Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Sept-Oct 2021 Page No. 1536-1553
Article History: Received: 10 August 2021, Revised: 25 August 2021, Accepted: 05 September 2021, Publication: 31 October 2021

Research on Analysis Method of Load-Displacement Relationship of Series Anchor Plates

Jie Liu, Qingguang Yang*, Xiya Tan*, Yue Ma
College of Civil Engineering, Hunan University of Technology, Zhuzhou, Hunan, China
*Corresponding Author.

Abstract:

To improve the pullout bearing capacity of anchor plate, the series anchor plate is proposed in this paper. Based on the theory of beam on elastic foundation and appropriate assumptions, this paper establishes both a theoretical analysis method and approximate analysis algorithm for the load-displacement relationship of series anchor plates embedded in clay. By the model test of six square series anchor plates of different sizes, two fitting parameters of relationship between proportion coefficient of bed coefficient of clay and horizontal displacement of anchor plates are obtained. Moreover, an approximate analytical formula for the relationship between the fitting parameters and edge length of square anchor plate is established. Finally, The theoretical analysis method is verified by three field tests of square series anchor plates with different edge length and embedded depth. At the same time, the influence of cohesion and internal friction angle on the pullout capacity of anchor plate is discussed. The results show that increasing the internal friction angle of soil is more effective than increasing the cohesion of soil in improving the pullout capacity of anchor plate.

Keywords*: Anchor plate, Pullout bearing capacity, Loading-displacement relationship, Analysis algorithm.*

I. INTRODUCTION

Anchor plates are widely used in infrastructures such as high voltage transmission line tower, retaining wall and port wharf as a kind of structure with effective pullout bearing capacity. Anchor plates have horizontal anchor plate, vertical anchor plates and inclined anchor plates according to embedded direction and pullout capacity direction. Vertical anchor plates which can resist active earth pressure and maintain the balance and stability of soil behind retaining structure are usually used in the retaining structure [1].It is easy to propose many new retaining structures by combinatorial method with other retaining structure for wide applicability of anchor plates. The pullout capacity and displacement are two important parameters which must been determined in design of retaining wall of anchor plates. Many studies have been conducted by systematic theory and test research on pullout mechanism of anchor plates. Pullout mechanism and influencing factors of pullout capacity of anchor plates have been studied by model test of small proportion[2-7].Pullout characteristic and calculation method for pullout capacity of anchor plate have also been studied by limit equilibrium theory and numerical simulations[8-13].Calculation model and theory method of ultimate pullout capacity of anchor plates have been proposed by upper bound method and associated flow laws of plasticity limit analysis[14-18].Although many calculation methods for pullout capacity of anchor plate have been proposed, but there are rare theoretical analysis method of load-displacement relationship of anchor plate. Base on statistical analysis of model test results, a fitting formula of load-displacement relationship of anchor plates is presented in this paper. Furthermore, the relationship of pullout capacity, displacement and the related parameters have been studied [19, 20]. A deformation analysis method of deep embedded anchor plate under horizontal load is proposed by Mindlin formula [21, 22].

The studies existed usually focus on the ultimate pullout bearing capacity but not bearing capacity and displacement mechanism of anchor plates. There are rarely analysis algorithms for load-displacement relationship and displacement characteristics. However, the mathematical expression of load-displacement relationship is the main way which can reflect the characteristics of anchor plates effectively and comprehensively.

At present, the pile-slab retaining structure design mostly adopts the vertical elastic foundation beam method for design calculation in engineering practice[23], Compared with the elastic line method commonly used in the past, this method can consider the influence of anchor point displacement on the earth pressure behind the wall, retaining structure deformation and internal force. Theoretical analysis and engineering practice indicate that the displacement of anchor plate has significantly effect on interior force of retaining structure, especially on retaining structure of large stiffness. The numerical simulations show that the ultimate positive bending moment declines by about fifty percent and the ultimate passive bending moment increases by several times when the displacement of anchor plate is 50mm.Meanwhile, larger horizontal displacement of retaining structure also leads to larger subsidence of ground. For displacements of 20mm to 50mm are normal to anchor plate in project, the study of load-displacement relationship and displacement characteristic are very important to anchor plate.

Based on study of the traditional anchor plate, to improve the pullout bearing capacity of anchor plate, the series anchor plate is proposed (as shown in Figure 1),and the mechanical model of interaction of series anchor plate and soil is presented in this paper. Based on the theory of Beam on Elastic Foundation and appropriate assumptions, this paper establishes an approximate analysis algorithm for the load-displacement relationship of series anchor plate. According to large scale model test, two fitting parameters of relationship between proportion coefficient of bed coefficient of clay soil and horizontal displacement of anchor plates are obtained by regression analysis. Finally, the theoretical analysis method is verified by comparing the curves of load-displacement relationship measured in field test with computed by theoretical analysis method.

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Sept-Oct 2021 Page No. 1536-1553
Article History: Received: 10 August 2021, Revised: 25 August 2021, Accepted: 05 September 2021, Publication: 31 October 2021

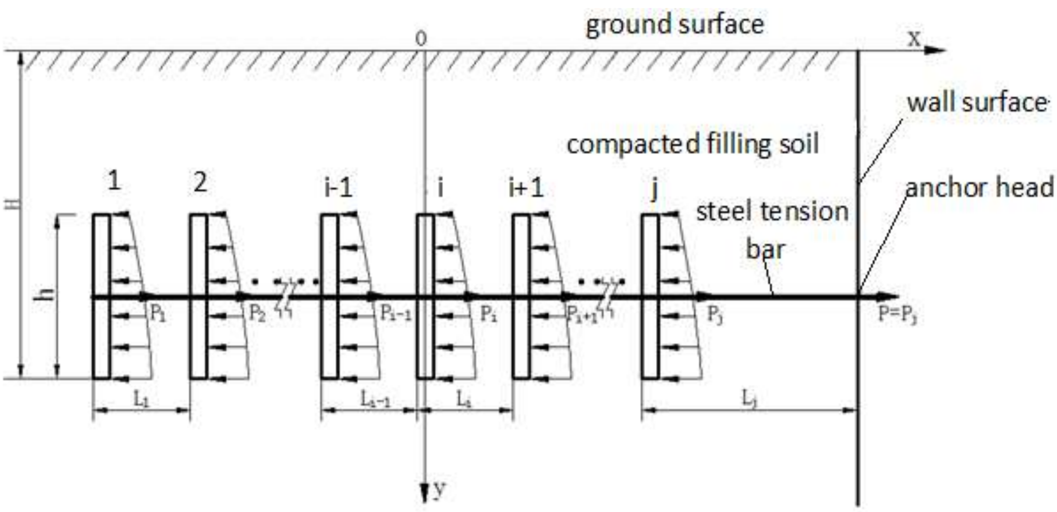

Fig 1: Structure sketch of series anchor plate

II. LOAD-DISPLACEMENT RELATIONSHIP OF SERIES ANCHOR PLATE

2.1 Basic Assumption

1) It is assumed that the anchor plate is absolutely rigid, and the friction resistance between the steel tie rod and the soil around the rod body is not considered.

2) Assume that the spacing between adjacent anchor plates is greater than the critical spacing. The series anchor plate structure is composed of J blocks of anchor plates (as shown in Figure 1). When the anchor plate reaches the ultimate bearing capacity, the leading edge of shear damage zone in front of the anchor plate contacts with the front anchor plate, and the distance between the front and rear anchor plates is called the critical distance [24] When the distance between adjacent anchor plates changes from smaller than the critical distance to larger than the critical distance, the flow mechanism of soil around the series anchor plates changes from "soil cylindrical failure mode" to "soil local independent failure mode"[24].

3) The anchor plate is regarded as a vertical elastic foundation beam. It is assumed that the coefficient increases linearly along depth and is zero at ground level. In other words, " m " method is used to calculate the resistance of soil in front of the anchor plate [25]. Then the soil foundation coefficient in front of the anchorage plate is:

$$k = my \tag{1}$$

Where the m is proportion coefficient of bed coefficient in front of anchor. y is the calculated point depth

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Sept-Oct 2021 Page No. 1536-1553
Article History: Received: 10 August 2021, Revised: 25 August 2021, Accepted: 05 September 2021, Publication: 31 October 2021

4) For anchor plate is usually applied in fill construction, the m is proportion coefficient of bed coefficient which is related to type of filling and compaction degree of filling. The m value is difficult to determine in normal project,more so for compacted filling project.However,the determination of cohesion and internal friction angle of clay soil filling is much easier than m .

Base on a series of indoor test of typical silty clay in the region, it is found that m has close contact with cohesion and internal friction angle and degree of compaction has obvious influence on cohesive and internal friction angle of silty clay.However,when the degree of compaction is above 93%,the influence will very small.Moreover,the result of indoor test also indicates that m of soil in the front of anchor plate is not constant，but is a power function with the horizontal displacement of the anchor plate.According to the adviced formula of m , c an φ in Code[26].

Considering the effect of horizontal displacement on proportion coefficient of bed coefficient, the relationship between proportion coefficient and the horizontal displacement of the anchor plate is defined:

$$m = k_1(0.2\varphi^2 - \varphi + c)x^n \tag{2}$$

Where x is the horizontal displacement of the anchor plate, φ is the internal friction angel of soil, c is the cohesion of soil, k_1 and n are regression parameters.

2.2 Theory Analysis Method

Under the action of tension, the anchor plate will produce translation and rotation. The no.i anchor plate is taken as the research object, and the mechanical model and established coordinate system are shown in Figure 2. Assuming that the horizontal displacement of the no.i anchor plate is x_i and the rotation angle is φ_i , then at the depth y below the ground, the resistance of soil in front of the anchor plate to the unit area of the anchor plate is:

$$\sigma_i = my[x_i + (H - \frac{h}{2} - y)\varphi_i] \tag{3}$$

Where H and h are embedded depth and height of the anchor plate respectively.

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Sept-Oct 2021 Page No. 1536-1553
Article History: Received: 10 August 2021, Revised: 25 August 2021, Accepted: 05 September 2021, Publication: 31 October 2021

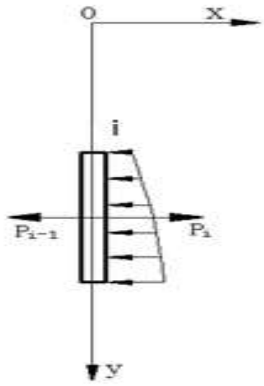

Fig 2: Mechanical model of anchor plate

Based on the balance conditions of the horizontal force and the torque balance conditions with the coordinate origin O as the center of moment, the following equation can be obtained:

$$\left.\begin{aligned} &P_i - P_{i-1} - \int_{H-h}^{H} \sigma_i b dy = 0 \\ &(P_i - P_{i-1})(H - \frac{h}{2}) - \int_{H-h}^{H} \sigma_i b y dy = 0 \end{aligned}\right\} (i = 1,2,3 \cdots j) \tag{4}$$

Substituting Eqs.(2) and (3) into Eq.(4),the load-displacement relationship of the ith plate can be expressed by:

$$P_i - P_{i-1} = k_1 k_2 k_3 k_4 x_i^{n+1} \qquad (i = 1,2,3 \cdots j) \tag{5}$$

Where b is width of anchor plate, p_i and p_{i-1} are axial tension of the ith and the $(i-1)th$ tension bar respectively. While $i = 1$, $p_0 = 0$ .and other parameters of eq.(5) can been obtained from the following equations:

$$\left.\begin{aligned} &A = 3(H - h/2)[H^2 - (H-h)^2] - 2[H^3 - (H-h)^3] \\ &B = 4(H - h/2)[H^3 - (H-h)^3] - 3[H^4 - (H-h)^4] \\ &k_3 = b\{4A[H^3 - (H-h)^3] - 3B[H^2 - (H-h)^2]\} \\ &k_4 = 1/[6(2AH - Ah - B)] \\ &k_2 = 0.2\varphi^2 - \varphi + c \end{aligned}\right\} \tag{6}$$

According to hooke's law of axial tension and compression and displacement coordination conditions between anchorage plates, the relation between the displacement of the ith and the $(i-1)th$ anchor plate can be obtained as follows:

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Sept-Oct 2021 Page No. 1536-1553
Article History: Received: 10 August 2021, Revised: 25 August 2021, Accepted: 05 September 2021, Publication: 31 October 2021

$$x_i = x_{i-1} + \frac{P_{i-1}L_{i-1}}{ES} \qquad (i = 2,3\cdots j) \tag{7}$$

Where L_{i-1} is distance of the $(i-1)th$ and the ith anchor plate, E is elasticity modulus of steel tension bar, S is sectional area of steel tension bar.

Substituting Eq.(7) into Eq.(5),the recursive formula of the axial tension of the tie rod between the anchor plates can be obtained as follows:

$$P_i = k_1 k_2 k_3 k_4 (x_{i-1} + \frac{P_{i-1}L_{i-1}}{ES})^{n+1} + P_{i-1} \quad (i = 2,3\cdots j) \tag{8}$$

According to hooke's law of axial tension and compression, the formula for calculating the displacement at the anchor head of the tandem anchor plate structure can be written:

$$x = x_j + \frac{P_j L_j}{ES} \tag{9}$$

Where x_j and P_j are displacement and axial tension of the last plate respectively.

Under the condition that regression parameters k_1 and n ,and related calculation parameters have been determined, the displacement and tension at anchor head of the anchor plate can be obtained in conjunction with Eqs (5), (8) and (9), so as to obtain the relationship curve between the tension of the series anchor plate and the displacement of anchor head.

To the method presented in this paper, firstly, for the first anchor plate, a serial of tensions $P_{1(1)}$、$P_{1(2)}$ $\cdots P_{1(i)}\cdots P_{1(n)}$ may been obtained by given a serial of displacements $x_{1(1)}$、$x_{1(2)}$、$\cdots x_{1(i)}\cdots x_{1(n)}$ .Secondly, the serial displacement $x_{j(1)}$、$x_{j(2)}$、$\cdots x_{j(i)}\cdots x_{j(n)}$ and tensions $P_{j(1)}$、$P_{j(2)}$、$\cdots P_{j(i)}\cdots P_{j(n)}$ of other plates can been achieved by recursion Eqs.(7) and (8). Finally, the serial displacements $x_{(1)}$、$x_{(2)}$、$\cdots x_{(i)}\cdots x_{(n)}$ on anchor head can been obtained. Moreover, the load-displacement relationship curves of the series anchor plate can be drawn.

III.MODEL TEST OF ANCHOR PLATE

3.1 Model Test Preparation and Test Parameters

A large scale model test is conducted to discuss m value and the research result will been applied to

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Sept-Oct 2021 Page No. 1536-1553
Article History: Received: 10 August 2021, Revised: 25 August 2021, Accepted: 05 September 2021, Publication: 31 October 2021

practical project by determining regression parameters k_1 and n.The model test is conducted in two large outdoor test tank(5.0m×5.0m×3.0m) which is filled by typical silty soil and by filling and compacting in layers.

To discuss the effect of dimension of anchor plate to m value, six anchor plates of 0.2m thickness and C30 strength grade are embedded in two ends of test tank in advance. The embedded position of anchor plates and test point layout are shown in Fig.3.The size of anchor plates and relevant parameters of six model tests list in Table 1 according to normal size of actual project. After 30 days of filling soil of model test, by geotechnical test of soil, the relevant geotechnical parameters of compacted soil are shown in Table 2.

To simple the produce of model test and load easily, a hole on the test tank is prepared on the position of embedded depth of anchor plate. The horizontal push force is applied to anchor plate by a 200kN jack through the hole on the test tank. The displacement of anchor plate is measured by two sensors installed on top and bottom of anchor plate. The horizontal push force and displacement are automatic recorded by test date acquisition system.

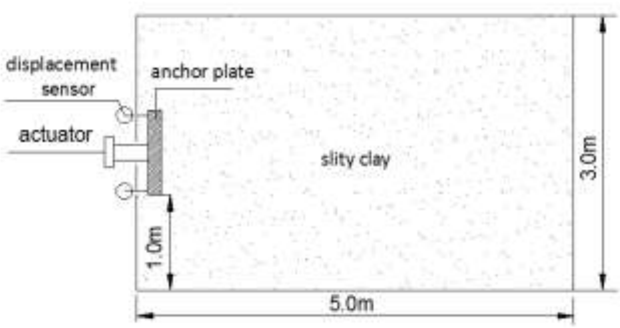

Fig 3: Schematic diagram of model test

Table 1: Size of anchor plate for model test

Plate No	Shape of plate	side length	embedded depth
#1	square	0.5m	2.0m
#2	square	0.6m	2.0m
#3	square	0.7m	2.0m
#4	square	0.8m	2.0m
#5	square	0.9m	2.0m
#6	square	1.0m	2.0m

Table 2: Parameters of compacted fill in model test

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Sept-Oct 2021 Page No. 1536-1553
Article History: Received: 10 August 2021, Revised: 25 August 2021, Accepted: 05 September 2021, Publication: 31 October 2021

soil	Density	Cohesion	friction angle	Compaction degree
slity clay	1.95g/cm^3	30.7kPa	19.6^0	92.5%

3.2 Determination of Regression Parameters k_1 and n

Formula (5) was used to fit the model test results of anchor plates 1# to 6# respectively. the two regression parameters in Equation (2) are obtained as shown in Table 3. The load-displacement relationship test and fitting curves of model experiments 1#, 4# and 6# are as shown in Fig.4 to Fig.6.As shown in Fig.4 to Fig.6, the fitting results agree very well with the test results. As shown in Table3,The regression parameter n is quite close, but k_1 varies considerably of six model tests. The research indicates that anchor plate size has a very small influence on parameter n and significant influence on parameter k_1 .Therefore, it is not necessary to regression parameter n thinking about anchor plate size. It is suitable that the average of n of six model tests can been used in theory research of anchor plate.

Table 3: Regression parameter k1 and n

Anchor plate	k_1	n
#1	6.0162	-0.4886
#2	5.6612	-0.4889
#3	4.4503	-0.4891
#4	3.9715	-0.4892
#5	3.6433	-0.4926
#6	3.4652	-0.4948
average	--	-0.4905

Based on regression parameter k_1 of different anchor plate size in Table.3 and regression formula of relation between coefficient of foundation and side length of square load plate[27], and regression parameter k_1 of anchor plate 1# as benchmark parameter, by regression analysis, the relationship of square anchor plate size and regression parameter k_1 is obtained as:

$$k_1 = k_s\left(\frac{b+0.5}{2b}\right)^2 \tag{10}$$

Where k_s is regression parameter of square anchor plate of b =0.5m.

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Sept-Oct 2021 Page No. 1536-1553
Article History: Received: 10 August 2021, Revised: 25 August 2021, Accepted: 05 September 2021, Publication: 31 October 2021

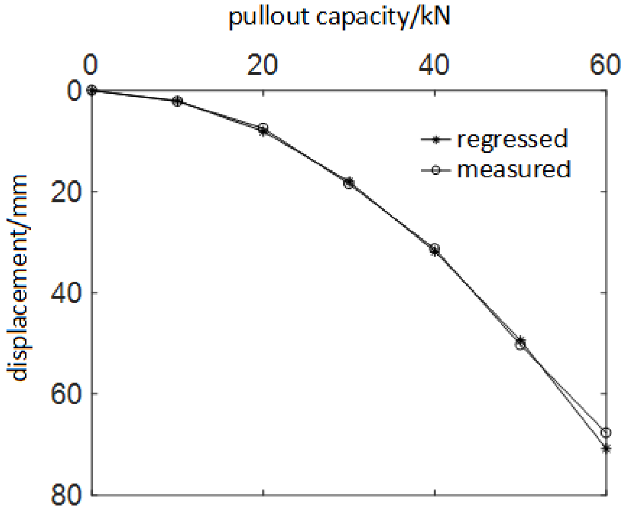

Fig 4: Test and fitting curves of anchor plate #1

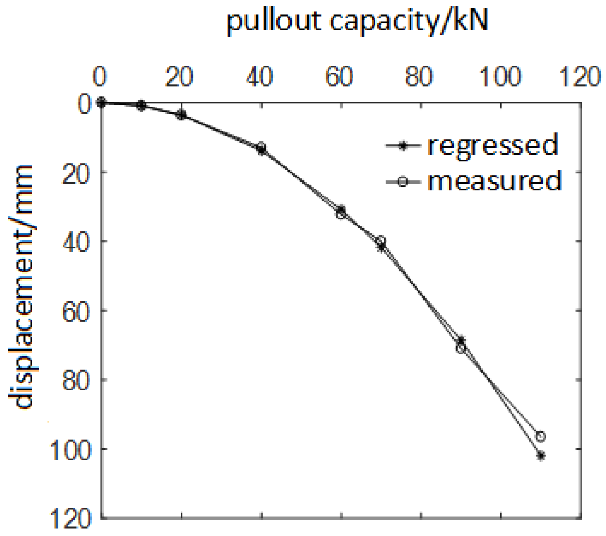

Fig 5: Test and fitting curves of anchor plate #4

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Sept-Oct 2021 Page No. 1536-1553
Article History: Received: 10 August 2021, Revised: 25 August 2021, Accepted: 05 September 2021, Publication: 31 October 2021

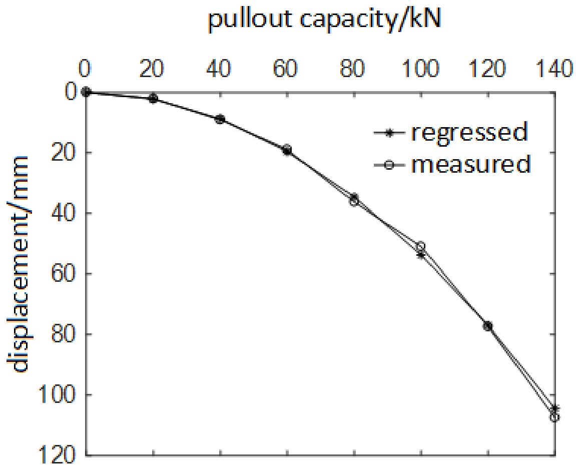

Fig: 6 Test and fitting curves of anchor plate #6

Ⅳ.NUMERICAL EXAMPLES AND VERIFICATION

The engineering case I: A soil slope of high filling is used to verify theoretical method of load-displacement relationship of anchor plate presented in this paper. The pile-slab wall of single anchor plate was used to stabilize a 12*m* slope at zhuzhou, China.

The square reinforced concrete piles of b=1.0*m* and Modulus of elasticity=$3.0\times10^7 kPa$ were installed along slope at a spacing of 4.0*m* to increase the factor of the whole slope. The reinforced concrete slab of 0.20m thickness and Modulus of elasticity=$3.0\times10^7 kPa$ was installed between piles. In this case, the square anchors of b=1.0*m*, 0.25*m* thickness and Modulus of elasticity=$3.0\times10^7 kPa$ were installed at a spacing of 4.0*m* (Fig.7). The length and embedded depth of steel bars manufactured by $3\phi^s 15.2$cable of Modulus of elasticity=$1.95\times10^{11} kPa$ are shown in Fig.7.The soil parameters for theoretical analysis is shown in Table. 4 by Site sampling for indoor testing after the soil was filled and compacted completely. The n=-0.4905 of the average of regression parameter and k_1=3.4652 of regression parameter of anchor plate 3# were used in theoretical analysis.

Table 4: Soil parameters

soil	Density	Cohesion	friction angle	Compaction degree
slity clay	$1.95g/cm^3$	34.5kPa	19.7^0	94.8%

To confirm the pullout capacity of anchor plate meets the design requirements or not two pullout tests of anchor plate are conducted in depth 5*m* and 8*m* below ground surface respectively.

The comparisons of results of load-displacement relationship of anchor plate are shown in Fig.8 and

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Sept-Oct 2021 Page No. 1536-1553
Article History: Received: 10 August 2021, Revised: 25 August 2021, Accepted: 05 September 2021, Publication: 31 October 2021

Fig.9. As shown in Fig.8 and Fig.9, the computed results agree excellently with measured.

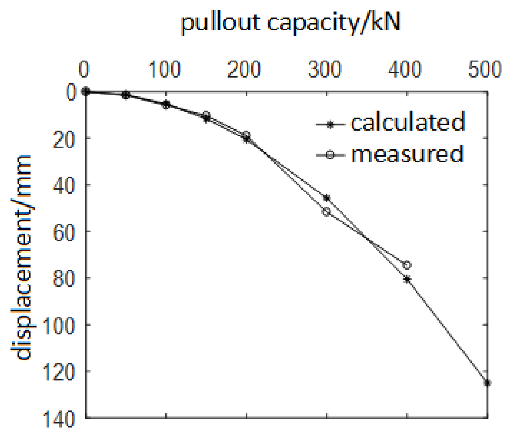

Fig 7: Configuration of pile-wall with anchor plate

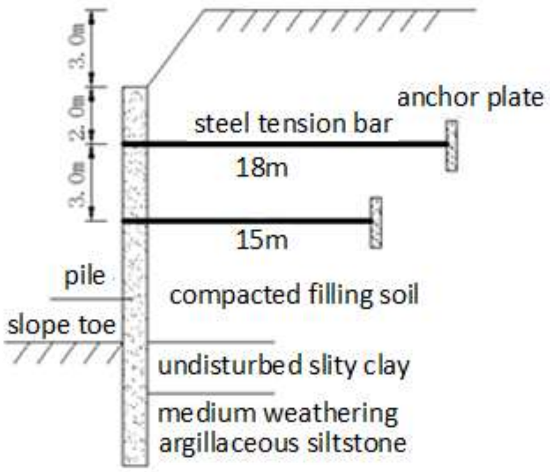

Fig 8: Comparison of results of displacement-load relationship of anchor plate in depth 5m

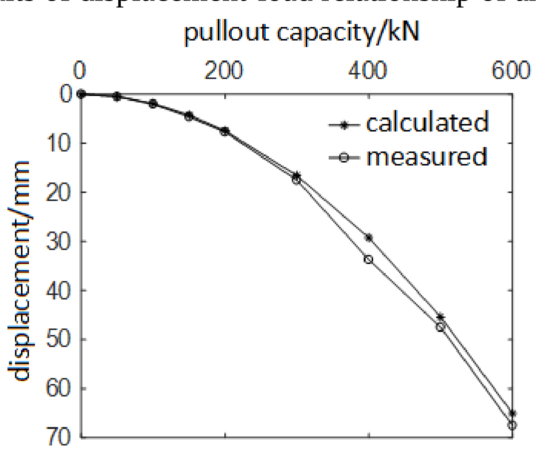

Fig 9: Comparison of results of displacement-load relationship of anchor plate in depth 10m

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Sept-Oct 2021 Page No. 1536-1553
Article History: Received: 10 August 2021, Revised: 25 August 2021, Accepted: 05 September 2021, Publication: 31 October 2021

The engineering case II: To confirm the theoretical method of load-displacement relationship of anchor plate presented in this paper further, another soil slope of high filling is presented in this paper. The pile-slab wall of serial anchor plate was used to stabilize a slope of 18m at zhuzhou, China.

The rectangle concrete piles of l×b=1.0*m*×1.2*m* and Modulus of elasticity=$3.0\times10^{7}kPa$ were installed along slope at a spacing of 4.0*m* to increase the safe factor of the whole slope. The concrete slabs of 0.20*m* thickness and Modulus of elasticity=$3.0\times10^{7}kPa$ were installed between piles. In this case, the square anchors of b=1.2*m*, 0.25*m* thickness and Modulus of elasticity=$3.0\times10^{7}kPa$ were installed at a spacing of 4.0*m* (Fig.10).The length and embedded depth of steel bars manufactured by $4\phi^{s}15.2$ cable of Modulus of elasticity=$1.95\times10^{11}kPa$ are as shown in Fig.10.The soil parameters for theoretical analysis are shown in table.5 by site sampling for indoor test after the soil was filled and compacted completely. The n=-0.4905 of the average of regression parameter and k_1=3.0183 of regression parameter of anchor plate were used in theoretical analysis.

Table 5: Soil parameters

soil	Density	Cohesion	friction angle	Compaction degree
slity clay	1.95g/cm^3	35.1kPa	19.3^0	93.3%

To confirm the pullout resistance of anchor plate meets the design requirements or not, a pullout test of anchor plate per row was conducted in depth 5m, 8m, 11m and 14m below ground surface respectively by random sampling.

The comparisons of results of load-displacement relationship of anchor plate are shown in Fig.11 to Fig.14.As shown in Fig.11 and Fig.12, the computed results agree excellently with measured. On the contrary, the computed results deviate the measured response evidently. As shown in Fig.14, the deviation between computed and measured results is the largest in four rows anchor plate. It is clear that the hypothesis of bed coefficient increasing linearly with depth of soil if the embedded depth is lower than the critical depth which will be discussed in other papers. If the depth is greater than the critical depth, the computed results will deviate the measured response evidently.

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Sept-Oct 2021 Page No. 1536-1553
Article History: Received: 10 August 2021, Revised: 25 August 2021, Accepted: 05 September 2021, Publication: 31 October 2021

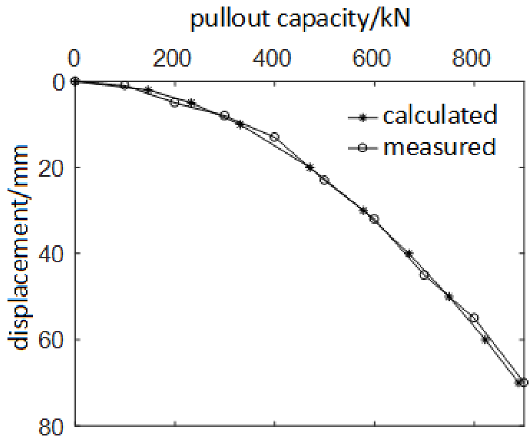

Fig: 10 Schematic diagram of pile-wall with anchor plate

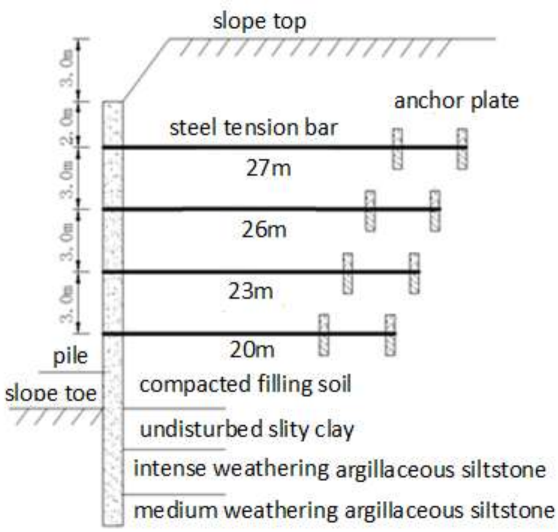

Fig: 11 Relationship between displacement and load of anchor plate in depth 5m

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Sept-Oct 2021 Page No. 1536-1553
Article History: Received: 10 August 2021, Revised: 25 August 2021, Accepted: 05 September 2021, Publication: 31 October 2021

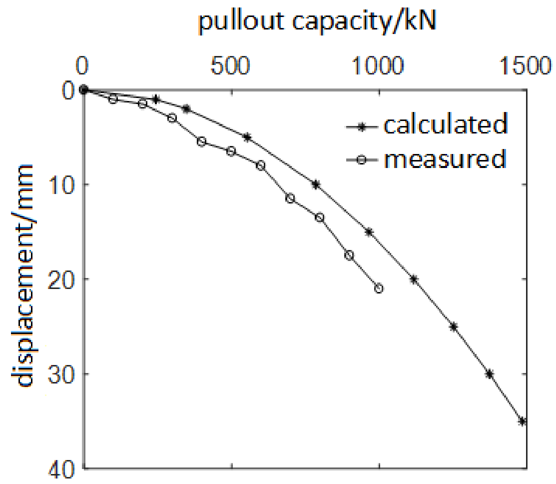

Fig: 12 Relationship between displacement and load of anchor plate in depth 8m

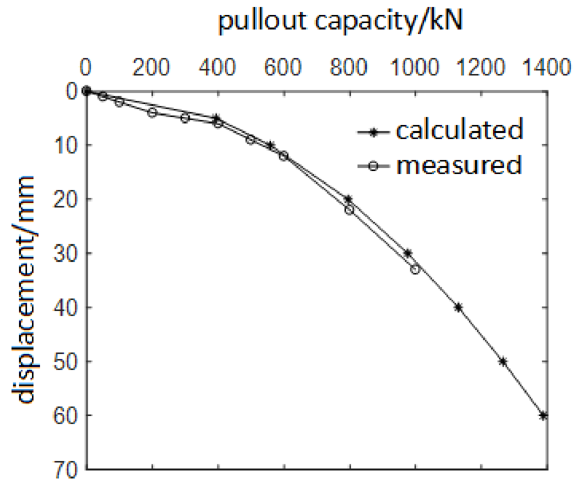

Fig: 13 Relationship between displacement and load of anchor plate in depth 11m

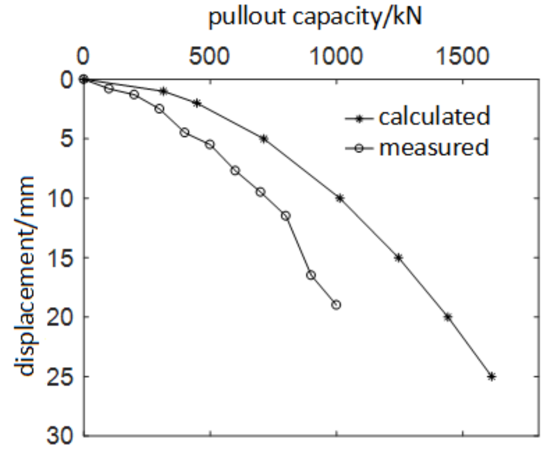

Fig: 14 Relationship between displacement and load of anchor plate in depth 11m

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Sept-Oct 2021 Page No. 1536-1553
Article History: Received: 10 August 2021, Revised: 25 August 2021, Accepted: 05 September 2021, Publication: 31 October 2021

The engineering case III: This case is from reference [28].Two square steel anchor plates of b=1.0*m* and 1.4m were embedded in compacted silty clay. The embedded depth were 4.9*m* and 6.7*m* respectively. The lengths of steel bars manufactured by 3φ25 rebar were 14m and 19m respectively. The pullout test was conducted by 600*kN* jack. The $\varphi = 22.36^0$, $c = 10kPa$ and $\gamma = 19.8kN/m^3$ were employed by Zhang et al.(1996) The comparisons of results of displacement-load relationship of anchor plate are shown in Fig.15.The computed results were agree with field test results very well as shown in Fig.15.

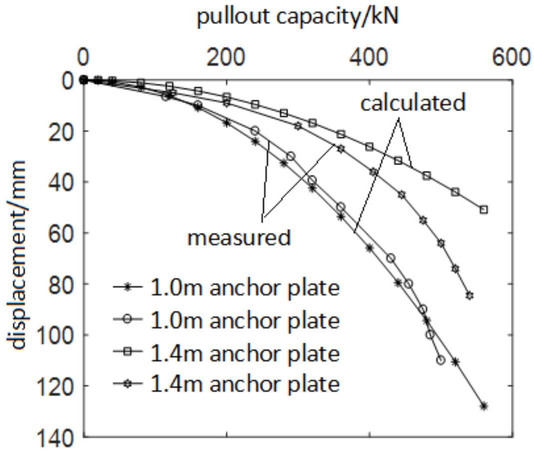

Fig: 15 Relationship between load-displacement of anchor plate

By comparing the displacement-load curves of eight anchor plates from three engineering cases with the experimental results, it can be seen that the theoretical analysis method proposed in this paper can accurately determine the load-displacement curves of anchor plates in compacted silty clay when the embedded depth of anchor plates is within a certain depth range. However, when the embedded depth of the anchor plate exceeds a certain depth range, the theoretical analysis result of the load-displacement curve of the anchor plate is quite different from the actual situation, which indicates that the assumption that the coefficient of the foundation bed k increases linearly with the depth can only be established in a certain depth range. What is the depth range? This will be discussed separately.

V. EFFECT OF SOIL COHESION AND INTERNAL FRICTION ANGLE ON BEARING BEHAVIOR OF ANCHOR PLATE

An square anchor plate of b=1.0*m* is employed to discuss the bearing characteristics of anchor plate. The embedded depth is 5*m* and weight of soil is 19.7*kN/m*^{3}.When the angle of internal friction of soil is 20^0, and the cohesion of soil increases from 10*kPa* to 40*kPa*, the comparison curve of displacement-load of anchor plate is shown in Fig.16.Moreover, when the cohesion of soil is 20*kPa*, and the angle of internal friction of soil increases from 20^0 to 40^0, the comparison curve of displacement-load of anchor plate is shown in Fig.16. The comparison curves of load-displacement relationship of anchor plate are shown in Fig.17.As shown in Fig.16 and Fig.17,the displacement of anchor plate declines with increasing of

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Sept-Oct 2021 Page No. 1536-1553
Article History: Received: 10 August 2021, Revised: 25 August 2021, Accepted: 05 September 2021, Publication: 31 October 2021

cohesion and internal friction angle of same load condition, but the reduce magnitude will decline with increasing of cohesion and internal friction angle. Moreover, it is more effective to decline displacement of anchor plate by increasing internal friction angle than cohesion. So, improving internal friction angle of soil can effectively increase pullout resistance.

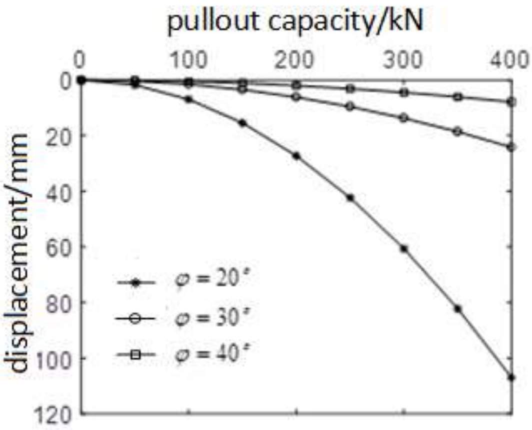

Fig.16 Comparison curves of load-displacement of anchor plate

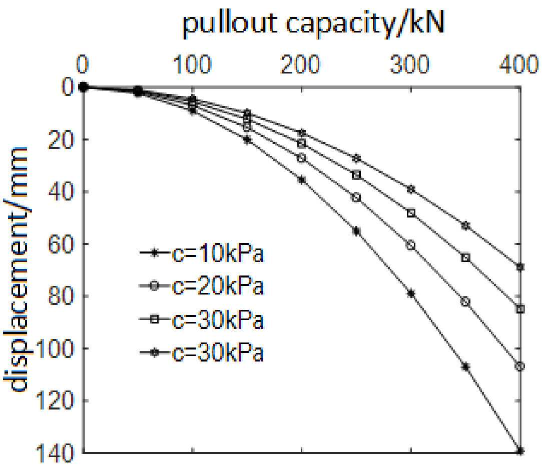

Fig.17 Comparison curves of load-displacement of anchor plate

VI. CONCLUSIONS

To improve the pullout resistance of anchor plate, the series anchor plate is proposed in this paper. Based on the theory of Beam on Elastic Foundation and appropriate assumptions, this paper establishes approximate analytic formula for the load-displacement relationship of series anchor plate and horizontal bed coefficient of soil by displacement of anchor plate. By model test and regression analysis, two fitting parameters of relationship between proportion coefficient of bed coefficient of clay soil and horizontal displacement of anchor plate are obtained. Finally, the load-displacement relationship by theoretical analysis method is verified by test in site.

On the one hand, the theoretical method presented in this paper is very favorable to theoretical basis which can been knew well by engineers for design of anchor plate according to the double standards of displacement and bearing capacity. On the other hand, for the normal embedding depth of the anchor plates in project, it is not necessary to artificially distinguish deep embedded anchor plate form shallow embedded anchor plate to determine the ultimate pullout resistance of the anchor plate.

In this paper, the m method employed to determine the resistance which increasing linearly with depth of soil in front of anchor plate is suitable if the embedded depth is lower than critical depth. When the embedded depth is greater than critical depth, the hypothesizes is not held. Further research is necessary to determine critical depth and soil resistance below critical depth.

ACKNOWLEDGMENTS

This research is supported by the National Natural Science Foundation of China (Grant No. 51978260) and Hunan Province Natural Science Foundation of China (Grant No. 2020JJ6080).

REFERENCES

[1] Cai, Z.Y., Hou, W., Guan, Y.F., "Mechanism of sheet-pile wharf with barrier piles," Chinese Journal of Geotechnical Engineering, vol.37, no.10, pp.1745–1750, 2015.
[2] Matsuo, M., "Study on the uplift resistance of footing (I)," Soils and Foundations, vol.7, no.4, pp.1–37, 1968.
[3] Meyerhof, G.G., Adams, J.I., "The ultimate uplift capacity of foundations," Canadian Geotechnical Journal, vol. 5, no.4, pp.225–244, 1968.
[4] Murry, E.J., Geddes, J.D., "Uplift of anchor plates in sand," Journal of Geotechnical Engineering, vol.113, no.3, pp.202–215, 1987.
[5] Saeedy, H.S., "Stability of circular vertical anchors," Canadian Geotechnical Journal, vol.24, no.3, pp.452–456, 1987.
[6] Ghaly, A., Haly, A., Hanna, A., "Ultimate pullout resistance of single vertical anchors," Canadian Geotechnical, vol.31, no.5, pp.661–672, 1994.
[7] Ghaly, A., Hanna, A., Hanna, M., "Uplift behaviour of screw anchors in sand. I: dry sand," Journal of Geotehcnical Engineering, vol.117, no.5, pp.773–793, 1991.
[8] Rowe, R.K., Davis, E.H., "The behaviour of anchor plates in sand," Géotechnique, vol.32, no.1, pp.25–41, 1982.
[9] White, D.J., Hite, D.J., Cheuk, C.Y., Bolton, M.D., "The uplift resistance of pipes and plate anchors buried in sand," Geotechnique, vol.58, no.10, pp.771–779, 2008.
[10] Hanna, A., Ayadat, T., Sabry, M., "Pullout resistance of single vertical shallow helical and plate anchors in sand," Geotechnical and Geological Engineering, vol.25, no.7, pp.559–573, 2007.
[11] Zhang, X., Yue, J.C., Liu, M.L., "Uplifting behavior and bearing capacity of plate anchors in sand," Chinese Journal of Geotechnical Engineering, vol.34, no.9, pp.1734–1739, 2012.
[12] Hao, D.X., Fu, S.N., Chen, R., "Experimental investigation of uplift behavior of anchors and estimation of uplift capacity in sands," Chinese Journal of Geotechnical Engineering, vol.37, no.11, pp.2101-2106, 2015.

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Sept-Oct 2021 Page No. 1536-1553
Article History: Received: 10 August 2021, Revised: 25 August 2021, Accepted: 05 September 2021, Publication: 31 October 2021

[13] Chen, R., Fu, S.N., Hao, D.X., “Scale effects of uplift capacity of circular anchors in dense sand,” Chinese Journal of Geotechnical Engineering, vol.41, no.1, pp.78-85, 2019.
[14] Wang, L.Z., Shu, H., “Pullout capacity of deeply embedded plate anchors in undrained clay,” Chinese Journal of Geotechnical Engineering, vol.31, no.6, pp.829-836, 2009.
[15] Huang, M.S., Yu, S.B., “Upper bound analysis of deep strip anchor based on rotational block set,” Chinese Journal of Geotechnical Engineering, vol.33, no.5, pp.685-692, 2011.
[16] Huang, M.S., Yu, S.B., “Pullout capacity of strip anchor plate in sand based on block set mechanism,” Chinese Journal of Geotechnical Engineering, vol.35, no.2, pp.201-207, 2013.
[17] Hu, W., Liu, S.K., Zou, G.H., “Unified theoretical solution for ultimate bearing capacity of vertical strip anchor,” Chinese Journal of Geotechnical Engineering, vol.40, no.2, pp.296-304, 2018.
[18] Hu, W., Gao, W.H., Zhao, P., “Three-dimensional unified theoretical researches on ultimate horizontal pullout capacity of vertical square anchors,” Chinese Journal of Geotechnical Engineering, vol.41, no.1, pp.111-120, 2019.
[19] Ding, P.M., Zhang, Q.L., Xiao, Z.B., “Study on load-displacement characteristic of anchor slab in sandy soil and calculation of uplifting displacement,” China Civil Engineering Journal, vol.37, no.6, pp.53-59, 2004.
[20] Zhu, B.T., Yang, M., Guo, W.D., “Pullout capacity of vertically-buried shallow anchor plates,” Chinese Journal of Geotechnical Engineering, vol.28, no.10, pp.1236-1241, 2006.
[21] Douglas, D.J., Davis, E.H., “The movements of buried footings due to moment and horizontal load and the moment of anchor plates,” Geotechical J, vol.14, no.2, pp.115-132, 1964.
[22] He, S.M., Zhang, X.G., Zhu, P.Y., “Deformation on analysis of deep buried anchor plate under horizontal load,” Chinese Journal of Rock Mechanics and Engineering, vol.23, no.1, pp.159-163, 2004.
[23] “Ministry of Transport of the People's Republic of China code for design and construction for quay wall of sheet pile (JTS 167-3),” Beiijing, China, Water Conservancy Press, 2009.
[24] Liu, J., Wang, Z., He, S.D., “Study on critical depth and critical spacing of double anchor plates in series,” Civil Engineering, vol. 9, no.12, pp.1371-1378, 2020.
[25] Tang, Y.Q., Wu, Q.S., “Calculation method and example of pile structure,” Beiijing, China, Railway Publishing House, 1977.
[26] “Ministry of Housing and Urban-Rural Construction of the People's Republic of China technical Specification for Retaining and Protection of Building Foundation Excavations (JGJ120),” Beiijing, China Building Industry Press, 2012.
[27] Yi, H., Fang, S.H., “Beams, plates, shells on elastic foundations,” Beiijing, China, Science and Technology Press, 2005.
[28] Zhang, X.X., Wu, X.M., Lu, Z.J., “Theory and practice of new retaining wall structure with retaining-anchor plate,” Beiijing, China, Railway Publishing House, 1996.