Reinforcement Group Effects on Reinforced Sand Behavior in Constant Pressure Direct Shear

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1 Introduction

Three groups (REPR, RAPR and RDPR) of constant pressure direct shear tests were executed [1], which are different respectively in the covering ratio (CR), the total stiffness, and the spatial dispersion of reinforcement. The reinforcing effects become larger as the reinforcement was arranged in a more dispersed way, due to the group effects of discrete reinforcement members, as interpreted by a simple model below.

2 Simulation model

To obtain the relationships between the shear displacement **(s)** and the shear stress **(τ_{vh})**, a distinct shear zone with uniform strain is assumed (Fig. 1). The ratio **(SR)** of the peak shear stress of reinforced soil to that of unreinforced soil was chosen as the input parameter to estimate the initial width **(w_i)** of this shear zone [2] based on the relationship between **SR** and **w_i** obtained from the analysis of the whole data. Considering the force equilibrium and displacement conditions (Fig.1), the average vertical stress **(σ_b)** in the shear zone is obtained as :

$$\sigma_b = \sigma_v + (R/A_s)\cos\theta \qquad (1)$$

where,

σ_v is the average vertical stress applied at the top of shear box, which is constant in a constant pressure test ;

R is the total tensile force of reinforcement in a shear zone;

A_s is the cross-sectional area of specimen;

$\theta = \arctan[s/(d_{cp}+w_i)]$, is the instantaneous rotation angle formulated as a function of **(s)** and dilatancy **(d_{cp})**;

Consequently, the average shear stress is obtained as:

$$\tau_{vh} = \sigma_b \tan\phi_b + (R/A_s)\sin\theta$$
$$= \sigma_v \tan\phi_b + (R/A_s)(\sin\theta + \tan\phi_b \cos\theta) \qquad (2)$$

where ϕ_b is the mobilized friction angle along the horizontal shear plane. To obtain the value of ϕ_b for a given **s** , a normalized parameter **$A=(\tau_{vh}/p_a)/(\sigma_v/p_a)^m$** (m=0.9) was introduced. Based on the test results of unreinforced sand, **A** can be formulated as **$A=f(s/w_i)$**. Therefore, ϕ_b is obtained as :

$$\phi_b = \arctan[f(s/w_i) / (\sigma_b/p_a)^{1-m}] \qquad (3)$$

By a similar procedure, a normalized parameter **$B=(d_{cp}/w_i)/(\sigma_v/p_a)^n$** was introduced to obtain the dilatancy **(d_{cp})** as:

$$d_{cp} = w_i \cdot g(s/w_i) \cdot (\sigma_b/p_a)^n \qquad (4)$$

where **$B = g(s/w_i)$** and n=-0.1.

The value of **R** in Eq.2 can be calculated as:

$$R = A_{RS} \cdot \tan\phi_{RS} \cdot \sigma_{RS} \qquad (5)$$

where **A_{RS}** is the total surface area of reinforcement; ϕ_{RS} is the mobilized interface friction angle; and σ_{RS} is the average normal stress acting on the reinforcement.

The mobilized ϕ_{RS} angle was assumed to be the same with that of the **f** and **s** relationship but with a different peak value. Because the mobilized ϕ_{RS} angle was not directly measured in the present study, the experimental result of REPR1 (with CR=100%) was used to obtain the peak value of ϕ_{RS}. Fig. 2 shows the back-analyzed peak value of ϕ_{RS} is equal to 35.5 °, which is slightly smaller than $(\phi_b)_{peak}$ of unreinforced Toyoura sand (= 41.7 °). The current model using actual **CR** (and **A_{RS}** value) can be viewed as a quasi-3 dimensional model (Q3D model).

3 Reinforcement group effects

The experimental results from RDPR series are shown in Fig. 3, in which the number **n** of reinforcement member was changed from 1 to 3 & 30 with a constant CR=60% (so the width of each strip was varied accordingly),. It can be seen that the higher degree of spatial dispersion of reinforcement (i.e. the larger **n**), the higher shear strength of sand. This reinforcement group effect can be explained as following. With the increase in the reinforcement spatial distribution, the total retrained soil volume surrounding the reinforcement increases and the stress concentration of σ_{RS} becomes more important. To estimate this factor by Q3D model, the local normal stress σ_{RS} should be estimated. However, due to the difficulty in correctly evaluating and modeling the local σ_{RS}, an equivalent two dimensional model (E2D model) concept has been proposed [3]. By using this concept, the covering ratio CR is assumed to be 100% for every case and an equivalent 2D peak value of ϕ_{RS} is adopted to obtain the respective equivalent results. Figs. 4 and 5 show the experimental and estimated results by the Q3D and E2D models respectively. It can be seen that with the increase in the reinforcement strip number, the group effects become apparent. In the results of the cases with **n**=1 and CRs less than 100%, the group effects are not noticeable. In Fig 6, the peak value of equivalent 2D $(\phi_{RS})_{E2D}$ angle without group effects can be formulated as :

$$[(\phi_{RS})_{E2D}]_{\text{without group effects}} = \arctan(CR^*\tan(\phi_{RS})_{\text{when CR=100\%}})$$

The value of $(\phi_{RS})_{E2D}$ with group effects were obtained so that the peak shear strength as the measured is simulated by the E2D model. Thus, under the same **CR**, the difference between the values of $(\phi_{RS})_{E2D}$ for each number **n** is only due to the group effect. Figs. 7and 8 summarize the simulated results of peak and residual state strength by the E2D model with group effects. Though the simulated peak strengths coincide the test results well, those of residual strength show a noticeable difference (see Fig. 3). This disagreement may be due to that the actual ϕ_{RS} would reduce with the shear displacement along the interface between the sand and the reinforcement much faster than that assumed in the present study.

References: **1)** Qiu, Tatsuoka and Uchimura (2000): Constant pressure and constant volume direct shear tests on reinforced sand, Soils and Foundations (accepted); **2)** Wu, Qiu, Uchimura, Tatsuoka (2000): Simulation of behavior of reinforced sand in constant pressure and constant volume direct shear, J.G.S. **3)** Peng, Kotake, Tatsuoka, Hirakawa and Tanaka (2000): Plain strain compression behavior of geogrid-reinforced sand and its numerical analysis, Soils and Foundations (accepted)

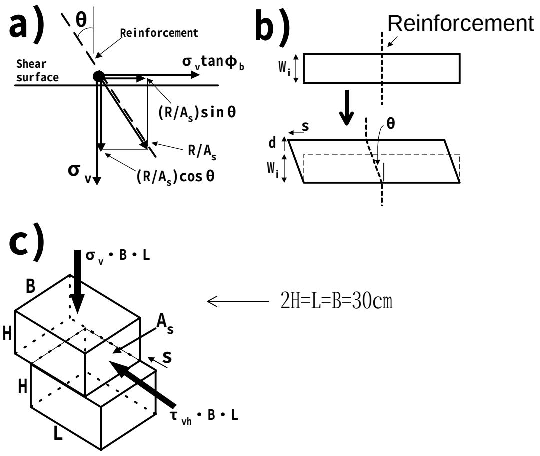

Fig.1 Force equilibrium in direct shear

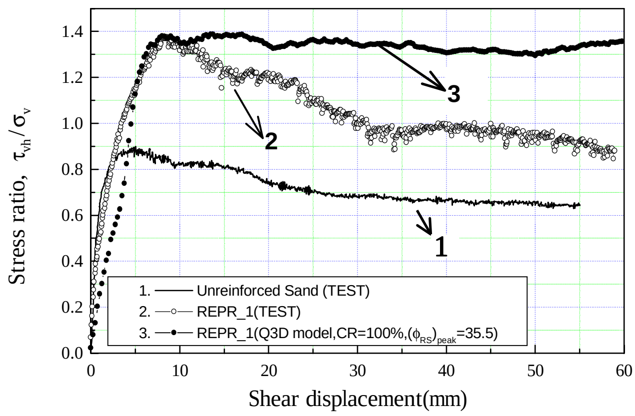

Fig.2 Back-analyzed ϕ_{RS} by Q3D model

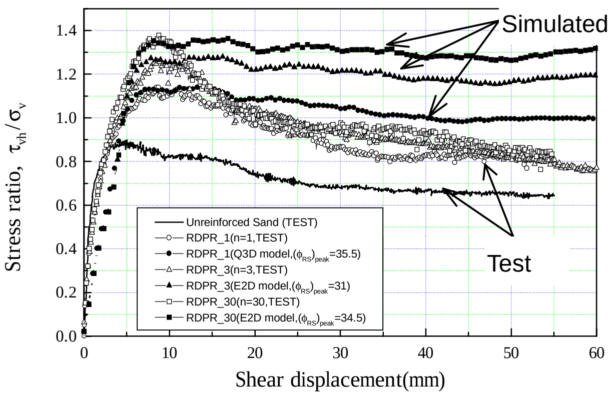

Fig. 3 Simulated and test results of RDPR series

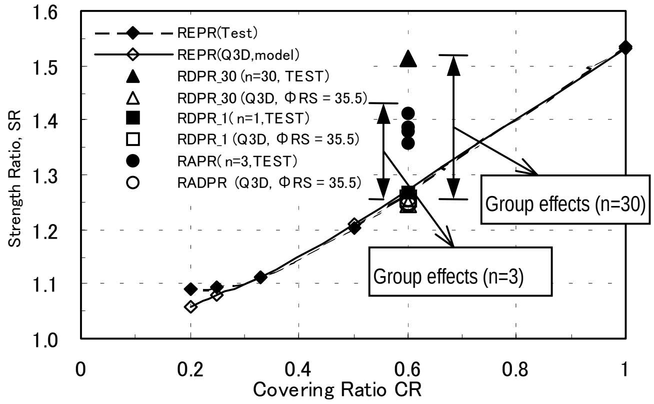

Fig. 4 Simulated results by Q3D model

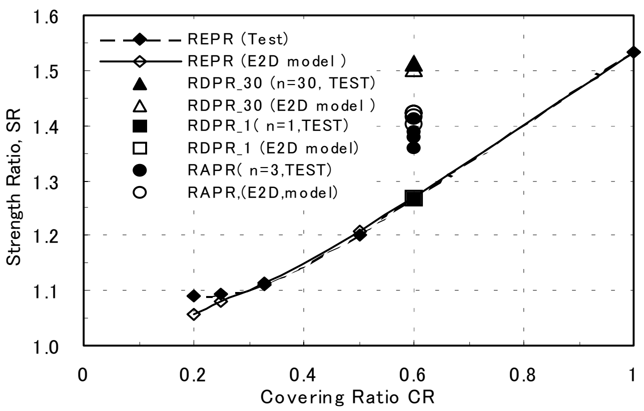

Fig. 5 Simulated results by E2D model

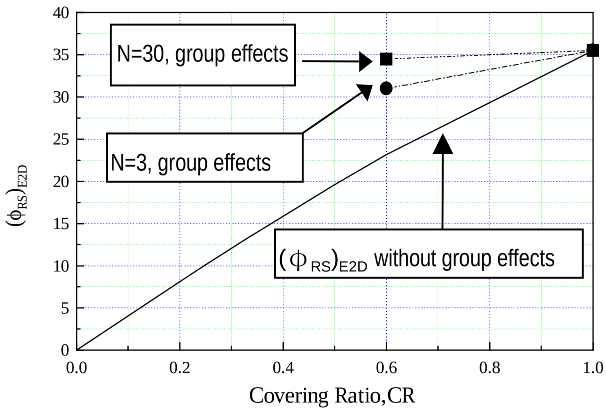

Fig. 6 $(\phi_{RS})_{E2D}$ with and without group effects

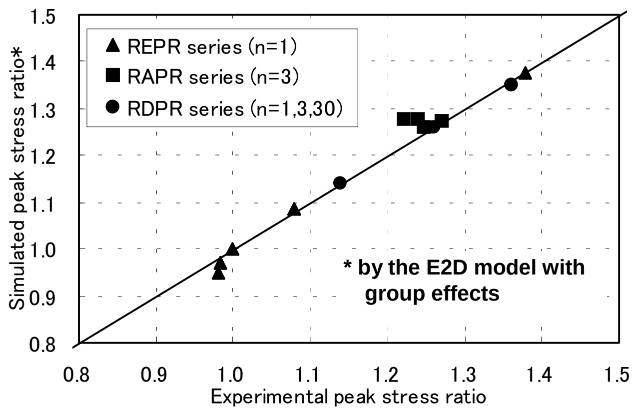

Fig. 7 Simulated and experimental peak stress ratios

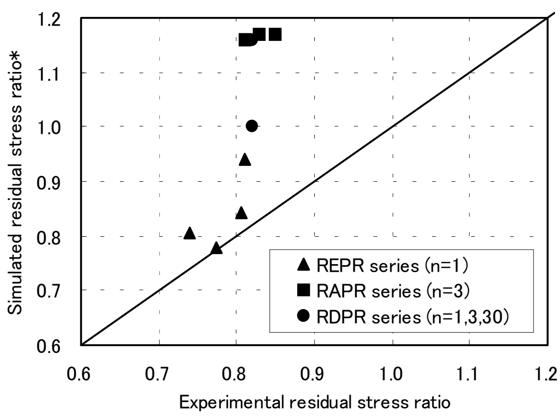

Fig. 8 Simulated and experimental residual stress ratios