An Application of Cutter Soil Mixing Cut-off Wall for Excavation in Wuhan

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Abstract

Diaphragm wall or Trench-cutting & Re-mixing Deep wall (TRD) directly embedded into the bedrock have been primarily adopted in Wuhan as a form of waterproof cut-off wall for excavations. However, the installation of diaphragm wall is expensive; the corners of TRD wall are vulnerable to seepage and the advantages of TRD method cannot be fully taken for an irregular cut-off wall involving more corners. This paper will discuss the constructability, quality and waterproof properties of a Cutter Soil Mixing (CSM) cut-off wall under high groundwater pressure through a case study of deep excavation for a medical complex construction in Wuhan. By investigating the technical scheme, construction method, costs and effect on the environment, CSM wall has been found to possess sound waterproof properties and can be installed in advance which will shorten the construction time. CSM wall is more cost-effective and environmentally-friendly than diaphragm wall or TRD wall and offers an new option for cut-off wall design in Wuhan.

Keywords: CSM cut-off wall, excavation, ground settlement

1 INTRODUCTION

The proposed medical complex of Tongji Hospital, Wuhan, will be composed of a main building, a podium and a two-level basement (Figure 1). The site with a perimeter of 365m will cover an area of 6600m2 and the excavation will be up to 11.5m deep and surrounded by a few existing buildings (Figure 2). The main challenge of this project would be how to contain any damaging effect on the surrounding environment due to the deep excavation under high groundwater pressure. The design for retaining wall and cut-off wall would be focused on, with limited budget, guaranteeing the stability of the retained soils and structures during the 1 year basement construction period and avoiding the occurrence of unacceptable amount of ground settlement due to rapid drop of groundwater table. The proposed cut-off wall should minimise the risk caused by ground settlement and reduce the amount of groundwater seepage to offer a dry site for basement construction. After comparing and analysing technical and economical data, a bored pile wall with 1 level of support would be adopted as retaining wall and CSM wall as cut-off wall located behind bored piles (Figure 3, Figure 4).

CSM is a relatively new method developed from Deep Soil Mixing (DSM). CSM wall is a cement reinforced wall composed of interconnected rectangular panels made by mechanical mixing of cement and soil. CSM has been used in projects involving high groundwater table in Tianjin and Shanghai in recent years since its introduction to China. This project is the first application of CSM in Wuhan.

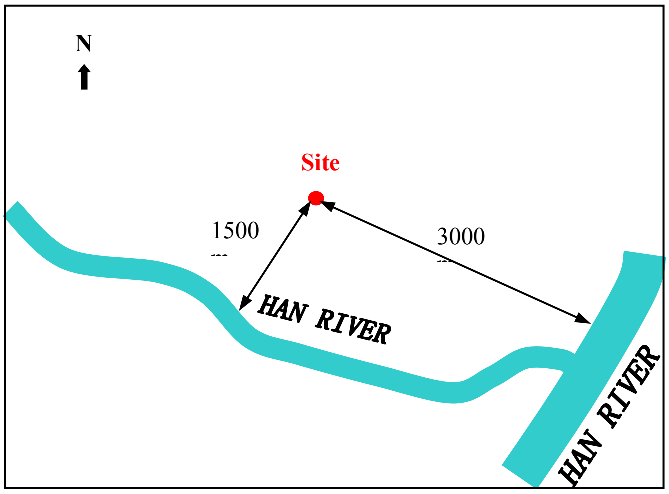

Figure 1. Location of the project

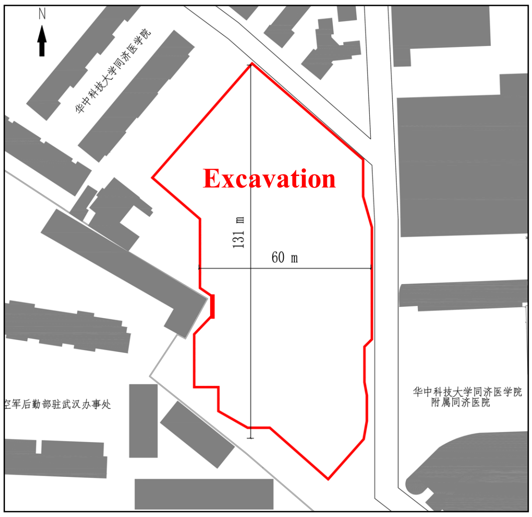

Figure 2. Site plan

2 ENGINEERING BACKGROUND

2.1 Soil

The site is located at the first terrace of Yangtze River. A geotechnical survey has found five soil layers and their geotechnical parameters are presented in Table 1.

Table 1. Geotechnical parameters of soil layers

	Natural Density γ [kN/m^3]	c′ [kPa]	ϕ' [°]	E_s [MPa]	k_h [m/s]	k_v [m/s]
Heterogeneous fill	18.5	10	8	4	8.0×10^{-6}	8.0×10^{-7}
Clay	19.3	16	8	4.5	6.0×10^{-10}	6.0×10^{-11}
Silty sands	19.0	6	25	11	1.0×10^{-4}	1.0×10^{-5}
Sand and Gravel	19.5	0	32	18	2.0×10^{-4}	2.0×10^{-5}
Mudstone bedrock	—	—	—	100	1.0×10^{-10}	1.0×10^{-11}

2.2 Groundwater

The site is located 1500m away from Han River and 3000m away from Yangtze River and the groundwater is closely related to two rivers. The groundwater table varies from 2 to 5 m below the ground level.

2.3 Surrounding Buildings

The project is located within a highly urbanised area and surrounded by a few buildings (lower than 7 storey) with shallow foundations (Figure 2). The effect on the existing buildings, substructures and roads caused by ground settlement due to drop of groundwater table must be fully considered.

3 CSM CUT-OFF WALL

According the local regulation, the ground and surrounding building settlement must be less than 30 mm and cut-off measures must be taken to prevent sharp change of groundwater table after excavation. In the past, there were successful examples using diaphragm wall or TRD wall. However, these methods would not be suitable for this project.

Although the excavation for 2-level basement would be only 11.5m deep, the diaphragm wall would be 50m deep in order to be embedded into the bedrock which would result in long construction period and high costs exceeding the budget. Furthermore, during installation of diaphragm wall, a large amount of mud would be produced and cause pollution.

TRD method would not be suitable either. 20 corners of the cut-off wall would make the installation very slow and seepage would occur in the overlapping sections. A 35m deep layer of sandy soil with gravel would reduce the efficiency of installation and extend construction period. Similarly, a large amount of mud generated during this process would be hazardous to the hospital.

Compared with the above mentioned cut-off walls, CSM method would be more suitable with following advantages:
- Soil would be mixed in site as construction material and not be moved out.
- The installation of CSM wall would be very adaptable and flexible for corners and the panels installed at different stages could be connected together smoothly.
- CSM could be used for various soil layers. Only a small amount of cement would be needed which would make the construction economical and sustainable.

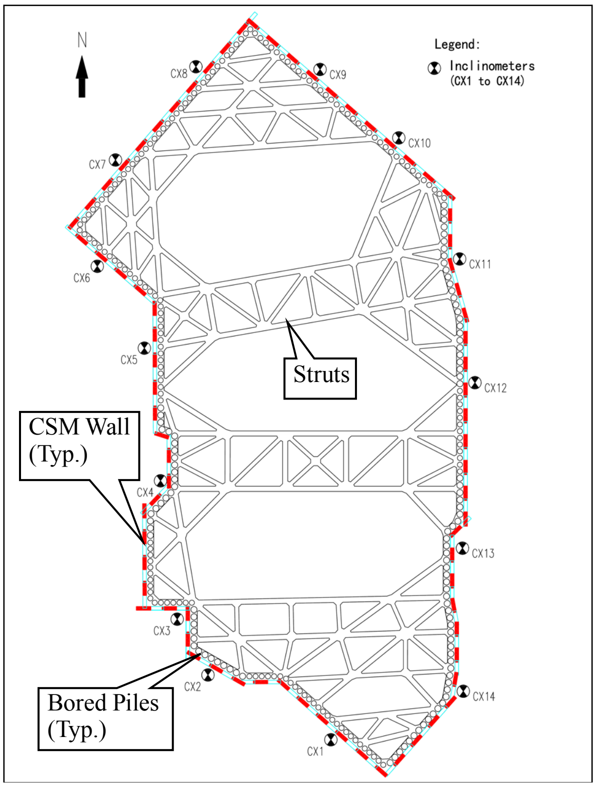

Figure 3. Plan of retaining and CSM walls

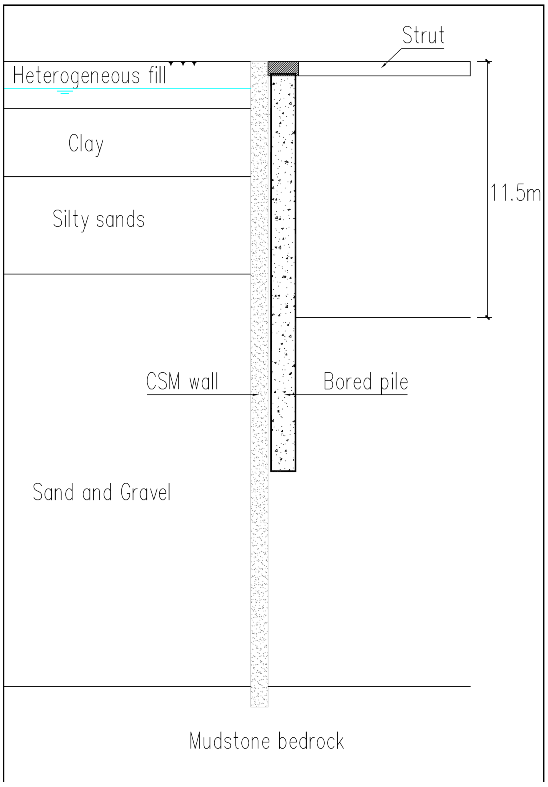

Figure 4. Typical section of excavation

4 ANALYSIS OF CSM WALL

The typical panel of CSM wall would be designed to be : 0.7m in thickness, 2.8m in width (0.3m overlapping for two adjacent panels), and 50m in depth with an embedded length of 1m (Figure 4). The maximum allowable vertical deviation would be 1/300. As the first CSM application in Wuhan, it would be difficult to achieve the ideal result as shown in Figure 5. For safety concerns, the worst case assuming the vertical deviation of two adjacent panels to exceed 1/300 in opposite direction would be analysed (Figure 6). For such a case, there would be a 4m high gap instead of a overlap at the bottom of two adjacent panels. The gap would be treated as a complete seepage (4m) to simplify the determination for the number of dewatering wells required to be set up inside the pit(Figure 7).

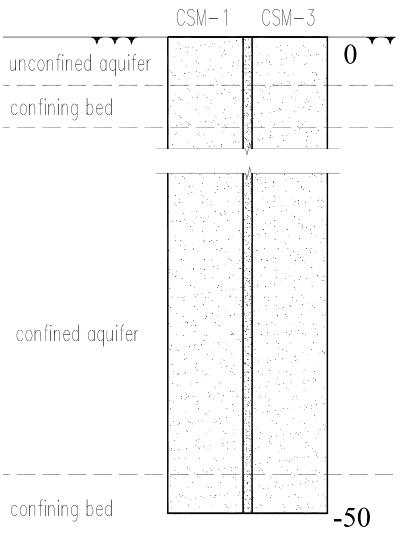

Figure 5. Ideal case

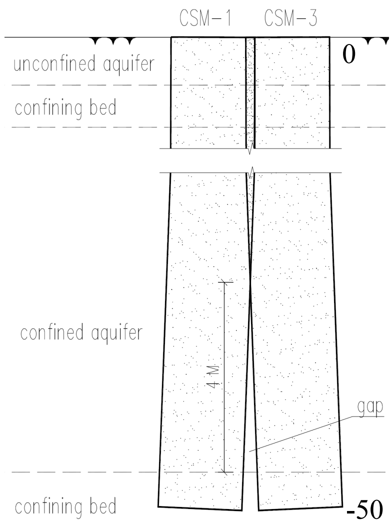

Figure 6. Worst case

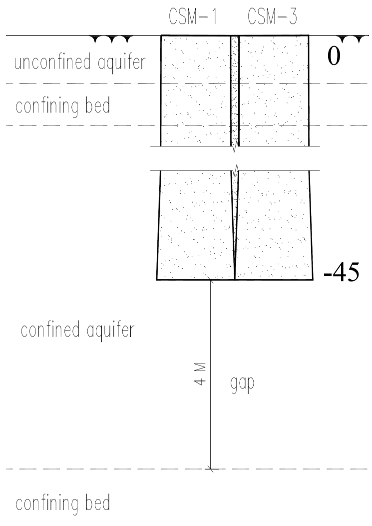

Figure 7. Simplified modelling

The analysis was simulated by Visual Modflow(Figure 8). The results show that for the worst case 7 pumps must be activated in order to lower the groundwater table to 1m below the bottom of the pit (i.e. -12.5) to provide a dry site. It can be seen (Figure 9) that the CSM wall increases the path of seepage to prevent groundwater table from sharp falling. By studying these results, it can be estimated that ground settlement caused by drop of groundwater table should be very small. CSM wall is effective for prevention of seepage and the occurrence of excessive ground settlement.

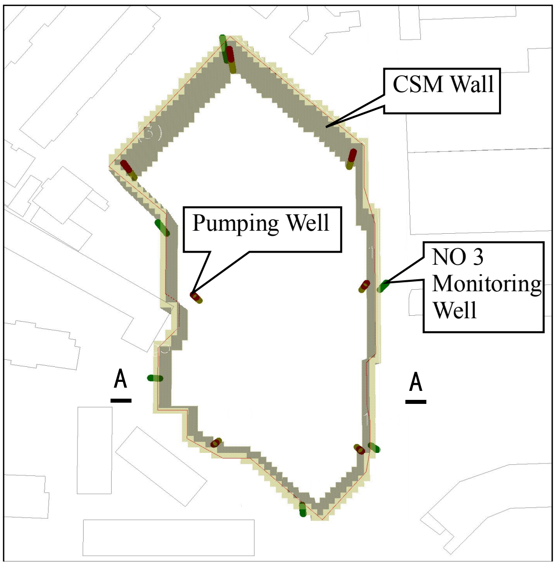

Figure 8. CSM wall plan

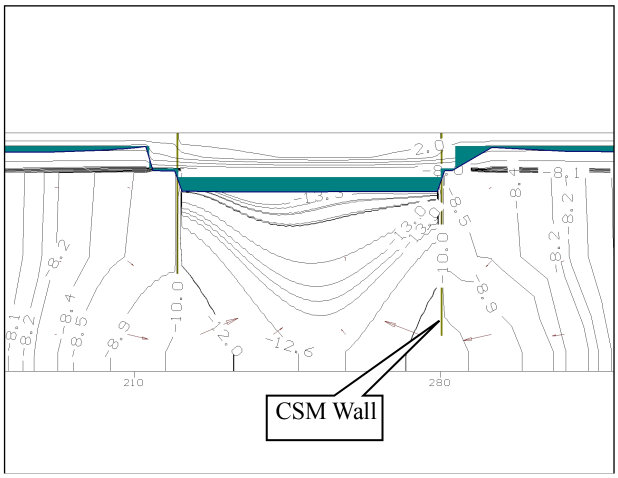

Figure 9. Contours of groundwater table for section A-A

5 CONSTRUCTION PROCESS

5.1 Trial Panel

As a new technology used in Wuhan for the first time, a trial panel was set up before the installation of CSM wall in order to evaluate the strength of the panel and parameters for mechanised construction. A trial panel was installed in the pit with following parameters: thickness 0.7m, width 2.8m, depth 50m, cement content 20% (wt%), water/cement ratio 1.5, maximum allowable vertical deviation 1/300 (Figure 10).

Figure 10. A trial CSM wall panel

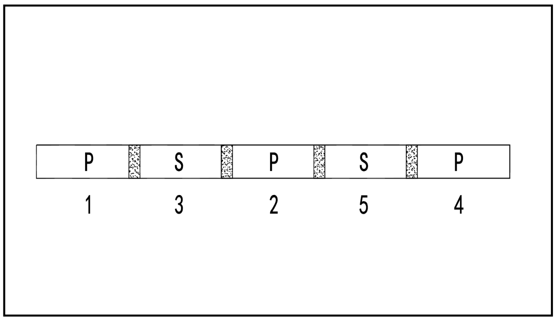

Figure 11. Construction procedure for a typical CSM wall section

5.2 Panel Test

After 28 days of curring, 6 samples were taken from the trial panel for compressive tests. Test results showed that the minimum value of strength was not less than 3.1MPa. If the safety factor was 2, the value of strength for design would be not less than 1.55MPa.

5.3 Formal Construction

Based on the parameters and test results obtained from panel test, cement content of CSM was finally set to be 18% (wt%) and other parameters were the same as those used for the trial panel. CSM wall was divided into 2.8m panels and the installation would be carried out following the procedure shown in Figure 11 with a overlap of 0.30 m between adjacent panels.

6 SITE MONITORING

6.1 Inclinometers

14 inclinometers were set up to monitor the lateral displacement of the retaining wall (Figure 3) and the maximum lateral displacement was 24mm which was below the allowable value specified by local standard. Figure 12 illustrates the monitored results for three typical points on west, north and east side respectively.

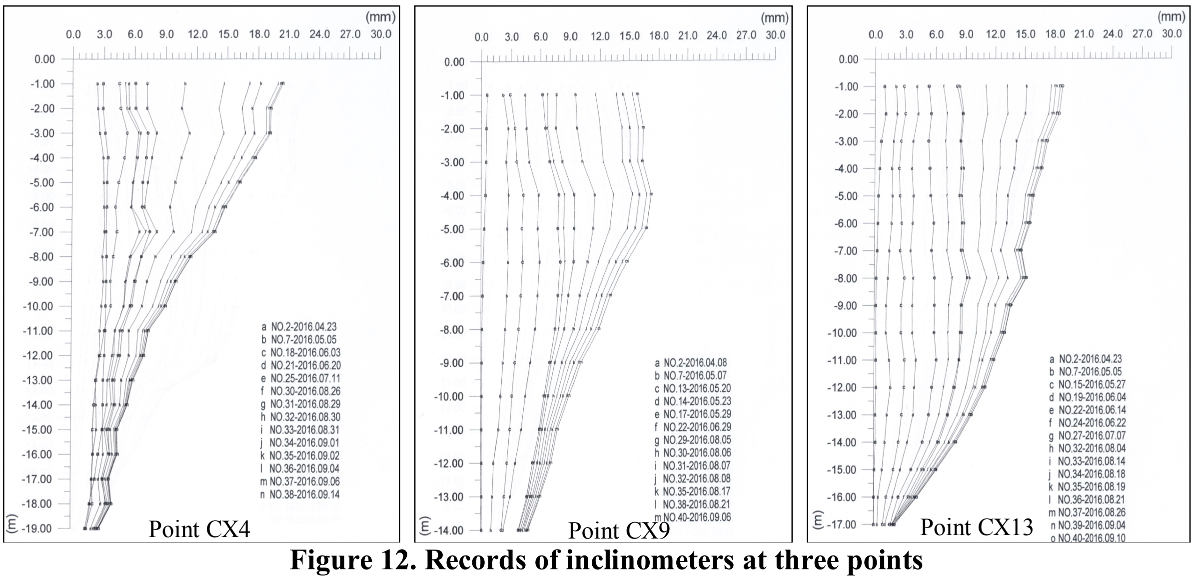

Figure 12. Records of inclinometers at three points

6.2 CSM Wall Strength

Samples were taken for 3 points from CSM wall after 28 days of curring. The compressive test results for 28 samples showed that the minimum strength was not less than 2.5 MPa. Even divided by a safety factor of 2, the actual strength was more than the standard value chosen for design (1.0 MPa).

6.3 Groundwater Monitoring

Groundwater monitoring was conducted for 6 months from the beginning of excavation to the completion of basement and the monitored results are shown in Figure 13. It can be seen that the groundwater tables at all monitoring wells except well No 3 were almost the same as the original values which mean seepage only occurred near well No 3. Even so, CSM wall had achieved cut-off effect as expected and the number of pumps actually activated was less than the proposed number for the worst case. CSM wall had minimized the amount of water pumped out and reduced ground settlement.

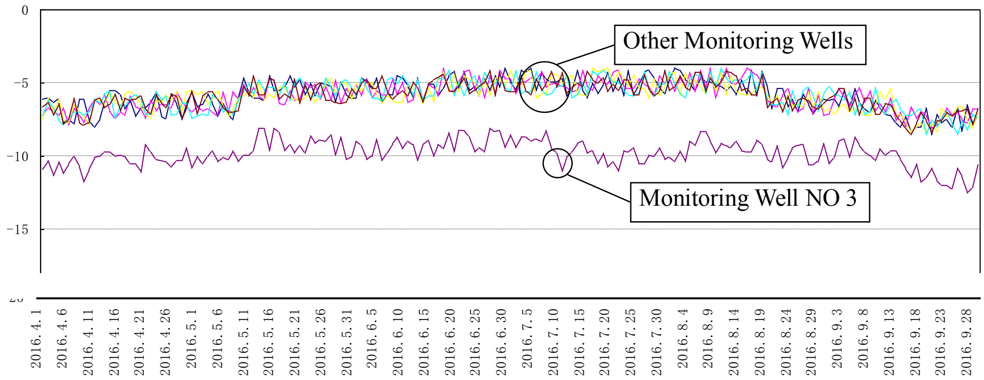

Figure 13.Groundwater tables monitored at three points

6.4 Ground Settlement Monitoring

The monitored results of building movement, ground and substructure settlement for adjacent buildings, roads and substructures indicated maximum settlement was 17mm. The maximum settlement near well No 3 at the east side where seepage occurred through CSM wall was 12mm. These results satisfied the requirement of the local standard and were acceptable.

7 COSTS

Table 2 shows comparison of costs for three types of cut-off wall. It has been found that, for the same depth, CSM wall is more economical than other types of cut-off wall and should be the best choice with limited budget.

Table 2.Comparison of costs for three types of cut-off wall

	Cement content [kg/m^3]	Concrete dosage [kg/m^3]	Costs [￥/m^3]
Diaphragm wall(0.8m thick)	/	2500	1400
TRD(0.8 m thick)	540(i.e. 30%)	/	1200
CSM(0.7m thick)	324(i.e. 18%)	/	900

8 CONCLUSIONS

CSM wall chosen for this project has technical, economic and environmental advantages. The application of CSM wall has minimized the effect of excavation on surrounding area. The amount of seepage occurring in the pit was small during excavation. The monitored results registered smaller drop of groundwater table and ground settlement. These results demonstrates that CSM is a better solution for cut-off effect.

CSM method can be widely used and is suitable for various types of soil. The quality and the homogeneity of CSM panel depend on several factors, particularly on overlapping width and the control of verticality. Therefore, quality control and monitoring are necessary. At the same time, as precautionary measures, certain number of dewatering wells must be set up and reserved for emergency in order to avoid groundwater inrush for the worst case, especially for the excavation projects involving complicated surrounding environment and excessive amount of groundwater. Based on the experience obtained from the application of CSM method in this project, CSM method has been successfully applied for a few similar projects in Wuhan (as an improvement, the maximum allowable vertical deviation is set to 1/400) and become a new choice with more advantages .

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