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# Modification of the Terzaghi's theory for the tunnel excavation in an inclined-layers ground

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**Introduction :** Experimental studies on the tunnel excavation in an inclined-layers mass have been carried out. As described in the previous research[1)], mechanical behaviors drawn from modeled inclined-layers ground are obviously influenced by the angle of inclined-layers. On the other hand, the theory of Terzaghi's earth pressure is selected to verify the experimental results. Original Terzaghi's theory[2)] is, however, based on the sandy ground, so that its extension would be demanded for the inclined-layers ground. In this paper, modification to extend the original Terzaghi's theory is attempted and parametric study is performed using some kinds of parameters such as the angle of ground surface and sliding surfaces, overburden, width of tunnel and coefficient of lateral earth pressure.

**For the Extended Model :** In generalizing for the extended model, it was assumed that ground surface and sliding surfaces are inclined as shown in **Fig. 1**. Lines of sliding surfaces *ac* and *bd* having the angle $\theta_1$ are the sliding surfaces and the angle of ground surface is $\theta_2$. $H$ is defined as the average height from the yielding strip(Tunneling Part) to the ground surface that presumed from the central line of the inclined section *ac* and *bd*.

**Fig. 2** shows a section through the space between two inclined sliding surfaces. Such as the original Terzaghi's model, the sum of the vertical components, which act on the small slice, must be equal to zero and this condition can be expressed by **Eq.1**,

$$\left(\overline{\sigma_v}+d\overline{\sigma_v}\right)D-\overline{\sigma_v}D+2\tau dz-\gamma Ddz=0 \tag{1}$$

where $\gamma$ is unit weight of soil, $D$ is width of strip, $\sigma_v$ is vertical stress, and $\sigma_h$ is horizontal stress.

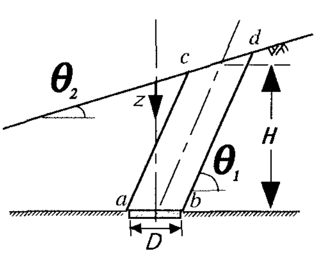


**Fig. 1.** Failure caused by inclined surfaces

In the case of the inclined section, the shearing resistance ($\tau$) of the earth should be determined by the following **Eq. 2**, and the normal stress ($\sigma_n$) that acts on the sliding surfaces with an angle $\theta_2$ can be described as **Eq. 3**,

$$\tau=c+\overline{\sigma_n}\cdot\tan\phi \tag{2}$$

$$\overline{\sigma_n}=\frac{\overline{\sigma_v}+\overline{\sigma_h}}{2}+\frac{\overline{\sigma_v}-\overline{\sigma_h}}{2}\cos 2\theta_1 \tag{3}$$

where $\phi$ is internal friction angle.

By substituting in **Eq. 1** into **Eq. 2** and **3**, the following equation can be obtained,

$$\frac{d\overline{\sigma_v}}{dz}=\frac{\gamma D-2c}{D}-\left\{\left\{(1+K_0)+(1-K_0)\cos 2\theta_1\right\}\overline{\sigma_v}\cdot\frac{\tan\phi}{D}\right\} \tag{4}$$

where $K_0(=\overline{\sigma_h}/\overline{\sigma_v})$ is coefficient of lateral earth pressure.

Solving **Eq. 4** with boundary condition, $\overline{\sigma_v}=0$ for $z=0$, $\overline{\sigma_v}$ can be expressed as follow;

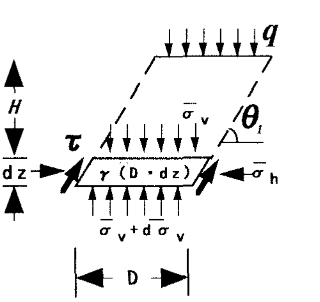


**Fig. 2.** Diagram illustrating extended model

$$\overline{\sigma_v}=\frac{\gamma D-2c}{\left\{(1+K_0)+(1-K_0)\cos 2\theta_1\right\}\tan\phi}\cdot\left(1-\exp\left[-\left\{(1+K_0)+(1-K_0)\cos 2\theta_1\right\}\tan\phi\cdot\frac{H}{D}\left\{1-\frac{\tan\theta_2}{\tan\theta_1}\right\}\right]\right). \tag{5}$$

*Key words* ; Terzaghi's theory, Modification, Inclined-layers ground, Tunneling, Parametric study

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One of the most crucial constraints to satisfy **Eq. 5** must be confirmed whether or not the existence of the value $H$. Namely$\theta_1$ should be greater than $\theta_2$ to generate the value $H$. To verify **Eq. 5** for generalization, by substituting successively the value $c = 0$, $\theta_1 = 90^0$ and $\theta_2 = 0^0$, it can be obtained the same equation of the original Terzaghi's equation.

**Assessments of the Extended Model :** Assessments are presented in terms of 5 parameters including three dimensionless factor, such as $\overline{\sigma_v}/\gamma D$ (normalized vertical load factor), $H/D$ (normalized overburden factor), $K_0$, $\theta_1$ and $\theta_2$. **Fig. 3, 4** and **5** give the normalized vertical load factor as a function of the normalized overburden factor for $\phi = 30^0$. **Fig. 3** illustrates the effect of varying $\theta_2$ on the acting load of the yielding strip for a fixed value of $\theta_1 = 60^0$. **Fig. 4** illustrates the effect of varying $\theta_1$ for a fixed value of $\theta_2 = 30^0$. And, **Fig. 5** shows the effect of $K_0$ for a fixed value of $\theta_1 = 60^0$, $\theta_2 = 30^0$, respectively. Also in **Fig. 3** and **4**, $K_0$ is fixed at 0.5. From these figures, following results can be drawn.

1. From **Fig. 3**, the acting pressure on the horizontal strip decreases as $\theta_2$ increasing. In the case of the normalized overburden factor, $H/D = 2$, the value of $\overline{\sigma_v}/\gamma D$ decreases from 1.05 to 0.62 as $\theta_2$ varies from $0^0$ (having horizontal surface) to $45^0$. These results owing to the variation of the angle of ground surface, however, cannot confirmed at the high value of the normalized overburden factor.
2. **Fig. 4** shows that $\theta_1$ has a significant effect on the load acting on the yielding strip. As the angle of the sliding surfaces decreases, the normalized vertical load factor decreases. And in all cases, the normalized vertical load factors become constant as $H/D$ increasing.
3. It can be easily understand from **Fig. 5** that, in the lower range of the normalized overburden factor 5, the normalized vertical load factor decreases rapidly. For a given normalized overburden factor 5, $\overline{\sigma_v}/\gamma D$ decreases from 1.27 to 0.62 as $K_0$ varies from 0.50 to 1.50. It should be also emphasized that the normalized vertical load factors become constant with increasing $H/D$.

**Conclusion :** Extended equation, based on the original Terzaghi's earth pressure is solved for the inclined-layers ground. It is concluded that the normalized vertical load factor acting on yielding strip is influenced by both the angle of sliding surfaces and ground surface.


## References

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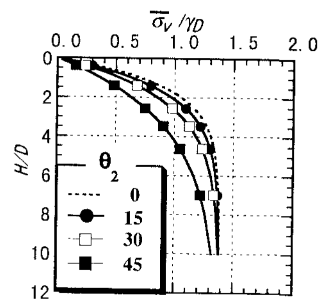


**Fig. 3.** Effect of the angle of ground surface on normalized vertical load factor

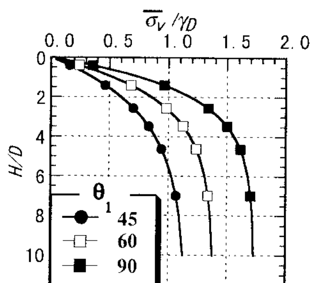


**Fig. 4.** Effect of the angle of sliding surfaces on normalized vertical load factor

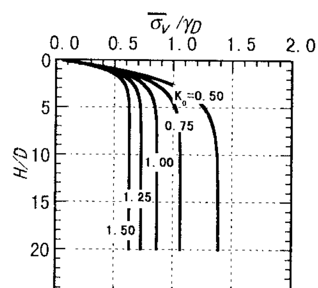


**Fig. 5.** Effect of the coefficient of lateral earth pressure on normalized vertical load factor