Measured and forecast settlements of buildings near deep pits in Vietnam

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Abstract. The design and construction of underground facilities in major cities in Vietnam, such as Hanoi and Ho Chi Minh city, have currently been expanded. Digging deep excavation pits for underground spaces or subway stations can lead to settlements of the surrounding buildings. Under the soft soils or water-saturated clay soils, the construction of underground spaces causes additional settlements to the surrounding soil mass. Therefore, it is necessary to consider the technological settlement, which is the effect of the construction process of deep excavations, to forecast the total settlement of surrounding buildings. This study proposes an equation to predict the building subsidence due to the influence of deep excavation accounting for the technological settlement.

1. Introduction

When digging deep pits, one of the problems is determining its effect on adjacent buildings located in the influencing zone of the underground construction. There are a lot of projects for the development of underground spaces in major cities of Vietnam like Hanoi and Ho Chi Minh City. Underground facilities built in deep pits include parking lots, basements of high-rise buildings, subway stations, and underground shopping centers. These structures are generally built in weak water-saturated soils, therefore, during the construction procedure, deformations of the ground surface and neighboring buildings are occurred.

Methods of forecasting the settlement of buildings located within the influencing zone of the underground facilities construction were studied numerously [1-8]. It is notable that in the construction process of a deep excavation, there are many factors that affect the settlement of the ground surface as well as adjacent structures. The main factors affecting the amount of precipitation are the depth of the pit, the distance from the diaphragm wall to the foundation of the neighboring building, the pressure on the ground surface, geological conditions, depth of the diaphragm wall, and the density of bentonite solution for installing the diaphragm walls. This paper proposes a formula for calculating the settlement of neighboring buildings in the construction of deep excavation pits using "top-down" or
"semi top-down" methods with a diaphragm wall system and taking into account the technological settlement during construction of the diaphragm walls.

2. Geological characteristics of the research area

The territories of the mega cities in Vietnam such as Ho Chi Minh city and Hanoi are composed of weak water-saturated soils, characterized by flowing clay soils, silts and loose [6, 9-13]. In recent studies [14, 15], engineering-geological sections found that the soil conditions in these cities were divided into five types. The physical and mechanical characteristics of the composing soil are presented in Table 1.

| Soil types | Main characteristics of soils | Region, city |
|------------|------------------------------|--------------|
| Type I: (0-20m) clay and loam soft plastic (more than 20m) clays with a consistency from firm-stiff to very stiff | $\phi = 4-6^0, c=5-6$ kN/m$^2$, $E=1.1 \times 10^6$ kN/m$^2$; $\phi = 12-16^0, c=24-28$ kN/m$^2$, $E=4 \times 10^6$ kN/m$^2$, SPT =12-30) | Ho Chi Minh City |
| Type II: (0-20m) clay and very soft-stiff loam (more than 20m) sandy loam (sometimes with gravel) | $\phi = 4-6^0, c=5-6$ kN/m$^2$, $E=1.1 \times 10^6$ kN/m$^2$; $\phi = 25-26^0, c=5.4-8.0$ kN/m$^2$, $E=5 \times 10^6$ kN/m$^2$ | Ho Chi Minh City |
| Type III: sandy loam (sometimes with gravel) | $\phi = 23-26^0, c=5.4-7.5$ kN/m$^2$, $E=(7-9) \times 10^6$ kN/m$^2$, SPT =12-30) | Ho Chi Minh City |
| Type IV: ((0-10 m) sandy very soft- stiff loam and very soft loam (10-20m) Sands of medium density, dusty and medium size (more than 20m) very soft loam | - $\phi = 7-14^0, c=14-21$ kN/m$^2$, $E=(7-12) \times 10^6$ kN/m$^2$; | Hanoi |
| | - $\phi = 32-34^0$, $E=15-28 \times 10^6$ kN/m$^2$, SPT =14-22); | |
| | - $\phi = 7-11^0$, $c=14-18$ kN/m$^2$, $E=(15-28) \times 10^6$ kN/m$^2$, SPT =7-11 | |
| Type V: (0-10 m) sandy very soft-stiff loam and very soft loam (10-40 m) sands from dusty medium density to gravel | - $\phi = 7-14^0, c=14-21$ kN/m$^2$, $E=(7-12) \times 10^6$ kN/m$^2$; | Hanoi |
| | - $\phi = 32-34^0$, $E=(15-50) \times 10^6$ kN/m$^2$, SPT =14-50 | |

3. Forecast the settlement of buildings in the influencing zone of deep pits

Based on the settlement formula for buildings in the influencing zone of deep pits presented in [1] and consideration of engineering-geological conditions in Vietnam [3, 15], the settlement formula of surrounding buildings is proposed, in which the lateral movement of the diaphragm wall in weak water-saturated soils and seismic effects is taken into account, expressed as

$$S_1(x) = k_s k_s u^5 \delta_1 [k_{uv} k_s \phi(x) + q/k]$$  \hspace{1cm} (1)

where $\delta_1 = \frac{A_1 f h_k^t}{\alpha^x + \alpha_y^x h_k^t}$; $A_1 = \frac{k}{\beta_j}$; $b = \frac{a}{h_k^t}$; $\phi(x) = \left[ \psi \left( \frac{b}{\lambda} - 1 \right) \right] \eta_{uv}(\xi) + \eta_{uv}(\xi) + e^{-b(x+\lambda)}$; $\phi(x) = \left[ \psi \left( \frac{b}{\lambda} - 1 \right) \right] \eta_{uv}(\xi) + \eta_{uv}(\xi) + e^{-b(x+\lambda)}$; $\eta_{uv}(\xi) = e^{-\xi \cos \xi}$;
\[ \eta_{IV}(\xi) = e^{-\xi \sin \xi}; \xi = \lambda x; \lambda = \sqrt[4]{\frac{k}{AE}}; \]

In which:
- \(k\) - the subgrade reaction coefficient [16];
- \(q\) - the contact pressure under the strip footing;
- \(k_s\) - coefficient depending on the type of spacer system;
- \(f_s\) - the ratio of the largest horizontal displacement to the depth of diaphragm wall;
- \(L\) - distance from the building to the pit;
- \(H_p\) - pit depth;
- \(EJ\) - stiffness of buildings with various floors [17];
- \(x\) - coordinate point along the length of the building;
- \(k_s\) - coefficient taking into account the seismic effect on the horizontal displacement of the diaphragm wall;
- \(k_s'\) - coefficient taking into account the construction method with seismic effects;
- \(k_{sw}\) - coefficient taking into account the relationship between the horizontal displacement of the diaphragm wall and the largest settlement of the soil surface around a deep pit. The coefficient values are given in the study of Nikiforova N.S. and Nguyen V.H. [15].

The technological settlement due to the diaphragm wall construction in the soil was determined by the formula (2), that was given for weak water-saturated clay soils of St. Petersburg in [18]:

\[ S_2 = -\alpha Ae^{B_L} \] (2)

\(S_2\) - foundation settlement of the building adjacent to the deep pit, mm;
\(A\) and \(B\) - coefficients depending on the geometrical parameters of diaphragm wall capture, density of mud and soil conditions; coefficient values are given in [18];
\(e\) - Euler's constant, equal to 2.71;
\(L\) - the distance from the diaphragm wall to the building, m;
\(\alpha\) - correction factor, set to 1.3.

By formula (2), it is proposed to determine the settlement along the length of the building, considering \(L\) as the distance from the diaphragm wall to a point along the length of the building.

The building’s settlement along its length in the influencing zone of the deep pit, taking into account the technology for constructing the diaphragm wall, is determined by formula (3) as the sum of settlement calculated in formulas (1) or (4) and (2):

\[ S(x) = S_1 + S_2, \text{ (mm)} \] (3)

To test formula (3), the calculated settlement was compared to the measured values obtained from the facilities in the underground part in Hanoi, Vietnam. In the calculations, the values of the coefficients \(k_s\), \(k_s'\) in formula (1) were set to zero since there were no seismic effects before the geotechnical monitoring.

If the building of the surrounding areas is erected on piles, for preliminary calculations, the \(S_1\) can be determined with a decreasing coefficient \(K_c = 0.5\) given in [19, 20], considering piles as a protective measure, expressed as

\[ S_i = K_c \cdot S_1(x), \] (4)

4. Underground geotechnical monitoring in Vietnam

4.1. Lao Dong newspaper headquarter building in Hanoi

The investigated building, which is located in Cau Giay district, Hanoi, is a multifunctional complex with three basements. The diaphragm walls are selected for the deep excavation protection. The thickness and depth of the diaphragm wall is 0.8 m and 28.5 m, respectively. The depth of the excavation pit, \(H_p\) is 10 m. The headquarters building of Lao-Dong newspaper is located in the influencing area of a deep excavation. The building has 9 above-ground floors with a basement and a pile foundation. Engineering-geological conditions of the construction site are of type V (see Table 1).
During the construction process, a geotechnical monitoring was carried out at the site (Figs. 1,2), including settlement observations of the surrounding buildings (Fig. 3) and horizontal diaphragm wall displacement along inclinometric bores observations (Fig. 4). The measured horizontal displacements of the diaphragm wall along the inclinometric bore from the Lao-Dong newspaper headquarter building are shown in Fig. 5.

**Figure 1.** Construction site of a multifunctional center in Hanoi

**Figure 2.** Construction of a multifunctional complex on Pham Van Bach Street, Cau Giay District, Hanoi

### 4.2. Comparison calculated settlements with geotechnical monitoring data

The following parameters were taken into account when calculating the settlement, which are the distance from the Lao Dong newspaper headquarter building to the pit \( L = 15 \) m; maximum horizontal displacement along an inclinometric mark \( u_0 = 55.8 \) mm (Fig. 4), coefficient \( k_r = 0.7 \), \( k_{uv} = 1.1 \) \[15\], foundation load \( q = 50 \) kN/m².

**Figure 3.** Lao Dong Newspaper headquarters settlement observation scheme, M1..M22- Building settlement monitoring mark, R1..R3- Deep reference benchmark.
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Figure 4. Layout of inclinometric bores for monitoring diaphragm wall displacement

Figure 5. Horizontal displacement of the diaphragm wall $u_{h}$ in point ICL5

Fig. 6 shows the building settlements calculated by formulas from (1) to (4) and measured settlements. The maximum values of the calculated and measured settlements as well as their comparison are shown in Table 2. Predicted and measured settlements taking into account the technological settlement have satisfactory convergence.

Figure 6. Graphs calculated taking into account the technological settlement and measured along the length of the headquarters building of Lao Dong newspaper in Hanoi: 1- calculated technological settlements (formula 2); 2- calculated settlements (formula 1); 3- measured settlements; 4- calculated settlements taking into account the technological part (formula 3,4)
Table 2. Comparison between calculated settlements taking into account the technological settlement and geotechnical monitoring data

| Construction object | Maximum settlement, mm | Divergence of the measured and calculated settlement |
|---------------------|------------------------|----------------------------------------------------|
|                     | Calculation based on formula (4) | Technological settlement based on formula (2) | Total settlement estimation based on formula (3) | Measured settlement |
| The headquarters building of Lao Dong Newspaper in Hanoi | 9.8 | 6.2 | 16.0 | 14.0 | 12 % |

5. Conclusion

Some conclusions are drawn based on the results of this study, as follows.
1. When we forecast the settlements of buildings in the influencing zone of deep pits, it is necessary to take into account the technological settlements caused by diaphragm wall construction.
2. The formula recommended in [18] for the soils of St. Petersburg is used to determine the technological settlements due to the diaphragm wall construction under the weak water-saturated soils of Vietnam.
3. The comparison between calculated and measured settlements indicates the possibility of using the proposed calculation method for settlement prediction of the buildings located within deep excavation influencing zone in weak water-saturated soils in Vietnam. The proposed formula is able to consider the effect of diaphragm wall construction process on the adjacent building settlements.

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