I－527 Effect of Strength Anisotropy on Dynamic Failure Mechanism of Fill-Type Dam Model

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Introduction Seismic stability of fill type dams has been investigated by using various analytical approaches. However, in most of these previous analyses, the effect of strength anisotropy has received little attention. In this study, the dynamic stability of a dam model made of sand with a significant strength anisotropy was investigated.

Strength Anisotropy and Shear Band Direction A series of plane strain compression (PSC) tests has been conducted on loose wet-tamped Onahama samd (D_{50}=0.176mm, U_C=1.32 and G_S=2.71). Its anisotropy in stress-strain relations was investigated by changing the angle δ between σ_1-direction and the direction of bedding plane[1]. Fig.1 shows the variation of shear strength ratio $\tau_f(\delta)/\tau_f(\delta=90^\circ)$ with δ, where τ_f is the maximum shear stress. A clear tendency of anisotropy can be seen. The angle θ_f between the direction of shear band and σ_3-direction is usually considered to be equal to $45^\circ+\phi/2$ (Fig.4a). However, it has been shown that θ_f is a distinct function of the angle δ (Fig.4b)[2]. Fig.2 shows a variation of θ_f with δ, obtained from PSC tests on Toyoura sand. The relation was assumed to be applicable to Onahama sand. In addition, a series of direct shear box tests was performed to evaluate the strength parameters at extremely low pressures (less than 0.05 kgf/cm^2).

Dam Model Tests[3] and Dynamic Stability Analysis Dam models made on a shaking table with Onahama sand were 40cm in height, the crest width was 5cm and the slopes of both faces were 1:2.0 and 1:2.1, respectively. Models were shaken sinusoidally at a constant frequency of 5 Hz. The amplitude was gradually increased until the model failed. The static and dynamic analysis of stress within the dams was performed using FEM. The dynamic response analysis was performed by using a equivalent linear method. The stability of the dam was evaluated by a procedure proposed by Tamura et al. (1982)[4]. The effect of strength anisotropy was incorporated in the procedure as follows;

1) The shear strength $\tau_f(\delta=90^\circ)$ can be expressed by Mohr-Coulomb failure criterion:

$$\tau_f(\delta=90^\circ)=c_{ds}\cdot\cos(\phi_{PSC}(\delta=90^\circ))+(\sigma_1+\sigma_3)/2\cdot\sin(\phi_{PSC}(\delta=90^\circ))$$

where c_{ds} and $\phi_{PSC}(\delta=90^\circ)$ are the cohesion and the friction angle obtained from the direct shear and PSC tests at $\delta=90^\circ$, respectively. In the following, it is assumed that at any point in the model with a calculated value of δ, the anisotropic shear strength $\tau_f(\delta)$ is given by; $\tau_f(\delta)=f^*(\delta)\cdot\tau_f(\delta=90^\circ)$, where $f^*(\delta)$ is obtained from the relation represented by the solid line in Fig.1. When isotropic strength was considered, $f^*(\delta)$=1.0 was used.

2) The distribution of $\Delta\tau=\tau_f-\tau_{max}$ is calculated, where τ_{max} is the calculated maximum shear stress within the dam. The area in which $\Delta\tau$ is smaller than zero is called the potential failure zone (see Fig.3).

3) The angles θ $(=45+\phi_{PSC}(\delta=90^\circ)/2)$ and θ_f are calculated for isotropic and anisotropic assumptions for the strength, respectively. The angle θ_f can be obtained from the curve shown in Fig.2. Within the potential failure zone, they are called the direction of the potential sliding.

A typical stability analysis was made for the dam at the condition of w=1.44% and e=0.807, which corresponds to c_{ds}=1grf/cm^2 and $\phi_{PSC}(\delta=90^\circ)=42^\circ$. The analysis was performed for the following two cases. Namely; the strength is isotropic (Case I) and anisotropic (Case I-A). Figs.5(a)～(d) show the results of analysis, where θ and θ_f are indicated by solid and broken lines, respectively. The following points can be seen: (a) At the base acceleration of 400gals, there are two potential failure zones developed in the zones near the crest and left-hand toe, while for Case I-A near the toe the failure zone developed more predominantly. Furthermore, for Case I-A, the two different failure zones were connected to each other, whereas for Case I the lower failure was still at the stage of developing even at the base acceleration of 425 gals (Fig.5c);

(b) At points on or near the lower face of the slope, a more pronounced outward slide took place in Case I-A (see Figs.5b and d).

This tendency can also be seen in Photo.1. This is the side view of the model at failure. Namely, in the lower zone of the slope, the shear band appeared more predominantly and its direction near the slope face was almost horizontal.

Conclusions The results of the present study showed: (a) The strength anisotropy has a distinct effect on the dynamic stability of the dam model. (b) The strength anisotropy tends to cause the failure zone to develop predominantly around the toe and accelerates it to expand upward. (c) The strength anisotropy casues a more pronounced outward slide to take place near the toe. These tendencies are qualitatively in agreement with those observed in the model tests.

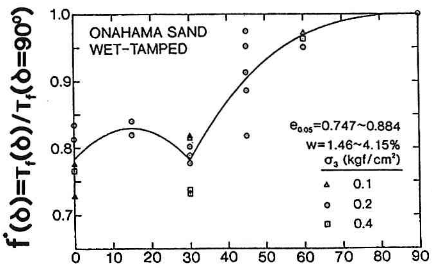

Fig.1

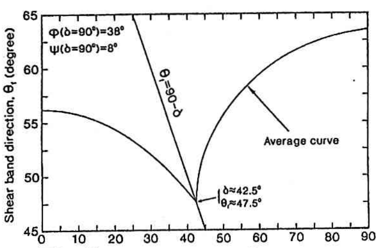

Fig.2 Bedding plane direction, δ (degree)

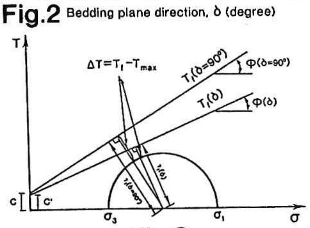

Fig.3

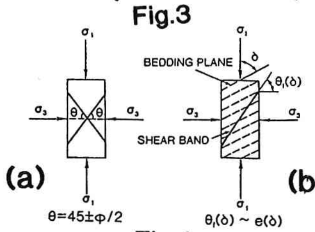

Fig.4

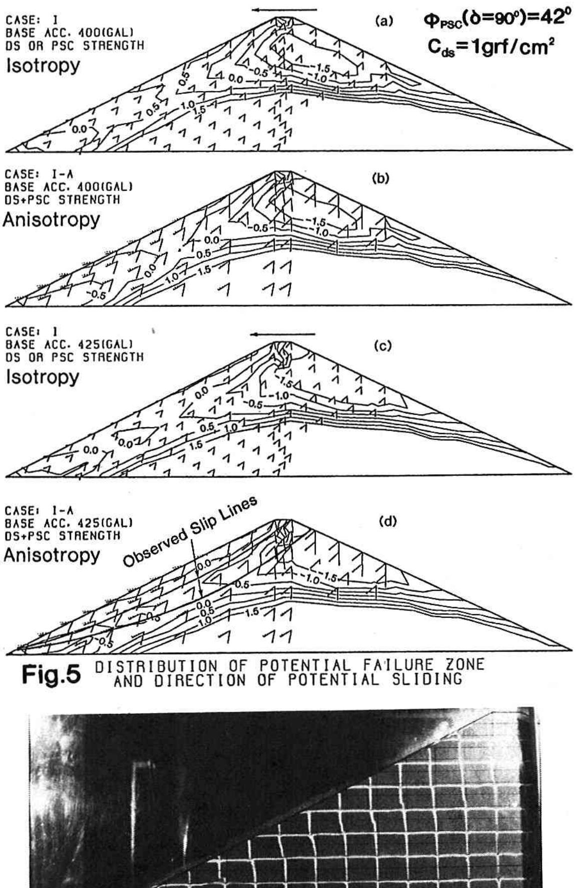

Fig.5 DISTRIBUTION OF POTENTIAL FAILURE ZONE AND DIRECTION OF POTENTIAL SLIDING

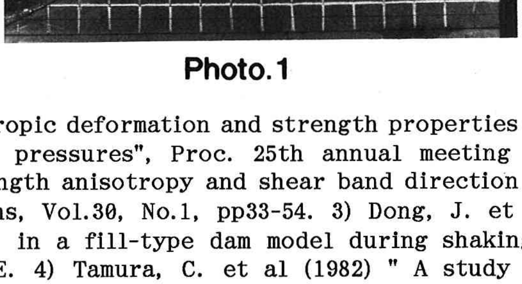

Photo.1

References 1) Dong, J. et al (1990) "Anisotropic deformation and strength properties of wet-tamped sand in plane strain at low pressures", Proc. 25th annual meeting of JSSMFE. 2) Tatsuoka, F. et al (1990) "Strength anisotropy and shear band direction in plane strain tests", Soils and Foundations, Vol.30, No.1, pp33-54. 3) Dong, J. et al (1989) "On the formation of shear band(s) in a fill-type dam model during shaking", Proc. of 44th annual conference of JSCE. 4) Tamura, C. et al (1982) " A study on vibration failure mechanism of sand models of fill type dam", 16th Symp. of EE of JSCE.