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Research Article

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A discrimination method of "Ripping up the riverbed" in the Yellow River

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ABSTRACT

According to the mechanism of "ripping up the Riverbed" and lifting mode of clay block, constructed a lifting analysis model of clay block broken. Considering the combined effect factors of clay block lifted (for example, clay block density, thickness, mechanical strength, peak flow and sediment concentration, the duration of the flood process, river channel morphology parameters, fluctuations lifting force in the velocity indirection of siltation layer etc.) and the most adverse load combinations conditions, making use of the flexural strength experimental data of clay block on "Ripping up the bottom" river reach, establish critical lifting mechanics equation of clay block and solve it. The research results enrich calculation theory of "Ripping up the Riverbed".

Keywords: "Ripping up the riverbed"; Clay block; fracture; flexural strength;

INTRODUCTION

"Ripping up the riverbed" is a special phenomenon of sediment transporting and channel adjustment reaction under complex flow state and riverbed boundary condition. "Ripping up the riverbed" often lead to strong riverbed erosion, sometimes, a flood peak can washed riverbed several meters deep, so that the riverbed and the water level dropped significantly, while scouring action often causes the main channel migration, seriously damage the hydraulic engineering along river bank. Seventies of last century, the question of "Ripping up the riverbed" has aroused great concern of water conservancy workers in home and abroad. Present the study method of "Ripping up the riverbed" problem can be divided into three categories: The first method is the use of the measured data of hydrological station to analyze the water and sediment condition of "Ripping up the riverbed"; The second method is the use of the concept of sediment transport capacity to study the water and sediment condition when the clay block starting. The third method is the use of the flume experiment to simulate the phenomenon of "Ripping up the riverbed", analyze the mechanism of "Ripping up the riverbed", the mode of "Ripping up the riverbed" and the water and sediment condition. Whether riverbed sludge block can be lifted, depending on the combined result of a variety of conditions, including pre-silting patterns and adjustments of riverbed, sludge density and relative roughness, deposited pieces formation and thickness, deposited pieces boundary conditions, the mechanical strength of deposited pieces, peak flow and sediment concentration, the duration of flood, channel morphology parameters, layer vertical pulsating pressure. At present, for the study of "Ripping up the riverbed", because research tools, method, objection and research emphases and so difficult, the criterion and discriminant indies of this issue is still lock of a unified understanding, the research literature of considering combined effect factors of clay block lifted and mechanical strength of clay block has not yet found. The authors of reference [3] simulated the phenomenon of "Ripping up the riverbed" through flume experiments and constructed dynamic model of "Ripping up the riverbed" , and proposed the instantaneous uplift force that caused by upper and lower surface of clay block possessing different fluctuations pressure wave propagation velocity is the real mechanism of "Ripping up the riverbed". This paper constructs an analysis model of clay block broken lifted based on the reference [3] proposed mechanism and mode of "Ripping up the Riverbed", and considering the comprehensive effect factors of clay block lifted and the most unfavorable load combine conditions, establish mechanics equations of clay block critical lifted and solve. The research results of this paper enrich the calculation theory of "Ripping up the riverbed", and provide the possibility to collect data real-time of "Ripping up the riverbed".

2 The lifting model of clay block broken

"Ripping up the Riverbed" often occur in the beach land or riverbed of "dry bottom of the river" and diversion river channel. Some workers who engaged in hydrological observation in Yellow Longmen station said that before "Ripping up the riverbed" phenomenon occur, the general silting quite serious in the riverbed, and longitudinal gradient and cross-sectional shape has a certain degree of adjustment. “Ripping up the riverbed" frequently occurs in above riverbed conditions, the reason is that because this riverbed exists fissures, when the flood passed, “Ripping up the riverbed" are frequently occurs in the riverbed conditions, the reasons is that because this riverbed exists fissures, when the flood passed, since the oscillation water body and pulsating water pressure in fissures, resulting the fissures development, making the adhesion force of around clay block reduced, thus, creating condition for having a structural strength clay block lifted. For a strong resist erosion performance clay block, as diving water flow in the fissures acting, the sludge around clay block being scoured, with scouring to last, the vacant area of clay block is growing, while meeting the lifted condition, the clay block will be lifted. The diagram of hierarchical structure riverbed being scoured is shown figure 1. Figture.2 is the model of clay block broken lifted. In order to facilitate theoretical analysis, assuming clay block is a hexahedron, clay block length is a , it’s width is b, and thickness is c , the length of cantilever scoured is l , the area of clay broken is $A = l \times b$, the volume weight of clay block is γ_s , the depth of clay block surface to water surface is h , muddy water density is γ_m , slope of water surface is J , the gravitational acceleration is g .

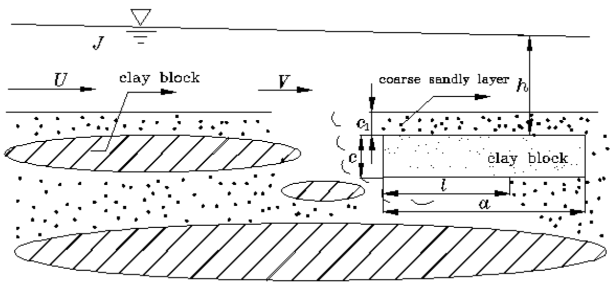

Fig.1 The diagram of hierarchical structure riverbed being scoured

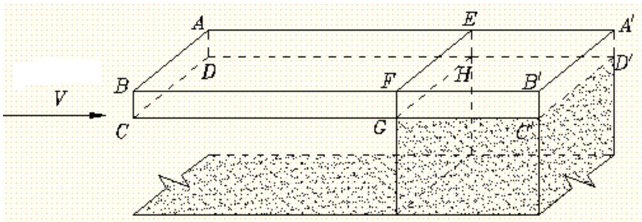

Fig.2 The diagram of clay block broken along FEGH cross-section

3 The critical water flow condition computed when clay block is broken

The force analysis of clay block broken shown in Figure 3:

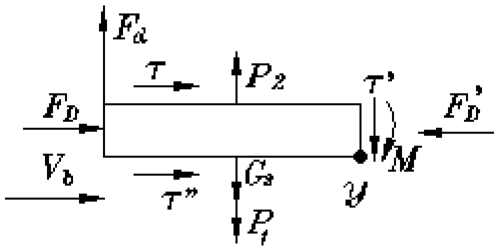

Fig.3 The force analysis of clay block broken lifted

The front thrust force of water flow F_D [1]:

$$F_D = \frac{\gamma_m C_D}{2} V_b^2 bcg \tag{1}$$

Where, V_b is the flow velocity of riverbed, C_D is the resisting force coefficient, γ_m is the density of muddy water, b is the width of clay block, c is the thickness of clay block.

$F_D^{'}$ is the opposite reaction of F_D :

$$F_D^{'} = -\frac{\gamma_m C_D}{2} V_b^2 bcg \tag{2}$$

$\tau^{'}$ is vertical shear force of clay block broken surface, it does not produce torque on the y-axis, can be ignored. τ is water drag force of clay block upper surface:

$$\tau = \frac{\gamma_m C_D}{2} V_b^2 lbg \tag{3}$$

$\tau^{''}$ is water drag force of the clay block lower surface, it does not produce torque on the y-axis, can be ignored. G_s is the weight of clay block:

$$G_s = \gamma_s lbcg \tag{4}$$

P_1 is water pressure of clay block:

$$P_1 = \gamma_m lbhg \tag{5}$$

P_2 is buoyant force of clay block:

$$P_2 = \gamma_m lb(h + c)g \tag{6}$$

$F_{d\,\max}$ is the maximum flow fluctuating uplift force[4]:

$$F_{d\,\max} = K\gamma_m JV_b^2 lb \tag{7}$$

Where, K is linear coefficient, unit is $kg\cdot m\cdot s$, range: 3～4.2， J is slope water surface.

Considering the most unfavorable load combination, set the y-axis torque balance equation:

$$F_{d\,\max}\, l + P_2 \frac{l}{2} + \tau c - G_s \frac{l}{2} - P_1 \frac{l}{2} = Mbc \tag{8}$$

Where, M is the clay blocks flexural strength, it is given by flexural test.

$$V_b^2 = \frac{2Mc + l^2 cg(\gamma_s - \gamma_m)}{2KJl^2\gamma_m + lcg\gamma_m} \tag{9}$$

The cantilever length of clay block scoured in Δt time period uses empirical formula to compute [5]:

$$l = C_1 \Delta t(\tau_s - \tau_c) e^{-0.013\tau_c / \gamma_c} \tag{10}$$

Where, C_1 is riverbed erosion coefficient, τ is the drag force of silt particles around clay block, τ_c is the critical shear stress when riverbed sludge scoured, γ_c is bulk density of river sediment.

Flow shear stress of riverbed τ :

$$\tau = C_D^{'} \alpha_D d_i^2 \frac{\rho_m V_b^2}{2} \tag{11}$$

Where, $C_D^{'}$ is drag force coefficient, its value is 0.4, α_D is area coefficient of the sediment particles, its value is $\frac{\pi}{4}$, ρ_m is muddy water density, d_i is particle size of sediment eroded, other symbols as before. Using average particle diameters of the movable siltation around clay block D to substitute d_i, Organizing the formula (11) to give:

$$\tau = 0.16D^2\rho_m V_b^2 \tag{12}$$

The critical shear stress of riverbed siltation τ_c [2]:

$$\frac{\tau_c}{(\gamma_c - \gamma_m)d_i} = A\left(1 + \xi\frac{d_m}{d_i}\right) \tag{13}$$

Where, A is comprehensive influence coefficient, its value range is 0.015~0.034, median value is 0.0245, ξ is a coefficient with related to sediment exposure degree, its value range is between 0 and 1, d_m is average particle diameter of eroded siltation.

Substituting formula (12) and (13) into formula (10), the formula of scoured cantilever length l can be obtained:

$$l = C_1\Delta t\left[0.16\rho_m V_b^2 D^2 - Ad_i(\gamma_c - \gamma_m)\left(1 + \xi\frac{d_m}{d_i}\right)\right]e^{-0.013Ad_i(\gamma_c - \gamma_m)\left(1+\xi\frac{d_m}{d_i}\right) / \gamma_c} \tag{14}$$

Clay block sediment median diameter is in the range of orders of 10^{-5} (m) magnitude, by particle analysis test of clay block sediment from "Ripping up the river bottom", considering eroded sediment lay in the transition layer between clay layer and its adjacent despition layer, and therefore the median particle size of sediment eroded is also essential in the range of orders of 10^{-5} (m) magnitude, the variable A is in the range of orders of 10^{-2} （m）magnitude, and $\frac{\gamma_c - \gamma_m}{\gamma_c} < 1$, so $e^{-0.013Ad_i(\gamma_c - \gamma_m)\left(1+\xi\frac{d_m}{d_i}\right) / \gamma_c} \approx 1$. Organizing the formula (14) to give:

$$l = C_1\Delta t\left[0.16D^2\rho_m V_b^2 + AD(\gamma_c - \gamma_m)(1 + \xi)\right] \tag{15}$$

To V_b^2, l as variable, simultaneous equations (9) and (15) is solved:

$$l^3 - \frac{C_1\Delta tAD}{2}(2\gamma_c + 2\xi\gamma_c - \gamma_m - \xi\gamma_m)l^2 - \frac{C_1\Delta tADcg}{2KJ}(\gamma_c + \xi\gamma_c - \gamma_m - \xi\gamma_m)l - C_1\Delta tD^2\rho_m c[0.32M + 0.16g(\gamma_s - \gamma_m)] = 0 \tag{16}$$

Let:

$$a^{'} = -\frac{C_1\Delta tAD}{2}(2\gamma_c + 2\xi\gamma_c - \gamma_m - \xi\gamma_m)\quad b^{'} = -\frac{C_1\Delta tADcg}{2KJ}(\gamma_c + \xi\gamma_c - \gamma_m - \xi\gamma_m)$$

$$c^{'} = -C_1\Delta tD^2\rho_m c[0.32M + 0.16(\gamma_s - \gamma_m)]\quad l^{'} = l - \frac{a^{'}}{3}$$

the formula (16) was converted to formula (17):

$$(l^{'})^3 + pl^{'} + q = 0 \tag{17}$$

Where, $p = \left(\frac{(a^{'})^2}{3} + b^{'}\right)$

$$q = \frac{2(a^{'})^3 - 9a^{'}b^{'} + 27c^{'}}{27}$$

According to solving root formula of a three order equation,we have:

$$l = \left\{ -\frac{q}{2} + \left[\left(\frac{q}{2}\right)^2 + \left(\frac{p}{3}\right)^3 \right]^{\frac{1}{2}} \right\}^{\frac{1}{3}} + \left\{ -\frac{q}{2} - \left[\left(\frac{q}{2}\right)^2 + \left(\frac{p}{3}\right)^3 \right]^{\frac{1}{2}} \right\}^{\frac{1}{3}} + \frac{a'}{3} \quad (18)$$

The formula (18) into equation (9), we can be calculated V_b^2.

$$V_b^2 = F(C_1, \Delta t, \gamma_c, \gamma_s, \gamma_m, c, J, K, M, D) \quad (19)$$

CONCLUSION

This paper construct clay blocks broken lifted analysis model based on "Ripping up the riverbed " mechanism and clay block lifted mode. Consider the combined effect factors of clay block lifted and the most unfavorable load combination conditions (the maximum arm of flow fluctuating lifting force), and using flexural strength experimental data of "Ripping up the riverbed " , establishing mechanical equations of clay block critical lifted and to solve it. We can see from the calculated formula: the critical flow velocity of clay block broken lifted is a fuction about riverbed erosion coefficient C_1, erosion lasted Δt, bulk density around of sludge around clay block γ_c, bulk density of clay block γ_s, muddy water density γ_m, clay block thickness c, riverbed gradient J, clay block flexural strength M, sludge particle size D, the combined effects coefficient of flow fluctuating uplift force. The formula is currently the most comprehensive formula of considering the combined effect factors of clay block lifted. This paper results enrich calculaton theory of "Ripping up the riverbed" problem and provide the possibility to predict whether a flood lead to "Ripping up the riverbed" phenomenon.

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