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The Study on Earth Pressure against Retaining Wall Considering Displacement

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Abstract—**Several typical existing calculation methods of earth pressure considering displacement are introduced and compared; Typical methods are used to calculate the condition of laboratory tests and the result is compared with that from Rankine earth pressure results to explain which is more reasonable. Based on the experimental model and data of Fang, it shows that the Lu's and Mei's calculation methods are still operational, and Mei's method is more close to the test data, which reflects the change of the earth pressure with the displacement of retaining wall better.**

Keywords-earth pressure; Rankine's earth pressure theory; displacement; movement mode; retaining wall

I. INTRODUCTION

In geotechnical engineering, the retaining structure of piles, the underground continuous wall, the anchored plate retaining wall, the steel sheet pile and the anchor piles are all important forms of flexible retaining structure. In practical engineering, the determination of the earth pressure on the retaining structure is an important content in the design of the retaining structure. The accurate calculation of the earth pressure is beneficial to the stability and safety of the structure, and also to reduce the cost of the project.

The classical theory of Rankine earth pressure has been in existence for 142 years, but there are two obvious shortcomings in Rankine 's theory of earth pressure: the first is that it requires the deformation of the soil reaches the limit condition of the limit state. Second, the Rankine earth pressure theory itself comes out in the condition of the existence of retaining wall , retaining wall stiffness is very large, only to allow translation or rotation of two rigid displacement. The fact that it is inconsistent with today's rapidly developing engineering practice and a lot of measured data requires us to respond to the new situation and conduct in-depth research and substantial improvement. Therefore, domestic and foreign scholars have done a lot of research on the earth pressure of rigid retaining wall.

Ciwei Gu et al.[1] conducted a study on the shape of the slip in the back filling soil of retaining wall. It is concluded that the slip body in the filling soil of the retaining wall is part of the soil surrounded by the retaining wall, the balance arch and the sliding surface. Yingying Zhou[2] has carried out the model test not only on the sand filler, but also the viscous filler under different movement modes of the rigid retaining wall. Yekai Chen[3] has the EPRESS.F90 program to calculate the distribution of passive earth pressure on rigid retaining walls under the rotation mode of RTT, RTB and T. Based on the consideration of the soil arching effect, Paik[4] has studied the active earth pressure distribution of the rigid retaining wall under the moving mode. Yuanzhan Wang et al.[5]has further considered the friction interaction between the soil micro elements in the triangular soil wedge, and assume the direction of the friction effect in the RB and RT mode respectively.

Based on the researches above, in this paper several typical existing calculation methods of earth pressure considering displacement were introduced and compared; Typical methods were used to calculate the condition of laboratory tests and the result was compared with that from Rankine earth pressure results to explain which result is more reasonable.

II. TYPICAL CALCULATION METHODS OF EARTH PRESSURE CONSIDERING DISPLACEMENT

When the retaining wall moves away from the filling, the time the filling behind the wall reaches the limit equilibrium state, the earth pressure on the retaining wall is called active earth pressure; when the retaining wall move to the filling the direction of filling, the time the filling behind the wall reaches the limit equilibrium state, the earth pressure acting on the retaining wall is called the passive earth pressure; when the retaining wall moves neither toward nor back the filling, that is the wall keep still, the earth pressure is called the static earth pressure. Among the three kinds of earth pressure the active earth pressure is the smallest, the passive earth pressure is the largest, and the static earth pressure is between the two.

Based on the analysis of the relationship between active earth pressure, passive earth pressure, resting earth pressure and displacement, calculation methods ,including method of Guosheng LU[6],method of Guoxiong Mei[7] et al ,considering the displacement are proposed according to the theory of Langham earth pressure.

A. Lu's Method

Earth pressure includes active earth pressure, passive earth pressure and resting earth pressure, the actual earth pressure in practical engineering may be a value between active earth pressure and passive earth pressure. The general relationship between the three earth pressures and the displacement of the retaining wall is shown in Figure.1.

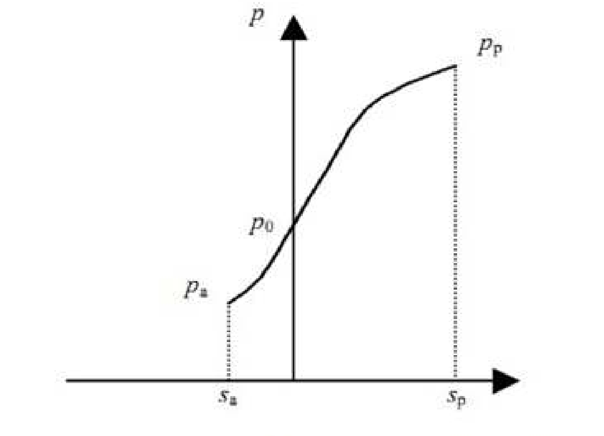


FIGURE I. RELATIONSHIP BETWEEN EARTH PRESSURE AND DISPLACEMENT

The graph curve can be fitted with a function. Based on the parametric sensitivity analysis of the fitting function, the formula considering the displacement of calculating the earth pressure based on the Rankine earth pressure theory can be obtained.

For quasi-active earth pressure:

$$p_a' = \frac{p_0}{1+\frac{1}{4.7}\ln\left(\frac{k_p+k_a}{k_a}\right)^3\sqrt{\frac{s_a'}{s_a}}} - \frac{2c\frac{s_a'}{s_a}}{1+\left(\frac{k_p-k_a}{k_p+k_0+k_a}\right)\frac{s_a'}{s_a}} \quad (1)$$

For quasi-passive earth pressure:

$$p_p' = p_0\left[1+\frac{\sqrt[3]{s_p'/s_p}}{\frac{k_p+1.16k_a}{0.96k_p^3}+\frac{\frac{k_p+1.16k_a}{1.79k_p^3}}{1+\frac{8c}{\gamma Z}}\frac{s_p'}{s_p}}\right] \quad (2)$$

For k_0:

$$\begin{cases} k_0 = 1-\sin\varphi' \\ k_0 = 0.95-\sin\varphi' \\ k_0 = \sqrt{OCR}(1-\sin\varphi') \end{cases}$$

Where: Where: p_0 stands for resting earth pressure, γ stands for weight of soil, k_0 stands for coefficient of earth pressure at rest; c is cohesion; s_a' is the displacement under quasi - active earth pressure; s_a is the displacement under active earth pressure; φ' is effective internal friction angle; OCR stands for ratio of soil over consolidation.

This method is a good way to reflect the earth pressure changing with the displacement of retaining wall, and also consider the effect of filling characteristics on earth pressure. This method is a good way to reflect the change of earth pressure with the displacement of retaining wall, and also consider the effect of filling characteristics on earth pressure. The relationship between passive earth pressure and displacement of the wall and cohesion is consistent with the deformation characteristic under the earth pressure and the results calculated by the finite element method, but it still needs to be verified experimentally.

B. Mei's Method

The earth pressure acting on the retaining wall may be any value between the active earth pressure and the resting earth pressure or between the static earth pressure and the passive earth pressure. It is generally believed that the displacement is (0.001 to 0.003) H (H is the height of the retaining wall) when the pressure reaches active earth pressure, s_a is used to stand for it; And the time the pressure reaches passive earth pressure the displacement is about (0.02 ~ 0.05) H, we call it s_p. The amount of displacement required for different types of soils to reach different stress states in different displacements is shown in Table 1.

TABLE I. THE AMOUNT OF DISPLACEMENT CORRESPONDING TO DIFFERENT EARTH PRESSURES

Type of soil	Stress state	Form of Displacement	Displacement
Sandy soil	Active	Translation	(-0.001~-0.005)H
	Passive	Translation	>0.05H
	Active	Rotation	(-0.001~-0.005)H
	Passive	Rotation	>0.1H
Clay	Active	Translation	(-0.004~-0.010)H
	Passive	Rotation	(-0.004~-0.010)H

Based on the above analysis, the earth pressure model considering the deformation is established as follows:

$$p = \left[\frac{k(\varphi)}{1+e^{-b(s_a,\varphi)s}} - \frac{k(\varphi)-4}{2}\right]p_0 \quad (3)$$

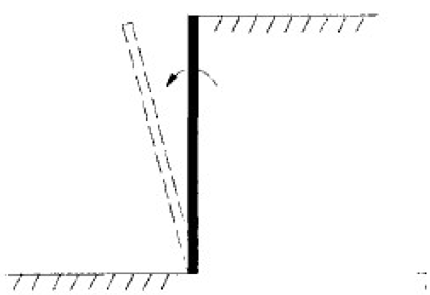
where: p_0 is the half of static earth pressure; $k(\varphi)$ is a function of internal friction angle; $b(s_a,\varphi)$ is the function of active earth pressure displacement and internal friction angle, and $b>0$.

For k , b and p_0 , they can be obtained by inversion of the three points $(p1, s1)$, $(p2, s2)$, $(p3, s3)$ obtained by the in situ test.

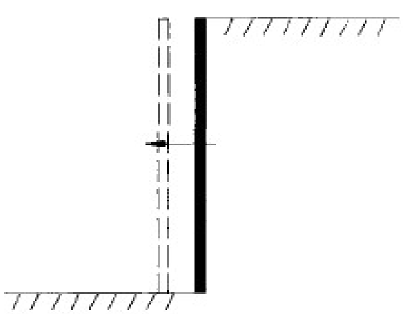
This model is a good reflection of the relationship between earth pressure and deformation, and the coefficient of the model can be calculated by the earth pressure coefficient and the displacement corresponding to the active earth pressure.

III. ACTIVE EARTH PRESSURE OF RIGID RETAINING WALL UNDER ACTIVE DISPLACEMENT

In order to compare the effect of the above two methods in practical engineering, the numerical simulation tool ABAQUS is used to study the size and distribution of the active earth pressure of backfill behind wall under the typical displacement mode, such as RB and T displacement mode (Figure.2). And the results of the test done by Fang [8] in 1986 on the wall under different displacement modes are used for comparison.



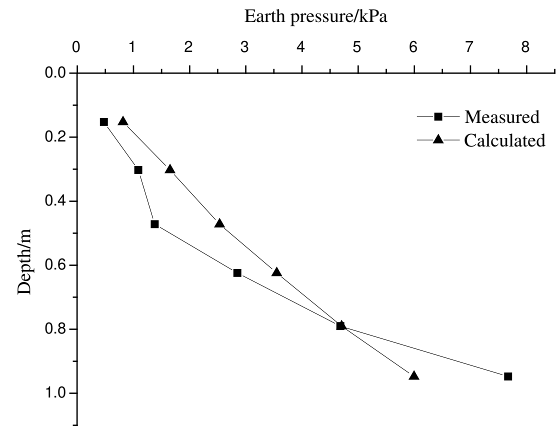
(A) RB mode



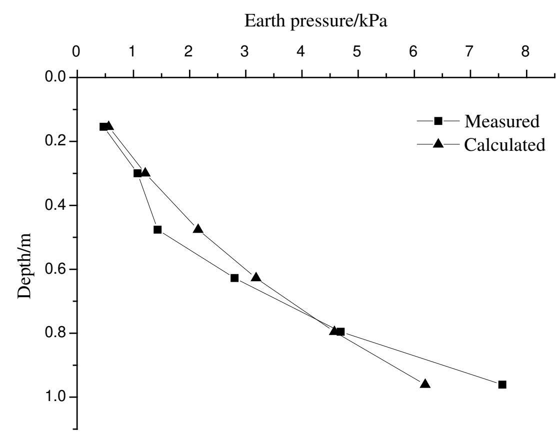
(B) T mode

FIGURE II. TYPICAL DISPLACEMENT MODE OF RIGID RETAINING WALL

Lu's and Mei's methods of calculating earth pressure have showed the earth pressure distribution of the retaining wall along along the height direction under different displacement modes. Before the earth pressure reaches the active equilibrium state, the earth pressure behind the retaining wall obviously loses the linear distribution of earth pressure at rest, showing the law of nonlinear distribution. And different displacement patterns have different distribution rules, we can see, the traditional earth pressure calculation model which has not considered the wall rotation mode is very limited. The earth pressure distribution curves of the retaining wall under the RB and T displacement modes are calculated and compared with the results of Fang's tests (Figure.3 and Figure.4).

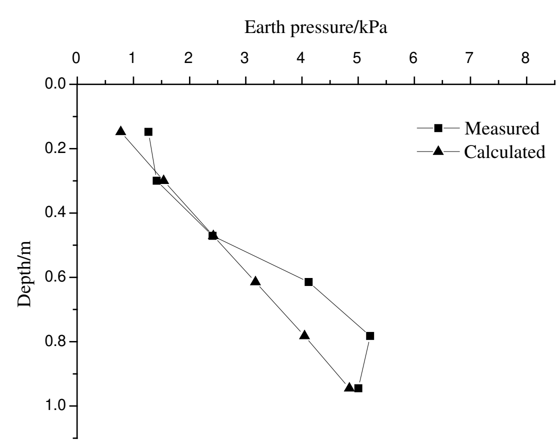


(A) Comparison between Lu's method and measured

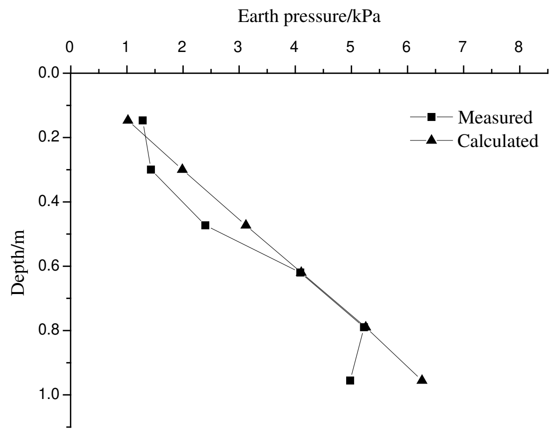


(B) Comparison between Mei's method and measured

FIGURE III. RB MODE $\theta = 0.0005rad$



(A) Comparison between Lu's method and measured



(B) Comparison between Mei's method and measured

FIGURE IV T MODE $d = 0.0001m$

From the above two figures we know that when the soil reaches the active state, the earth pressure distribution shows obvious nonlinear, and the distribution is affected by the wall movement mode.

Under the RT mode, after the wall around the foundation has a slight rotation, the horizontal earth pressure decreases rapidly. With the further rotation of the wall, the active limit state of the soil downward, the earth pressure inflection point will also move down.

Under the T mode, the variation law of the horizontal pressure coefficient of different soils is consistent, and it is declining in the process of wall deformation. This may be due to the T displacement mode, the wall displacements along the height direction are the same, so the wall after the soil run into the active limit of the state at the same speed, and the horizontal pressure coefficient is almost synchronized to achieve a stable value.

It can be seen from the figures that the change of earth pressure undergoes a change process from linear to nonlinear and then to near linear. Mei's method can better reflect the development of active earth pressure distribution along the wall with the displacement of the wall, especially in the static earth pressure, it can better reflect the changes in the development of soil.

IV. CONCLUSION

Based on the experimental model and data of Fang, the test data is processed by Lu's and Mei's calculation method, and the calculated results are compared with the measured data. Although there are some errors in the graph or the calculation data, it is very close to the test data. And in the experiment there are systematic errors and human error, so it shows that the Lu's and Mei's calculation methods are still operational.

Considering the active earth pressure in the RB and T displacement modes, Mei's method is more close to the test data, which reflects the change of the earth pressure with the displacement of retaining wall better.

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