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Studying on the structural design partial coefficients of the inner stability of reinforced earth structures based on the least square principle

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ABSTRACT: According to the determining methods of the structural design partial coefficients, under two basic combinations of loads, the optimum action and resistance partial coefficients are obtained about the inner stability of reinforced earth structures based on the least square principle. They include permanent action partial coefficient γ_G = 1.2, heap load partial coefficient γ_{Q1} = 1.3, vehicle load partial coefficient γ_{Q2} = 1.4, reinforced materials resistance-breakage partial coefficient γ_{R1} = 1.56, resistance-pulled out partial coefficient γ_{R2} =1.52, and the results show reasonable by engineering examples checking. The paper provides a reference to the new code based on probability critical state in reinforced earth structure design.

1 INTRODUCTION

At present, the safety factor codes of fixed value method is applied in the design of reinforced earth structures. Some theoretic defects is recognized in this method and the new design ways is in urgent expectancy. Early in 1992, the design method of probability critical sate expressed by partial coefficients has been required in *Unification Code in Engineering Structure Reliability* promulgated by Construction Ministry. For the design method of probability critical sate expressed by partial coefficients has been applied in more codes related to the reinforced earth structure design and construction, the design expression of structure partial coefficients in reinforced earth structure is more approximately. In this paper, critical state partial coefficients of inner stability bearing capacity of reinforced earth structures will be calculated according to the confirmed method of structure design partial coefficients.

2 CONFIRMATION OF STRUCTURE DESIGN PARTIAL COEFFICIENTS

2.1 *Principal for confirmation of structure design partial coefficients*[1]

Usually, the principal for confirmation of structure design partial coefficients is:

(1) A same effect has the same partial coefficient to kinds of members, and different effects have different partial coefficients.
(2) Different kinds of members have different resistance partial coefficients. The same kind of members has the same resistance partial coefficient under any alterable effect.
(3) To different kinds of moments under different effect ratio, and to structure design with the selected γ_G, γ_Q, γ_R, the calculated reliability index β is closest to the aimed reliability β_0 index.

2.2 *Structural design partial coefficient expressions*

The design partial coefficient expression of bearing capacity critical state is:

$$\gamma_G S_{GK} + \gamma_Q S_{QK} \leq R_K/\gamma_R \quad (1)$$

In it, S_{GK}, S_{QK}, R_K are the standard values of permanent effect, of alterable effect and of structural member resistance; γ_G, γ_Q, γ_R are the partial coefficient of permanent effect, of alterable effect and of structural member resistance.

2.3 *Confirmation of aimed reliable index*

In this paper, the safety grade of general reinforced earth quay structure is No. 2. The reliability index β_0 adopts 3.5 in this paper[2].

2.4 *Confirm the structural design partial coefficient by resistance least square method*[2]

For the l kinds of usual members, there are m simple combination with a permanent effect and an alterable effect (like eternal load + cargo storage load, eternal load + vehicle load), and j ratios of usual alterable effect and permanent effect (like $\rho = 0.1, 0.25, 0.50, 0.75, 1.0, 1.5, 2.0, 2.5$); permanent effect partial coefficient γ_G is selected, and alterable effect partial coefficient γ_Q is assumed to X-values. So, for some kind of simple combination of every member, γ_G and γ_Q have X groups values. The resistance least square method can be used to confirm the structural design partial coefficients. The process is as follows:

(1) To select possible value of a group of γ_G and γ_Q, and to calculate effect S_j for the No. m simple combination of No. l member:

$$S_j = \gamma_G(S_{GK})_j + \gamma_Q(S_{QK})_j,\ j = 1, 2, \ldots J \tag{2}$$

(2) To calculate the member resistance R^*_{Klj} related to the Code:

$$R^*_{Klj} = \mu_{Rlj}/K_{Klj} \tag{3}$$

In this formula, K_{Klj} are the statistical parameters of member resistance, and μ_{Rlj} is the means of member resistance which is calculated by checking points method (in this paper by sub-program) according to aimed reliable indexes, means to effect random viable and variable coefficient of structural resistance.

(3) To calculate resistance partial coefficient γ_{Rl}: The best resistance partial coefficients of member will make

$$H_l = \sum_j^J (R^*_{Klj} - \gamma_{Rl} S_j)^2 \tag{4}$$

least. That will make $\dfrac{\partial H_l}{\partial \gamma_{Rl}} = 0$, then

$$\gamma_{Rl} = \frac{\sum_{j=1}^{J} R^*_{Klj} S_j}{\sum_{j=1}^{J} S_j^2} \tag{5}$$

(4) To calculate resistance R_{Klj}:

$$R_{Klj} = \gamma_{Rl} S_j = \gamma_{Rl}(\gamma_G S_{GK} + \gamma_Q S_{QK})_j \tag{6}$$

(5) To calculate I according to certain group of γ_G and γ_Q.

$$I = \sum_{j=1}^{J} \left(\frac{R^*_{Klj} - R_{Klj}}{R^*_{Klj}} \right)^2 = \sum_{j=1}^{J} \left(1 - \frac{R_{Klj}}{R^*_{Klj}} \right)^2 \tag{7}$$

(6) To take the possible values of X groups of γ_G and γ_Q to formula (5) and (7) in turn, and to obtain X values of γ_{Rl} and I *of No. l.* The γ_G, γ_Q and γ_{Rl} related to the least values of I are the optimized effect and resistance partial coefficients of this kind of member under this kind of combination.

(7) To obtain $m \times l$ γ_Q according to above steps under m alterable combinations to l members. The alterable effect γ_{Qm} can be calculated by method of weighted mean under the same alterable effect γ_{Qml} of different members. Then γ_{Rl} can be obtained by γ_G and γ_Q though step (3).

At the same reason, under any alterable effect combination, γ_{Rl} of a structure can be calculated by method of weighted mean though γ_{RQml} of the same structure. The calculation processes program in this paper according least square method.

3 CALCULATION FOR STRUCTURAL DESIGN PARTIAL COEFFICIENT OF INNER STABILITY OF REINFORCED STRUCTURE

The main point of reinforced structure is the checking computation for inner stability. When carrying out the optimized calculation for structure design partial coefficient of inner stability, two kinds of disable models of reinforced structure shall be considered. These two models are tensile strength failure of reinforced material (tensile failure) and pull-out strength failure of reinforced material[3]. To the characters of reinforced quay structure, two kinds of effects combination will be adopted, that is, eternal load + cargo storage load, and eternal load + vehicle load. The statistical parameters of random variable refer to literature[4] (Liu Ming-wei, 2002).

When considering the random variables are independent, error transmission formula of multivariate function, and distribution probabilistic models and statistic parameters of random variables according with liter[5] (li Yang-hai, 1992), the statistic parameters of action and resistance under any effect combinations and failure models are showed as Table 1 and Table 2.

Table 1. Action and resistance factors of reinforced material statistical table (eternal load + heap load).

Failure Models	Statistic parameters of action and resistance					
	μ_{KG}	δ_{KG}	μ_{KQ}	δ_{KQ}	μ_{KR}	δ_{KR}
Tensile failure	1.10	0.131	0.78	0.174	1.11	0.10
Pull-out failure	1.10	0.131	0.78	0.174	1.10	0.0930

3.1 *Optimized calculation for structural design partial coefficients of stability in reinforced earth*

When the optimized calculation is executed, two failure modes (tensile strength failure and pull-out failure of

Table 2. Action and resistance factors of reinforcing material statistical table (eternal load + vehicle load).

Failure Models	Statistic parameters of action and resistance					
	μ_{KG}	δ_{KG}	μ_{KQ}	δ_{KQ}	μ_{KR}	δ_{KR}
Tensile failure	1.10	0.131	0.696	0.188	1.11	0.10
Pull-out failure	1.10	0.131	0.696	0.188	1.10	0.093

reinforcing material), two effect combinations of quay structure of reinforced earth (eternal load + heap load, eternal load + vehicle load) and ten action ratios (ρ = 0.10, 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00, 2.50) are selected and optimized calculation of structure design partial coefficients are executed according to the statistic results of comprehensive variables showed as Table 1 and Table 2.

In the program of optimized calculation, partial coefficients γ_G of permanent effect will be 1.1, 1.2 and 1.3, and partial coefficients γ_Q of alterable effect will be 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, and 1.6 according to experience.

Result analysis:

(1) Form Fig. 1 and Fig. 2, under 2 effect combinations, after calculating I of two failure models under two effect combinations and comparing 3 curves (γ_G = 1.1, 1.2, 1.3), γ_G = 1.2 is better according to the requirement of minimum I. And the result is similar to Code of Port Engineering.

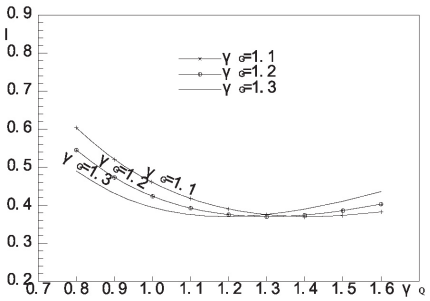

Figure 1. Relationship of I with γ_G and γ_Q first combination of loads: eternal load + heap load.

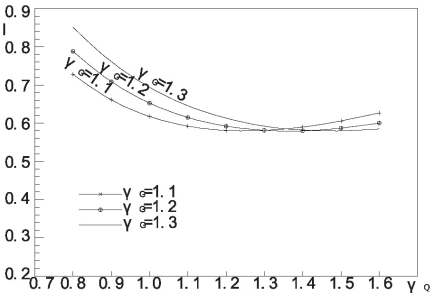

Figure 2. Relationship of I with γ_G and γ_Q second combination of loads: eternal load + vechicle load.

(2) When γ_G = 1.2, according to two effect combinations, after calculating I under two failure models, curve is shown as Fig. 3. From Fig. 3, according to the requirement of minimum I, it can be concluded that the partial coefficient of alterable effect is γ_Q = 1.3 under the first combination (eternal load + heap load) and the partial coefficient of alterable effect is γ_Q = 1.4 under the second combination (eternal load + vehicle load). The results are shown as Table 3.

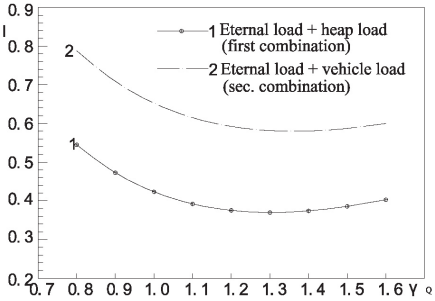

Figure 3. Relationship of I with γ_Q (γ_G = 1.2).

Table 3. Action partial coefficient table.

Effect combination models	Action partial coefficient	
	γ_G	γ_Q
Eternal load + heap load (first combination)	1.2	1.3
Eternal load + vehicle load (Sec. combination)	1.2	1.4

From Table 3, when partial coefficient of permanent effect γ_G is 1.2 after optimization and under the first combination (eternal load + heap load), the partial coefficient of alterable effect γ_Q is 1.3, under the second combination (eternal load + vehicle load), the partial coefficient of alterable effect γ_Q is 1.4. It can be concluded that the variation coefficient t of alterable is higher its partial coefficient is higher and the variation coefficient t of alterable is lower its partial coefficient is lower.

(3) After confirming γ_G = 1.2, γ_Q = 1.3 under the first combination and γ_Q = 1.4 under the second combination, to two failure models, weighted average will be done respectively to the optimized resistance partial coefficients under two combinations. Then optimized resistance partial coefficient of two failure models will be obtained. And the results are shown as Table 4.

(4) For inspecting the optimized partial coefficients, calculation of β of ten kind of ρ under two combinations is executed according expression

Table 4. Resistance partial coefficient table.

Failure model	Aimed reliable index	γ_{RL}
Tensile failure	3.5	1.56
Pull-out failure	3.5	1.52

Table 5. Structures resistance partial coefficient γ_{Ri} & relevant reliability indexes β.

Failure model	γ_{Ri}	β (mean)	Aimed reliable index
Tensile failure	1.56	3.513	3.5
Pull-out failure	1.52	3.510	3.5

(1), $\gamma_G = 1.2$, $\gamma_{Q1} = 1.3$, $\gamma_{Q1} = 1.4$ and the best γ_{Ri} of two failure models. And the averages are done as Table 5.

From Table 5, the calculation results of two failure models are close to the aimed reliable indexes. So the optimizing effect can meet the requirement.

3.2 *Result inspection*

The action and resistance partial coefficients, after optimization in this paper, are applied in representative sections of revetment works of West Segment in Jiangjing of Chongqing. The checking project is tensile checking of reinforcing material under design low-water level. Resistance is $R = 36.0$ KN, effectaction $S = S_G + S_Q = 17.15$ KN, $S < R$ and the assurance factor is 2.10 by constant method, and it can meet the requirement. Resistance is $R = 36/1.56 = 23.08$, effect action $S = 16.30 \times 1.2 + 0.85 \times 1.3 = 20.66$ and $S < R$ with the structural design partial coefficients calculated in this paper, and it can meet the requirement. It can be concluded that the structural design partial coefficients calculated in this paper is appropriate.

4 CONCLUSION AND DISCUSSION

The action coefficients of inner stability of reinforced earth structure calculated by least square method of resistance are: the partial coefficient of eternal load $\gamma_G = 1.2$, the partial coefficient of heap load is $\gamma_{Q1} = 1.3$, the partial coefficient of vehicle load is $\gamma_{Q2} = 1.4$. The corresponding partial coefficients of resistance are: tensile coefficient of reinforcing material is $\gamma_{R1} = 1.56$ and pull-out coefficient is $\gamma_{Q2} = 1.4$.

Through engineering checking computation, the structural design partial coefficients calculated in this paper are appropriate. And it can provide some foundations and reference for emending Design Codes of Enforced Earth Structure.

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