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APPLICATION OF GROUND SPRING MODEL IN EXCAVATION SUPPORTED BY DEEP CEMENT MIXING

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ABSTRACT: An application of Deep Cement Mixing (DCM) as a retention system in deep excavation becomes gradually popular in very dense population areas because of less noise and environmental impact of the construction process than other systems. In addition, this new kind of retention system has various forms of utilization, which depend on the designer's experience and considerations. For better understanding of this system, full scaled test, down scaled physical model test, and numerical analysis are required to tackle the interested problem. To effectively discuss the behaviors observed from the full-scale numerical analysis and physical model test, the scaling factor must be seriously considered. However, it is difficult to scale down the properties of soft clay in the physical model test. Therefore, the soil and its lateral pressure transferred to the wall are modeled as a series of springs and lateral forces in the model, respectively. To ensure the effectiveness of this modeling, preliminary evaluation is necessary. In this study, a 2D plane strain Finite Element model of an excavation with the DCM retaining wall had been validated with field monitoring data, then the 2D model was compared to a 3D Finite Element model with a series of ground springs to take the lateral stiffness of the in-situ soil behind the wall into consideration. The results of this numerical investigation reveal that the ground spring model has sufficient accuracy to represent the lateral soil-structure interaction.

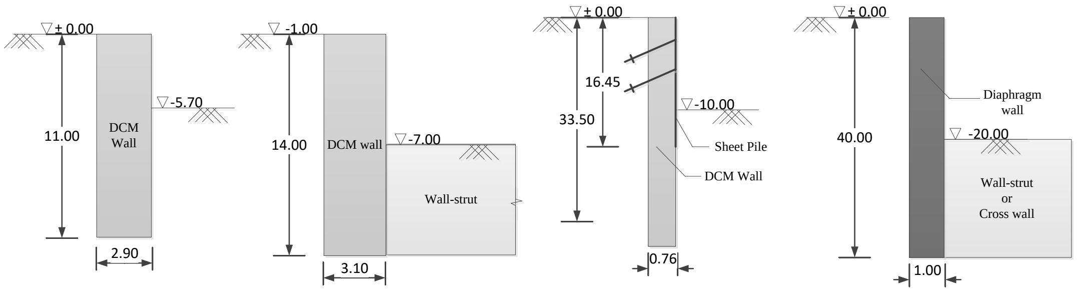
Keywords: Ground Spring Model, Excavation, Deep Cement Mixing, Retention system

1. INTRODUCTION

Since the demand of land utilization in the city becomes increasing with time, a large number of new buildings are commonly constructed with basement levels. During the excavation process, problem relevant to lateral movement is expectedly occurred. To control the excessive displacement that will affect to the adjacent structures, retaining wall is needed. The commonly used walls are either steel sheet pile, diaphragm wall, or contiguous pile wall.

Some of congested urban areas require extra conditions of construction method such as very low noise and vibrating [1]. Deep Cement Mixing wall, as an alternative of retaining structure is introduced to meet the requirements. There were several reports of case history using Deep Cement Mixing wall to support the excavation in various forms of applications, e.g., DCM wall without bracing [1], DCM wall with wall-strut [2], combination of DCM, sheet pile, and tie back supported excavation [3], and DCM cross walls installation with diaphragm wall [4] and shown in Fig. 1. Utilization of DCM in excavation were not only the support system, but also a ground improvement for soft soil in passive zone of an excavation [5]. However, they are still highly empirical in terms of analysis and design with several assumptions due to unclear understandings on DCM wall behavior. To fulfill this lack of knowledge, a series of numerical analysis, physical model test, and full-scale test are important to systematically tackle the problem. Despite that the full-scale test is the most reliable method to study the actual behaviors because the actual condition can be reproduced. The test expense is high and it is difficult to repeat the test with constant condition. While the physical model requires the complicated scaling down technique, it can control the circumstances and the interested parameters can be varied. To compensate the limitations of the full - scaled test, the study on DCM wall, thus focuses on the physical model test and numerical analysis.

In order to scale down the problem from the field for setting up the physical model in the laboratory, scaling law is the significant factor in the consideration. Because the test is to conduct under 1g condition, the properties of soft clay surrounding the wall cannot be correctly scaled down to meet the required values during the preparation if large scaling factor is considered. To solve this problem, set of springs is introduced to substitute the soil in the unexcavated side whereas point loads are represented as lateral loads of soil on the excavated side. Consequently, only the small scale DCM wall is to be prepared in the test. However, the continuously distributed pressures (both excavation and un-excavation sides) are discretely represented by numbers of springs and



a) DCM wall without bracing [1] b) DCM wall with wall-strut [2] c) DCM with tie-back sheet pile wall [3] d) Diaphragm wall with DCM Cross wall [4]

Fig. 1 Various patterns of DCM wall used in case histories.

point loads in the physical model tests. It is thus necessary to evaluate the effect of numbers of springs and point loads on the model accuracy. Moreover, the minimum require numbers of both springs and point loads are preferred to minimize the effort during the preparation and test. To achieve this, preliminary analysis of DCM wall excavation using ground spring model in comparison to conventional continuum mechanics is carried out in this study. In the analyses with ground spring model, numbers of springs and point loads are varied and the results are discussed with those from the finite element analysis on the basis of same excavation problem.

2. 2D NUMERICAL ANALYSIS OF THE REFERENCE CASE STUDY

The excavation with un-braced DCM wall was adopted to validate 2D numerical model used as a reference in this study. The excavation was constructed in Bangkok subsoil as shown in Fig.2 that the soil stratum consists of 2.5 m thick fill crust overlying 13.5 m thick soft clay. Stiff clay layer started at a level of -16.00 m with the thickness of 5 m. There is 1 m of clayey sand, sandwiched between the stiff clay layer and 12 m thick very stiff clay. The excavation was conducted to the maximum excavation depth and width of 5 m and 27 m, respectively. Three rows of 1 m in diameter deep cement columns were overlapped for the 2.8 m wide DCM block pattern wall with a depth of 15 m. The walls were installed by a jet grouting method with a cement content of 250 kg/m3 of soil to obtain the designed unconfined compressive strength of 1200 kPa at curing time of 28 days. During the construction process, horizontal movements along wall depth were observed by inclinometer for construction control and the validation.

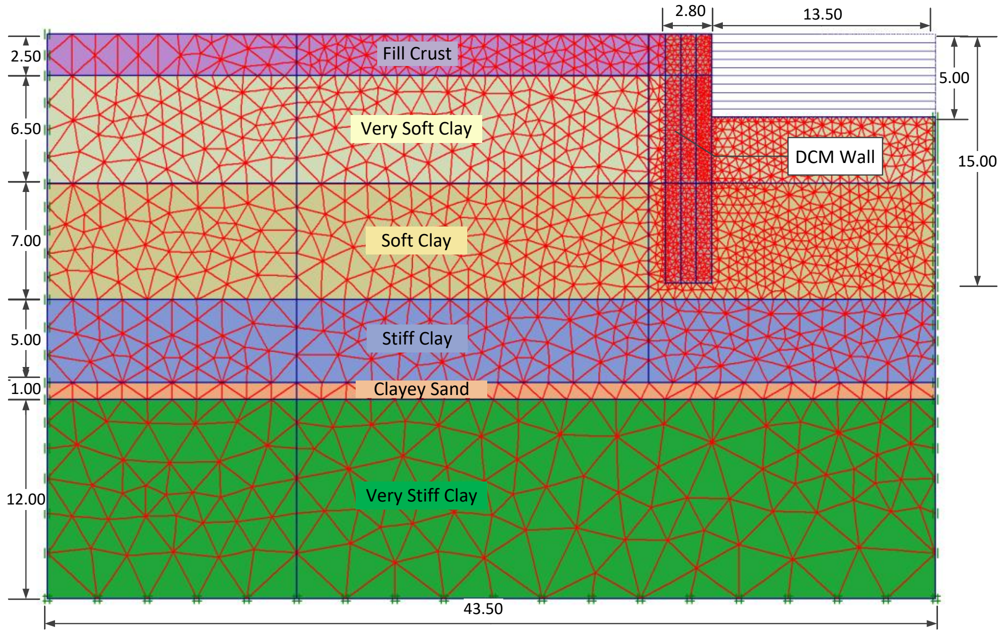


Fig. 2 Geometry and mesh of 2D plane strain model.

Table 1 Materials Properties

Materials	Model	c' kPa	ϕ deg	E_u MPa	E_{50}^{ref} MPa	E_{oed}^{ref} MPa	E_{ur}^{ref} MPa	$G_{\max}$ MPa	$\gamma_{0.7}$	υ_{ur}
DCM	MC	c_u=600	0	300						
Fill Crust	MC	c_u=60	0	42						
Very Soft Clay	HSS	1	21		7.2	7.2	36	72	1×10^{-3}	0.2
Soft Clay	HSS	1	22		12.2	12.2	48	75	8×10^{-4}	0.2
Stiff Clay	HSS	15	26		45	45	150	170	1×10^{-5}	0.2
Clayey Sand	MC	0	36	E'=80						
Very Stiff Clay	HSS	40	26		80	80	300	350	1×10^{-5}	0.2

Note: MC was stand for Mohr Coulomb Model, and HSS was Hardening Soil Model with Small Strain.
p_{ref} =100 kPa, and m=1for all materials using HSS.

Due to the symmetrical geometry of the excavation, half of the problem was modeled in plane strain condition using PLAXIS 2D software as shown in Fig. 2. The soil parameters were obtained from experimental and empirical data, listed in Table 1. Since the excavation was completed within less than 3 months, undrained analysis was used in the simulation. A retaining wall was classified as a small strain characteristic structure [6]. Numerical simulation of various cases of deep excavation in Bangkok subsoil revealed that the excavation simulation by using the Hardening soil model with small strain (HSS) provided high accurate results [7]. The HSS was thus adopted to represent the soft to stiff clay behaviors, while Mohr Coulomb model (MCM) was selected for fill crust, clayey sand and DCM wall. The excavation was simulated following the actual construction sequence. Figure 3 showed the comparison between analysis results and field observation of wall horizontal displacements occurred at the final level of excavation. It is seen from the figure that good prediction was provided in the validation, the analysis by 2D plane strain model together with the parameters used can reasonably use as a reference model.

3. 3D NUMERICAL ANALYSIS WITH GROUND SPRING MODEL

Although field case study is the most reliable method to study the structural behaviors, it cannot provide the failure state of excavation and vary the influence parameters. Therefore, the physical model test is preferable to overcome these limitations. In case that the test will be carried out in the laboratory under 1g condition, the scale down technique must be involved. Modeling of the studied problem is composed of DCM wall, surrounding clay layer, and earth pressure. Due to the fact that the height of wall in physical model is limited by the ceiling of the room and device capacity, the scaling factor must be large enough to scale down the actual 15 m high wall in laboratory test. The difficulties in the preparation of correctly scaled down clay layer thus occur. An idea of using set of springs and point loads instead of clay both sides of the scaled down wall was introduced and it is called as “ground spring model”. The set of springs and point loads are discretely applied on the wall. To do a feasibility study and ensure that this model can represent the excavation work, therefore the preliminary analysis of using the idea of ground spring model in excavation is performed.

The validated 2D model of field case study and input parameters in previous section were used as references in this analysis. ABAQUS program was utilized for a three dimensional analysis of a unit cell excavation. Mohr Coulomb Plasticity was employed for DCM wall properties.

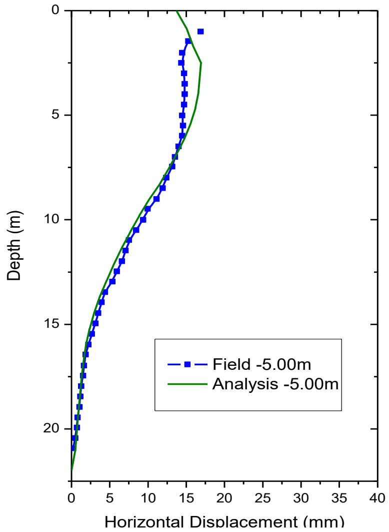
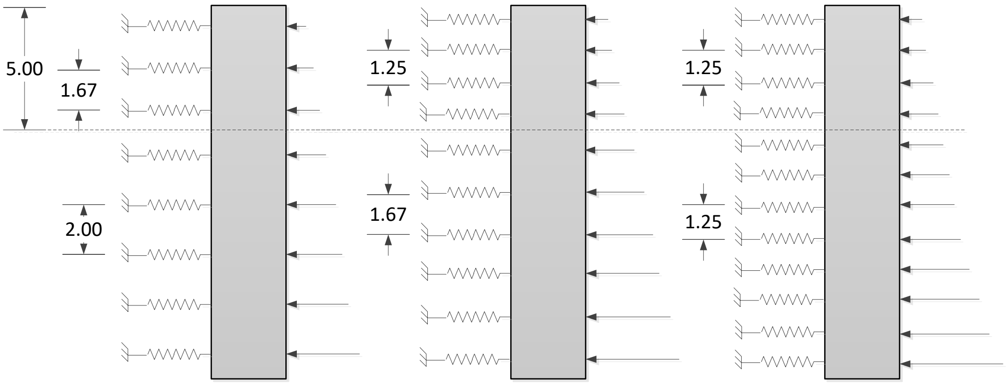


Fig. 3 Calibration of horizontal displacement



(a) (b) (c)

Fig. 4 Comparison of models in parametric study of spring quantities; (a) 8 springs case, (b) 10 springs case, and (c) 12 springs case.

To reduce complexities of the problem, the soil layers are simplified as homogeneous layer in both of 2D and 3D models. Set of point loads was calculated from earth pressure of soil, which were varied in each excavation sequence. In the same manner, stiffness of spring in Eq. (1) is depended on horizontal subgrade reaction value and interval length. Vesic's equation [8] was adopted for horizontal subgrade reaction calculation as shown in Eq. (2). Basis of horizontal subgrade reaction was applied in laterally loaded piles [9] and excavation [10]

$$K_h = k_{sh} \times B \times L \tag{1}$$

$$k_{sh} = \frac{0.65E_s}{B(1-\nu^2)} \sqrt[12]{\frac{E_s B^4}{E_w I_w}} \tag{2}$$

Which K_h : Horizontal stiffness of spring
k_{sh} : Horizontal subgrade reaction
B : Width of wall
L : Interval length of spring
E_s : Soil's elastic modulus
ν : Poisson's ratio of soil
E_w : Wall's elastic modulus
I_w : Wall's moment of inertia

The purposes of this analysis are not only to check the reliability of spring model but also to be a prototype in the down-scaled physical model test. Parametric study of spring quantities was thus conducted. Figure 4 shows a comparison of each case in the parametric study including modeling with 8 springs, 10 springs, and 12 springs. As the wall depth is kept constant, an interval length of springs is varied by number of springs. Three different interval lengths of springs including 1.25 m, 1.67 m, and 2 m, was considered in the models. Rigid plate was used to improve the interaction between springs or loads to DCM wall. Assembled model was shown in Fig. 5, composing of rigid plates tied with springs in the ground (unexcavation) side and rigid plates tied with point loads in the excavation side. Following to the construction sequences, each spring was removed to simulate an excavation of soil layer. The final level of excavation was located at 5 m from wall top.

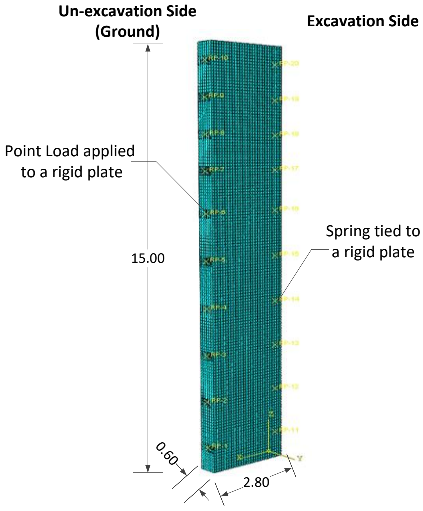


Fig. 5 Assembled model and mesh of 3D with ground spring model.

4. RESULTS

In this section, the analysis results from ground-spring model with different numbers of springs and point loads are compared together with that of the result from 2D plane strain continuum analysis. The results to be shown and discussed include horizontal displacement, principal and shear stresses. It is noted again that all analyses consider the same problem under homogeneous soil layer.

Horizontal displacement, a common parameter used in excavation monitoring, was shown in Fig. 6.

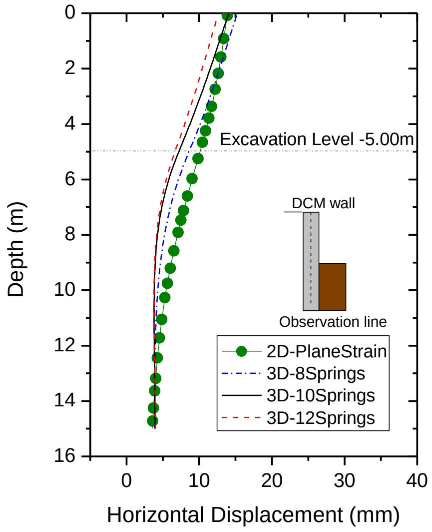


Fig. 6 Horizontal displacement results.

It is seen from the figure that all cases with ground spring model represent a good tendency with the reference 2D continuum analysis. Not only the shape of horizontal displacement profile that are resemble, the predicted values are also in the same order with results from 2D analysis. The maximum horizontal displacement occurred at the top and decreased with depth. The inflection point of the horizontal displacement profile of all cases appear at the depth of about 5 m which is the excavation level. Among three cases of ground-spring analyses, the horizontal displacement decreases with increasing number of springs. However, only drastic increase of horizontal displacement was observed when spring quantity was changed from 8 to 10. In contrast, insignificant change can be seen in the region below the excavation level when the number of springs increased from 10 to 12. This implies that 10 springs are sufficient, for this case study, to simulate the DCM wall excavation.

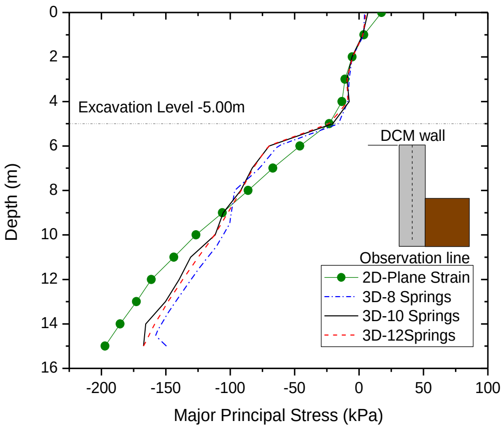


Fig. 7 Major principal stress at center of the wall.

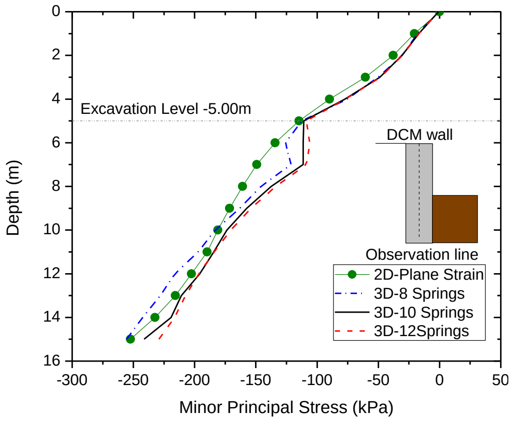


Fig. 8 Minor principal stress at center of the wall.

Considering at the center of wall thickness, the predicted major and minor principal stresses from three analysis cases by ground-spring model gave the same tendency with continuum analysis results as shown in Figs. 7-8. All analysis cases yield similar results, particularly for the depth located above the final excavation level. The results between 8 and 10 springs cases for the depth located below the excavation level was slightly different but almost the same value was obtained when increasing the number of spring from 10 to 12. This observation also suggests that the minimum required number of spring is 10. The maximum shear stress distribution along the wall height is shown in Fig. 9. The predicted results from all cases have good agreement to that from continuum analysis except those in the range of 5 m below excavation level. For the depth above excavation level, all cases gave nearly the same value. The results below the excavation level were much different from that of the continuum analysis. The predicted results by soil-spring model between using 10 and 12 springs were very close.

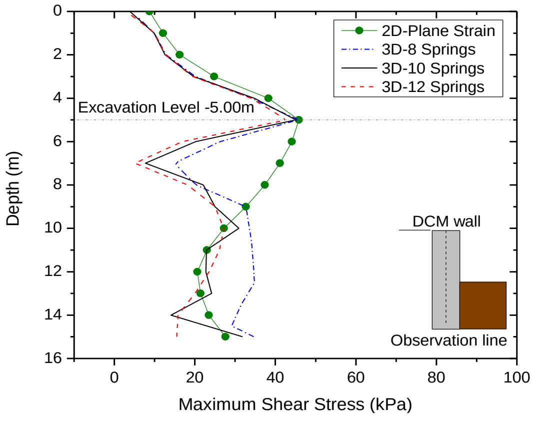


Fig. 9 Maximum shear stress at center of the wall.

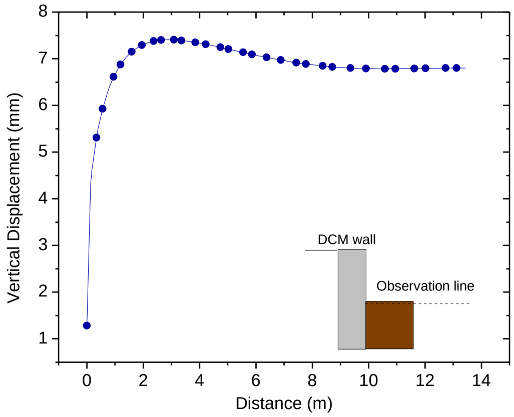


Fig. 10 Vertical displacement along excavation width from 2D continuum analysis.

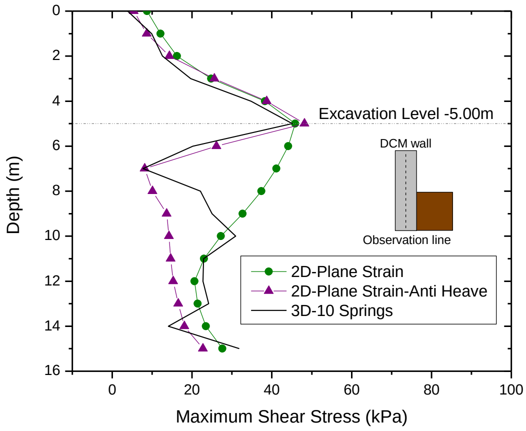


Fig. 11 Maximum shear stress at center of the wall and effect of soil heave.

Since the excavation process reduces overburden pressure, vertical displacement results of 2D plane strain analysis (Fig. 10) showed that soil heave occurred at the excavated side of the wall. Note that, the 3D model with soil-spring does not consider this effect. In real practice, some counter measures, such as concrete lean, are utilized to suppress this adverse effect. Reanalysis of 2D continuum model with applying the overburden pressure back to the excavated level was performed and the comparison was shown in Fig. 11. When soil heave was eliminated, the maximum shear stress decreases to the same way of the 3D model results. The investigation prove that, if the effect of soil heave was eliminated or sufficiently minimized, the ground spring model can capture the shear stress distribution in the DCM wall.

5. CONCLUSION

A case study of Deep Cement Mixing wall as a retaining structure in deep excavation work in Bangkok subsoil was numerically simulated under 2D plane strain assumption and 3D approach using ground-spring model. The 2D simulation was validated by field observation using the monitored horizontal displacement of the wall. Then the 2D simulation can be used as a reference case to verify the proposed analysis method using the ground - spring model. The model is composed of a set of springs representing the ground in front of the wall (excavated side) and a series of point loads representing the lateral ground pressure applied to the wall (unexcavated side). Analyses by varying number of springs were carried out and both stress and deformation were observed in the study. According to the investigated results, the ground-spring model can reasonably reproduce the stressed induced in the wall as well as wall deflection behavior. Notwithstanding, the reproduced stresses in the wall can be much altered if the soil heave at the excavation bottom occurred. Under the reference excavation case, the minimum required number of springs is 10.

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