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A PARAMETRIC STUDY OF THE BUTTRESS WALLS BEHAVIOUR IN LIMITING THE DIAPHRAGM WALL DISPLACEMENTS

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ABSTRACT

Buttress walls represent a construction technique used to reduce diaphragm wall displacements induced by deep excavations. Three-dimensional finite element analyses were performed to assess the effectiveness of buttress walls in limiting diaphragm wall displacements during deep excavation. Accordingly, a parametric study was carried out by varying several geometric parameters, such as excavation depth, buttress wall length and the spacing between them. To investigate the influence of the soil type, both cohesive and cohesionless soil were used. Also, the impact of frictional resistance between the buttress walls and the adjacent soil was considered. The results show the influence of all these parameters on the behaviour of the buttress walls.

Keywords: buttress wall, 3D numerical modelling, deep excavation, lateral displacements

INTRODUCTION

The classic solutions adopted for deep excavation retaining walls are diaphragm walls or pile walls. The anchorage, steel struts or the concrete slabs (the top-down method) can be used to limit the excavation induced movements. Another solution that can be used to limit the retaining wall displacements are the buttress walls which can be used individually or in combination with the classical solutions.

Buttress walls are auxiliary elements constructed perpendicular on the main retaining wall, with a finite length, prior to excavation. The buttress walls can be located inside the excavation zone or outside it, the last one also being named counterforts.

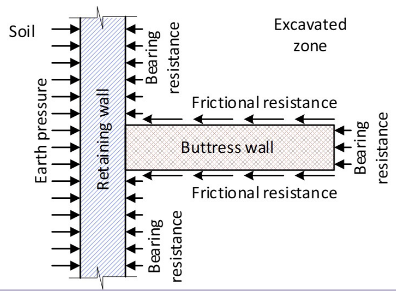

Figure 1 *Buttress wall configuration (Ou et al., 2006)*

The buttress walls limit the retaining wall displacements, mainly, through the frictional resistance developed between the two sides of the buttress wall and the adjacent soil. Also, the buttress wall enhances the main retaining wall flexural rigidity, the formed system having an effect similar to the reinforced concrete T-beam (Hsieh et al., 2018).

A numerical parametric study was performed (Hsieh et al., 2015) in order to explain the buttress walls mechanism in reducing the lateral displacements of the main retaining wall. They find out that the lateral displacements of the retaining wall when the frictional resistance between the buttress walls and the adjacent soil was not considered is almost equal to that without buttress walls. Otherwise, when frictional resistance is considered, the wall deflection was less than that without buttress walls.

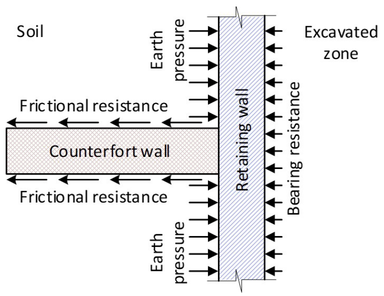

Figure 2 *Counterfort wall configuration (Erginag et al., 2017)*

Increasing the buttress wall length leads to a decrease in lateral displacements of the retaining

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wall. The optimal length of the buttress wall should be chosen in a way that the largest relative shear stress is mobilized (Hsieh et al., 2015).

Another numerical parametric study carried out by (Hsieh et al., 2018) indicates that reducing the distance between the buttress walls can help mitigate the displacements of the retaining wall, while increasing the length of the buttress walls proves to be more effective. Furthermore, the recommended depth of the buttress walls is 2/3 of the excavation depth. However, increasing the depth of the buttress walls beyond this value does not lead to significant reductions in the lateral displacements of the retaining structure.

Based on the results of their study, (Chen et al., 2011) recommend that the distance between the counterforts walls to be chosen equal to 1-2 of the excavation depth.

This paper presents the results of a parametric study which has been conducted using the 3D finite element method.

MATERIALS AND METHODS

To analyse the mechanism of the buttress and counterfort walls in restraining the deflection of the diaphragm wall, the 3D finite element method was employed. The numerical modelling was carried out using the Plaxis 3D design software.

A parametric study has been carried out in which the excavation depth (H_{excv}), the length of buttress wall (L_B) or counterfort wall (L_C) and the distance between them (S_C, S_B) have been varied. The excavation depth has values between 5-20m and the length of the diaphragm wall (H_D) is twice the excavation depth. The distance between the buttress/counterforts walls has been varied between 3-21m, and their length between 3-9m.

Also, to analyse the influence of the frictional resistance, the strength reduction factor, Rint has been varied, with values between 0.2-1.

For all the numerical models, the cohesive and cohesionless soil have been used. The parameters for the two types of soil are shown in Table 1. The hardening soil constitutive model has been used.

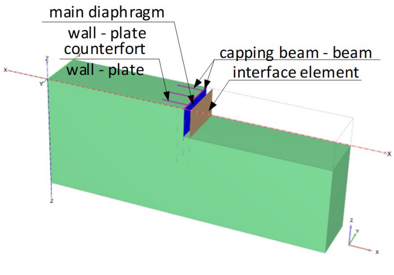

Figure 3 *Counterfort walls numerical model*

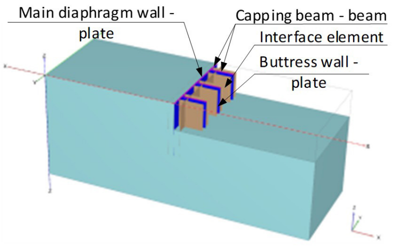

Figure 4 *Buttress walls numerical model*

Table 1 *Soil parameters used in the numerical analysis*

Soil type	γ	γ_{sat}	E_{50}^{ref}	E_{oed}^{ref}	E_{ur}^{ref}	ν_{ur}	m	c'	ϕ'	R_{inter}
	[kN/m³]	[kN/m³]	[kPa]	[kPa]	[kPa]	[-]	[-]	[kPa]	[°]	[-]
Cohesionless	19.5	20.50	25000	25000	75000	0.30	0.5	5	30	0.67
Cohesive	19.5	20.50	15000	15000	45000	0.35	0.6	40	15	0.67

Where:

γ	Unit weight
γ_{sat}	Saturated unit weight
E_{50}^{ref}	Secant stiffness in standard drained triaxial test
E_{oed}^{ref}	Tangent stiffness for primary oedometer loading
E_{ur}^{ref}	Unloading/reloading stiffness
ν_{ur}	Poisson's ratio for unloading-reloading
m	Power for stress-level dependency of stiffness
c'	Effective cohesion
ϕ'	Effective angle of internal friction
R_{inter}	Strength reduction factor

In total, a number of 488 numerical models have been carried out.

The diaphragm walls, as well as the buttress and counterfort walls, are modelled as plate, while the capping beam is defined as a beam element. The diaphragm wall thickness is 0.60m and the height and width of the capping beam are 0.80x0.60m. The linear elastic constitutive model has been used for each. For both, diaphragm walls and capping beam, the concrete modulus of elasticity is $3.1 \cdot 10^7$kPa, the Poisson's ratio is 0.2 and the unit weight is 25kN/m^3.

RESULTS AND DISCUSSIONS

Figure 5 shows the variation of the maximum displacement reduction ratio ($\Delta\delta_{max}$) with the strength reduction factor (R_{int}), for different distance between counterfort walls and the two type of soil.

The maximum displacement reduction ratio ($\Delta\delta_{max}$) defines the efficiency of the counterforts walls and is calculated as follows:

$$\Delta\delta_{\max} = \frac{\delta_{\max} - \delta_{\max,c}}{\delta_{\max}} \cdot 100 \qquad (1)$$

where δ_{max} is the maximum lateral displacement of the retaining system without counterforts walls and R_{int}=1, and $\delta_{max,c}$ is the maximum lateral displacement of the retaining system with counterforts walls, with different R_{int} values.

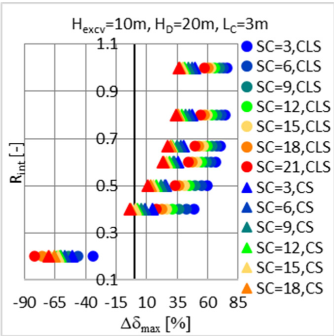

Figure 5 *Variation of the maximum displacement reduction ratio with R_{int}*

For R_{int}=1, when the frictional resistance between counterforts walls and the adjacent soil is considered, even with a short counterfort wall of 3m, the maximum displacement reduction ratio has values between 57 - 75% for the cohesionless soil and 36-50% for the cohesive soil.

At values of R_{int} between 1 and 0.67 (or 2/3) the variation of the displacement reduction ratio is very small (maximum 8%). Below this range, the variation of the displacement reduction factor becomes considerable.

If R_{int}=0.2, due to the very small frictional resistance between counterforts walls and the adjacent soil, even the flexural rigidity of the retaining system is greater than that of the one without counterfort walls, the maximum lateral displacements are much bigger.

That being said, the counterfort walls limit the lateral displacements of the retaining system, mainly through the frictional resistance between them and the adjacent soil. Also, the effect of the counterfort walls is more important when they are executed in cohesionless soil.

Figure 6 shows the variation of the maximum displacement of the buttress walls with the length of the buttress walls and the distance between them for an excavation depth of 10m, depth of the diaphragm wall of 20m, R_{int}=1 model in cohesionless soil.

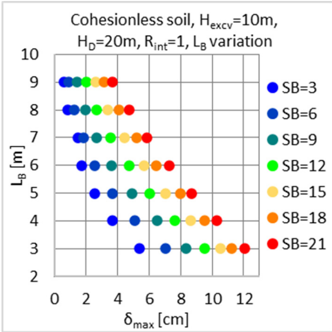

Figure 6 *Variation of the maximum buttress walls displacements with buttress walls length and with the distance between them, cohesionless soil*

The maximum lateral displacement of the buttress wall is reduced with increasing of the buttress wall length. Also, reducing the distance between the buttress walls increase their effect.

However, increasing the buttress wall length has a more significant effect than decreasing the distance between them.

The same behaviour can be observed for buttress walls model in cohesive soil (Figure 7).

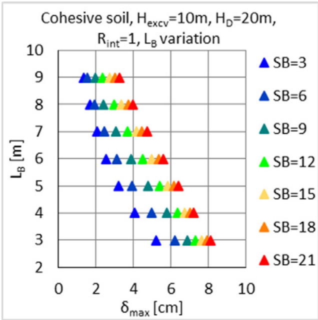

Figure 7 *Variation of the maximum buttress walls displacements with buttress walls length and with the distance between them, cohesive soil*

For the case of counterforts walls, the effect of their length and the distance between them is similar. However, for certain cases, the influence of the counterfort wall length is smaller than that of the distance between counterforts walls (Figure 8).

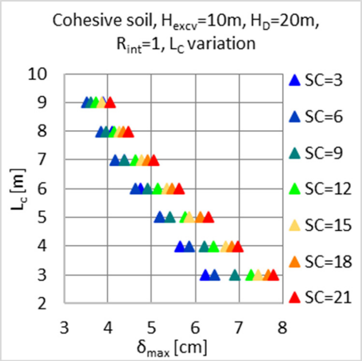

Figure 8 *Variation of the maximum counterforts walls displacements with buttress walls length and with the distance between them, cohesive soil*

CONCLUSIONS

These paper presents a parametric study regarding the buttress and counterforts walls behaviour, in which the excavation depth (H_{excv}), the length of buttress wall (L_B) or counterfort wall (L_C) and the distance between them (S_C, S_B) have been varied. Also, two types of soil have been used: cohesionless and cohesive.

For this study, the 3D finite element method has been used to perform the numerical calculus.

The results show the influence of the frictional resistance between the counterforts walls and the adjacent soil. Thus, the counterfort walls reduce the lateral displacements of the retaining system mainly through the frictional resistance between them and the adjacent soil, and less through the flexural rigidity of the system.

This type of auxiliary elements is more effective in cohesionless soil.

Both the length and the distance between buttress or counterforts walls have an effect on reducing the lateral displacements. Reducing the distance between auxiliary elements or increasing their length limit the lateral displacements of the retaining system.

Generally, increasing the buttress or counterforts walls length has a better effect in limiting the lateral displacements of the retaining system than decreasing the distance between them.

REFERENCES

Chen, S. L., Ho, C. T., Li, C. D., Gui, M. W. (2011) Efficiency of buttress walls in deep excavations, Journal of GeoEngineering, Volume 6, pp. 145-156, http://doi.org/10.6310/jog.2011.6(3).4.

Erginag, U. C., Ozden, G. (2017). A numerical study on counterfort and buttress type retaining walls, In: 3rd International Soil-Structure Interaction Symposium, Izmir, Turkey, pp. 444-453.

Hsieh, P. G., Ou, C. Y. (2018) Mechanism of buttress walls in restraining the wall deflection caused by deep excavation, Tunnelling and Underground Space Technology, Volume 82, pp. 542-553, http://doi.org/10.1016/j.tust.2018.09.004

Hsieh, P. G., Hsieh, W. H., Ou, C. Y., Chien, S. C. (2015). A study of the efficiency of excavations with the installation of buttress walls in reducing the wall deflection, In: The 15th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering, Fukuoka, Japan, pp. 1441-1446. http://doi.org/10.3208/jgssp.TWN-04

Ou, C. Y., Lin, Y. L., Hsieh, P. G. (2006) Case record of an excavation with cross walls and buttress walls, Journal of GeoEngineering, Volume 1, pp. 79-86, http://doi.org/10.6310/jog.2006.1(2).4.