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# A study of the relationship between deposit density and debris flow type

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**Abstract** The density of debris flow samples after settling in laboratory (the deposit density) is a kind of limiting density of debris flow,m which depends only on the solid component in debris flow including particle composition, size distribution and arrangement. It does not change with the amount of water, This property of deposit density characteristics the type of debris flow. The tendency as well as the reason for change between deposit density and particle component is analysed in the paper. Samples from moving flow in the Jiangjia Ravine near Dongchuan City were obtained and the natural density and deposit density measured. The ratio of natural density to deposit density as a function of debris flow structure, the type and the properties of debris flow ere further researched.

## DEPOSIT DENSITY ($C_{vs}$)

Deposit density $C_{vs}$ is a kind of limiting density of debris flow in which the solid particles are most closely arranged. It is obtained after the deposited sample is achieves its firm state. $C_{vs}$ depends only on the solid component in debris flow, such as the particle composition, size distribution and arrangement. If different debris flows are of fixed solid component, their $C_{vs}$ will be the same regardless of the amount of water. According to studies by Fei Xiangjun (1981) the $C_{vs}$ for samples with the same particle composition is the same. Theoretically, when solid particles in debris flow are spheres with equal diameter, $C_{vs} = 0.5236$, is a constant calculated by Bagnold. In fact, the $C_{vs}$ at different sample changes because of: the non-spherical particles in debris flow, the various diameters of solid particles (from clay to boulder) in debris flow.

### $C_{vs}$ of a fine particle system

The finer the particles in debris flow, the greater their total surface area, and the greater the amount of bound water. Therefore, a great deal of water cannot be separated out in the natural state. Moreover, during the course of deposition of fine particles, a small chain arrangement, which enlarges to become a sponge like structure because of interparticle forces. It is seen from Fig. 1 that the sponge structure leads to quite a large total porosity, even larger than that of total solid particles.

The two phenomena described above, result in the $C_{vs}$ value of a fine particle system being smaller than its theoretical value $C_{vs} = 0.5236$.

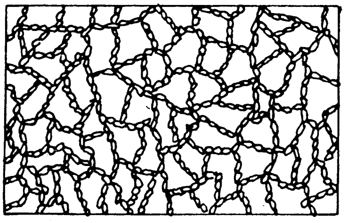

**Fig. 1** Sponge-like structure.

### $C_{vs}$ of a bulky particle system

This system comprises specially solid particles with various diameters. Its $C_{vs}$ value is bigger than the theoretical value 0.5236. The reasons for this are: (a) affected slightly by bound water, there is a firm contact between big particles; (b) finer particles of various sizes filled the pores between bigger particles to form a filling structure. It can be seen from Fig. 2 that such a structure, with porosities volume much smaller than that of a system of even particles, contains more solid material than usual.

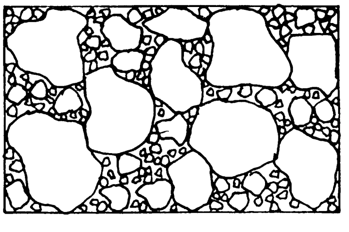

**Fig. 2** Filling structure.

The finer the solid particles in debris flows, the lower the $C_{vs}$ value, and conversely. This variation of $C_{vs}$ values is the essential prerequisite to differentiate types of debris flow.

## RELATIONSHIP BETWEEN $C_{vs}$ AND NATURAL DENSITY

Theoretically, a relationship between $C_{vs}$ and natural density does not exist because $C_{vs}$ concerns only the solid component in debris flow including the particle composition, size distribution and arrangement, but the natural density is affected by both the solid component and the water content. Clearly, natural density changes with more water, but $C_{vs}$ does not. Only when in natural condition, solid component, percentage of solid and of water are mixed in a proper ratio,m forming a special combination, can a relationship between $C_{vs}$ and natural density be established. This is the basis for dividing types of debris flow.

### Method of $C_{vs}$ test

Samples obtained from moving flow reach an ultimate stable state after deposition for a long enough time in a laboratory. With water separated out from samples, the maximum sample density may be obtained. That is called $C_{vs}$ (Fig. 3). After calculating the maximum sample density $\gamma_{c\max}$, $C_{vs}$ can be obtained according to the following equation:

$$C_{vs} = \frac{\gamma_{c\max} - 1}{\gamma_s - 1} \tag{1}$$

here, $\gamma_s$ is the density of solid particles in a debris flow.

The key point is to decide the ultimate stable state for samples as the $C_{vs}$ test proceeds. The chosen criterion is that $h_1$ or $h_2$ (see Fig. 3) does not change in 24 h.

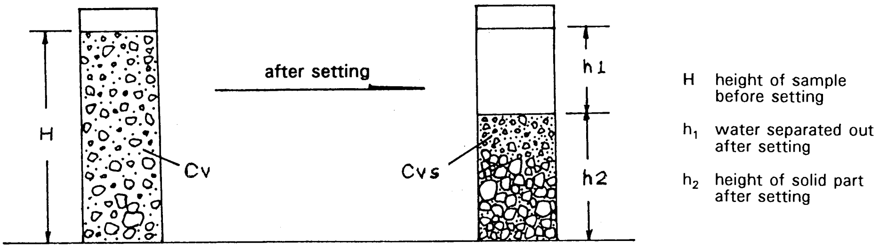


**Fig. 3** The settling of the sample.

### Relationship between $C_{vs}$ and natural density

In the Jiangjia Ravine near Dongchuan City, 21 sets of samples were obtained for measurement of $C_{vs}$ and natural density. With natural densities from 1.070 to 2.271 g cm$^{-3}$, the samples represent all types of debris flow. It can be seen from Table 1 and Fig. 4 that there is a linear relationship between $C_{vs}$ and natural density:

$$C_v = 1.0674\,C_{vs} - 0.1294 \qquad r = 0.998 \tag{2}$$

## RELATIONSHIP BETWEEN $C_{vs}$ AND TYPE OF DEBRIS FLOW

$C_{vs}$ reflects mainly the properties of the solid particles in debris flow, and

**Table 1** Test results of $C_{vs}$ and natural density $C_v$.

| Sample number | Natural density ($C_v$) | Deposit density ($C_{vs}$) | Sample number | Natural density ($C_v$) | Deposit density ($C_{vs}$) |
|---|---|---|---|---|---|
| 1 | 0.042 | 0.153 | 12 | 0.458 | 0.575 |
| 2 | 0.096 | 0.219 | 13 | 0.512 | 0.630 |
| 3 | 0.126 | 0.255 | 14 | 0.584 | 0.668 |
| 4 | 0.154 | 0.262 | 15 | 0.608 | 0.696 |
| 5 | 0.173 | 0.279 | 16 | 0.675 | 0.735 |
| 6 | 0.193 | 0.293 | 17 | 0.663 | 0.749 |
| 7 | 0.228 | 0.325 | 18 | 0.689 | 0.768 |
| 8 | 0.265 | 0.356 | 19 | 0.706 | 0.795 |
| 9 | 0.337 | 0.451 | 20 | 0.728 | 0.825 |
| 10 | 0.408 | 0.476 | 21 | 0.765 | 0.825 |
| 11 | 0.412 | 0.522 | | | |

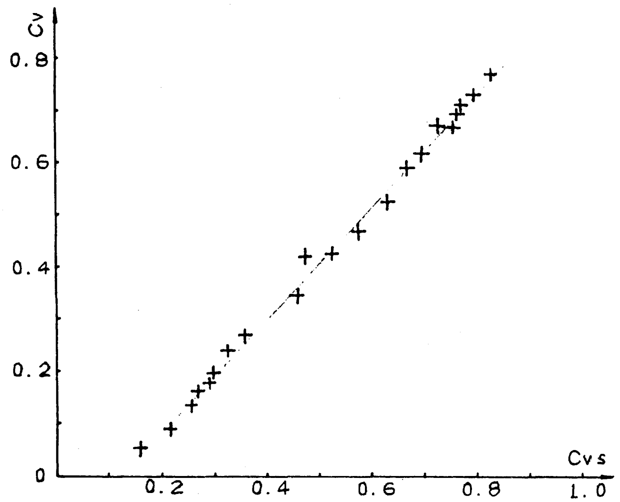

**Fig. 4** Relation between $C_{vs}$ and $C_v$.

cannot be used for dividing into types of debris flow. Debris flow is a two-phase body of water and solids, and mans natures of it are affected by the two factors. Therefore, $C_{vs}$ should be combined with $C_v$ to explain the structure, the movement and the type of debris flow.

When $C_{vs}$ is smaller, the volume of solid material after settling is less, and the amount of water separated out is greater. Under this condition, the particles in debris flow are finer. There are more, bigger spaces between solid particles in debris flow turbulence state appears in moving flow. By contrast, the bigger the $C_{vs}$, the more the solid material and the bigger the $C_{vs}$. This reflects that particles in debris flow become larger. No water can be separated out when tested in the laboratory, and the amount of solid material in the debris flow reaches an ultimate saturation state. In this case, particles are tightly packed and restrain and sustain each other. There is no space for particles to move in the debris flow, so the laminar state or structural state is observed in moving flow.

The relationship between $C_v$ with $C_{vs}$, them can be expressed by the equation $C_v = 1.0674\ C_{vs} - 0.1294$. As a structure coefficient of debris flow,

$$K = C_v / C_{vs} \qquad (C_v \leq C_{vs}) \tag{3}$$

It can be used to explain the characteristics of structure and movement, and the type of debris flow (Table 2).

**Table 2** Types of debris flow according to the value of the structure coefficient $K$.

| Structure coefficient ($K = C_v/C_{vs}$) | Moving state | Type of debris flow |
|---|---|---|
| >0.91 | Structure state | Highly-viscous debris flow |
| 0.87-0.91 | Laminar state | Viscous debris flow |
| 0.76-0.86 | Transition state | Sub-viscous debris flow |
| 0.62-0.75 | Turbulent state | Slightly-viscous debris flow |
| <0.62 | Turbulent state | High-sediment flood |

(a) **When $K > 0.91$; highly-viscous debris flow.** The movement is in a structural state with high density. No or little water separated out, $C_v$ is close to $C_{vs}$. Bulky particles in debris flow restrain and sustain each other. Mud slurry composed of water and fine particles (diameter <2 mm), fills up pores between bigger particles. Flow becomes approximately one-phase. The condition for movement of the fluid must be overcoming the inner-friction between particles; according to test results the inner-friction angle is usually $\phi = 25°$ to $40°$.

(b) **When $K = 0.87$ to $0.91$: viscous debris flow.** In this case, less water separated out, $C_{vs}$ is slightly lower than $C_{vs}$. Bulky particles spread each other out, and the inner-friction is reduced much more by the action of mud slurry. The shear movement in debris flow is not limited by bulky particles. So the fluid of debris flow, can there be obviously turbulent exchange of bulky particles, because of the large space in front of the debris flow.

(c) **When $K = 0.76$ to $0.86$: sub-viscous debris flow.** The difference between $C_v$ and $C_{vs}$ increases, which shows that the water and the distance between bulky particles has increased. Not only the shear movement with collision exists between bulky particles, but also vertical exchange appears. Therefore, the fluid of debris flow moves in both a laminar and turbulent state (transition state for short).

(d) **When $K = 0.62$ to $0.75$: slightly-viscous debris flow.** The difference between $C_v$ and $C_{vs}$ is increased continuously, which shows that the percentage of solid material has decreased, but the distance between bulky particles has increased. There is a big enough space for particles to move, and, solid particles are carried by floating force and ascending force. So the fluid of debris flow moves in a turbulent state.

(e) **When $K = 0.62$: high-sediment flood.** In this case, the percentage of water is much greater than that of solids and the difference between $C_v$ $C_{vs}$ increases greatly. No link-action of mud slurry exists between water and solid material. Particles are transported by the turbulent force of water.

## REFERENCE

Fei Xiangjun (1981) Viscosity of high-sediment flood (in Chinese). *Hydraulic Engineering Department, Qinghua University*, 1-27.