Verification Analysis of the Relationship Between Soil Pressure and Displacement of Retaining Structure

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Abstract. Variation laws of earth pressure accounting for the displacement of retaining wall can be well described by mathematical fitting in the study of the relationship between earth pressure and retaining wall displacement. The common mathematical function expressions of earth pressure displacement of retaining wall can be divided into sinusoidal function model, exponential like function model, hyperbolic function model, fitting function and semi-numerical and semi-analytical model function, etc. The characteristics and shortcomings of the current expression of earth pressure displacement function are summarized. Then combined with the field test and model test, the applicability and characteristics of various mathematical functions in predicting the displacement of earth pressure with retaining structures are analyzed. The results show that when the displacement is small, the sinusoidal function model and the quasi-exponential function model are close to the measured results. When the displacement of retaining structure is large, the fitting results of hyperbolic model and semi-numerical and semi-analytical model are better. For the prediction of earth pressure displacement relationship in passive area, the buried depth has a great influence. And the error between the theoretical value and the actual value has a great influence on the fitting result of the model.

Keywords: Soil Earth Pressure Displacement Relation, Function Expression, Active Earth Pressure, Passive Earth Pressure.

The study of earth pressure has always been a complicated subject. Most of the studies are conducted based on the classical Rankine and Coulomb theories to analyze the ultimate earth pressure when it reaches the failure state. However, in order to reach the state of the ultimate earth pressure, the corresponding deformation proves to be larger, which usually exceeds the allowable deformation of the project. Therefore, the classical theory of limit earth pressure fails to reflect the intermediate state of change of earth pressure with the displacement of barricade, which fails to guide the engineering based application. Therefore, it is of great theoretical and engineering application value to study the relationship between the whole change process of earth pressure and the displacement of retaining structure.
Terzaghi, the founder of soil mechanics, first gave a diagram of the relationship between earth pressure and deformation [1], as shown in Figure 1. Subsequently, many scholars carried out a series of field tests [2,3] and laboratory model tests [4-7] on the relationship between earth pressure and deformation. On the basis of field test and indoor model test, the influence of soil properties, mode of barricade, height of barricade and stiffness of barricade on earth pressure was ignored, and the influence of displacement of retaining wall was mainly analyzed. Some scholars proposed a theoretical method to describe the soil deformation law of wall back by various nonlinear pressure displacement curves [8-10] and the expression of the relation function of earth pressure displacement. Each kind of fitting function has its own characteristics, and its applicable scope is not specified. Analyzed the influence of the size of the retaining wall displacement, some scholars have put forward various nonlinear description of back pressure displacement curve method of soil deformation law theory [10] the relationship between earth pressure and displacement function expression. Each kind of fitting function has its own characteristics, and its applicable scope is not specified.

In this paper, the calculation method of earth pressure of barricade is initially studied, and various fitting function expressions of displacement relation of earth pressure are summarized, which can be divided into sinusoidal function model, quasi-exponential model, hyperbolic function model, fitting function model and half duty analytic model. The typical model is compared with the in-situ test and the indoor model test to analyze the rationality and applicability of the fitting function, and point out the next research direction.

![Figure 1. Relationship curve between earth pressure and retaining wall displacement](image)

1. Expression of Earth Pressure and Displacement Function

Based on the model test and theoretical study of retaining structure, the experimental study demonstrates that the earth pressure curve is pertinent to the displacement of retaining structure. As the retaining structure moves uniformly, the soil behind the wall gradually yields with the increase of the displacement of the retaining structure. As a sliding fracture surface is formed in the soil behind the wall, the soil reaches the ultimate state. Providing the displacement of retaining structure is zero, the earth pressure means the initial static earth pressure, and the soil is in elastic equilibrium state. For some reasons, the retaining structure has corresponding lateral deformation (deviating from or pointing to the fill), which causes the relaxation or increase of the body stress, and the static earth pressure gradually transforms into the non-limit earth pressure. Assuming that the lateral displacement reaches the displacement required by the soil in the ultimate state, the soil is in the plastic limit equilibrium state, and the soil pressure is the dynamic or passive soil pressure. Since this balance is plastic equilibrium, the soil stress will not decay or increase with the continuous increase of displacement.

Therefore, when the retaining structure moves away from the soil behind the wall or toward the soil behind the wall, causing the whole soil to become loose or compressed in the horizontal direction, and thus making the horizontal soil pressure to be relax or increase, $p_r$ is defined as relaxation pressure, $p_s$ serves as compression pressure, and $p_0$ as the static earth pressure when displacement is not
produced by soil. According to Figure 1, the earth pressure equation can be described in the following form to expound the curve of the relationship between earth pressure and displacement:

\[ p_{a}^\prime = p_0 - p_r \] (1)
\[ p_{p}^\prime = p_0 + p_s \] (2)

In the equation: \( p_{a}^\prime \) is the earth pressure under positive state; \( p_{p}^\prime \) is the earth pressure in the passive state.

Thus, it can be seen that the relationship between earth pressure and displacement depends on the relationship between relaxation pressure and compression pressure and displacement. The relationship between displacement and earth pressure can be obtained providing that the relationship between relaxation pressure and compression pressure and displacement can be established correctly. When the soil mass is in ultimate equilibrium, that is, when the displacement of retaining wall reaches the maximum value, the corresponding ultimate relaxation pressure and compression pressure are:

\[ p_{0a_{rmax}} \] (3)
\[ p_{0s_{max}} \] (4)

In the equation, \( p_{acr} \) stands for the positive earth pressure and \( p_{acr} \) is the passive earth pressure.

In order to consider the relationship between displacement and relaxation pressure and extrusion pressure, the displacement functions \( K_a \) and \( K_p \) are introduced here, so that:

\[ p_r = K_a \cdot p_{r_{max}} \] (5)
\[ p_s = K_p \cdot p_{s_{max}} \] (6)

Based on the properties of displacement function \( K_a \) and \( K_p \), the relationship between relaxation pressure and extrusion pressure and displacement can be expressed as sinusoidal function model, exponential like function model, hyperbolic function model, fitting model and semi-numerical and semi-analytical model.

1.1 Sine Function Model

The sinusoidal function model is one of the earliest models to be studied. Because the sinusoidal function model is relatively intuitive and simple relation curve of reacted earth pressure, the earth pressure equation can be expressed as:

\[ p = b_1 \sin(a_1 \cdot \delta) \] (7)

In the equation, \( a \) and \( b \) represent sine function coefficients; \( \delta \) signifies the displacement.

According to the characteristics of excavation of foundation pit, Zhang Wuyu and Xu Riqing established the calculation equation of earth pressure with sinusoidal function simulation as displacement is taken into account as well as static earth pressure to active earth pressure:

\[ p_{a}^\prime = p_0 - \sin\left(\frac{\pi\delta}{2\delta_{cr}}\right)(p_a - p_0) \] (8)

Static earth pressure to passive earth pressure:

\[ p_{p}^\prime = p_0 + \sin\left(\frac{\pi\delta}{2\delta_{cr}}\right)(p_p - p_0) \] (9)

Where, \( \delta_{cr} \) is the displacement of the retaining structure when it reaches the ultimate earth pressure.
1.2 Exponential-Like Function Model

The earth pressure relation curve reflected by the exponential function model can be expressed by the following expression:

\[ p = b_2 \cdot \delta \cdot e^{a_2 \cdot \delta} \]  

(10)

In the equation, \( a_2 \) and \( b_2 \) represent the coefficients of exponential-like functions.

Chen Yakai studied the changes of flexural deflection of the earth pressure acting on the retaining structure in foundation pit engineering. This relationship can be described by an exponential function, from static earth pressure to active earth pressure:

\[ p_a' = p_0 - \frac{\delta}{\delta_{cr}} e^{a \left(1 - \frac{\delta}{\delta_{cr}}\right)} (p_a - p_0) \]  

(11)

Static earth pressure to passive earth pressure:

\[ p_p' = p_0 + \frac{\delta}{\delta_{cr}} e^{a \left(1 - \frac{\delta}{\delta_{cr}}\right)} (p_p - p_0) \]  

(12)

Where: \( a \) is the parameter related to soil properties and other factors, and \( 0 \leq a \leq 1 \). Tian Peixian believes that the value of parameter \( a \) is different in different soil layers, and there is no standard definition of the value at present. In this paper, for the convenience of comparison, parameter \( a \) takes the value of 0.9.

Chen Caitong proposed a hyperbolic-like tangent function model considering the relationship between soil relaxation pressure and compression pressure and displacement when lateral deformation and displacement of supporting structure occurred. The active zone and passive zone can be respectively expressed as:

\[ p_a' = p_0 - \tan^\frac{1}{3} \left[ \tan^2 \left( \frac{\pi}{4} + \frac{\varphi}{2} \right) \left( \delta_{cr} \right)^2 \right] (p_a - p_0) \]  

(13)

\[ p_p' = p_0 + \tan^\frac{1}{3} \left[ \tan^2 \left( \frac{\pi}{4} + \frac{\varphi}{2} \right) \left( \delta_{cr} \right)^2 \right] (p_p - p_0) \]  

(14)

In the equation: \( \varphi \) is the value of the internal friction angle of the soil layer.

1.3 Hyperbolic Function Model

Hyperbolic function model is one of the models most studied by scholars at present. Hyperbolic model was first proposed by Duncan-Chang. The earth pressure f equation can be expressed as:

\[ p - p_0 = \frac{\varepsilon}{a + be} \]  

(15)

In the equation, \( \varepsilon \) represents axial strain; \( a \) and \( b \) represent the hyperbolic function coefficients. Selecting reasonable values of \( a \) and \( b \) is the key and difficult point to accurately describe the hyperbolic model.

Duncan et al. [11] introduced the failure ratio \( R_f \) and soil strain was concerted into displacement combined with Duncan-Chang model. The equation of passive displacement earth pressure proposed is as follows:

\[ p - p_0 = \frac{\delta}{K_{max} \cdot P_{cr} \cdot R_f} \]  

(16)

In the equation, \( K_{max} \) signifies the maximum resistance coefficient of soil, \( R_f \) is the failure ratio, \( P_{cr} \) means the earth pressure in ultimate state.

Xia Tang et al. introduced parameter \( \lambda \) optimization based Duncan model to make the initial modulus \( E_i \) of \( \lambda K_{max} \) and Duncan-Chang to be equal, and the application range of Equation (13) is extended to the whole displacement process of retaining wall.
Lu Ruiming et al. proposed a calculation model of earth pressure using hyperbola to fit the relationship between displacement of retaining structure and earth pressure, which can be expressed as:

\[ p - p_0 = \frac{\delta}{k_i} \frac{\delta}{p_{cr} - p_0} \]  

(17)

In the equation: \( k_i \) is the horizontal coefficient of subgrade reaction of soil. When active displacement occurs, \( k_i = k_a \). When passive displacement occurs, \( k_i = k_p \). The hyperbolic displacement earth pressure equation proposed by Jiang Zhiqiang et al. for active and passive sections is as follows:

\[ p_a' - p_0 = \frac{\delta}{(1 - B_1)\delta_{acr}} + \frac{B_1\delta}{p_a' - p_0} \]  

\[ B_1 = 1 - \frac{p_a' - p_0}{k_{ai}\delta_{acr}} \]  

(18)

\[ p_p' - p_0 = \frac{\delta}{(1 - B_2)\delta_{pcr}} + \frac{B_2\delta}{p_p' - p_0} \]  

\[ B_2 = 1 - \frac{p_p' - p_0}{k_{pi}\delta_{pcr}} \]  

(19)

In the equation, \( k_{ai} \) and \( k_{pi} \) are respectively the initial tangent slope of the active and passive segments of the displacement earth pressure curve of the retaining wall, namely, the coefficient of subgrade reaction, and \( k_{ai} \neq k_{pi} \).

Zhang Wenhui et al. chose the hyperbolic function and introduced the correction term to eliminate the significant difference between the calculated value and the actual value. The earth pressure formulas proposed in the active zone and the passive zone are as follows:

\[ p_a' - p_0 = \frac{\delta}{k_{ai}} + C\delta_{acr} \left( p_a' - p_0 \right) \]  

\[ p_p' - p_0 = \frac{\delta}{k_{pi}} + C\delta_{pcr} \left( p_p' - p_0 \right) \]  

(20)

\[ C = \frac{R_f}{(R_f - 1)\sigma_3 + p_{cr} - p_0 R_f} \]

In the equation: \( R_f \) is the failure ratio. \( \sigma_3 \) is the vertical stress of soil at the point. And \( k_{ai} \) and \( k_{pi} \) are respectively the initial tangent slope of the active segment and the passive segment of the retaining wall displacement earth pressure curve, namely, the coefficient of subgrade reaction.

Yao Haiming and Hu Zhiping et al. proposed the hyperbolic displacement earth pressure formula under active state as follows:

\[ p_a' = p_0 - \frac{2\delta}{\delta_{acr}} \frac{\delta}{p_a' - p_0} \]  

(21)

In the equation, \( \delta_{acr} \) is the displacement of retaining wall soil to active earth pressure.

1.4 Fitting Function Model

Lu Guosheng, integrating the Rankine earth pressure theory and the internal friction angle and cohesion of soil, put forward the equation of displacement earth pressure as follows:
\[
p_a' = \frac{p_0}{1 + \frac{1}{\Delta_e} \ln \left( \frac{k_p + k_{acr} \Delta_e}{k_a} \right)} - \frac{2c \Delta_e}{k_p + k_0 + k_{acr} \Delta_e}
\]
(22)

\[
p_p' = p_0 \left[ 1 + \frac{3 \Delta_e}{k_p + 1.16k_{acr} \left( k_p + 1.16k_{acr} \right) / \left( 1.76k_p^2 \right)} \right]
\]
(23)

Where, \( g \) is the weight of soil; \( k_a, k_0 \) and \( k_p \) are respectively the main positive earth pressure coefficient, static lateral pressure coefficient and passive earth pressure coefficient. \( C \) is the cohesion of the fill.

The positive earth pressure coefficient \( k_a \), passive earth pressure coefficient \( k_p \) and static earth pressure coefficient \( k_0 \) are determined by soil mechanics:

\[
k_a = \tan^2 \left( 45^\circ - \frac{\varphi}{2} \right)
\]
(24)

\[
k_p = \tan^2 \left( 45^\circ + \frac{\varphi}{2} \right)
\]
(25)

\[
k_0 = 1 - \sin \varphi
\]
(26)

In the equation: \( \varphi \) is the internal friction angle of soil. By combining the equations (22), (23), (24), (25) and (26), the relationship curve of the model in reference [25] can be determined.

1.5 Semi-Numerical and Semi-Analytical Model

Based on the analysis of the field measured earth pressure data, Mei Guoxiong et al. proposed the equation for predicting the displacement earth pressure curve as follows:

\[
p = \frac{p_0}{2} \left( \frac{k(\varphi)}{1 + e^{-n(\varphi)}} - \frac{k(\varphi) - 4}{2} \right)
\]
(27)

In the equation, \( b(\varphi) \) is the function of active limit displacement of retaining wall and friction angle in soil body. \( k(\varphi) \) is the function of the internal friction angle of soil.

On the basis of Equation (27), Zai Jinmin et al. obtained the Rankine earth pressure equation of sand considering the displacement of retaining wall as follows:

\[
p = \left( \frac{B}{1 + e^{-n(\varphi)}} \right) \left( \frac{B - 4}{2} \right) \left( 1 - \sin \varphi \right) \gamma h
\]

\[
A = \frac{t \gamma^2 \left( 45^\circ + \varphi / 2 \right) - t \gamma^2 \left( 45^\circ - \varphi / 2 \right)}{t \gamma^2 \left( 45^\circ + \varphi / 2 \right) - 2 \left( 1 - \sin \varphi \right) + t \gamma^2 \left( 45^\circ - \varphi / 2 \right)}
\]

\[
B = \frac{4t \gamma^2 \left( 45^\circ + \varphi / 2 \right)}{1 - \sin \varphi} - 4
\]
(28)

In the equation: \( \varphi \) is the friction angle of soil, \( \varphi' \) is the effective friction angle of soil, \( \gamma \) is the bulk density of soil. \( h \) is the burial depth of points for the soil layer.

1.6 Discussion

According to the mathematic function expression of earth pressure for retaining structure displacement studied by predecessors, the mathematic characteristics of the function is used in the mathematic function expression equation to express the variation trend of earth pressure displacement, and then to determines the parameters according to various working conditions. Considering the form, range and rationality of the current earth pressure displacement relation curve, the following points are summarized:
1) The displacement earth pressure equation studied by predecessors is characterized with the same purpose, that is, the earth pressure of the retaining structure in the non-limit state can be obtained by using a certain mathematical function to describe the variation law of earth pressure with displacement of the retaining wall in Figure 1. The mathematical expression is easy to use, clear, which has been applied in engineering design.

2) At present, there are mainly two methods for mathematically fitting equation of tectonic displacement earth pressure. The former is based on the definition of the relationship function between additional stress and displacement. As the static earth pressure condition is taken into account, the non-limit active earth pressure and passive earth pressure of soil are determined, such as the sinusoidal model, the quasi-exponential model and the hyperbolic model. The latter, based on model test or field test data, constructs the expression of earth pressure displacement and fits the curve of test results. Specific function parameters are introduced to express the influencing factors and has a wider research scope.

3) Mathematical fitting equation for displacement earth pressure focuses on studying the influence of retaining wall displacement on earth pressure. When considering the influence of soil property, time effect, space effect of foundation pit excavation, water seepage and multi-factor coupling effect, etc., it is generally realized by the recombination of different types of mathematical functions, which is rarely studied at present.

4) At present, the boundary conditions and initial values are satisfied and the parameters are clearly defined according to the actual measurement and model test of a certain project, so there is little theoretical basis and it cannot be widely used as a unified expression.

2. Case Verification

2.1 Comparative Analysis of Field Tests

The maximum width of the foundation pit of Tianlin Road in Shanghai is about 20.0m and the maximum excavation depth is about 17.1m. The simplified foundation soil composition of the excavation layer in this section is shown in Table 1.

| Soil property | moist unit weight γ/(kNm^-3) | Soil cohesion c/kPa | Frictional angle φ/(°) |
|---------------|--------------------------------|---------------------|-----------------------|
| Silty clay    | 18.5                           | 19.0                | 19.0                  |

On the project site, in situ tests such as lateral pressure tests were carried out, and the test results when the soil depth was 4.5m and 10m were taken to obtain the value of ΔP and ΔR, where ΔP represents the difference between the test pressure and the initial pressure, and ΔR represents the difference between the test pressure and the initial pressure corresponding to the radial displacement.

The data of different soil depths were obtained by Wang Hongxin's side pressure test, and the parameters of hyperbolic function were fitted in the literature, so the hyperbolic function could be determined. Since the displacement and earth pressure in the ultimate state were not measured by this in-situ test, the ultimate displacement should be determined according to the previous field test data. It is now assumed that the ultimate displacement is about 0.05% of the retaining wall height of the foundation pit. Then the Rankine passive earth pressure at different depths can be determined by soil mechanics:

\[ p_p = \gamma Z k_p + 2c \sqrt{k_p} \]  \hspace{1cm} (29)

In the equation, \( Z \) represents soil depth; \( k_p \) is the passive earth pressure coefficient.
Therefore, the relation curves of sinusoidal function model, quasi-exponential model and literature model can be determined, and the results obtained by the above calculation method can be compared with the in-situ test results of Tianlin Road in Shanghai.

It can also be found that the fitting results of the four models are better presented when the burial depth is small. As the burial depth is large, the variation trend of earth pressure displacement of Chen Yankai’s exponential model and Zhang Wuyu's sinusoidal function model are proved with more difference with the experimental results in variation trend. The passive earth pressure could not be fully given full play due to the influence of many factors in the field engineering, so the actual earth pressure should be expressed by the failure ratio. However, in field tests, engineering experience and Rankine earth pressure theory are often used to determine the ultimate displacement and the ultimate earth pressure, ignoring the influence of failure ratio. As a result, the specific parameters of the function cannot reflect the actual situation. Therefore, the earth pressure displacement curve of this model is quite different from the actual results.

2.2 Comparative Analysis of Model Tests

Model test 1

This paper refers to the test results of passive earth pressure model of Fang et al.[5], and the test results under the retaining wall translation mode are adopted for the data. The effective wall height of the model is $H=0.55m$, the unit weight of soil is $\gamma = 1.5kN/m^3$, the filling of wall back is sandy soil, and the internal friction angle of the fill is $\varphi = 30.9^\circ$. Lubricating layer is used to reduce the friction between the side wall and the backfill, so the friction angle between the wall and the soil can be ignored. See reference [5] for the specific test process.

![Figure 2. Fang passive earth pressure test device](image)

Due to the displacement of the retaining wall away from the soil, the earth pressure behind the wall gradually decreases from the static earth pressure at the beginning, and finally decreases to the active earth pressure. According to the literature, the partial curve of active earth pressure at various depths when the retaining wall in the T-displacement mode is moving, and the earth pressure distribution behind the wall in different displacement stages is obtained. It can be seen that the soil at different depths almost reaches the state of positive earth pressure at the same time. In different displacement stages, the distribution of earth pressure is basically shown with linear relationship until the soil fails. Literature has analyzed that when the displacement of retaining wall meets $S_{max}=1.41.6mm$, $S/H=0.00140.00_{max}$, and the soil behind the wall reaches an active state, and then the active earth pressure coefficient is $k_a = 0.28$. Therefore, the static earth
pressure of the soil, the positive earth pressure at different depths and the displacement of the retaining wall corresponding to the active earth pressure $\delta_{cr}=0.0014 \sim 0.0016H$ can be determined. However, due to the constraint effect of the lower boundary and the left boundary of the model, the calculation results of earth pressure at the bottom of the retaining wall have certain deviation. Therefore, the numerical simulation results of measuring point depths $H=600\text{mm}$, $H=700\text{mm}$ and $H=900\text{mm}$ are selected to compare and analyze the above calculation methods with the results of model test.

The fitting results of Chen Yankai's active earth pressure model test show that the initial tangential modulus of the predicted earth pressure is too large and the predicted results are too low. The earth pressure predicted by Zhang Wuyu's sinusoidal function model in the ultimate displacement range is relatively small, and the error decreases with the increase of the retaining wall displacement, and the influence of different depths is not obvious. In the positive state, the predicted value of Chen Yakai's quasi-exponential model for small displacement is lower and the deviation is larger, but when approaching the ultimate displacement, the curve fits well with the experimental results, which can well represent the gradual change process of active earth pressure. The tangential modulus of the relationship curve predicted by Chen Caitong's hyperbolic-like tangent function model is large, the curve is steep with large deviation with the experimental results. Lu Ruiming's hyperbolic model deviates greatly from the experimental results, and the predicted initial tangential modulus is very large, so it is not suitable for predicting the earth pressure under the active state in this experiment. The prediction results of Yao Haiming's hyperbolic model can reflect the variation process of earth pressure displacement in $0 \sim \delta_{cr}$, which is in good agreement with the experimental results. But if $\delta \geq \delta_{cr}$ occurs, the function expression will lose its meaning, its result can not be used as the forecast value to guide the project. Lu Guosheng fitting function model under two kinds of depth of active earth pressure under the states of displacement fitting result is not ideal, which is possibly the result of ignoring the filled soil angle of internal friction along with the change of displacement of the trend of change, and the coefficient of positive earth pressure $k_a$ and passive earth pressure coefficient $k_p$ and the coefficient of static earth pressure $k_0$ at the theoretical calculation formula is not suitable for application in the model. The earth pressure curve predicted by Mei Guoxiong's model matches the experimental results, and the predicted earth pressure matches with the experimental results.

3. Conclusion
After analyzing the calculation theories of various earth pressures and the results of field tests and model tests, the following conclusions are drawn as:
1) The earth pressure displacement relation of the retaining structure usually takes the static earth pressure as the demarcation point, and the curve representation of the earth pressure displacement of the retaining structure in the positive or passive state is expressed by the way of mathematical function construction. At present, there are many expression functions, all of which aim to describe the curve law of earth pressure displacement more accurately.
2) The mathematical fitting equations of earth pressure mainly include sinusoidal function model, exponential like function model, hyperbolic function model, fitting function model and semi-numerical and semi-analytical model in the form of function. The main difference of mathematical fitting formulas lies in the choice of function form and the difference of undetermined parameters and values, which leads to the diversity of mathematical fitting formulas and the universality of research. Reasonable boundary conditions, initial values and clear meaning of parameters can accurately and truly reflect the interaction between retaining wall and soil.
3) When the displacement of retaining structure is small, the prediction results of most models, such as sinusoidal function model and hyperbolic model, are close to the measured results. When the displacement of retaining structure is large, the fitting results of quasi-exponential model and half duty analytic model are better. And it can be found that the deeper the burial depth of the fitting results are more ideal.
4) There are few studies on the influencing factors such as the displacement mode of retaining structure, unsaturated soil, collapsible loess and expansive soil, etc., and the above function expressions are not considered. Therefore, there is a lack of theory and further study is needed.

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