A New Method for Calculating Landslide Initial Surge Height

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Abstract — **Large high-speed landslide in a reservoir river would bring great disaster to personnel within the area of influence, the people living near a river and downstream of the dam are under great threat because of the surge. Surges of threat level are closely related to the height of the initial surge. The surges are divided into volume and impulsive waves in this paper and their mechanism of action are analyzed. Landslides are divided into rock landslides, soil landslide and integrity, bulk granular landslide, based on two parts of the mechanism of action of surges. The volume conversion law and the displacement formula of mass below water level are used to calculate the initial surge height on the premise of landslide classification. Different from past calculation formula, this paper calculates the initial surge height without involving landslide volume, due to the fact that in the event of an actual landslide the initial surge height is directly related to the volume of landslide for the first time into the water, that is the subsequent part of the landslide and the initial surge height are not related. The results of initial surge height by landslide in reservoir research is shown to be significant.**

Keywords - Landslide; surge; maximum height of head wave; calculation methods

I. INTRODUCTION

Landslide in reservoir region is the large amounts of rock and soil in the river on both sides pour into the river in a shorter time, not only will be blocked rivers but also will Provoke surge. Due to the frequent water movements in the reservoir Bank slope is instability, so the reservoir landslide occurred in high frequency. on June 25, 2015, wushan NingHe jiangdong temple north shore a massive landslide sudden a massive landslide occurred, cause the great surge up to 6 meters, two people were Killed and many people were injured, many small vessels capsized at the other side. So accurate study of the formation of landslide surge and the damage is very meaningful.

Currently at home and abroad the research methods of landslide surge are mainly composed of the analytical solution, numerical simulation and model test. A representative is E. Noda [1] , he Considering the landslide's two states that is plummeted and horizontal movement, combined with the analytical solution and model test and the calculation formulae are worked out. Rudy Slingerland and Barry Voight based on the model test , the empirical formula between maximum surge height and dimensionless kinetic energy was obtained. Pan Jiazheng proposed the research of Initial surge and impulsive waves. Wang Yang in the studies on the distribution patterns of the initial surge and attenuation mode of surge has made certain progress.

In this paper, based on the formation mechanism of landslide surge, at first classify the landslide, different type of the landslide surge's calculation parameters are different. Then the surges will be divided into volume and impulsive waves. Based on the volume conversation law, deriving the alculation formula of the initial surge height.

II. THE FORMATION MECHANISM OF LANDSLIDE SURGE

The formation of landslide surge must have three basic conditions, first, the landslide must have a certain volume; second, when the landslide pour into water it must have a high speed; third, the landslide has a certain area in positive side; Satisfy the three conditions of landslide will impact of the contact surface of the water bodies and drained water where the landslide invade the volume of water, therefore the landslide surge can think consists of two parts, that is volume and impulsive waves, the impulsive waves that is without considering drainage water condition, positive side of landslide with certain area at a certain speed push water movement then generated surge wave, and the impact-surge that is without considering promote water body condition, when landslide displaces the water at a certain invasion volume rate then generated surge wave. In a semi-infinite water body, the impulsive waves can be considered as the surge provoked by a thin plate regardless of the volume with a certain area and speed to push water to movement.
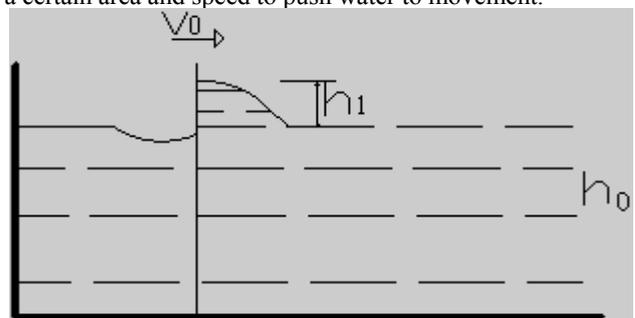

Fig. (1). the schematic diagram of impulsive waves' mechanism of production.

As shown above, in the process of a thin plate regardless of the volume with a certain area and speed to push water to movement, in front of the water body due to inertia and

resistance the speed rate will be lower than the thin plate lead to high water level in front of the thin plate that is impulsive waves. volume waves is that displaces a certain volume of water within a certain amount of time lead to high water level around the landslide. Landslide surge could be regarded as formed by this two parts, but in reality both consider cannot exist alone and cannot be isolated. The landslide surge process can be simplified as in promoting the water form the impact-surge at the same time displaces a certain volume of water, as shown below.
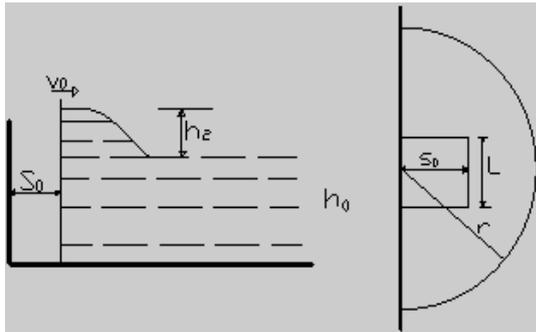

Fig. (2). the schematic diagram of landslide surge's mechanism of production

The thin plate from the bank started at a certain speed drive water movement, meanwhile displaces water in the space of its passing. With the surge formed by this process can replace the research in initial surge.

III. THE CLASSIFICATION OF LANDSLIDE

At home and abroad the study of initial surge height have made some achievements, Through the analytical solution, numerical simulation and model test method, the calculation formula of initial surge height had been worked out. But the calculation methods existing common problem is its applicable range is not big. And in the process of the study of landslide surge the factors of the landslide itself had been ignored. In reality, due to the different circumstances of landslide, the surge is also in bigger difference, this is the reason why the result is not accurate when some existing surge height calculation method used for the different landslide . Therefore, before the study of landslide surge we should classify landslide at first.

According to the formation mechanism of landslide surge, considering from the formation mechanism of volume surge, the landslides can be divided into rock landslides and soil landslide, in the process of the former landslide pour into the water, due to landslide mass's porosity is small, So we can think that the volume of landslide mass is equal to the volume of the water body which was displaced by the landslide mass . But for the soil landslide, the landslide mass with larger porosity, the volume of landslide mass is less than the volume of the water body which was displaced by the landslide mass; from the formation mechanism of impact-surge, landslides can be divided into wholeness and loose landslide. The former landslide in the process of the invasion of water the positive side's shape basically remain unchanged, While the latter landslide into bulk granular, the

landslide mixed with water, regularity is not strong, it's suitable to study by physical model tests.

IV. THE CALCULATION OF THE INITIAL SURGE

A. the volume conservation principle of landslide surge

Water was regarded as incompressible while in the whole process of the landslide pour into water, it's meet the volume conservation principle. In the semi-infinite water bodies, Landslide displaces a part of the volume of water, it will spread in all directions when spread to the top that is volume surge. The landslide in the process of the promoting water movement, the water's water resistance is larger where in positive side's leading edge, so it's speed will be slower than the landslide mass, the part of the different water will spread in all directions when spread to the top that is impact-surge.

In this process, assumes that the surge in semi-infinite water will be semicircular evenly distributed. With entry points for the center , mean distribution radius $r = c_1.t_1$, where c_1 is wave celerity in water t_1 is the time after the landslide mass pour into water.

B. The calculation of the impact-surge

When study of impact-surge, assume a fixed volume of water does not flow, to facilitate study of fluid in the movement. due to the complexity of granular landslide, we only consider the integrity landslides. In the process of landslide pour into the water, in a short time , the surface area of positive side is Constant and it's speed of movement is , the displacement is , the displacement of water where in positive side's leading edge is S_2 . While:

$$s_1 = v_0.\Delta t \qquad (1)$$

Dynamic equation of the water body：resistance coefficient is

$$m\frac{d_v}{d_t} = -\frac{1}{2}c_d\rho v^2 A \quad , \quad c_d \qquad (2)$$

work out：

$$s_2 = \frac{\ln(Bv_0\Delta t + 1)}{B}$$

$$B = \frac{c_d\rho A}{2m} \qquad (3)$$

Landslide is divided into two cases when pour into the water, in one case the height of landslide is greater than the depth of the water, another case just the opposite, the volume of water which is the part of the different water is:

$$V_1 = L*h_0*(s_1-s_2) = L*h_0*(v_0\Delta t - \frac{2m*\ln(\frac{c_d\rho Lh_0}{2m}v_0\Delta t+1)}{c_d\rho Lh_0}) \quad (4)$$

the part of the different water will spread in all directions, so The volume of impact surge is:

$$V_1' = \frac{V_1}{4} \qquad (5)$$

So we can conclude:

$$V_1 = 2*\pi(c_1\Delta t)^2 h_1 \qquad (6)$$

is the travelling wave velocity, according to the related literature:

$$c_1 = (h_0 + h_1)\sqrt{\frac{2g}{2h_0 + h_1}} \qquad (7)$$

as show in[2], To (4), (5), (7) into (6) we can get:

$$L * h_0 * (v_0 \Delta t - \frac{2m * \ln(\frac{c_d \rho L h_0}{2m} v_0 \Delta t + 1)}{c_d \rho L h_0})$$

$$= 4 * \pi g * \Delta t^2 * \frac{h_1(h_0 + h_1)^2}{2h_0 + h_1} \qquad (8)$$

This is the integrity landslide, during the , when the height of landslide is greater than the depth of the water, the relational expression about the height of impact surge: ,the width of landslide mass: ,the depth of water: ,the speed of landslide mass: ,the time to computation: ,The weight of fixed part of water: and the water' s resistance coefficient . The formula is a invisible expression about . we can adopt the bisection method with inverse iteration to solve it.

In another case , analogy (8), we can get :

$$L * H_0 * (v_0 \Delta t - \frac{2m * \ln(\frac{c_d \rho L H_0}{2m} v_0 \Delta t + 1)}{c_d \rho L H_0})$$

$$= 5 * \pi * g * \Delta t^2 * \frac{h_1(h_0 + h_1)^2}{2h_0 + h_1} \qquad (9)$$

In two cases, the height of the impact surge's calculation formula is described above.

C. the calculation of volume surge

Volume surge is the surge caused by the landslide displaces water, according to the principle of volume conservation, the part of the water which was displaced by landslide mass will spread in all directions, assuming that the volume of water is the same in all directions. As was stated above, the rock landslides and soil landslide can be described by coefficient that is k . So in soil landslide, the volume of the water which was displaced by landslide mass: $V_3^{'} = k * V_3$, V_3 is the volume of landslide mass into the water, of which $0 < k < 1$, when $k = 1$ that is rock landslides, and this value is related to the porosity of the landslide, but not equal.

According to figure 2, the volume of water discharged by landslide mass which cause the volume surge is:

(1)When $h_0 \leq H_0$

$$V_3 = k * L * h_0 * v_0 * \Delta t \qquad (10)$$

(2)When $h_0 > H_0$

$$V_3^{'} = k * L * H_0 * v_0 * \Delta t \qquad (11)$$

Assumes that the volume surge is same as impact surge, the surge in semi-infinite water will be semicircular evenly

distributed with entry points for the center. we can get the relational expression is :

When $h_0 \leq H_0$

$$V_4 = g * \pi * \Delta t^2 \frac{h_3 * (h_0 + h_3)^2}{2h_0 + h_3} \qquad (12)$$

when $h_0 > H_0$

$$V_4^{'} = g * \pi * \Delta t^2 \frac{h_3^{'} * (h_0 + h_3^{'})^2}{2h_0 + h_3^{'}} \qquad (13)$$

Take the formula (13) and (14) into the above equation, we can conclude the Formula about the height of landslide surge :, depth of water:,the width of landslide mass:,the time to computation:,the speed of landslide mass:

(1)when $h_0 \leq H_0$

$$k * L * h_0 * v_0 = 4 * g * \pi * \Delta t \frac{h_3(h_0 + h_3)^2}{2h_0 + h_3} \qquad （14）$$

(2)When $h_0 > H_0$

$$k * L * H_0 * v_0 = 5 * g * \pi * \Delta t \frac{h_3^{'}(h_0 + h_3^{'})^2}{2h_0 + h_3^{'}} \qquad (15)$$

Them is a invisible expression too. we can adopt, the bisection method with inverse iteration to solve it.

As mentioned above, in the integrity landslide when the height of landslide mass is greater than or equal to water depth, the formula of the impact surge's height as show in (8); the formula of the volume surge's height as show in (14). when the height of landslide mass is lessen than water depth, , the formula of the impact surge's height as show in (9); the formula of the volume surge's height as show in (15). This formula are concluded on the basis of the principle of volume conservation and the assumption, in the formula the time Δt is a short time, so we must get the formation time of the initial surge at first , that is t_c , Then the integral from 0 to t_c of the calculation formula, that is $h_x = \int_0^{t_c} f_x(\Delta t) d(t)$, h_x is the height of impact and volume surge in the two cases And $H_x = f_x(\Delta t)$ of which $H_x = h_1, h_1^{'}, h_3, h_3^{'}$ conclude from the formula (8),(9), （13）, （14） . So we can get the height of impact and volume surge eventually.

V. THE CALCULATION OF THE INITIAL SURGE

The above computing method of landslide surge's height, is based on the calculation model as shown in figure 1, figure 2. The calculation model is different with the actual situation, the slope is assumed to be upright, the actual situation of the most landslide is different. But this calculation model can be simplified to distinguish the impact and volume surge, To facilitate the research respectively. when classifying landslides based on the mechanism of action of landslide surge, the rock landslides and soil landslide can be described by coefficient that is k .

But for the integrity and bulk granular landslide, The specific study for the latter needs through physical model experiment. the calculation method of landslide surge is related to the width, ,height, velocity of landslide mass, the water depth and time after landslide mass pour into the water. It is the major effect of the initial surge, but due to the limitations of calculation model, Some other influential factors to the initial surge has been ignored. If it's need specific research , it should be combined with physical model test .

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