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STUDY OF INFLUENCE ON COHESIVE DEPOSITS INCIPIENT MOTION AND EROSION BY DRY BULK DENSITY

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ABSTRACT

According to the essential character of coherent deposits, different dry bulk density have different consolidation degree, moreover, different consolidation degree have different cohesive force between particles, meantime the erosion-resisting concrete is very different, which causes the depositing is easy but the eroding is difficult. From the motion mechanism of cohesive deposits to start with, the motion mechanism of cohesive deposits and the similarity between the cohesive sediment starting and the cohesive soil slope gliding failure in soil mechanics, firstly the corresponding microcosmic motion pattern, is establishing; and then through theoretical analysis and supplement with testing information, the cohesive deposits critical motion shear stress, erodes velocity of flow as well as erode rate, which influence by dry density, are studied. The research results show that the incipient motion and the erosion of cohesive deposits are greatly influenced by the dry bulk density.

Key words: cohesive deposits, dry bulk density, incipient motion velocity and erosion rate

1. INTRODUCTION

There are many reservoirs in China and the deposition problem is severely serious. Therefore, developing the research on cohesive deposits incipient motion and eroding rule is very important and has already become the aim of many research topics.

The dry bulk density of cohesive deposits not only can synthetically reflect the great criterion structure function and cohesive forces between particles, but also can be easily measured. Moreover, dry bulk density is also the ultimate result of the entire deposition process during the cohesive fine particles flocculate, deposit, form flocculation net and drain water densely in the turbid water. Different dry bulk densities mean different consolidation degrees and different consolidation degrees have different cohesive forces between particles, so the erosion-resisting capacity is different which causes easy depositing but difficult eroding.

Whereas the above characteristic of cohesive deposits dry bulk density, at the beginning of cohesive deposits starting mechanism, the corresponding microscopic motion pattern is established, and the influence of the dry bulk density on cohesive deposits incipient motion and erosion by using correlative experimentation datum is sought.

2. THE COHESIVE DEPOSITS INCIPIENT MOTION OF DIFFERENT DRY BULK DENSITIES

Cohesive sediment's motion mechanism is different from non-cohesive sediment's. Non-cohesive sediment move in unit (Shao Xuejun 2005;Han Qiwei 1999).For the new cohesive sediment, due to the influence of cohesive force between particles, and along with dry bulk density increasing, namely cohesive force increasing, the bed sediment-starting phenomenon is also obviously different. When dry bulk density is smaller and water content is bigger, the interior cohesive force of deposits is smaller according to Gu Chengquan's (2005) research results. So the starting still mainly maintains the single particle's characteristic, during the gradually increasing of dry bulk density, the deposits pellet skeleton slowly compresses, the pore water slowly removes, cohesive forces between particles become bigger and bigger and the starting also gradually transits towards micelle. When dry bulk density becomes big enough to a certain degree, the micelle starting characteristic is completely obvious, that is to say starting runs piece by piece.

In soil mechanics, the clayey soil slope gliding failure and the cohesive sediment starting in the rivers or the reservoir have certain similarity. The two are harder to destroy when they are more compact. Therefore, we may take the clayey soil slope stability analysis research results to analyze the cohesive sediment motion in the rivers or the reservoirs for reference (Xiao Rencheng 2006; Huang Suiliang 1997).

The research object here is the cohesive sediment solidified for a period of time, so the consideration object is free micelle body; therefore we mainly aim at free micelle body to carry on the force analysis.

Hypothesis: The bed deposit is continuously even; the side shear resistance of the free micelle body (shadow in Figure 1) is ignored; the starting destroys for circles circular arc central point **O** to roll.

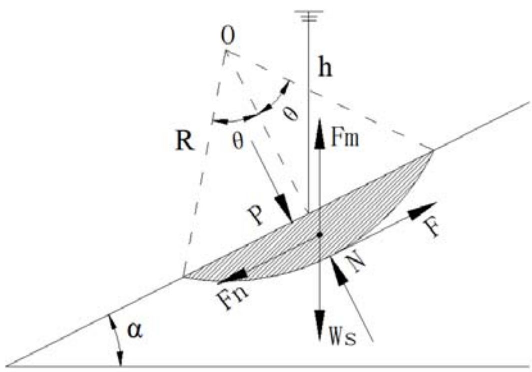


Figure 1 Force analysis of free micelle body

1) The submarine gravity W_s : considered influence of the shape (Shu Caiwen 2005):

$$W_s = a_1 \frac{\pi}{6}\left(\gamma' - \gamma\right) D^3 \quad (1)$$

Where a_1 is form factor; γ' is dry bulk density; γ is bulk density of water, D is the diameter of micelle.

2) Cohesive force F : can be defined as (Li Huaguo 1995):

$$F = \xi D \left(\frac{\gamma'}{\gamma'_{max}} \right)^{3.25} \quad (2)$$

Where ξ is cohesive force coefficient; $\gamma'_{\max}$ is stable dry bulk density.

3) Uplift force F_m:

$$F_m = a_2 C_m \frac{\pi D^2}{4} \frac{\rho U_d^2}{2} \tag{3}$$

Where F_m is the m direction uplift force; C_m the m direction friction coefficient, ρ is the density of water; U_d is function to deposits surface velocity of flow.

4) Drag force F_n:

$$F_n = a_3 C_n \frac{\pi D^2}{4} \frac{\rho U_d^2}{2} \tag{4}$$

Where F_n is the n direction drag force; a_3 is shape coefficient; C_n the n direction friction coefficient.

5) Hydraulic pressure P: Produces by the water depth, is the function of water depth *h*:

$$P = \gamma h R^2 \sin^2 \theta \tag{5}$$

6) Normal stress N: The base brings pressure to bear on the free micelle body.

The free micelle body obeys the equilibrium of moments in the starting flash, namely:

$$0 = W_s L_{W_s} + F L_{t_f} + F_m L_{F_m} + F_n L_{F_n} + P L_P + N L_N \tag{6}$$

Gave the force and arm of force，the riverbed slopes are all smaller, namely $\alpha \to 0$; As well as the micelle diameter is also small, namely $\theta \to 0$, we get:

$$\rho U_d^2 = \frac{4Dq}{3(a_2 C_m \alpha - a_3 C_n)} \left[\alpha(\gamma' - \gamma) - \frac{6\xi}{a_1 D^2 \pi} \left(\frac{\gamma'}{\gamma'_{\max}} \right)^{3.25} \right] \tag{7}$$

For cohesive deposits, its cohesive force is bigger much than the gravity (Xiao Rencheng 2006; Huang Suiliang 1997), therefore the previous formula may further simplify as:

$$\rho U_d^2 = \frac{8\xi}{\pi D (a_3 C_n - a_2 C_m \alpha)} \left(\frac{\gamma'}{\gamma'_{\max}} \right)^{3.25} \tag{8}$$

According to the formula of velocity of logarithm distribution got U_d:

$$\frac{U_y}{U_*} = 5.75 \lg \left(30.2 \frac{y\chi}{K_s} \right) \tag{9}$$

Where U_y is away from the bed surface y place velocity of flow; U_* is friction velocity; K_s is bed roughness, χ is emendation parameter.

Supposes U_d is the bottom velocity when $y = K_s$:

$$U_d = 5.75U_* \lg(30.2\chi) \tag{10}$$

By (8) and (10), we finally obtain the critical motion shear stress τ_c:

$$\tau_c = \frac{1}{[5.75\lg(30.2\chi)]^2} \cdot \frac{8\xi}{\pi D(a_3C_n - a_2C_m\alpha)} \left(\frac{\gamma'}{\gamma'_{\max}}\right)^{3.25} \tag{11}$$

Accordingly, for the natural river, α is very small, therefore the influence on cohesive deposits motion shear stress mainly is the dry bulk density, simultaneously also relate to micelle diameter, it is the function of $(\gamma')^{3.25}$ and D, namely $\tau_c = f\left(D, (\gamma')^{3.25}\right)$.

3. EFFECT OF COHESIVE DEPOSITS CRITICAL MOTION SHEAR STRESS BY DRY BULK DENSITY

Previously we get $\tau_c = f\left(D, (\gamma')^{3.25}\right)$, as we know the bulk density is easier to measure in much situation, bulk density has the direct relation with dry bulk density,

$$\gamma = (1 + W)\gamma' \tag{12}$$

Where W is water content, if assigns water content, τ_c also should satisfy $\tau_c = f\left(D, \gamma^{3.25}\right)$, in order to explain it, we directly research the relations between τ_c and $\gamma^{3.25}$ without considering the influence of D. Here we use Robets' (1998) experimental datum, which is straight got by grain diameter, and its research object is bulk density but not dry bulk density, the range of variation is 1.65g/cm^3~1.95 g/cm^3. We compiled its datum and drew relation figures between τ_c and $\gamma^{3.25}$ with same diameter (*d*=5.7μm, 14.8μm, 18.3μm, 48μm, 75μm).

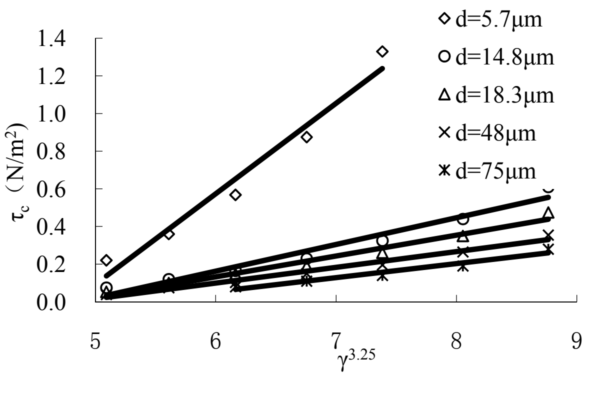
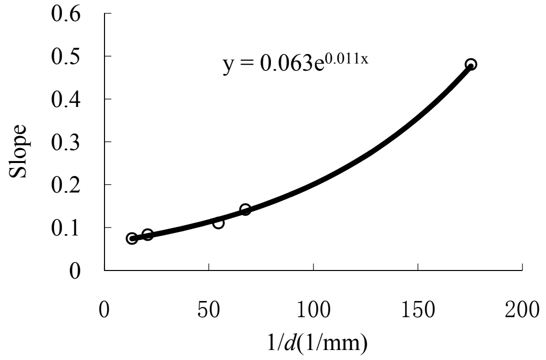


Figure 2 Relation between τ_c and $\gamma^{3.25}$

Figure 2 show the good linear relationship between τ_c and $\gamma^{3.25}$ of the fine sediment in the same diameter, but the linear relationship is dissimilar with different d.

However, from formula (11) we may find that relations between τ_c and $1/D$ is close, therefore we draw relation between the regressive coefficient and $1/d$ chart which under different diameter d as follows:



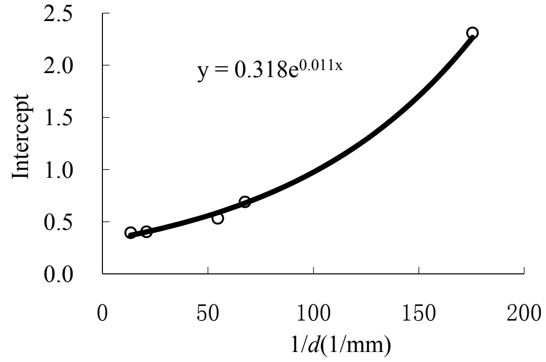


Figure 3 Relation between slope and 1/d   Figure 4 Relation between intercept and 1/d

From the data point distribution, we can see that slope and intercept all satisfy a certain law, and it is the exponential function distributed rule, then analyze the linear relation which fitting.

$$0.0115 \approx 0.0112;\ 5 \times 0.0636 \approx 0.3183$$

So

$$f(\text{intercept}) = 5f(\text{slope}) = 0.318e^{0.0113\frac{1}{d}} \tag{13}$$

Critical motion shear stress can be represented as:

$$\tau_c = 0.0636e^{0.0113\frac{1}{d}}\left(\gamma^{3.25} + 5\right) \tag{14a}$$

Considered water content and indicated with dry bulk density, namely:

$$\tau_c = 0.0636e^{0.0113\frac{1}{d}}\left[\left((1+W)\gamma'\right)^{3.25} + 5\right] \tag{14b}$$

Formula (14b) reflects the influence of the cohesive deposits critical starting shear stress by dry bulk density.

4. EFFECT OF THE MOTION VELOCITY BY DRY BULK DENSITY

Here we quote Li Qingsong's (Han Qiwei 1999) experimental datum to study the question. Li Qingsong's experimental datum is the natural sediment, which comes from Hangzhouwan and Huayuankou, its experimental datum mainly includes dry bulk density, the water depth and the critical velocity (Here starts standard is even full-face erodes).

Firstly we analyze the influence to critical velocity by the water depth when dry bulk density is the same. Therefore, according to experimental datum, we draw four kinds of situations relations between the water depth and the critical velocity when dry bulk density equal to 0.650g/cm^3, 0.700g/cm^3, 0.800g/cm^3, 1.025g/cm^3 (Figure 5).

From Figure 5, it's not difficult to see that the critical velocity change lags by far with the water depth change when dry bulk density is the same, namely the water depth has little influence on the critical velocity, the data points slope can show it better, Table1 is the corresponding slope which regresses the above various data points.

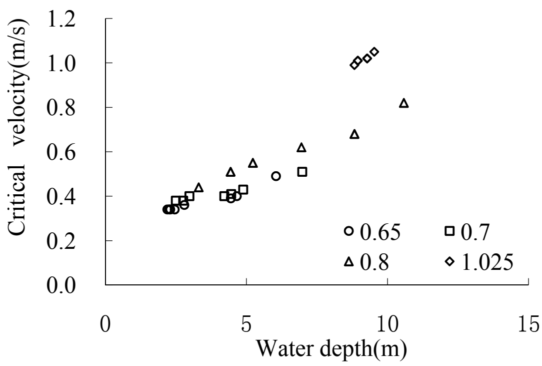


Figure 5 Relation between critical velocity and water depth

Table 1 Different dry bulk density and corresponding Regression line slope

Dry bulk density（g/cm^3）	0.6500	0.7000	0.8000	1.0250
Regression line slope	0.0345	0.0274	0.0483	0.0757

Slope is very small; it indicates that the critical velocity change is not obvious when the water depth changes little.

Next we analyze relations between dry bulk density change and the corresponding critical velocity, therefore, then draw the figure to show the relation between surface critical velocity and dry bulk density as follows(Figure 6).

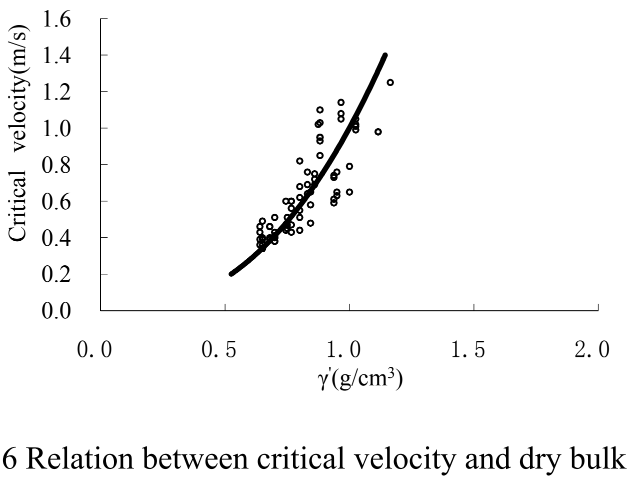


Figure 6 Relation between critical velocity and dry bulk density

In Figure 6, the range of dry bulk density is 0.64g/cm^3~1.164g/cm^3, Figure 6 shows that the critical velocity is increasing along with dry bulk density increasing, and the critical velocity change quicker than dry bulk density. With the above processing method, regresses the data points, the slope is 1.5628, which is 45.30, 57.04, 32.36, 20.64 times that of the table 1, this also reflects dry bulk density to critical velocity the influence to be bigger than the water depth.

Figure 6 also shows that all data points' arrangement has the certain regularity, namely: When dry bulk density is big, the critical velocity is big too; when dry bulk density changes $\Delta\gamma'$, the critical velocity changes ΔU_q, which isn't the same, ΔU_q is small when the correspondence dry bulk density is small, and vice versa. It approximately satisfies the power function linear; therefore, by carrying on the power function regress to all experimental data points, we obtain relations a simple functional relation, namely:

$$U_q = f\left((\gamma')^{2.5}\right) \tag{15}$$

Where U_q =critical velocity, m/s; γ'=dry bulk density, g/cm^3.

Formula (15) reflects influence of critical velocity on dry density.

5. EFFECT OF THE ERODE RATE BY DRY BULK DENSITY

In order to estimate the change of deposition, we must know not only its incipient motion velocity or the critical motion shear stress, but also its erosion rate. As a true, erosion rate is defined as the total mass of sediment transport per time and area with the following form:

$$S_r = W_s / AT \tag{16}$$

Where S_r= erosion rate; W_s= total mass of transport sediment; A= erode area of bed; t= erode time.

Now, let's qualitative analyzes the effect of the erosion rate by dry bulk density when eroded by the clear water. When clear water erodes, the effect factors of the cohesive deposits' erosion rate may summarize as $S_r = f(J, H, \tau_c)$, τ_c is a synthesis factor, according to the Li Huaguo's (1995) research results, silt erosion rate and critical motion shear stress approximately satisfies the 2-power (1.85). According to the anterior inferential reasoning, there is approximate 3.25-power relationship between the cohesive deposits critical motion shear stress and dry bulk density. Considering these two factors, silt erosion rate and dry bulk density should approximately satisfy the 6th power. Therefore, when clear water erodes, the influence of dry bulk density of silt on erosion rate is extremely big. This also explains that influence of dry bulk density on cohesive deposits is very big when clear water erodes.

6. CONCLUSIONS

1) Based on the motion mechanism and motion pattern of cohesive deposits motion, we can conclude that the mainly influence on the cohesive deposits critical motion shear

stress is dry bulk density, and the other influence is the micelle diameter D, it is a function of $(\gamma')^{3.25}$ and D, and a concrete formula is gave.

2) By using isolated factor method and Robets' experiment datum, the influences of dry bulk density and particle diameter to the cohesive deposits critical motion shear stress are researched, and a corresponding formula for critical motion shear stress is established.

3) Through analyzing influence factors on cohesive deposits motion velocity which even full-face erodes, we conclude that comparing with dry bulk density ,water depth has very little influence on incipient motion velocity (less than 5%), and according to the existing experimental datum, we fits a simple empirical curve relations between dry bulk density and motion velocity.

4) For non-cohesive sediment, dry bulk density has little influence on the erosion rate, and can be ignored; for the cohesive sediment, dry bulk density has more and more influence on the erosion rate along with the particle size reducing, the cohesion enhancing and the dry bulk density increasing; for the silt, erosion rate and dry bulk density approximately wear the 6th power.

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