The application of composite soil nailing wall in China

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ABSTRACT

The soil nailing wall is a retaining structure widely used all over the world, while the composite soil nailing wall is a composite retaining structure developed on the basis of it, and it is so popular in China as to be used in thousands or more of foundation pit supporting projects each year. The composite soil nailing wall is made up of soil nailing wall and one or more type of the composite components such as ground anchor, cement-soil wall and mini pile, it could be applied to almost all kinds of soil, especially to soft soil layer. Like soil nailing wall, it gets many advantages such as rational construction, low cost, short construction period, convenient installation, simple mechanical equipment, etc. When ground anchor, cement-soil wall or mini pile works separately with soil nailing wall, it will form the three basic composite structures, and when two or three of them work together with soil nailing wall, the other four composite structures will be formed. The concepts, structural features, the overall stability check formulas of the seven structure types of the composite soil nailing wall, and a successful cases about foundation pit with the depth about 21 m are described in this paper.

Keywords: composite soil nailing wall, mini pile, cement-soil wall, ground anchor, overall stability check formula

1 INTRODUCTION

The soil nailing wall (SNW) is a retaining structure widely used all over the world, while composite soil nailing wall (CSNW) is a composite retaining structure developed on the basis of it. CSNW is made up of SNW and one or more type of the composite components such as ground anchor, cement-soil wall and mini pile, it could be applied to almost all kinds of soil, especially to soft soil layer. Like SNW, it gets many advantages such as rational construction, low cost, short construction period, convenient installation, simple mechanical equipment, etc., and it overcomes the most defects of SNW, greatly widens the application range of SNW technology. CSNW is so popular in China as to be used in thousands or more of foundation pit supporting projects each year, and application proportion is far more than soil nailing wall and the other foundation pit supporting technology.

2 CLASSIFICATION AND SUMMARY

CSNW is divided into seven types, as shown in the figure below. When ground anchor, cement-soil wall or mini pile works separately with SNW, it will form the three basic composite structures named as anchor composite soil nailing wall (ACSNW), cement-soil wall composite soil nailing wall (CCSNW) and mini pile composite soil nailing wall (MCSNW). When two or three of them work together with SNW, the other four composite structures will be formed.

Fig. 1 Seven types of the composite soil nailing wall
1-soil nail; 2-shotcrete layer; 3-ground anchor; 4-cement-soil wall; 5-mini pile.

In the composite components, cement-soil wall mainly refers to the deep mixing pile, sometimes is jet grouting pile; mini pile is mainly small diameter bored piles and the frame is steel or steel pipe pile, sometimes is prestressed pipe pile, SMW, etc. In generally, when the foundation pit is below the underground water level or the soil is weak, cement-soil wall will be applied to prevent the groundwater or to support in advance; and when the foundation pit is deeper or the soil is worse, mini pile will be applied to improve the shearing strength of the composite soil or to support in advance; and when foundation pit is deeper, anchor will be applied to reduce deformations of foundation pit. The
work performance of the mini pile-CCSNW like CCSNW with higher shear strength. The anchor doesn’t significantly effect total safety factor in general, so the work performance of the anchor-CCSNW mainly depends on the cement-soil wall, and anchor-MCSNW mainly depends on the mini pile. All composite components can be used under complex conditions.

3 OVERALL STABILITY CHECK FORMULA

3.1 The formula

There is a technical standard named Technical Code for Composite Soil Nailing Wall in Retaining and Protection of Excavation in China. CSNW should be overall stability checked by the code, brief figure and the formulas are shown below:

Fig. 2 The stability diagram for analysis and calculation of the composite soil nailing wall

\[ K_s = K_{so} + \eta_s K_{s1} + \eta_t K_{s2} + \eta_p K_{s3} + \eta_{sk} K_{s4} \]  
\[ K_{s0} = \frac{\sum c_i l_i + \sum W_i \cos \theta_i \tan \phi_i}{\sum W_i \sin \theta_i} \]  
\[ K_{s1} = \frac{\sum N_{i,j} \cos(\theta_i + \alpha_j) + \sum N_{i,j} \sin(\theta_i + \alpha_j) \tan \phi_i}{\sum W_i \sin \theta_i} \]  
\[ K_{s2} = \frac{\sum P_{i,j} \cos(\theta_i + \alpha_j) + \sum P_{i,j} \sin(\theta_i + \alpha_j) \tan \phi_i}{\sum W_i \sin \theta_i} \]  
\[ K_{s3} = \frac{\tau_{i} A_i}{\sum W_i \sin \theta_i} \]  
\[ K_{s4} = \frac{\tau_{i} A_i}{\sum W_i \sin \theta_i} \]

In the formula:
- \( K_s \)—overall safety factor, usually takes 1.25~1.35;
- \( K_{s0} \) —partial factor of resistance, it is the ratio of resisting moment and falling moment separately produced by soil, soil nail, ground anchor, cement-soil wall and mini pile;
- \( c_i, \phi_i \) —cohesion and internal frictional angle of the soil stripe on the assumed sliding surface;
- \( L_i \) — circular arc length of soil stripe on the assumed sliding surface;
- \( W_i \) —weight of the \( i \)th soil stripe, contains the soil weight and the additional load \( q \) on it;
- \( \theta_i \) —angle between surface normal and vertical plane on the midpoint of the assumed sliding surface of the \( i \)th soil stripe;
- \( \eta \) —reduction coefficient of the partial factor of resistance when soil nail, anchor, cement-soil wall and mini pile work together, its values should meet the following requirements: (a) \( \eta_1 = 1.0 \); (b) \( \eta_2 = 0.5 \)~0.7, the value is diminishing when \( P_{n,j} \) is increasing, anchor’s amount is rising, and the difference of material properties between anchor and soil nail is increasing; (c) \( \eta_3 = 0.3 \)~0.5, the value is related to craft, row numbers, ages, shear strength values and construction level of cement-soil wall, it is increasing as the cement-soil strength by different process more stable, less row numbers, longer age, better uniformity, etc.; (d) \( \eta_4 = 0.1 \)~0.3, the value is related to craft, row numbers, ages, construction level, and the position relationship between it and cement-soil wall, etc.;
- \( s_{i,j} \) —average distance of the \( i \)th soil nails, anchors or mini piles;
- \( P_{n,j} \) —pull-out resistance of the \( j \)th ground anchor in stable region(outside the assumed sliding surface);
- \( \alpha_j \) —angle of the \( j \)th soil nail or the \( j \)th anchor;
- \( \theta_j \) —angle between the arc tangent and horizontal plane on the intersect of assumed sliding surface with the \( j \)th soil nail or the \( j \)th anchor;
- \( \phi_j \) — internal frictional angle of the soil on the intersect of assumed sliding surface with the \( j \)th soil nail or the \( j \)th anchor;
- \( \tau_j \) —shear strength characteristic values of cement-soil on the intersect of assumed sliding surface with the cement-soil wall at the corresponding age, generally between 150~800kPa, while 150~400kPa in deep mixing pile;
- \( \tau \) —shear strength characteristic values of the mini pile on the intersect of assumed sliding surface with the mini pile at the corresponding age, it could be taken up the shearing strength characteristic values of all the materials of mini pile;
- \( A_i \) —sectional area of a single mini pile or of cement-soil wall within each calculation length;
- \( N_{n,j} \) —pull-out resistance of the \( j \)th soil nail in stable region(outside the assumed sliding surface), it should meet the requirements of formula and together.

\[ N_{n,j} \leq \pi d_i \sum l_i \]  

In the formula:
- \( d_i \) —anchoring diameter of the \( j \)th soil nail;
- \( q_{u,k} \) —characteristic values of the bond strength of the \( j \)th soil nail between soil and the anchoring length;
- \( l_i \) —length of the \( j \)th soil nail in the \( j \)th stable soil region(outside the assumed sliding surface).

\[ N_{n,j} \leq f_{j} A_j \]  

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In the formula:

\[ A_j \]—sectional area of rod body of the \( j \)th soil nail;
\[ f_{jy} \]—design value of tensile strength of rod body of the \( j \)th soil nail.

### 3.2 Some explanations for the formulas

Some simplifications and assumptions for formula are made according to the following rules because of convenience in study: (a) Failure mode is assumed as circular arc sliding surface; (b) The soil nails are the major force components; (c) The soil nails and anchors could be considered only tensile, cement-soil walls and mini piles only the shear, the other functions of components are ignored; (d) When destroying, soil nails and soil could give play to the roles of total resistance, but the composite components could only play a part, their resistance should be reduced according to certain rules; and component strength is higher, the more types and worse composite state, the reduction is greater; (e) The normal component and tangential component of anchor’s pull-out resistance could reach the limit value at the same time; (f) When slip plane is through the cement-soil wall or mini pile, it parallels to the normal section of the wall or pile; (g) The shear strength indexes of the soil and bond strength between soil and soil nail could be affected by groundwater; (h) The seismic action is regardless; (i) The safety factor is defined as the ratio of resisting moment and falling moment on the assumed sliding surface.

In fact, the most dangerous sliding surface shape can’t be determined in advance, it depends on the slope surface geometry, soil properties and the parameters of the soil nail, additional load and many other factors, and circular arc form is adopted mainly because it is most close to experimental results and engineering practice, and analysis and calculation is relatively easier. In some special cases, circular sliding mode may not be the best. Because mini pile, cement-soil wall and anchor is joining, the calculation errors are not great between the assumed sliding shapes such as circular arc, logarithmic line, spiral, or the other shape, and the errors could be accepted by the engineering.

In Technical Code for Composite Soil Nailing Wall in Retaining and Protection of Excavation, overturning failure mode, sliding failure mode, soil bearing capacity failure mode, and so on needn’t check for these failure modes may don’t occur.

### 4 A CASE

The foundation pit named Great Wall Shengshi Home Phase ii is located at DongguaLing in shenzhen city. It is roughly rectangular, the area is about 163m × 124m, there are litchi trees at north side of pit, and the other three sides are adjacent to the municipal roads and buildings, and there are municipal pipelines under the roads. The main soil layers are: (1) artificial filled soil; (2) quaternary swamp facies sedimentary organic matter silty clay; (3) quaternary pluvial slope silty clay; (4) quaternary salt in the diluvial coarse sand; (5) quaternary residual silty clay; (6–7) fully or heavy weathered sinian system granite gneiss. The embedded depth of groundwater table is 0.5~2.5m. The excavation depth of north side is 20.65m, the other three sides are 13.45~14.65m. The CSNW are designed as shown in the figures below.
The physico-mechanical parameters of main soil layers and bond strength between soil and soil nail are shown below. The diameter of soil nail is 100mm, the angel of soil nail is 10° and of the anchor is 15°, and the pull-out resistances of anchors are respectively 400kN, 600kN, 600kN and 600kN on north side and 480kN, 400kN, 400kN on the other side. The resistance of the deep mixing pile is ignored, and the mini pile takes I-steel shear strength.

<table>
<thead>
<tr>
<th>soil layers ID</th>
<th>thickness /m</th>
<th>Density γ/(kN·m$^{-3}$)</th>
<th>internal frictional angle φ/°</th>
<th>cohesion c/kPa</th>
<th>bond strength /kPa</th>
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<tr>
<td>(1)</td>
<td>0.6(4.8)</td>
<td>16.0</td>
<td>10</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>(2)</td>
<td>0(1.2)</td>
<td>17.8</td>
<td>8</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>(3)</td>
<td>5.7(0)</td>
<td>18.5</td>
<td>18</td>
<td>20</td>
<td>35</td>
</tr>
<tr>
<td>(4)</td>
<td>0(1.6)</td>
<td>18.9</td>
<td>25</td>
<td>0</td>
<td>80</td>
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<tr>
<td>(5)</td>
<td>7.6(5.4)</td>
<td>18.5</td>
<td>22</td>
<td>28</td>
<td>50</td>
</tr>
<tr>
<td>(6)</td>
<td>6.6(3.2)</td>
<td>19.0</td>
<td>25</td>
<td>35</td>
<td>60</td>
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<tr>
<td>(7)</td>
<td>/</td>
<td>21.0</td>
<td>30</td>
<td>60</td>
<td>100</td>
</tr>
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</table>

Note: The data outside () is on behalf of north side.

The calculation results by the formula 1 are like thus: on north side, $\eta_2=0.7$, $K_s=1.31$; on the other sides, $\eta_2=0.7$, $\eta_4=0.2$, $K_s=1.39$.

After the excavation and before backfilling, average horizontal displacement on north side is about 39mm and the maximum about 58mm, while the average settlement about 44mm; on the other sides, average horizontal displacement is about 53mm and the maximum about 69mm, while the average settlement about 74mm. Project is successful.

3) The overall stability analysis theory of the composite soil nailing wall has been almost mature, and it can be used to guide the engineering practice.

4) China has become the main market and the main driving force to developing the soil nailing wall technology at home and abroad, and in the future decades will continue to be so.

REFERENCES


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