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Research Article

A Practical Method for Calculating Soil Mixing Wall Retaining Structure by Means of a "Simple Beam Method"

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SMW is the abbreviation of soil mixing wall. H-type steel, also known as the new cement mixing pile wall, is inserted into the cement pile, which combines the bearing load with the impervious water retaining, and has the two functions of stress and impervious retaining wall of the supporting structure. In the design of conventional foundation pit engineering, the active Earth pressure calculated by Rankine's theory is not consistent with the engineering practice because the soil behind the retaining structure has not reached the limit equilibrium state. The embedded depth and the horizontal supporting force of the retaining structure are usually calculated with the equivalent beam method, but the method is complicated. Taking the supporting structure of a foundation pit called "soil mixing wall retaining wall and bolt" as a case, in this paper, the lateral pressure is used to calculate the active Earth pressure at any depth, and the "simple beam method" is used to calculate the embedded depth, the horizontal supporting force, and the internal force of the SMW continuous wall, which intends to find out the first and second supporting points as the pivots of the "simple beam method" under the most unfavorable conditions. When the first pivot is used as the supporting point of the "simple beam method," the soil pressure is ignored because it is within the critical depth of the Rankine active Earth pressure; while the second pivot is used as the supporting point of the "simple beam method," the forces on it are balanced to the torque of the second pivot, only considering the moment balance of the active and passive Earth pressure on the isolation body under the second pivot point. The results are in good agreement with the results of the equivalent beam method and the measured values, and they are much closer to the measured values, which provides a practical method for designing SMW retaining structures.

1. Introduction

The SMW retaining wall pile, namely, the shaped-steel cement mixing pile, inserts the H-beam into the cement soil mixing pile, increasing the bending and shear resistance of the cement soil mixing pile, thus improving the retaining and antipenetration ability of the SMW retaining wall. It possesses the advantages of simple structure, good sealing performance, short construction period, low cost, and low environmental pollution and is widely used among the various types of foundation pit engineering at present [1–3]. Regarding the mechanical properties of SMW pit enclosure structure, scholars have conducted a lot of research studies on the mechanical properties of cement piles [4–10], the joint action mechanism of steel and cement [10–13], field observations [14–17], design calculation methods [18–20], etc., showing that SMW pit enclosure structure makes full use of the stiffness and strength of steel to control deformation and resist shear. At the same time, the steel sections and the cement work together to utilize the strength and stiffness of the cement, which makes the SMW pit enclosure structure economically effective in the project. The results of a laboratory study conducted by Suzuki and Kokuto [21] using cemented soil materials in the SMW method showed that under the condition of equal injection of cement, the less water content in the cemented soil and the greater sand content in the cemented soil could increase the compressive strength of the cemented soil, while the increase of sand content made the water permeability of the cemented soil larger. The experimental results were applied to the regression analysis in the statistical analysis method to obtain the empirical formula. Wang et al. [22] considered the contribution of cement stiffness in the design calculation of SMW walls, derived the formula for the stiffness of steel-cement combination, and conducted flexural tests on the test elements composed of steel and cement to analyze the data obtained. Naito et al. [23] concluded that the shear stress transfer between H-beam and cement in the SMW method was not continuous and complete. In contrast, Ding et al. [24] previously analyzed the force mechanism of a circular working well constructed by the SMW method under the action of top force, proposed that the vertical and circular reaction force distribution of the soil behind the load-bearing semicircle is proposed to be normally distributed, and obtained the calculation formula that the soil behind can withstand the extreme value of the soil reaction force. Chai et al. [25] obtained the calculation formula of the lateral displacement caused by deep mixing pile based on the theory of a circular hole expansion equation for calculating the lateral displacement caused by construction. However, due to the fact that the retaining wall is a mixture of cement-stabilized soil and steel structure, people still hold different opinions on its assumptions, models, and selection of parameters.

At present, the Earth pressure of retaining structure is calculated by the Rankine Earth pressure [26], while the Rankine Earth pressure is the lateral pressure when the soil reaches the limit equilibrium state. In the actual foundation pit, the retaining structure does not allow the excessive displacement, and the soil does not reach the limit equilibrium state. It is not in conformity with the engineering practice to calculate the active Earth pressure by the Rankine theory. The embedded depth and the horizontal supporting force of the retaining structure are usually calculated with the equivalent beam method [27], but the method is complicated. The calculation of the horizontal support force in Technical Specification for Retaining and Protection of Building Foundation Excavations [28, 29] needs the detection of the horizontal displacement values at the supporting point in the field; however, it is difficult to get the measured value when the retaining structure is initially designed.

This paper provides a practical computational method called the "simple beam method," which calculates the active Earth pressure at any depth by means of the lateral pressure. Calculation of the embedment depth, the horizontal support force, and the internal force of the SMW retaining wall using the "simple beam method" for the "SMW retaining wall + anchor"

2. The General Situation of a Foundation Pit Supporting Structure and Computational Methods

2.1. The General Situation of a Foundation Pit Supporting Structure. A foundation pit of a building with the plane size 80 m × 100 m and its ground formation conditions are shown in Figure 1. The pit was excavated to a depth of 9.0 m and was supported by a SMW retaining wall plus two rows of retrievable anchors. The setting depth of the two rows of recoverable bolts is −1.5 m and −5.0 m, respectively, and the ground load is 10 kPa. The working conditions of the foundation pit are as follows: the first is to dig to −2.0 m (constructing the first row of bolt); the second is to dig to −5.5 m (constructing the second row of bolt), and the third is to dig to the bottom of the foundation pit, that is, −9.0 m. The basic physical parameters of the soil layers are indicated in Table 1.

The design of SMW retaining wall (that is, inserting the H-beam into the cement soil mixing pile) is as follows: H-beam is H—482 × 300 × 11 × 15, the spacing is @ = 0.45 m, the cross-sectional area is $A = 146.4\,\text{cm}^2$ per stick, the section modulus is $Wx = 2520\,\text{cm}^3$ per stick, moment of inertia is $Ix = 60800\,\text{cm}^4$ per stick, the radius of gyration is $ix = 20.4$ cm per stick. $[\sigma_b] = 215\text{MPa}$, $[\tau] = 125\text{MPa}$.

2.2. The Calculation of Earth Pressure. The lateral pressure is used to calculate the soil pressure. The value of the lateral pressure coefficient of silty clay is $K = 0.3$, and the value of the lateral pressure coefficient of gravel mixed clay is $K = 0.4$.

On the ground,

$$e_a = 10 \times 0.3 = 3.0\,\text{kPa}. \quad (1)$$

At −2.45 m,

$$e_a = (10 + 17 \times 2.45) \times 0.3 = 15.5\,\text{kPa}. \quad (2)$$

At −6.55 m,

$$\begin{aligned} e_a^{\text{upper}} &= (10 + 17 \times 2.45 + 18 \times 4.1) \times 0.3 = 37.6\,\text{kPa}, \\ e_a^{\text{under}} &= (10 + 17 \times 2.45 + 18 \times 4.1) \times 0.4 = 50.2\,\text{kPa}. \end{aligned} \quad (3)$$

At −9.0 m,

$$e_a = (10 + 17 \times 2.45 + 18 \times 4.1 + 19 \times 2.45) \times 0.4 = 68.8\,\text{kPa}. \quad (4)$$

The Earth pressure at −1.5 m, −2.45 m, −5.0 m, −6.55 m, and −9.0 m is calculated by Rankine Earth pressure, as shown in Figure 2.

The PL-TY25 type vibrating wire Earth pressure gauge is used, and it is buried at depths of −1.5 m, −2.45 m, −5.0 m, −6.55 m, and −9.0 m, respectively. The test results are also shown in Figure 2.

As shown in Figure 2, the Rankine active Earth pressure is negative value when it is above the critical depth, and the three kinds of soil pressures increase with the depth, but the calculating results of the lateral pressure are much closer to the measured Earth pressure, indicating that it is feasible to use the lateral pressure to calculate the active Earth pressure. In order to simplify the calculation, the lateral pressure distribution is assumed as Figure 3, and the active Earth pressure is as follows:

$$e_a = 3.0 + 6z\,(\text{kP}_\text{a}). \quad (5)$$

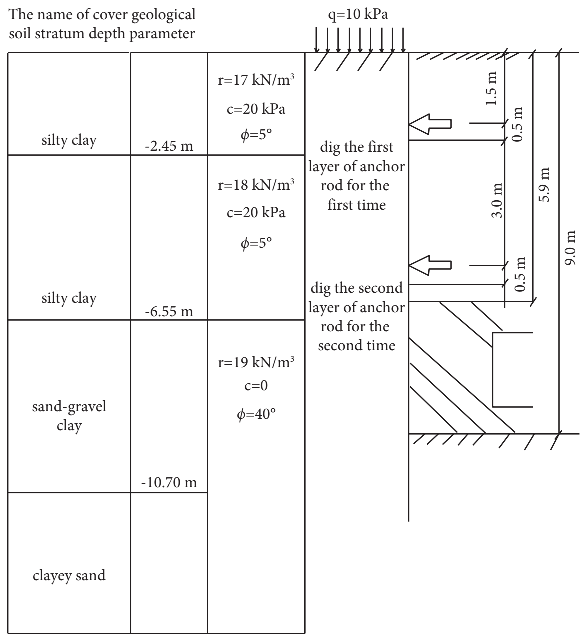

Figure 1: Engineering geological section of foundation pit.

Table 1: .Indicators of basic physical parameters of soil layers.

Name	Thickness (m)	γ $(\mathrm{kN{\cdot}m^{-3}})$	c (kPa)	φ (°)
Powdery clay	2.45	17.0	20	5
Powdery clay	4.10	18.0	20	5
Sand- and gravel-mixed clay	4.15	19.0	0	40
Cohesive gravel		19.0	0	35

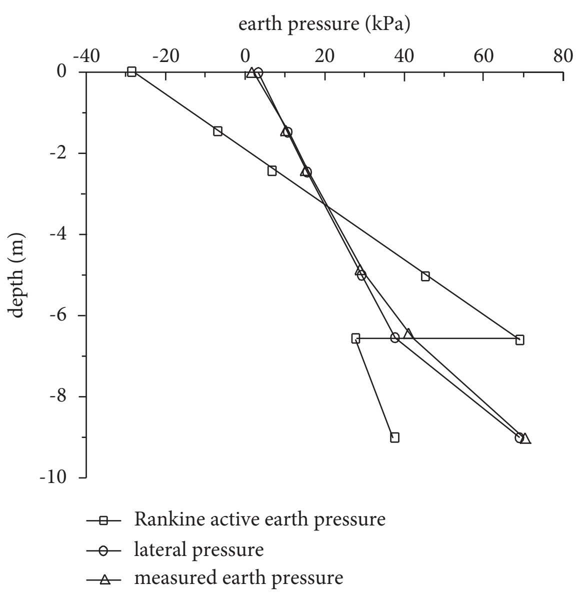

Figure 2: Soil pressure variation with depth.

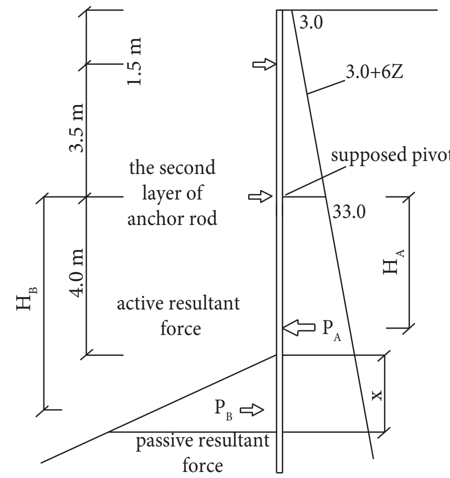

Figure 3: Schematic diagram of retaining wall 1.

2.3. The Computational Method of "Simple Beam Method". When calculating the embedded depth of SMW retaining wall, the supporting force of anchor, and the internal force of retaining wall, the action points of two rows of anchors are taken as the supporting points, respectively. When the first pivot is used as the supporting points of the "simple beam method," the active Earth pressure is ignored (which is above the critical depth of Rankine's main Earth pressure). When the second pivot is used as the supporting points of the "simple beam method" (center of gyration), the active Earth pressure and the first supporting force balance the moment of the second fulcrum, and only the equilibrium of moments of isolation under the second fulcrum is considered. The SMW retaining wall is taken 1 meter wide along the longitudinal direction to carry out the calculation.

3. Calculation of Embedded Depth

When excavating to the bottom of the foundation pit, the moment equilibrium of the active and passive Earth pressure acting on the lower end of the diaphragm wall at the second supporting point is obtained, as shown in Figure 3, that is, $P_A \times H_A = P_B \times H_B$

$$
\begin{aligned}
H_A &= \frac{33.0 + 2 \times [3.0 + 6 \times (9.0 + x)]}{33 + [3 + 6(9.0 + x)]} \times \frac{x + 4.0}{3} m, \\
P_A &= \left(\frac{\{33.0 + [3.0 + 6(9.0 + x)]\} \times (x + 4.0)}{2} \right) \left(\frac{kN}{m} \right), \\
H_B &= 4.0 + \frac{2}{3} x, \\
P_B &= \frac{1}{2} x \left\{ 19x \times tg^2 \left(45^0 + \frac{40^0}{2} \right) \right\} \\
&= 43.7x^2.
\end{aligned} \tag{6}
$$

The answer is $x = 2.2$ m; considering safety reserves, we suppose that $X = 2.2$ m; $D = 1.2x = 1.2 \times 2.2 = 2.64$ m.

Therefore, the total length of embedded depth of SMW retaining wall (including H-beam) is as follows: $9.0 + 2.64 = 11.64$ m. When taking integer, it is 12 m.

Using the equivalent beam method, the computational result of embedded depth of SMW retaining wall is 12.5 m (the process is omitted).

4. Calculation of the Sustaining Power of an Anchor Rod

4.1. Reaction Force of the First Layer of an Anchor Rod. When it is dug to −5.5 m in the second working condition, the bolt at the first layer is in the most unfavorable situation and counterforce at the pivot point is the largest. The calculation of the isolation under the first pivot and the moment balance of the main and passive Earth pressure at the first pivot is shown in Figure 4. The calculating processes are as follows:

$$\begin{aligned}
H_A P_A &= H_{B1} P_{B1} + H_{B2} P_{B2},\\
H_A &= \frac{12 + 2 \times (6x + 36)}{6x + 36 + 12} \times \frac{4.0 + x}{3} m,\\
P_A &= (12 + 6x + 36) \times \left(\frac{4.0 + x}{2}\right)\left(\frac{kN}{m}\right),\\
H_{B1} &= 4.56\, m,\\
P_{B1} &= \left(\frac{57.64\, kN}{m}\right),\\
H_{B2} &= \frac{2 \times (87.4x - 4.83)}{87.4x - 4.83} \times \frac{x - 1.05}{3} + 5.05\, m,\\
P_{B2} &= \left(\frac{(87.4x - 4.83) \times (x - 1.05)}{2}\right)\left(\frac{kN}{m}\right),
\end{aligned} \tag{7}$$

$$x^3 + 4.8x^2 - 12.2x - 3.0 = 0.$$

The answer is $x = 2.01$ m; therefore, the point of resultant force of passive Earth pressure is at 5.21 m.

The point of resultant force of passive Earth pressure and the first anchor point are supposed to be the supporting points of the "simple beam method" in the excavation stage, as shown in Figure 5. The reaction force of the anchor point at the first layer R_A is as follows:

$$\begin{aligned}
R_A &= \frac{1}{2}\left(e_{a1} + e_{a2}\right) \bullet \frac{b(l - a)}{l} - \frac{1}{6}\left(e_{a1} + 2e_{a2}\right)\frac{b^2}{l}\\
&= \frac{1}{2} \times (12.0 + 36.0) \times \frac{4.0 \times 5.21}{5.21} - \frac{1}{6} \times (12.0 + 2 \times 36.0) \times \frac{4.0^2}{5.21}\\
&= \frac{53.0\,\mathrm{kN}}{m}.
\end{aligned} \tag{8}$$

4.2. Reaction Force of the Second Layer of an Anchor Rod. When it was excavated to the bottom of the pit −9.0 m, the bolt at the second layer is in the most unfavorable situation and counterforce at the pivot point is the largest. With the abovementioned point, the point of resultant force of passive Earth pressure in the wall is obtained, which is used as a hypothetical fulcrum, as shown in Figure 6. The reaction force of the anchor point at the second layer R_A is as follows:

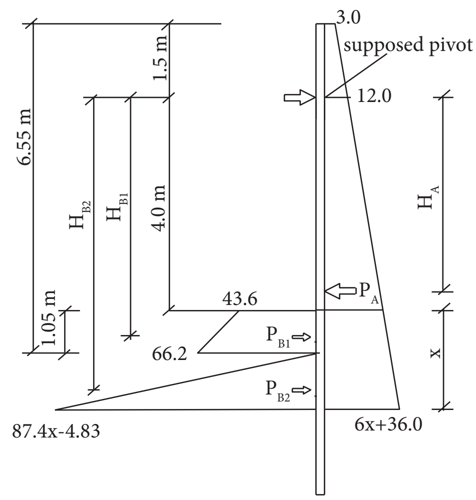

FIGURE 4: Schematic diagram of retaining wall 2.

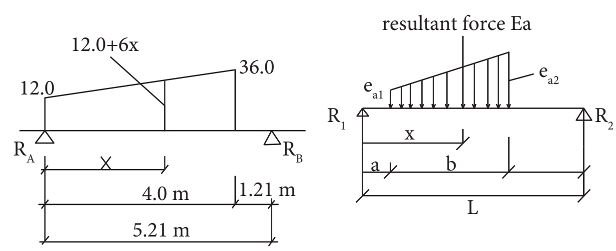

FIGURE 5: A schematic diagram of the force of "simple beam method 1."

$$R_A = \frac{1}{2}(33.0 + 57.0) \bullet \frac{4.0 \times 5.68}{5.68} - \frac{1}{6}(33.0 + 2 \times 57.0) \bullet \frac{4^2}{5.68} = \frac{111.2\,\text{kN}}{m}. \quad (9)$$

4.3. Calculation of an Anchor Rod. The computational process of the length of anchor rods is omitted. The length of the first anchor rod at first layer is 11.5 m, and the length of the second anchor rod at second layer is 9.5 m.

The design of the anchor force is as follows:

$$T = \frac{RS}{\cos\theta}. \quad (10)$$

In the abovementioned formula, R represents the reaction force at the supporting point, and its unit is kN/m; s represents anchor spacing; θ represents construction angles and it meets the conditions $\theta \le 15^0$.

The anchor rods cannot be set too densely due to the pile group effect. The anchor spacing at first and second layers S is the integral multiple of the anchor spacing, that is, $s = 450 \times 8 = 3600$; the value of the angle θ is 15°, and the diameter of the anchorage is $D = 135$ mm. The design of load is as follows:

The first layer is as follows:

$$T_1 = \frac{R_1 s}{\cos\theta_1} = \frac{53.0 \times 3.6}{\cos 15^0} = \frac{197.5\,\text{kN}}{\text{anchor}}, \quad (11)$$

the second layer is as follows:

$$T_2 = \frac{R_2 s}{\cos\theta_2} = \frac{111.2 \times 3.6}{\cos 15^0} = \frac{414.4\,\text{kN}}{\text{anchor}}. \quad (12)$$

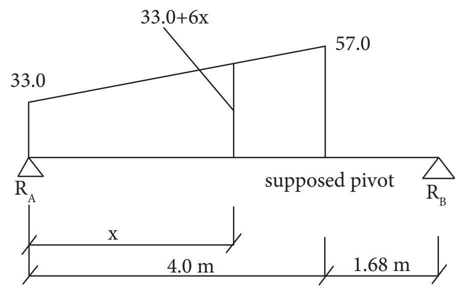

Figure 6: A schematic diagram of the force of "simple beam method 2."

Table 2: Contrast table of three methods of anchor point counter force.

Calculated value and measured value	Equivalent beam method	Simple beam method	*Ultimate uplift test of anchor rod*	
Reaction force of the anchor rod	(kN/m)	(kN/m)	(kN/anchor)	(kN/m)
Reaction force of the first layer of anchor rod	51.4	53.0	201.0	53.9
Reaction force of the second layer of anchor rod	98.2	111.2	420.3	112.8

4.4. A Comparison of Three Methods of Reaction Force of Anchor Points. The equivalent beam method is used to calculate the counterforce of the first and second anchor pivots, which are 51.35 kN/m and 98.15 kN/m, respectively. *Detection of Pulling resistance of Anchor.* Three anchor rods are selected to do the pulling resistance test from anchor rods at the first and second layers, and the ultimate bearing capacity of the anchor is measured. The standard value of the ultimate uplift bearing capacity of the bolts is recommended for the average of 3 test values when the extreme difference of the ultimate uplift bearing capacity is not more than 30% of the average. The ultimate uplift bearing capacity of anchors at first and second layers are 201.0 kN/root and 420.3 kN/root, respectively. Table 2 shows the comparison of the counterforce at the supporting points at first and second layers under the equivalent beam method, the simple beam method, and the test value of field uplift force (Table 2).

After comparing with the three methods mentioned above, it can be obtained that the results are close to each other, especially the results calculated by the "simple beam method," which are much closer to the measured values.

5. Calculation of Internal Force of SMW Continuous Wall

After the basement construction is finished (which is at 5.9 m underground) and the two layers of anchor rods are removed and dug to the bottom of the pit, the internal force of the continuous wall is the largest, the continuous wall at 5.9 m underground is in the state of cantilever beam, and the calculation of the internal force of the SMW continuous wall is shown in Figures 7 and 8.

The height of lateral resultant force point is as follows:

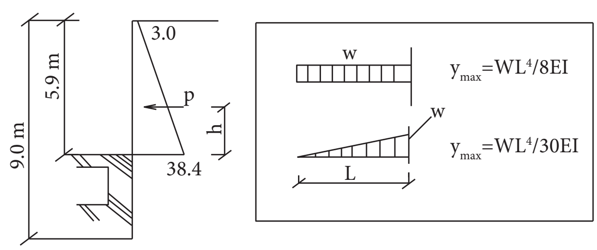

Figure 7: A schematic diagram of internal force calculation for SMW continuous wall.

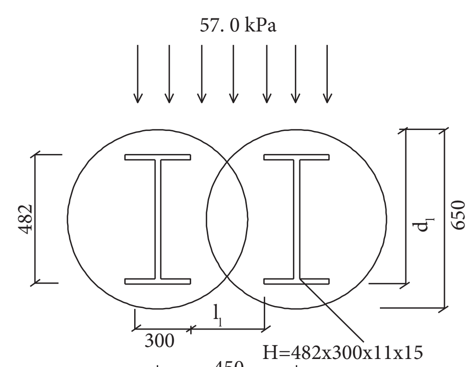

Figure 8: Schematic diagram of cement soil accounting.

$$h = \frac{3 \times 2 + 38.4}{3 + 38.4} \times \frac{5.9}{3} = 2.11\,m. \tag{13}$$

The lateral resultant force is as follows:

$$Ea = \frac{(3 + 38.4) \times 5.9}{2} = \frac{122.1\,\text{kN}}{m},$$
$$M_{\max} = E_a h = \frac{257.6\,\text{kN}\bullet m}{m}, \tag{14}$$
$$Q_{\max} = \frac{122.1\,\text{kN}}{m}$$
$$\delta = \frac{3 \times 5.9^4}{8\,EI} + \frac{(38.4 - 3) \times 5.9^4}{30\,EI} = 6.64\,mm.$$

The spacing of core material is 0.45 m, and sectional area is $A = 146.4\,\text{cm}^2$ per stick, and the modulus of section is $Wx = 2520\ \text{cm}^3$ per stick, and the radius of gyration is $ix = 20.4\,\text{cm}$ per stick.

5.1. Internal Force Accounting. The maximum internal force of each core material is as follows:

$$M_{\max} = 257.6 \times 0.45 = 115.9\,\text{KN} \cdot m,$$
$$Q_{\max} = 122.1 \times 0.45 = 55.0\,KN. \tag{15}$$

The deflection is shown as follows:

$$\sigma_b = \frac{M_{\max}}{W_x} = \frac{115.9 \times 10^3}{2.52X10^{-3}} = 46\,\text{MPa} \le [\sigma_b] = 215\,\text{MPa}. \tag{16}$$

5.2. Cement Stabilized Soil Accounting. Maximum excavation depth is 9.0 m, and the largest Earth pressure of the site is as follows:

$$Pa = 3 + 6 \times 9.0 = \frac{57\,\text{kN}}{m^2}. \tag{17}$$

The diameter of the powder jetting pile is 650 mm and the pile spacing is 450 mm.

The effective thickness of shear plane is as follows:

$$\text{d}_1 = \sqrt{\left(\frac{650}{2}\right)^2 - 150^2} + 241 = 529.3\,\text{mm}. \tag{18}$$

The spacing of shear plane is as follows:

$$l_1 = 450 - 300 = 150\,\text{mm}. \tag{19}$$

The shear is as follows:

$$Q = \frac{l_1 p}{2} = \frac{0.15 \times 57 \times 1}{2} = 4.28\text{kN}. \tag{20}$$

Shear stress of the action is as follows:

$$\tau = \frac{Q}{100\,d_1} = \frac{4280}{100 \times 0.5293} = 80.86\,\text{kPa} \le [\tau]. \tag{21}$$

We suppose that F_c is the designed value of the standard compressive strength of the cement stabilized soil, and $[\tau] = F_c/6$.

Therefore, the requirement for F_c is that it should be more than the value.

$$F_c = 6[\tau] = 6 \times 80.86 = 485.2\,\text{kPa}. \tag{22}$$

The accounting of cement stabilized soil is shown in Figures 7 and 8.

6. Design of Waist Beam and Bearer Supporting Bracket

Two H-beams (H—$300 \times 300 \times 10 \times 15$) are applied in the waist beam, and the strong axis direction is used to resist load in the horizontal direction, and the weak axis direction is used to resist load in the vertical direction. As shown in Figures 9 and 10, the geometric properties of the shear plane of H-beam are as follows:

$$A = 104.8\,\text{cm}^2,$$
$$W_x = 1150\,\text{cm}^3, \tag{23}$$
$$W_y = 393\,\text{cm}^3.$$

(1) *Calculation of Stress In the Strong Axis Direction.*

(a) The first layer (in Figures 9 and 10) is

$$\begin{aligned}
M_{max} &= \frac{R_1 l^2}{8} \\
&= \frac{53.0 \times 3.6^2}{8} \\
&= 85.9\,\text{kN}\bullet\text{m}, \\
Q_{max} &= \frac{R_1 l}{2} \\
&= \frac{53.0 \times 3.6}{2} \\
&= 95.4\,\text{kN}, \\
\sigma &= \frac{M_{max}}{2W_x} \\
&= \frac{85.9 \times 10^3}{2 \times 1150 \times 10^{-6}} \\
&= 37.3 < [\sigma] \\
&= 215\,\text{MPa}, \\
\tau &= \frac{Q_{max}}{2A_{middle}} \\
&= \frac{95.4 \times 10^3}{2 \times 1.0 \times (30 - 2 \times 1.5) \times 10^{-1}} \\
&= 17.7\,\text{MPa} < [\tau] \\
&= 125\,\text{MPa}.
\end{aligned} \tag{24}$$

(b) The second layer (in Figures 9 and 10) is

$$\begin{aligned}
M_{max} &= \frac{R_2 l^2}{8} = \frac{111.2 \times 3.6^2}{8} = 180.1\text{kNm}, \\
Q_{max} &= \frac{R_2 l}{2} = \frac{111.2 \times 3.6}{2} = 200.2\,\text{kN}.
\end{aligned} \tag{25}$$

(2) *Calculation of Stress In the Weak Axis Direction* (considering only the H-beam mentioned above).

$$\begin{aligned}
P_v &= R_1 s_1 \mathrm{tg}\theta = 53.0 \times 3.6 \times \mathrm{tg}45^0 = 190.8\,\text{kN}, \\
M_{max} &= \frac{P_v l_2}{4} = \frac{190.8 \times 0.45}{4} = 21.5\,\text{kN}\bullet\text{m}, \\
Q_{max} &= \frac{P_v}{2} = \frac{190.8}{2} = 95.4\,\text{kN}, \\
\sigma &= \frac{M_{max}}{W_y} = \frac{21.5 \times 10^3}{393 \times 10^{-6}} = 54.7 < [\sigma] = 215\,\text{MPa}, \\
\tau &= \frac{Q}{A_{side}} = \frac{200.2 \times 10^3}{2 \times 1.5 \times 30 \times 10^{-1}} = 22.24 < [\tau] = 125\,\text{MPa}, \\
\sigma &= \frac{M_{max}}{2W_x} = \frac{180.1 \times 10^3}{2 \times 1150 \times 10^{-6}} = 78.3 < [\sigma] = 215\,\text{MPa}, \\
\tau &= \frac{Q_{max}}{2A_{middle}} = \frac{200.2 \times 10^3}{2 \times 1.0 \times (30 - 2 \times 1.5) \times 10^{-1}} = 37.07 < [\tau] = 125\,\text{MPa}.
\end{aligned} \tag{26}$$

6.1. Design of the Waist Beam. Consider that the upper bracket bears the self-weight of the upper H-beam, while the lower bracket bears the shear forces caused by the anchor pull and its own self-weight.

The first layer of waist beam is as follows:

$$Q_v' = Q_v + \text{its own weight} = 95.4 + 0.94 \times \frac{3.6}{2} = 97.1\,\text{kN}. \tag{27}$$

The second layer of waist beam is as follows:

$$Q_v' = Q_v + \text{its own weight} = 200.2 + 0.94 \times \frac{3.6}{2} = 201.9\,\text{kN}. \tag{28}$$

The bearer supporting brackets is composed of angle steel ($\angle 75 \times 75 \times 12$), and its section properties are as follows:

$$\begin{aligned} A &= 16.56\,\text{cm}^2, \\ W_x &= W_y = 15.7\,\text{cm}^3, \\ i_{min} &= 1.44\,\text{cm}. \end{aligned} \tag{29}$$

6.2. The Accounting of Upper Chord of the Bearing Supporting Brackets

$$\begin{aligned} P_i &= Q_v' \text{tg}\theta = 201.9 \times \text{tg}40^0 = 169.4\,\text{kN}, \\ \sigma_t &= \frac{P_t}{A} = \frac{169.4}{16.56} \times 10 = 102.3\text{Mpa} < [\sigma] = 215\,\text{MPa}. \end{aligned} \tag{30}$$

6.3. Calculation of Diagonal Rod

$$\begin{aligned} P_c &= \frac{Q_v'}{\cos\theta} = \frac{201.9}{\cos 40^0} = 263.6\,\text{kN}, \\ \lambda &= \frac{l_0}{i_{min}} = \frac{62.3}{1.44} = 43. \end{aligned} \tag{31}$$

The schematic diagram of the seat design is shown in Figure 11.

According to the value of λ, it can be consulted in Norm that the value of $[\sigma_c]$i s 190.7Mpa.

$$\sigma_c = \frac{P_c}{A} = \frac{263.6 \times 10^3}{16.56\text{X}10^{-4}} = 159.2 < [\sigma_c] = 190.7\,\text{MPa}. \tag{32}$$

7. Comparison of SMW Retaining Wall Horizontal Displacement Monitoring Values with Calculated Results

When using the “simple beam method” proposed in this paper for the design calculation of SMW support structure, two deep horizontal displacements of the soil were calculated and monitored at a distance of 10m from both sides of the pit (MTX15 and MTX23), and a recording point was set up every 1m from the top of the pit downwards. The active Earth pressure at any depth was calculated by using the lateral pressure in this paper, and the horizontal displacement of each recording point was calculated by using the elastic resistance method (omitted due to the limitation of space). Under each working condition, the monitoring results of the deep horizontal displacement of the soil outside the pit are shown in Figure 12.

As can be seen from Figure 12, the SMW retaining wall horizontal displacement monitoring values, and the

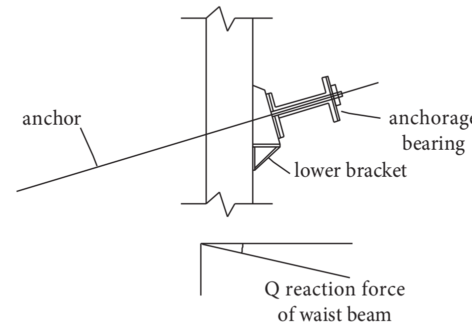

Figure 9: A schematic diagram of the design of the waist beam 1.

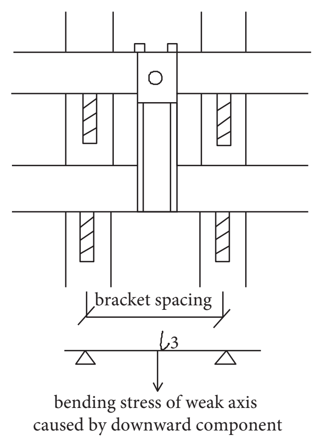

Figure 10: A schematic diagram of the design of the waist beam 2.

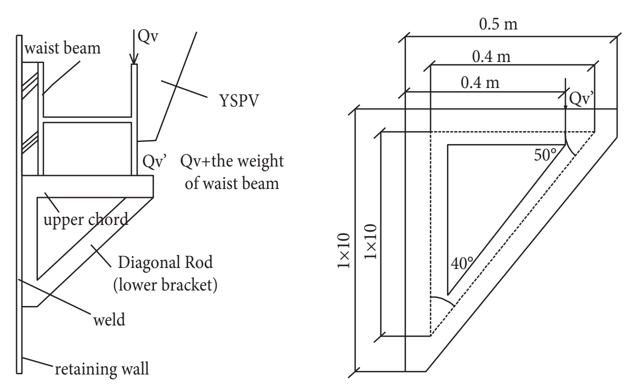

Figure 11: Schematic design of bracket.

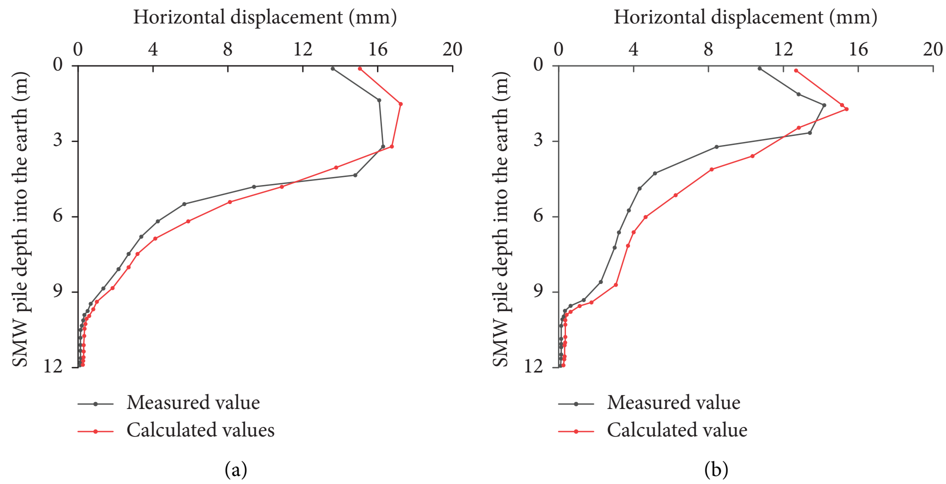

Figure 12: Variation curve of SMW retaining wall horizontal displacement with depth. (a) Horizontal displacement at point MTX15. (b) Horizontal displacement at point MTX23.

calculation results, the two agree well, thus verifying the reliability of the calculation method in this paper.

8. Conclusion

(1) Compared with the measured Earth pressure value, it can be seen that the active Earth pressure at any depth calculated by lateral pressure is more suitable for the actual engineering situation.

(2) Using the "simple beam method" to calculate the embedment depth, horizontal support force, and internal force of the SMW retaining wall with two rows of anchor rods as support points, when the first support point is the fulcrum of the "simple beam method," the active earth pressure is ignored (above the critical depth of Rankine earth pressure). When the second support point is the fulcrum (center of rotation) of the "simple beam method," the active Earth pressure and the first support force balance the moment of the second fulcrum and only consider the moment balance of the isolation body kept below the second fulcrum. The abovementioned calculated values are close to the measured values, and the degree of agreement is higher than that of the traditional equivalent beam method.

(3) The SMW retaining structure design method of "simple beam method" proposed in this paper is applied to practical engineering. The monitoring value of SMW retaining wall horizontal displacement is in good agreement with the calculated results, which proves that the method is feasible.

Data Availability

All data used and analyzed during the present study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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