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Phan Thị Cúc

FORECAST THE IMPACT OF EXPLOITING UNDERGROUND SPACE TO LAND SUBSIDENCE

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ABSTRACT

Exploiting underground space is understood as creating space in the ground to use for different purposes such as: Mining; Construction of traffic tunnels, subways; Construction of infrastructure tunnels, tunnels for water supply and drainage; Construction of underground warehouses and cultural facilities; Construction of multi-storey house basements; Groundwater exploitation is also considered as a form of underground space exploitation

Exploiting underground space in soft soil layer and putting shallow shall cause land subsidence. This is a problem that needs attention.

In the world, there have been many scientific publications on this issue.

In Vietnam, this issue has not been paid enough attention. Some scientific publications have not been adequately addressed, incomplete and incomplete.

In this article, the authors have given the calculation method to forecast land subsidence based on supplementing and completing previous studies of foreign authors.

Key words: *Land subsidence, underground space exploitation, underground constructions.*

1. Introduction

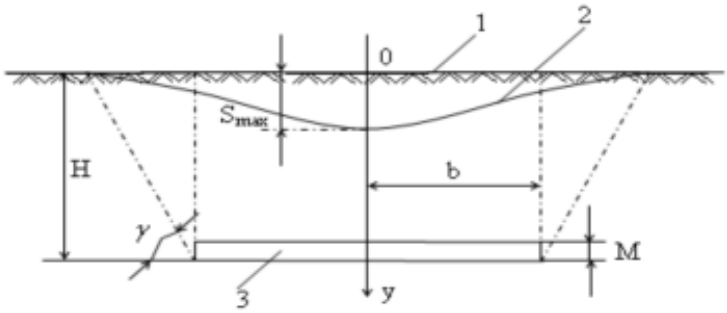
Construction of underground works in weak and shallow soils will cause consequences: causing the ground to sink. Investigations on ground subsidence caused by underground construction in Vietnam have not really been paid enough attention, and few works have been adequately addressed to these issues. The subsidence of Van Thanh tunnel in Ho Chi Minh City is one of the warnings on this issue. Currently in Ho Chi Minh City, Hanoi and many other localities are planning urban construction, roads, underground storage with the use of increasingly urban underground space. Many scientists have warned of the possibility of land subsidence when building these works.

In this paper, the authors refer to the determination of the ground subsidence curve when underground works are being constructed. The scope of the problem: only consider the factors causing ground settlement caused by creating space in the ground. The paper does not take into account the impact of other subsidence factors.

2. Problem to be solved

Assume that people dig a space in the ground to build the underground structure (Figure 1). Geometric dimensions of the space are given. We need to determine the shape of the subsidence curve, the

maximum amplitude and subsidence at the x coordinate.



1 - ground in initial status; 2 - subsidence curve;
M - height of underground structure; H - depth of underground structure;
b - ½ width of the structure; γ - angle of influence.

Figure 1. *Layout of underground works*

3. Some solutions of the problem

3.1. First approach

By empirical observations and measurement, an empirical formula is established to describe the subsidence curve "2" by the following equation (1):

$$S_{(x)} = S_{max}\left(1 - \frac{x}{l} + \frac{1}{2\pi}\sin\left(2\pi\frac{x}{l}\right)\right) \quad (1)$$

Where: $S_{(x)}$ - ground settlement at x considering coordinates; x - coordinates from symmetry axis; l - distance from the center to the limit when $S_{(l)} = 0$; S_{max} - the maximum settling value corresponding to the point whose coordinates $x = 0$.

Empirical studies were conducted to determine Smax and l values. Some of the empirical studies, that are really verified and widely used, help us to determine these values are as follows (2, 3):

$$S_{max} = \sqrt{\eta_1 \eta_2}.a.M.\cos\alpha \quad (2)$$

$$l = b + H\cot g\gamma \quad (3)$$

Where: $\eta_1 = \frac{l_x}{H}$; $\eta_2 = \frac{l_e}{H}$; a - Coefficient, depending on the method for supporting created underground space; M - height of underground structure; α - the angle of the structure compared with the direction Ox; l_X - the length of the structure in the azimuth direction of the rock formations; l_e - width of the structure along the rock slope; γ - angle of the limit impact of subsidence.

In the case of the horizontal structure: α = 0 and

$$\sqrt{\eta_1 \eta_2} = \sqrt{\frac{l_x l_e}{H^2}} = \frac{1}{H}\sqrt{F} \quad (4)$$

F - Plane acreage of underground structure

The value of a regulates in interval 0f 0,15÷0,35.

In constructing underground structures with temporary flexible casing, the value of a is larger than in the case of hard temporary casing. The value of an also depends on the coefficient solidity f of rock.

The angle γ depends not only on mechanical specific features of upper layered rock formations above the structure but also on the depth H of the structure position.

The weaker of rock the smaller of angle γ, and in contrary, the stronger of rock, the lager of angle γ. Real observations show that γ = 35÷65°.

Based on researches of geotechnical conditions for underground construction and real investigations, we propose the formula for determination of γ as follow (4):

$$\gamma = \left(\varphi - \frac{kf\rho}{H}\right)\Big/2, \text{ degrees} \qquad (5)$$

Where: φ - angle of internal friction of the rock above the underground structure; f - coefficient solidity of rock according to Protodiaconov; ρ° - the natural specific weight of the rock, kg/m^3; H - depth of construction positioning, m; k - coefficient of calculation; that varies between 5 and 15 and depends on the cohesion strength of the rock: k increases as cohesion strength of the rock increases. For rock with cohesion strength $C = 0$, then $k \approx 5$.

The formula (5) above needs to be proven experimentally. In the scope of this paper the authors are not able to mention about these works, but the content of this paper is not influenced by the proposal mentioned in formula (5). This is a topic to be clarified in another paper.

3.2. The second approach

Other scientists, by observing large number of ground subsidence, provide an empirical formula for determining the subsidence curve S_{max} according to the following equation (5):

$$S_{(x)} = S_{max}\exp\left(-nx^2\right) \qquad (6)$$

$$n = \frac{S_{max}}{l^2.C_{tb}} \qquad (7)$$

x - distance from the center O to the interested point; $l = b + H\text{tg}\gamma$ - distance from axis Oy to limit border where $S_{(l)} = 0$; C_{tb} - the average value of the direct roof rock displacement of the underground structure. This value is determined experimentally or by solving the problem of displacements of the boundary of the underground structure in the selected rock medium, that is mentioned in other materials on mechanics of underground works (6).

4. Use plastic model to solve the problem

For weak soil, clay containing water, the soil is described by plastic model.

Accept some of the following assumptions when solving the problem in the plastic deformation model:

- At any cross section of the rock above the horizontal structure, subsidence occurs equally with a volume of rock sloping into the structure:

$$\bar{V} = -2\sum_{0}^{\infty} C(x)dx; C(x) \qquad (8)$$

- x - vertical displacement coordinates

- The vertical displacement of the topsoil directly on the underground structure is the largest quantity, equal to aM;

- The horizontal displacement of the points on the symmetry axis y will be zero.

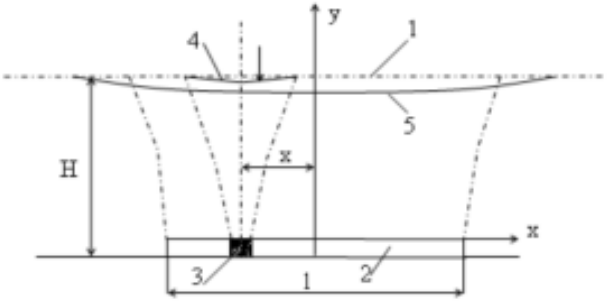
- When the x coordinate is quite far from the axis of symmetry, the settlement reaches zero, the subsidence curve is stopped;

- The rock displacement of the soil environment above a fundamental tunnel element is not affected by the

displacement of the points above the other beside fundamental tunnel elements.

To describe the plastic deformation of rock (Figure 2), we can use following equilibrium equation (6):

$$\begin{cases} \frac{\partial v_x}{\partial t} + v_z \frac{\partial v_x}{\partial x} + v_x \frac{\partial v_x}{\partial y} = X + \frac{\eta}{\rho} \nabla^2 v_x \\ \frac{\partial v_y}{\partial t} + v_z \frac{\partial v_y}{\partial x} + v_x \frac{\partial v_y}{\partial y} = Y + \frac{\eta}{\rho} \nabla^2 v_y \\ \frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} = 0 \end{cases} \quad (9)$$



1 - Soil surface; 2 - Tunnel (underground structure); 3 - Basic tunnel element; 4 - Subsidence curve formed by the basic tunnel element 3; 5 - Total subsidence curve

Figure 2. *Diagram for subsidence calculation of above layered soil of underground structure according to plastic model*

In the formulas (9): η - viscosity of the medium; v_X, v_Y - displacement components; ∇^2 - Laplace operator; X, Y - Total projection on the x and y axes; ρ - density of rock/soil.

When determining the settlement at the end of the displacement process, it is possible to ignore the components $\frac{\partial v_x}{\partial t}$ and $\frac{\partial v_y}{\partial t}$ (assuming v_X, v_Y are constant functions over time). Using the above assumptions, it is possible to derive the vertical displacement component for a point on the surface ($y = H$) with respect to a basic tunnel element would be (6):

$$\partial s \partial x = \frac{aM}{2} th\left(\omega \frac{x}{H}\right) dx \quad (10)$$

Where: s - the vertical displacement component generated by basic tunnel element; ω - quantity characterizing the physic - mechanical properties of rock/soil; th - hyperbolic tangent function $\left(th = \frac{1}{2}\left(e^x + e^{-x}\right)\right)$

Solving integral (10) from $-\frac{l}{2}$ to $+\frac{l}{2}$ give us the entire settlement created by the underground structure:

$$S_{(x)} = -\frac{aM}{2}\left[th\left(\omega \frac{x - l/2}{H}\right) - th\left(\omega \frac{x + l/2}{H}\right)\right] \quad (11)$$

The value of ω can be chosen by comparing the settlement line $S_{(x)}$ constructed according to equation (11) with observable fact.

Example 1: Suppose M = 10 m; a = 0,2; ω = 4; l = 400 m; H = 20 m; $l/2$ = 200 m.

So that:

$$S_{(x)} = -\frac{0,20.10}{2}\left[th\left(4\frac{x - 200}{20}\right) - th\left(4\frac{x + 200}{20}\right)\right] \quad (12)$$

$$S_{(x)} = th\left(\frac{x + 200}{5}\right) - th\left(\frac{x - 200}{5}\right) \quad (13)$$

The results of calculation of $S(x)$ are presented in following table (By the symmetry of x, the values of x were taken with $x \geq 0$, specifically $x = 0 \div 220$):

x, m	0	50	100	150	190	200	210	220
$S(x)$, m	2.0	2.0	2.0	1.9999	1.9640	1.000	0.0359	0.0006

Example 2: Under the assumptions in Example 1, change the values ω = 2, 6, 8 and define $S(x)$, m:

ω \ x	0	50	100	150	190	200	210	220
2	2.0	2.0	1.9999	1.9999	1.7615	1.0000	0.2384	0.0359
4	2.0	2.0	2.0	1.9999	1.9640	1.0000	0.0359	0.0006
6	2.0	2.0	2.0	2.0	1.9950	1.0000	0.0049	0.00001
8	2.0	2.0	2.0	2.0	1.9993	1.0000	0.0006	$0.2.10^{-6}$

Example 3: Remain the values as in example 1, change the value H = 10, 20, 30 and 40 m to determine $S(x)$, m:

H \ X	0	50	100	150	190	200	210	220
10	2.0	2.0	2.0	2.0	1.9993	1.0000	0.0006	$0.2.10^{-6}$
20	2.0	2.0	2.0	1.9999	1.9640	1.0000	0.0359	0.0006
30	2.0	2.0	2.0	1.9999	1.8700	1.0000	0.1299	0.0096
40	2.0	2.0	1.9999	1.9999	1.7615	1.0000	0.2384	0.0359

5. Conclusions

The calculated results show that with the plastic deformation model:

- The subsidence curve on the ground surface caused by underground construction has a maximum value at x = 0 and on the neighborhood with $x = \pm l/2$; it is symmetrical over the y axis and will fade when x approaches a limit value ($x \geq l/2 + 0{,}1\ l/2$)

- The maximum value of subsidence depends on the height of the underground structure M, the method of supporting underground structure in digging and the geological factors of the construction medium.

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