Calculating the maximum pressure on the diaphragm wall subjected to seismic loading accounting for geotechnical conditions of Vietnam

Nadezhda Nikiforova$^{1,2}$ and Nguyen Van-Hoa$^{1,3}$

$^{1}$ Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, Russia, n-nikiforova@yandex.ru
$^{2}$ Research Institute of Building Physics of the Russian Academy of Architecture and Building Sciences, 21, Lokomotivny st., 127238, Russia
$^{3}$ Department of Civil Engineering, Vinh University, 182 Le Duan, Vinh, Vietnam, vanhoakxd@vinhuni.edu.vn

E-mail: n-nikiforova@yandex.ru, vanhoakxd@vinhuni.edu.vn

Abstract. The Russian standards have not provided a method for calculating the pressure on the diaphragm wall under seismic impacts. Vietnamese geotechnical standards use the approach outlined in Eurocode-8. In this study, an empirical and analytical method for determining the maximum pressure on the diaphragm wall for typical types of engineering and geological conditions in Vietnam are proposed based on the pseudo-static method and numerical studies. The results are compared with the values obtained from PLAXIS-2D program, showing a good agreement.

1. Introduction

According to the studies Nguyen [1] and Mai [2] in Vietnam from the XIII century to 2002, 152 earthquakes were recorded (144 in the XX century), including two strong ones, not less than 6 Richter.

The above-mentioned author pointed out that according to the maps of the General seismic zoning (GSZ) of Vietnam, as well as detailed seismic zoning (DSZ) of Hanoi and neighborhoods, the seismicity zone of Hanoi is fallen into a magnitude 7 - 8 (MSK-64 scale). Additionally, the results of numerous studies in various engineering and geological conditions showed that the manifestation of seismic intensity on the earth’s surface can vary from +2 to -2 levels. Areas of distribution of loose watered deposits are the most dangerous zone during seismic excitations. In this regard, the design of the diaphragm wall should be taken into account the seismic effects.

Analytical calculations of the horizontal pressure on the diaphragm wall, taking into account seismic effects, are developed by numerous works such as Mononobe and Mastuso (1929) [3], Okabe (1924) [4], Seed and Whitman (1970) [5], Richards and Elms (1979) [6], Nadim and Whitman (1983) [7], Whitman and Liao (1985) [8], Fishman and Richards (1996)[9], and Steedman and Zeng (1996) [10]. Numerical studies on the stress-strain relationship of the soil mass surrounding deep excavations, protected by diaphragm walls, in Vietnam under seismic influences were given in the authors’
works[11-14]. The pseudo-static method was used in analytical calculations of pressure on diaphragm walls under seismic impacts.

Engineering and geological conditions for the construction of underground facilities in Vietnam are complicated because of the presence of a large thickness of highly compressible soils, including those with organic matter and having thixotropy. Additionally, a high level of underground water, possible liquefaction of loose sands during earthquakes, as well as the occurrence of suffusion are possibly occurred [15]. The procedure for determining the pressure on the diaphragm walls based on the pseudo-static method is presented in the standard EN 1998-5:2004 (EC8) [16]. Vietnamese geotechnical standards use the approach outlined in this document. The Russian standards do not provide a method for calculating the pressure on the diaphragm walls under seismic impacts. The pseudo-static method was also used in ODM218.2.053-2015 [17].

2. Methods determination of the maximum soil pressure acting on the diaphragm wall taking into account seismic effects

In the work of Stavnitse[18], the calculation of the anti-landslide pressure of the soil taking into account seismic influences, which is also based on the pseudo-static method, is presented in Figure 1.

![Figure 1. Calculation scheme for determining the anti-landslide pressure of the soil, taking into account seismic effects [18]](image)

They formed the basis of the method for determining the maximum pressure on the diaphragm walls, enclosing a deep excavation in the engineering and geological conditions of Vietnam. Working in this direction under the leadership of Nikiforova N.S., a primary study was developed by Dam [19]. The method is designed for deep excavation with the depth of 10 m, protected by diaphragm walls.

Similar to the recommendations for determining the landslide pressure of the soil under seismic effects [18], we accept the settlement scheme (in Figure 2) to determine the pressure on the diaphragm wall taking into account seismic effects.

The total pressure on the diaphragm wall is characterized by the sum of

\[ P_{\text{eq}} = P_i + \Delta P_{\text{eq}} \]  

where \( P_i \) is the static pressure on the diaphragm wall in \( i \)-m the estimated compartment, applied at a height of 1/3 of the base of the section; \( \Delta P_{\text{eq}} \) is the seismic pressure on the diaphragm wall in the \( i \)-m compartment, applied at a height of 2/3 from the base of the section; \( h_i \) is the height of the \( i \)-section.

The calculation of the pressure on the diaphragm wall is made for the band of 1 m, with following parameters.

- \( G_i \) – the weight of the compartment;
- \( a \) – acceleration of vibrations;
- \( a_v, a_h \) – vertical and horizontal components of vibration acceleration;
- \( G_{iv} = \pm k_v G_i \) – vertical component of the inertia force;
- \( G_{ih} = \pm k_h G_i \) – horizontal component of the inertia force;
\( k_v = \pm \frac{a_v}{g} \); \( k_h = \pm \frac{a_h}{g} \) — dimensionless values of calculated accelerations in fractions of gravity acceleration;
\( N_i \) — normal reaction on the sliding surface;
\( T_i \) — holding force.

From the calculation of diagram, the equilibrium conditions for horizontal and vertical projections of forces are as follows:

\[
P_{i,eq} - K_h G_i - P_{i-1,eq} + T_i \cos \alpha_i - N_i \sin \alpha_i = 0
\]
\[
G_i (1 \pm K_v) - T_i \sin \alpha_i - N_i \cos \alpha_i = 0
\]

where \( T_i = c_i I_i + N_i \tan \varphi_i \).

From the above equations, we obtain a formula for the total pressure on the diaphragm wall, taking into account seismic effects:

\[
P_{i,eq} = \sum_{i=1}^{n} \left\{ G_i [K_h + (1 \pm K_v) \tan (\alpha_i - \varphi_i)] \right\}
\]

The " + " sign represents the direction of the vertical component of acceleration going down, and the " - " is for up direction.

The static pressure on the diaphragm wall is determined under the condition \( K_v = K_h = 0 \),

\[
P_{i,eq} = E_i - G_i \tan (\alpha_i - \varphi_i) - \frac{c_i \cos \varphi_i}{\cos (\alpha_i - \varphi_i)}
\]

Seismic pressure, \( \Delta P_{i,eq} \) can be obtained by subtraction (5) and (4):

\[
\Delta P_{i,eq} = \sum G_i [K_h \pm K_v \tan (\alpha_i - \varphi_i)]
\]

To use the above formulas in calculating the pressure on the diaphragm wall, it is necessary to determine the slip line of the soil behind the diaphragm wall and its lower point (see Figure 2).

Figure 2. Calculation scheme for determining the pressure on the diaphragm wall taking into account seismic effects

Values \( B_i, B_2, H_i, H_2, L_i, L_2, \alpha_i, \alpha_2 \) (in Figure 2) are determined from the displacements of the soil, obtained by geotechnical modeling of seismic impacts in PLAXIS 2D 2018 using the accelerogram of the 2001 Dien Bien earthquake (Vietnam), as shown in Figure 3.
Figure 3. Accelerogram of the 2001 Dien Bien earthquake [13].

Geotechnical calculations were performed for deep excavation with a depth of 8 m and 10 m, protected by diaphragm walls, with spacer mounts in the form of reinforced concrete slabs and anchors. We considered 5 types of geological conditions typical for Hanoi and Ho Chi Minh city from the proposed by the authors in the works [15, 20], as presented in Table 1.

| Soil types | Main characteristics of soils | Region, city |
|------------|-----------------------------|--------------|
| Type I:    |                             | Ho Chi Minh City |
| 0-20m clay and loam soft plastic (more than 20m) clays with a consistency from firm-stiff to very stiff | $(\phi = 4-6^0, \, c=5-6 \, \text{kN/m}^2, \, E=1.1 \times 10^4 \, \text{kN/m}^2)$; $(\phi = 12-16^0, \, c=24-28 \, \text{kN/m}^2, \, E=4 \times 10^3 \, \text{kN/m}^2, \, \text{SPT}=12-30)$ | |
| Type II:   |                             | Ho Chi Minh City |
| 0-20m clay and very soft-stiff loam (more than 20m) sandy loam (sometimes with gravel) | $(\phi = 4-6^0, \, c=5-6 \, \text{kN/m}^2, \, E=1.1 \times 10^4 \, \text{kN/m}^2)$; $(\phi = 25-26^0, \, c=5.4-8.0 \, \text{kN/m}^2, \, E=5 \times 10^3 \, \text{kN/m}^2)$ | |
| Type III:  |                             | Ho Chi Minh City |
| Sandy loam (sometimes with gravel) | $(\phi = 23-26^0, \, c=5.4-7.5 \, \text{kN/m}^2, \, E=(7-9) \times 10^3 \, \text{kN/m}^2, \, \text{SPT}=12-30)$ | |
| Type IV:   |                             | Hanoi |
| 0-10m 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 | - $(\phi = 7-14^0, \, c=14-21 \, \text{kN/m}^2, \, E=(7-12) \times 10^3 \, \text{kN/m}^2)$; - $(\phi = 32-34^0, \, E=15-28 \times 10^3 \, \text{kN/m}^2, \, \text{SPT}=14-22)$; - $(\phi = 7-11^0, \, c=14-18 \, \text{kN/m}^2, \, E=(15-28) \times 10^3 \, \text{kN/m}^2, \, \text{SPT}=7-11)$ | |
| Type V:    |                             | Hanoi |
| 0-10m sandy very soft-stiff loam and very soft loam (10-40m) sands from dusty medium density to gravel | - $(\phi = 7-14^0, \, c=14-21 \, \text{kN/m}^2, \, E=(7-12) \times 10^3 \, \text{kN/m}^2)$; - $(\phi = 32-34^0, \, E=(15-50) \times 10^3 \, \text{kN/m}^2, \, \text{SPT}=14-50)$ | |

Dispalacements of soil mass with geological type V and reinforced concrete slabs are shown in Figure 4.
The internal friction angles for determining the active ($\phi_1$) and passive ground pressure ($\phi_2$) are calculated using the formula:

$$\phi_{1,2} = \sum \phi_i h_i$$  \hspace{1cm} (7)

where $\phi_i$ is the friction angle layer of the $i$-th soil layer ($^0$), $h_i$ is the layer thickness of the $i$-th soil layer to a depth $H_i$ (m).

The calculation of the maximum pressure acting on the diaphragm walls, taking into account seismic effects, is performed according to the formulas (8)-(12):

$$P = P_1 + \Delta P_{1,eq} + \Delta P_{2,eq} - P_2$$  \hspace{1cm} (8)

$$P_1 = G_1 t g(\alpha_1 - \varphi_{1,eq}) - \frac{c_{11} \cos \varphi_{1,eq}}{\cos(\alpha_1 - \varphi_{1,eq})}$$  \hspace{1cm} (9)

$$P_2 = G_2 t g(\alpha_2 - \varphi_{2,eq}) - \frac{c_{11} \cos \varphi_{2,eq}}{\cos(\alpha_2 - \varphi_{2,eq})}$$  \hspace{1cm} (10)

$$\Delta P_{1,eq} = G_1 [K_h \pm K_v t g(\alpha_1 - \varphi_{1,eq})]$$  \hspace{1cm} (11)

$$\Delta P_{2,eq} = G_2 [K_h \pm K_v t g(\alpha_2 - \varphi_{2,eq})]$$  \hspace{1cm} (12)

The results of calculating the maximum wall pressure in the diaphragm wall according to the proposed method and obtained from the PLAXIS 2D program are presented in Table 3.
Table 3. Comparison of the results of calculating the maximum pressure acting on the diaphragm wall, obtained by the Plaxis2D program and the proposed method

| Types of engineering and geological sections | Spacer system | \( H_k \) (m) | \( P \) (kN/m) | \( P_{\text{plaxis}} \) (kN/m) | \( \Delta_1 \) (%) |
|---------------------------------------------|---------------|------------|-------------|-----------------|-------------|
| III                                         | II            | 8          | 587         | 538             | 8.4         |
| II                                          | II            | 8          | 947         | 885             | 6.6         |
| V                                           | II            | 8          | 1295        | 1192            | 8.0         |
| V                                           | A             | 10         | 1379        | 1252            | 9.3         |
| IV                                          | A             | 8          | 1356        | 1506            | -11.8       |

where \( \Delta_1 = \frac{P - P_{\text{plaxis}}}{P_{\text{plaxis}}} \) (%)

The discrepancy between the values of the maximum pressure on the diaphragm walls, taking into account the seismic effects obtained by numerical simulation and the proposed empirical-analytical method, is ranged within 7% -12%.

3. Conclusion

1. An Empirical-analytical method for determining the maximum pressure in diaphragm walls for deep excavation with a depth of 8-10 m, taking into account seismic effects in the engineering and geological conditions of Hanoi and Ho Chi Minh, is proposed.
2. The results of calculations by the proposed method have satisfactory convergence with those obtained by numerical simulation using PLAXIS 2D program.

References

[1] Nguyen Duc Manh, “Engineering and geological support for the development of the underground space of the city of Hanoi (Vietnam)” Saint Petersburg state mining Institute, GV Plekhanov, 2010.
[2] Mai Duc Minh, "Calculation of tunnels for seismic effects" Abstract.dis.... PhD. sciences', Moscow, 2014.
[3] N. Mononobe and H. Matsuo, "On the determination of earth pressure during earthquakes: Proceedings of the World Engineering Congress," ed: Tokyo, 1929.
[4] S. Okabe, "General theory on earth pressure and seismic stability of retaining wall and dam," Proc. Civil Engrg. Soc., Japan, vol. 10, pp. 1277-1323, 1924.
[5] H. W. Seed, R.V, "Design of earth retaining structures for dynamic loads," in ASCE Specialty Conf.-Lateral Stress in the Ground and Design of Earth Retaining Structures, 1970.
[6] R. Richards Jr and D. G. Elms, "Seismic behavior of gravity retaining walls," Journal of Geotechnical and Geoenvironmental Engineering, vol. 105, 1979.
[7] F. Nadim and R. V. Whitman, "Seismically induced movement of retaining walls," Journal of Geotechnical Engineering, vol. 109, pp. 915-931, 1983.
[8] R. V. Whitman and S. Liao, "Seismic design of gravity retaining walls," Massachusetts Inst of Tech Cambridge Dept of Civil Engineering1985.
[9] K. Fishman and R. Richards Jr, "Seismic analysis and model studies of bridge abutments," in Analysis and design of retaining structures against earthquakes, ed, 1996, pp. 77-99.
[10] R. Steedman and X. Zeng, "Rotation of large gravity walls on rigid foundations under seismic loading," in Analysis and design of retaining structures against earthquakes, ed, 1996, pp. 38-56.
[11] Nikiforova N.S., Nguyen Van-Hoa, Konnov A.V., " Deformation of weak soils when digging deep pits in seismic areas and protection of the environment " Bulletin of Construction Equipment (BST), vol. 6, pp. 62-64, 2018.

[12] Nguyen Van Hoa, Nikiforova N.S, and Nguyen Duy Duan, "Semic displacement prediction of retaining walls upon deep exavations in Ha Noi," Journal of Transportation Science and Technology, vol. 27+28, pp. 192-197, 2018.

[13] Nikiforova N.S., Nguyen Van-Hoa, Nguyen Duy-Duan, "Prediction of soil displacement surrounding deep excavations in Ha Noi," in Proceeding of the international conference on the 55th anniversary of establishment of Viet Nam institute for building science and technology, 2018, pp. 413-418.

[14] Nikiforova N.S., Konnov A.V., Nguyen Van-Hoa, L.A. Prostotina, " Influence of Installing Cut-off Screens Executed According to the Jet Technology on Settling of Surrounding Development," Housing Construction, vol. 7, pp. 3-8, 2019.

[15] Nguyen Van-Hoa & Nikiforova N.S, 2017. Consideration of the features geological conditions when developing the underground space of Vietnam., Conferences Geotechnical engineering surveys, design and construction of foundations and underground structures. Saint Pt, p277-281.

[16] E. E. pre-standard), Design Provisions for Earthquake Resistance of Structures-Part 5: Foundations Earthquake Resistance of Structures-Part 5: Foundations. The Commission of the European Communities, 1994.

[17] ODM218.2.053-2015, " Recommendations of the methodological document apply to the construction of public roads," ed: Росавтодор, 2015, p. 66.

[18] Stavnitser L.R., Seismic resistance of bases and foundations. Moscow: Publishing house of Association of construction universities, 2010.

[19] Dam Huu Hung, " Study of the wall in the ground in the container -geological conditions in Vietnam, taking into account seismic effects, " Master’s thesis., MGSU, Moscow, 2018.

[20] N. Nikiforova and N. Van-Hoa, "Prediction of settlement of buildings surrounding deep excavations in Viet Nam," Geotechnics Fundamentals and Applications in Construction: New Materials, Structures, Technologies and Calculations, p. 205, Saint Petersburg, Russia, 6-8 February, 2019.