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Evaluation of confining effect in geogrid-reinforced retaining wall related to the practical application

N. YASUFUKU, H. OCHIAI, K. OMINE & Y. NINOMIYA, Kyushu University, Fukuoka, Japan
T. KAWAMURA, Shinshu University, Nagano, Japan

ABSTRACT: Two-dimensional small model tests for simulating the geogrid-reinforced retaining wall is performed to clarify the mobilized additional effect, named as confining effects, comparing with the tensile ones in the model retaining wall. The reinforced effects are estimated by the changes of the active earth pressure in the retaining wall without and with geogrid-reinforcement. The characteristics of the resulting confining effect are investigated paying attention to the vertical spacing and the unit length of geogrid, which is prepared by splitting the reinforced element. Further, the effective way of introducing the confining effect into a Japanese design guideline in geotextile reinforced steep slope embankments is also discussed.

1 INTRODUCTION

In current practical problems, the reinforced effects, which are applied to the stability analysis of a geogrid-reinforced structure, are generally evaluated based on the tensile force of geogrid. Fukuda et al. (1986) reported, based on the in-situ measurements, that the tensile force of a geogrid, which should be mobilized for the stability of a structure, was not mobilized in soil, although the structure maintained sufficient stable. The similar tendency has also been reported by field performance of a geotextile reinforced soil wall with concrete facing blocks (Tajiri et al., 1996). These studies suggest that an additional reinforced effect exists in addition to the tensile effect due to tensile force of a geogrid. The reinforced effects of geogrid-reinforced soil were also experimentally examined by using a special shear test apparatus by authors (Ochiai et al., 1996, 1998; Kawamura et al., 2000). As an important result, the existence of an additional reinforced effect in laboratory tests was confirmed, which was called as a confining effect. The additional reinforced effect mobilized in the reinforced soil mass was independent on the tensile force of a geogrid.

In this study, two-dimensional small model tests for simulating the geogrid-reinforced retaining wall have been performed to clarify the mobilized confining effects in the reinforced model retaining wall, comparing with the tensile ones. The reinforced effects are estimated by the changes of the active earth pressure in the retaining wall without and with the geogrid-reinforcing elements. The changes in resulting confining effect related to the active earth pressure are investigated paying attention to the vertical spacing of reinforcement layer and the unit length of reinforcing element by splitting. Further, based on the experimental properties related to the confining effect, a simple procedure for introducing the confining effect into the current design guideline in geogrid-reinforced steep slope embankments is discussed.

2 ADDITIONAL REINFORCED EFFECT IN SAND MIXED WITH SHORT FIBERS

Figure 1 shows the strength properties of sand mixed with short fibers, which has already been reported by Miki et al. (1997). The results are obtained from a series of triaxial compression tests under various confining pressures, where the length and diameter of the specimen is 200mm and 100mm, respectively,

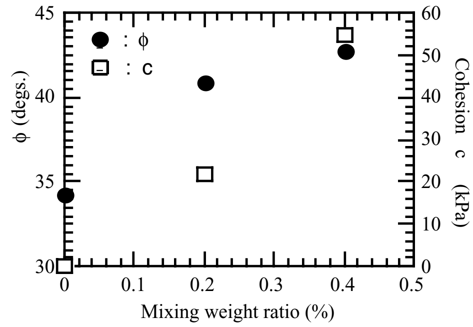

Figure 1 Strength prameters of sand with short fibers "

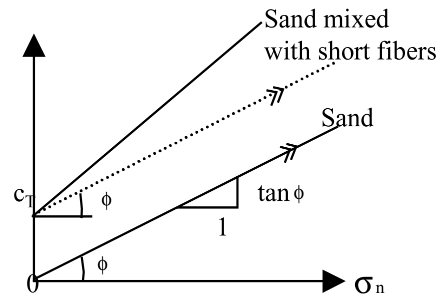

Figure 2 τ-σ_n relationship of sand with short fibers

and the length and diameter of the short fivers mixed in the specimen are 64mm and 0.04mm, respectively. It is clear that both cohesion and internal effective friction angle increase with the increasing mixing weight ratio of short fivers. Based on the results in Figure 1, the Mohr-Coulomb failure envelop for sand mixed with short fivers will be depicted as shown in Figure 2, in which the failure envelop has an cohesion, c_T and a stepper slope, $(1+\beta)\tan\phi$ than that of sand without short fibers. When considering that the short fibers in specimen correspond to a random distribution of discrete reinforcement, it is expected to exist an additional reinforcing effect except for tensile force of

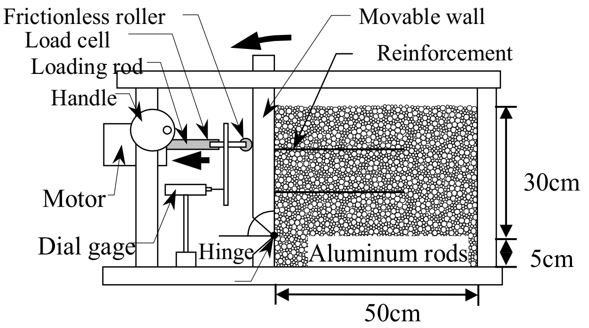

Figure 3. Schematic view of test apparatus.

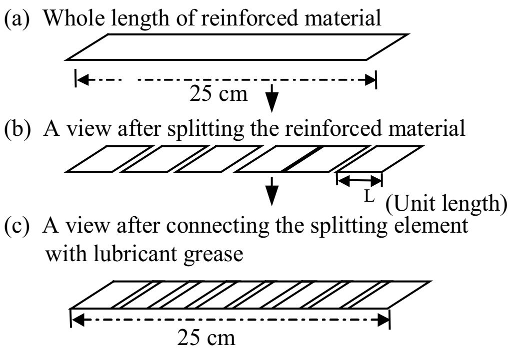

Figure 4 Schematic view of splitting reinforced material

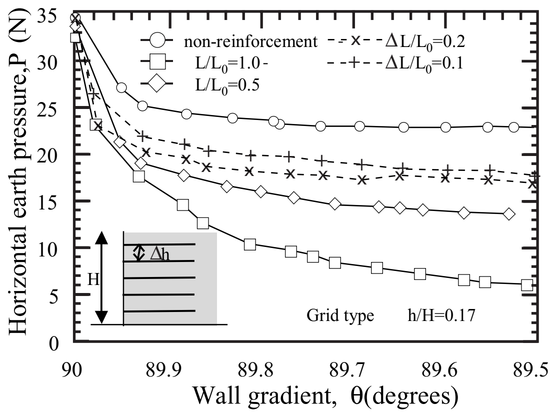

Figure 5 Effect of splitting of grid type reinforcing element on horizontal earth pressure

reinforcement.

In the following, the existence of the additional reinforcing effect in geogrid-reinforced wall structure and the characteristics of the effect are experimentally investigated based on the behaviour of the active earth pressure mobilized in geogrid-reinforced model retaining wall, paying attention to the vertical spacing in each reinforced layer.

3 EXPERIMENTAL OBSERBATIONS OF ADDITIONAL EFFECT

3.1 Test apparatus

Schematic view of the two-dimensional small model test apparatus used in this study is shown in Figure 3, for measuring the earth pressure of Aluminum rods stratum with split reinforcing elements in the geogrid-reinforced retaining wall. The length and effective height of the model ground are 50cm and 30cm, respectively. The vertical wall, which is supported by a loading rod with a frictionless roller and a load cell, can be rotated to the left hand-side in relation to the hinge joint. The motor through the loading rod controls the speed of the movement of the wall. The specimen is made of two types of aluminum rods, in which the diameters are 1.6mm and 3.0mm with the length of 50mm, where both rods are mixed and the three-fifth of them per weight is in 1.6mm Aluminum rod. The horizontal deformation and force acting on the wall during the movement are measured by a dial gage and a load cell, respectively, which are mounted to the loading rod. Two types of plastic materials are used as a model reinforced element, in which one is sheet type plastic film that is made of a smooth transparency sheet and the other is a grid type plastic material. The length of each element horizontally installed in the specimen was chosen as 25cm in length.

3.2 Test conditions

Two-dimensional small model tests are performed for simulating the geogrid-reinforced retaining wall. The reinforced effects are qualified by changes of an active earth pressure in the retaining wall without and with reinforced elements, which are easily calculated by the measured horizontal force. The changes in resulting reinforced effect are investigated, paying attention to the vertical spacing of each layer of reinforced elements, h and the unit length of the split reinforcing element L, which is prepared by cutting. However, even though a reinforcing element is split into two pieces, three pieces, five pieces and ten pieces by cutting, the whole length, L_0 is always kept constant as 25cm. It is noted that all the reinforcing elements are horizontally installed between the top of the specimen and the position of the hinge joint, in which the vertical spacing of each layer of reinforcing elements was always kept constant. Figure 4 shows the schematic view of a reinforced element split by cutting. The sheet type reinforced elements without and with splitting are shown in Figs.4(a) to (c), respectively, where L is the unit length of a piece of reinforcing element. Each piece of reinforcing element is put one upon another with lubricant grease to keep the total length of 25cm. In experiments, L/L_0 and h/H are changed in the range of 1.0 to 0.1 and 0.09 to 0.5 respectively.

3.3 Changes in reinforcing effect by splitting

Figure 5 shows the typical test results of the horizontal earth pressure against the angle of retaining wall, in Fig.3, in which the wall is counterclockwise rotated by the movement of the loading rod. The results of the case in grid type reinforcing elements laid in five layers with same vertical spacing are shown in this figure, together with the result without any reinforcing elements. Note that the difference in the results with reinforcing elements is in the length of a piece of split element. It is clear that 1) the horizontal earth pressure, P, for all cases gradually decreases with the decreasing wall gradient, , and then converge a certain value in each case, and 2) the magnitude of the

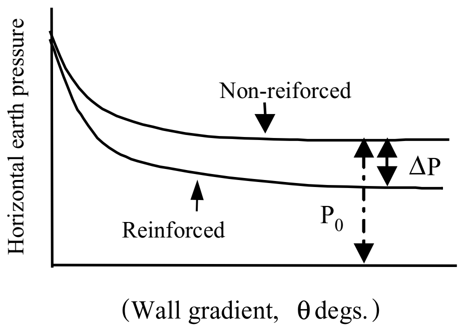

Figure 6 Definition of parameters to evaluate confining effect

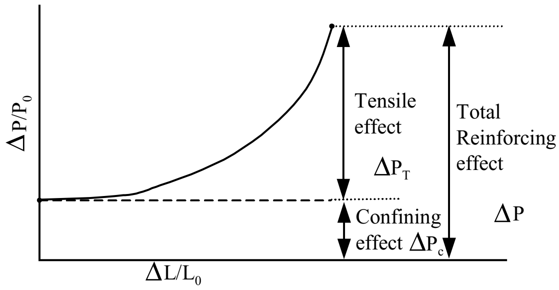

Figure 8 Definition of reinforced effects due to reduction of active earth pressure

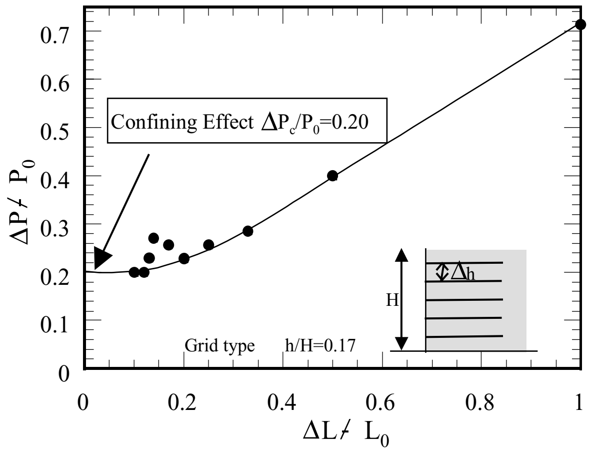

Figure 7 Relationship between reinforced effect and normalized unit length of reinforcing element

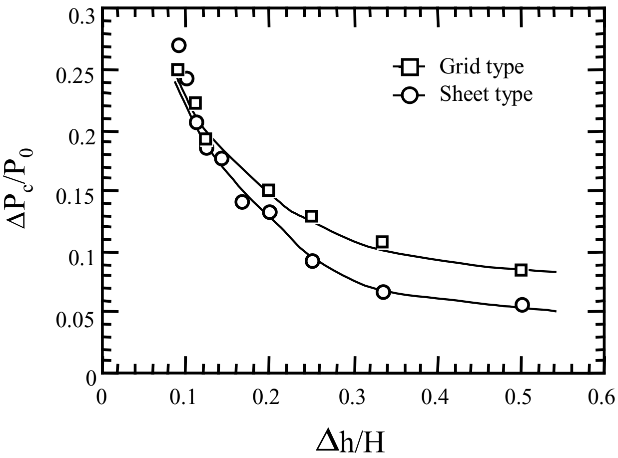

Figure 9 Relationship between confining effect and normalized vertical spacing in each layer

converged P increases as ΔL becomes smaller, that is, the number of the split reinforcing element becomes greater. This means that the reinforced effect decreases with the decreasing ΔL. One of the main reasons is considered to be in the reduction of the tensile force mobilized in reinforcing elements.

4 CHARACTERISTICS OF TENSILE FORCING AND CONFINING EFFECTS

4.1 Parameter to evaluate the reinforced effect

Figure 6 shows the schematic diagram to explain the definition of the parameters P_0 and ΔP. P_0 defines the mobilized horizontal earth pressure in active condition in the case of non-reinforced soil acting on the wall. ΔP is also defined as the difference between P_0 and the horizontal earth pressure in the case of reinforced retaining wall mobilized in the active condition. When the reinforced effect becomes greater, ΔP tends to become larger. In this study, the ratio $\Delta P/P_0$ is used as a parameter to express the degree of the reinforced effect.

4.2 Existing of confining effect

Based on the results in Fig. 5, the relationship between the normalized reinforced effect, $\Delta P/P_0$, and the normalized length of a piece of reinforcing element, $\Delta L/L_0$, is shown in Figure 7, where this is the case that the grid type reinforcing element is horizontally laid in five layers with same vertical spacing in each layer, that is, $\Delta h/H$ equals to 0.17. Note that $\Delta L/L_0$ in horizontal axis is defined as the ratio of the unit length of reinforcing element ΔL to the whole length L_0 given as 25cm. For instance, $\Delta L/L_0=0$ means that the reinforcing element with the length of 25cm is split into infinite number of pieces. It can be seen that $\Delta P/P_0$, reflecting the reinforced effect, gradually decreases with the decreasing $\Delta L/L_0$, and then tends to converge to a certain value when $\Delta L/L_0$ reaches about 0.2, in other words, when splitting the reinforcing element into around 10 pieces. It is clear that the converge value of $\Delta P/P_0$ is about 0.2. The decrease of the reinforced effect is considered to be caused by the decrease of the mobilized tensile force in reinforcing element by splitting. When $\Delta L/L_0$ becomes less than about 0.2, the tensile force acting on the reinforcing element seems to be totally small and thus in this situation, the reinforced effect caused by the tensile force approaches to zero. Nevertheless, as shown in this figure, the reinforced effect still exists, which is represented as a converge values of $\Delta P/P_0$. In this study, such reinforced effect calls the confining one as a reinforced effect excluding the effect mobilized by the tensile force. The confining effect is expressed as the value of $\Delta P/P_0$ at $\Delta L/L_0=0$, which is approximately determined as 0.2 by the extrapolation from the result in the $\Delta P/P_0$-$\Delta L/L_0$ relationship. It is important to point out that the similar tendency can be obtained in the case of the different layers of reinforcing element and the sheet type reinforced element(Yasufuku et al., 2001) Total reinforced effect, ΔP, tensile effect, ΔP_T and confining effect, ΔP_c related to $\Delta L/L_0$ is schematically represented in Figure 8.

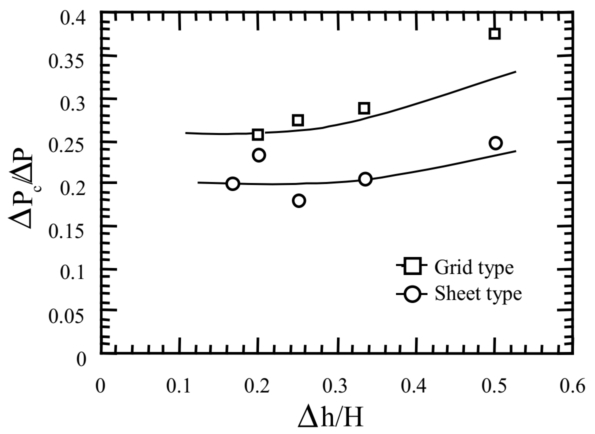

Figure 10 Ratio of confining effect to total reinforced one against normalized vertical spacing

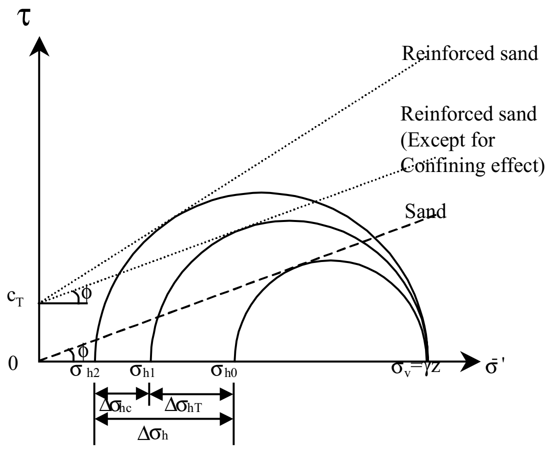

Figure 11 Mohr circles with reinforced effects

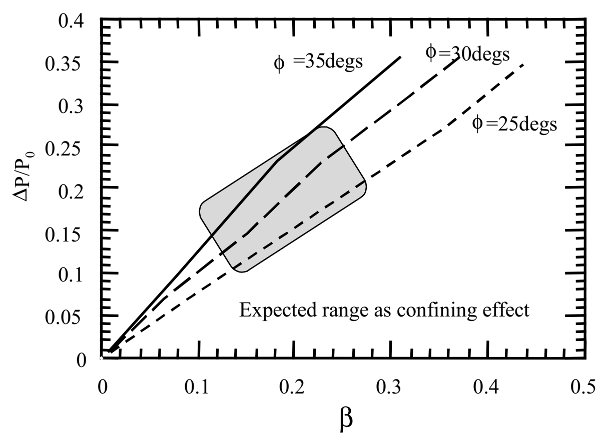

Figure 12 Expected relationship between $\Delta P_c/P_0$ and β

4.3 Relationship between confining effect and vertical spacing of reinforcement layer

The relationship between $\Delta P/P_0$ at $\Delta L/L_0$=0, $\Delta P_c/P_0$ and the normalized spacing of reinforcement, $\Delta h/H$ can be depicted in Figure 9. It is found that when the vertical spacing of a layer decreases from about 0.5 to 0.08, the corresponding normalized confining effect increases from about 0.05 to 0.25. The mobilized confining effect in both type of reinforcing elements differ from each other, especially at the region in relatively larger vertical spacing. One of the reasons of such phenomenon is considered to be in the difference of the frictional angle between aluminum rod mass and the reinforcing elements (Yasufuku et al., 2001). The difference in the normalized confining effect caused by a sort of reinforcing elements, however, becomes gradually smaller with the decreasing the spacing of each layer. There seems to be a reason that the effect restraining the movement of the aluminum rod mass is surpassed, when the vertical distance among the reinforcing elements becomes relatively small.

Figure 10 shows a ratio of the confining effect, ΔP_c to the total reinforced effect, ΔP against the normalized vertical spacing, $\Delta h/H$. It is clear that the ratio of the confining effect to the total reinforced one is in the range from 20% to 35%, depending on the type of the reinforcing elements. In order to verify whether such tendency is realistic or not, more practical prototype experiments will be still needed.

4.4 Strength of reinforced soil expected from earth pressure properties

The confining effect mentioned above should be evaluated as an averaged effect in reinforced retained wall structure. When assuming that 1) total earth pressure acting on the wall is calculated based on the Rankin earth pressure, and therefore the horizontal effective stress, σ_{h0} at an arbitrary depth, z is given by $\sigma_{h0}=K_a\gamma z$, where K_a is a coefficient of an active earth pressure and then assuming that 2) the reduction of σ_{h0} due to confining effect, $\Delta\sigma_{hc}$ is averaged as $\Delta\sigma_{hc}$= K_a z, $\Delta P_c/P_0$ and $\Delta\sigma_{hc}/\sigma_{h0}$ is easily related as follows:

$$\frac{\Delta P_c}{P_0}=\frac{\Delta\sigma_{hc}}{\sigma_{h0}} \qquad (1)$$

According to this relationship, the amount of averaged reductions of active earth pressure due to reinforced effect could be depicted by Mohr circles as shown in Figure 11. It is easily recognized that $\Delta\sigma_{hc}$, $\Delta\sigma_{hT}$ and $\Delta\sigma_h$ represent the amount of the reduction of active earth pressure at an arbitrary depth due to confining effect, tensile force in reinforcing elements and total reinforced effect, respectively. It is clear that $\Delta\sigma_{hc}=\Delta\sigma_h-\Delta\sigma_{hT}$. Further, it should be emphasized that when the Mohr circle, which reflects the total reinforced effect, is in contact with the failure line with a steeper slope comparing with that of non-reinforced case as already shown in Fig.1, the averaged reduction of the active earth pressure in a reinforced retaining wall is geometrically related to the increasing internal friction angle caused by a reinforced effect including the confining effect. When assuming that the steeper slope is given by $(1+\beta)\tan\phi$, $\Delta\sigma_{hc}$ and/or ΔP_c would be expressed as a function of β and ϕ such that:

$$\frac{\Delta P_c}{P_0}=\frac{\Delta\sigma_{hc}}{\sigma_{h0}}=\frac{(B+1)A+B-1}{(B+1)A}$$

$$A=\frac{1\ \ \sin\phi}{1\ \ \sin\phi} \qquad B=\frac{(1+\beta)\tan\phi}{\sqrt{\{(1+\beta)\tan\phi\}^2+1}} \qquad (2)$$

where term 'βtanϕ' means an increment of shear strength due to confining effect. Figure 12 shows the typical relationship between $\Delta P_c/P_0$ and β in Eq.2. The important thing is that when using Eq.2, the increment of the shear strength is in connect with

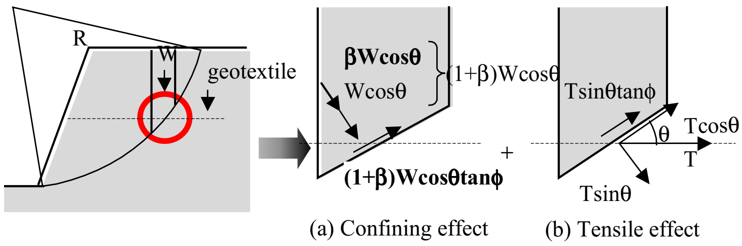

Figure 13 Introduction of confining effect into Safety factor in reinforced state

the reducing active earth pressure caused by the reinforced effects as a function of the internal friction angle.

5 INTRODUCTION OF CONFINING EFFECT INTO CURRENT DESIGN GUIDELINE

5.1 Strength of reinforced sand with different tensile force of reinforcement

The reinforced effects of geogrid-reinforced soil are often evaluated by only the tensile effect due to tensile force of a geogrid. Ochiai et al., and Kawamura et al.,(1996, 1998) carried out a series of special shear tests to clarify the reinforced effects on the sliding plane of the geogrid-reinforced soil mass. It was found that the shear strength properties of reinforced sands with different tensile force of reinforcement were summarized that 1) there exist the parallel straight lines with different apparent cohesion components, and 2) slope of the parallel straight lines is larger than that of non-reinforced sand and then 3) values of apparent cohesion component depend on the tensile force of reinforcement. Based on these experimental evidences, shear strength of reinforced sand is simply expressed as:

$$s_0 = \sigma_n tan\phi \qquad (3a)$$

$$s = s_0 + T^{'}\left(\cos\theta + sin\theta tan\phi\right) + \beta\sigma_n tan\phi \qquad (3b)$$

Where s_0 and s are the shear strength of non-reinforced and reinforced sand respectively, T' is the mobilized tensile force of the reinforcement per unit length, ϕ is the internal friction angle of sand, θ is the angle between the reinforcement and the sliding plane, σ_n is the normal stress on the sliding plane and β is a parameter to evaluate the degree of the confining effect. In Eq.3b, second and third terms represent the tensile and confining effects, respectively. The confining effect is considered to be an effect of the restriction of the sand particles by the reinforcing elements.

5.2 Introduction of confining effect into safety factor in reinforced steep slop embankments

According to Japanese design guideline in 1994, safety factor in reinforced state of geotextile reinforced steep slope embankment has been expressed as :

$$F_s = \frac{M_R + \Delta M_R}{M_D} \qquad (4)$$

where, M_R: resistance moment of soil mass in reinforced state, M_D: sliding moment of soil mass in reinforced state, ΔM_R: resistant moment due to tensile force of reinforcement, in which the concrete formula is derived by a slip circle method. ΔM_R in current guideline is given by:

$$\Delta M_R = R\sum\left(T\cos\theta + Tsin\theta tan\phi\right) \qquad (5)$$

where, R: radius of failure slip circle. Note that the current guideline evaluates the tensile effect of reinforcement alone, in spite of being expected that there exists an additional reinforced effect as a confining effect. Based on Eq.3, the existing confining effect is easily incorporated in Eq.5 such that:

$$\Delta M_R = R\sum\left\{\beta W\cos\theta tan\phi + \left(T\cos\theta + Tsin\theta tan\phi\right)\right\} \qquad (6)$$

where, W: weight of each sliding mass element .The second term reflects the confining effect in the resistant moment, which is schematically shown in Figure 13. It is pointed out that Eq.6 is considered to be an extended expression in Eq.5. Further, based on the design procedure including the confining effect, the required total tensile forces in design is reduced, comparing with that calculated based on Eq.5 and the amount of reduction is expressed as a function of the second term, 'ΣβWcosθtanϕ' in Eq.6. It means that the reasonable estimation of the confining effect in practical design is very important to establish an economical and rational design procedure in geotextile reinforced embankments reflecting the real performance of reinforcement.

6 CONCLUTIONS

1) The total reinforced effect in reinforced retaining wall, which is expressed as the difference between the whole horizontal active earth pressure in non-reinforced case and that in reinforced case, decreases with the decreasing unit length of reinforcing element by splitting even though the whole length keeps constant.
2) The reinforced effect still exists even though each reinforcing element splits into infinite number of pieces. This reinforced effect is defined as a confining effect due to reinforcement.
3) The confining effect tends to increase with the decreasing vertical spacing of reinforcing element laid in the model ground and the effect is expressed as a function of the normalized vertical spacing of reinforcing element.
4) In model retaining wall used, the ratio of the confining effect related to the active earth pressure to the total reinforced effect is in the range from 20% to 35% depending on the types of the reinforcing elements and the vertical spacing in each layer of geogrid.
5) A simple procedure for combining the reduction of active earth pressure due to reinforced effect with the corresponding increment of shear strength is presented as a function of the internal friction angle.

6) A simple procedure is presented for introducing the confining effect into safety factor of design guideline in reinforced steep slope embankment.

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