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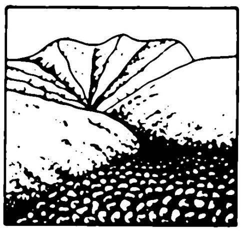
Пятигорск, Россия, 22-29 сентября 2008 г.



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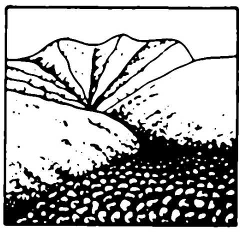

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При создании логотипа конференции использован рисунок из книги С.М. Флейшмана «Селевые потоки» (Москва: Географгиз, 1951, с. 51).
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Empirical equations of rheological parameters for mixtures of gravels and mud slurries

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Эмпирические уравнения реологических параметров для смесей из гравия и грязевой массы

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Исследованы реологические параметры смесей из гравия и грязевой массы. Для описания реологических свойств смесей использована модель Бингама, которая содержит два параметра: предел текучести по Бингаму и вязкость по Бингаму. Вначале изучены реологические свойства грязевых смесей с содержанием частиц менее 1 мм, а затем исследовано изменение параметров при добавлении в смесь гравийных частиц. Предложены два эмпирических соотношения предела текучести и вязкости по Бингаму для смесей из гравия и грязевой массы, основанные на экспериментальных данных.

Rheological parameters of the mixtures of gravels and mud slurries have been studied. The Bingham model was used to describe the rheological properties of the mixtures. The model contains two rheological parameters: the Bingham yield stress and Bingham viscosity. The rheological parameters of mud slurries with particle size less than 1 mm were investigated first, and then the change of rheological parameters due to addition of gravels into the mud slurry were studied. Two empirical relations of the Bingham yield stress and Bingham viscosity for the mixtures of gravels and mud slurry are proposed, on the basis of the experimental data of the present study.

1 Rheological parameters of mud slurries

Thirty-one sets of experimental data of mud slurries were collected for analyzing the dependence of the rheological parameters of mud slurries on their sediment concentration C_{vf} and sediment composition in the present study. The results showed that the both the rheological parameters τ_{Bf} (dyne/cm^2) and μ_{Bf} (centi-poise) of mud slurries (having sediment seize less than 1 mm) exponentially increases with the increase of C_{vf}, i.e., $\tau_{Bf} = A_1 \exp(B_1 C_{vf})$ and $\mu_{Bf} = A_2 \exp(B_2 C_{vf})$, as shown in figures 1 and 2. The coefficients B_1 and B_2 are about 0.20 and 0.18, respectively, with minor variation for the slurry simples collected in this study. However, the values of the coefficients A_1 and A_2 significantly varies with the content of fine sediments, particularly for the size less than 0.02 mm. The present study developed the relation of the coefficient A_1 (A_2) and $P_{0.02}$ ($P_{0.01}$), in which $P_{0.01}$ and $P_{0.02}$ denote the content of fine sediment having size less than 0.01 mm and 0.02 mm, respectively. They are $A_1 = 0.0014 \exp(0.095 P_{0.02})$ and $A_2 = 0.03 \exp(0.13 P_{0.01})$.

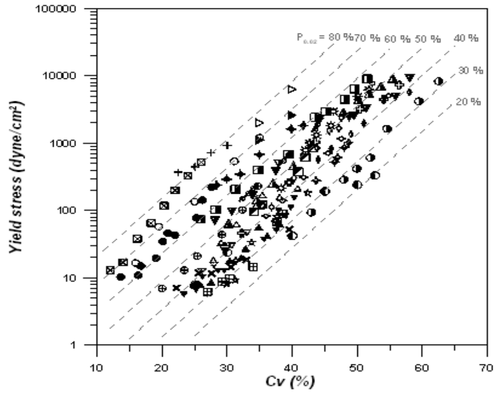

Fig. 1. Bingham yield stress of mud slurries at various sediment concentrations and the contents of fine sediment having size less than 0.01 mm.

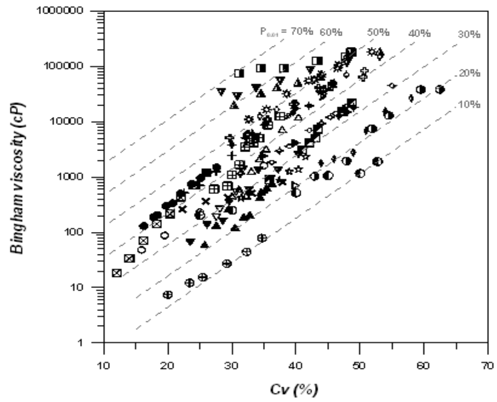

Fig. 2. Bingham viscosity of mud slurries at various sediment concentrations and the contents of fine sediment having size less than 0.01 mm.

Therefore, two empirical equations of rheological parameters for mud slurries can be written as

$$\tau_{Bf} = 0.0014\exp(0.20C_{vf} + 0.095P_{0.02}) \tag{1}$$

$$\mu_{Bf} = 0.03\exp(0.018C_{vf} + 0.13P_{0.01}) \tag{2}$$

2 Rheological parameters of mixtures of gravels and mud slurries

A certain amount of gravels were added into and well mixed with a mud slurry for form a gravel-mud slurry, as shown in Fig. 3. The effects of gravels on the rheological parameters of gravel-mud slurries (denoted as τ_{Bg} and μ_{Bg}) were experimentally studied by using a Brookfield rotational viscometer.

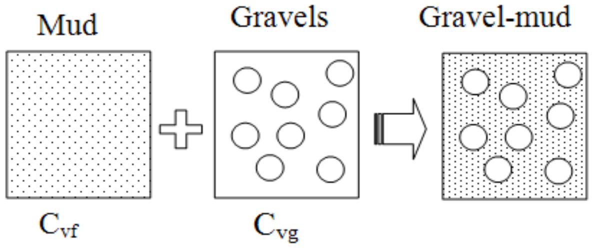

Fig. 3. Mixture of gravels and mud slurry.

The gravels used in experiments have diameters (D_g) of 5, 10, 16, and 24 mm, respectively, and the content of gravels (C_{vg}) in gravel-mud slurries varied from 7% to 20%. The dependence of τ_{Bg} and μ_{Bg} on C_{vf}, $P_{0.02}$ (or $P_{0.01}$), C_{vt}, C_{vg} and D_g are also evaluated in this study. The empirical relations of τ_{Bg} and μ_{Bg} for the mixtures of gravels and mud slurry were obtained as shown below.

$$\tau_{Bg} = \tau_{Bf}(C_{vf}, P_{0.02}) + \Delta\tau_B(C_{vt}, C_{vg}, D_g) \tag{3}$$

$$\mu_{Bg} = \mu_{Bf}(C_{vf}, P_{0.01}) + \Delta\mu_B(C_{vt}, C_{vg}, D_g) \tag{4}$$

Based on our experimental data, the increased Bingham yield stress $\Delta\tau_B$ and the increased Bingham yield stress $\Delta\mu_B$ due to the existence of gravels in the mixture can be empirically written as following equations.

$$\Delta\tau_B = 325\tau_{Bf}(C_{vg}/C_{vt})^7 \exp(-0.08D_g) \quad (5)$$

$$\Delta\mu_B = 0.9\mu_{Bf}(C_{vg}/C_{vt}) \quad (6)$$

The results showed that at the same total sediment concentration, the gravel-mud slurry has larger content of fine sediments has higher values of τ_{Bg} and μ_{Bg}. The existence of gravels has stronger effect on τ_{Bg} and μ_{Bg}. The larger gravels have less contribution on τ_{Bg} than that on μ_{Bg} at the same C_{vg} and C_{vt}. The gravel size D_g has no significant effect on μ_{Bg}. Provided that the data of C_{vf}, $P_{0.02}$ (or $P_{0.01}$), C_{vt}, C_{vg} and D_g (in mm) are available, we can use the following equations to estimate the rheological parameters of viscous debris flows. Figures 4 and 5 show the comparison of calculated and measured rheological parameters.

$$\tau_{Bg} = 0.0014\exp(0.20C_{vf} + 0.095P_{0.02})[1 + 325(C_{vg}/C_{vt})^7 \exp(-0.08D_g)] \quad (7)$$

$$\mu_{Bf} = 0.03\exp(0.018C_{vf} + 0.13P_{0.01})[1 + 0.9(C_{vg}/C_{vt})] \quad (8)$$

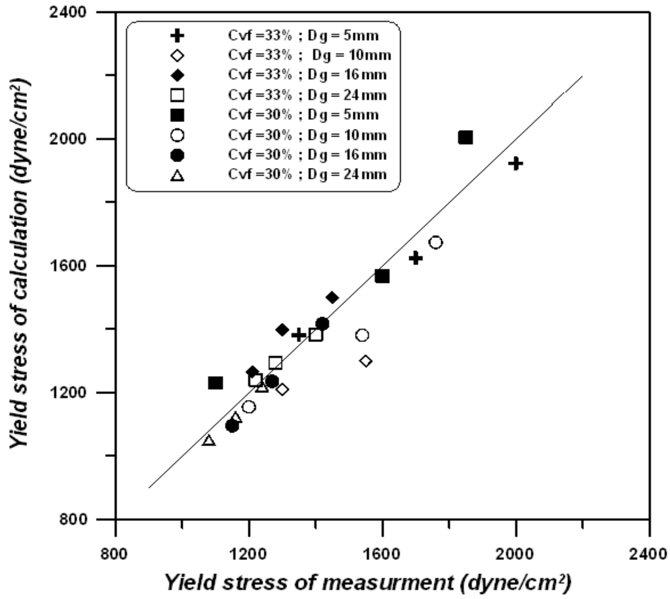

Fig. 4. Comparison of calculated and measured Bingham yield stress of gravels-mud mixtures.

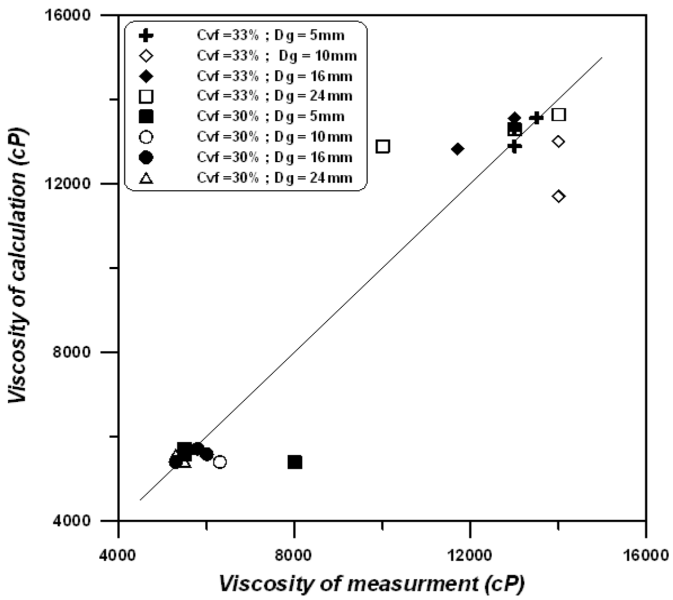

Fig. 5. Comparison of calculated and measured Bingham viscosity of gravels-mud mixtures.