive an increment pressure from succeeding lowering of trap doors (βi). For trap door B, the pressure firstly will increase through the line of curve from the level of $(0,1)$, then move upwards to a level of $(x_B,1+\alpha 1)$. The value of x_B expresses an equivalent of displacement of trap door B, which it is seen from the referred trap door (trap door A). Due to lowering itself, the pressure will continue decreasing in the given δ, measured from the point of x_B toward the left-hand side. Thereby the pressure on trap door B will be obtained. Continuing step of lowering will be taking with the same procedure, while the vertical pressures of step by step lowering before the lowering itself are approached with the equations in Table 2. It should be noted that the magnitude of pressure immediately above trap door D and trap door E will have the same value, where $\alpha 4$ is zero.

There are changes in pressure in the ground during sequential lowering. The change in pressures in undisturbed zones will remain the same, however the pressure in disturbed zones will increase proportional to the change in loosened pressure from one step lowering to further. After completing the procedure to get the value of vertical pressures on each trap door because of lowering itself, the following trace will relate to the value of βn. The change in pressure which equal ($\Delta r\sigma n-\Delta r\sigma i$) means, there will be an increment of pressures above disturbed zones in the amount of ($\Delta r\sigma n-\Delta r\sigma i$). This change will be distributed with taking consideration of distance between the referred trap door and the measured point. A symbol of i is an initial lowering ($i=1,\dots n^{th}$) of trap door.

4. SUMMARY

The value of loosened pressures above each tunnel, i.e. the pressure occurred immediately during each excavation stage, are also influenced by passive arching condition. This value can be predicted graphically by plotting the stress history, namely increment values in according to sequence of excavation, on a hysteretic curve of ground of single excavation. This approached method can be used conveniently for different sequences of excavation stage.

5. REFERENCES

Maulidya I.J, Nishimura K, Domon T. "Model test on redistribution of earth pressure in multi-excavation Stage" *Proceding of 54th Annual Meeting of JSCE,* 1999.