Experimental Research on Primary Wave Height Generated by Integral Landslide in Channel Type Reservoir

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***Abstract*—*For investigating the primary wave height generated by integral landslide in channel type reservoir, by adopting orthogonal experimental method to design experiment groups. Landslides occurrence and the exchanges progress between landslides and water were simulated through the conceptual model experiment. Experiment result analysis and variance analysis obtained primary wave height with the variation of the influencing factors and significant trends. Theoretical analysis and experimental results are the same.*

***Keywords*—orthogonal experiment, the conceptual model experiment, integral landslide, primary wave height.**

I. INTRODUCTION

Due to the fluctuation of reservoir water level during the initial stage or operation period, the potential landslide body in the reservoir area is under the condition of freezing and thawing, dry and wet alternate, it's prone to huge landslides. The landslides slide into the river in a short period of time of high-speed slide, inevitably aroused huge waves which caused serious damages: Affect the safety of the sail upstream and downstream, pose a threat to the residents' life and property along the river on both sides; If the wave height in the front of the dam is close to or exceed the height of the dam crest, it will inevitably cause flooding which will damage reservoir hydraulic structures; Surge overflow dam crest, the flood will destroy the farmland, houses, roads and railways of downstream and threaten the safety of lives and property of urban residents. Therefore, investigating the primary wave height aroused by the river reservoir landslide as well as its influencing factors and put forward the calamity degree of landslide surge have very important practical significance for effectively advance the prevention and reduction of disaster losses caused by the landslide surge on both sides of the river and dam building.

At present, many domestic and foreign scholars achieved certain results in the study of landslide physical model experiment. In the study of landslide surge, the experiment is divided into two kinds: the conceptual physical model experiment and specific physical model experiment for the landslide surge. In conceptual landslide surge physical model experiment, the most are just simple simulation of generalized, the factors to consider each are not identical and the parameter selection is not unified. The following are simple analysis of the existing landslide surge simulation:

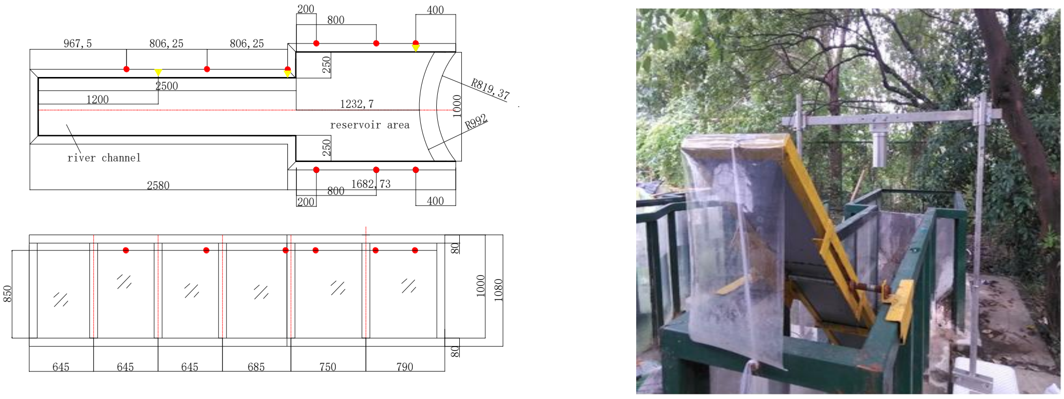
1. Edward.Noda(1970) [1] and Pan Jiazhen [2] mainly considered the two extreme sports of the rigid sliding block in horizontal and vertical, the factor of the obtained formula of landslide surge height is relatively single.
2. Kamphuis and Bowering(1970) [3] analyzed the characteristics of the landslide surge according to the physical model experiment and theory and put forward the main factors affecting surge height were the slider volume, the Froude number and the depth of water, but not considering the influence of entering water angle.
3. B. Ataie-Ashtiani [4] used the cement to make a rectangular and wedge shape as a rigid landslide model, the flexible landslide model was made by using the gravel and other granular materials. Considering the influence of the length, width and thickness of the landslide. The flexible landslide model was considered for the first time.
4. Changjiang River Scientiffic Research Institute of Changjiang Water Resources Commission [5-6] take the landslide initial state as rectangular grain stone deposit, the landslide was controlled by the box body and it will all broken after breaked away from the box. Deposit landslide model mainly consider the particle size of scattered stone.
5. China University of geosciences [7] manufactures the landslide with cement and gravel and considered the length, width and thickness of landslide. Making the shape of the landslide into a cuboid, six or seven of the wedge body.

In this paper, we take the landslide as the research object and carries on the conceptual physical model experiment. Synthesizing each kind of factors, such as landslide volume, sliding plane obliquity, water depth and slide head that impact the primary wave height. Obtained the primary wave height with the variation of the influencing factors and significant trends by variance analysis and carried on theoretical analysis.

II. PHYSICAL MODEL AND EXPERIMENT PLAN

2.1 Model Design

The experiment is based on the conceptual landslide physical model experiment. And in view of the river pattern in the northwest of China, the channel type reservoir size is 2.5m×0.5m (length×width), reservoir size is 1.5m×1.0m (length×width). The front end of the model is equipped with adjustable slide and slide slot size is 30cm wide, dip angle is from 15°-90°. The sliding surface is faced with smooth film in order to more conducive to the slider sliding into the water. Experiment model is shown in figure 1.



(a) **(b)**

FIGURE 1: EXPERIMENT MODEL AND SIZE

2.2 Experimental Design

According to the purpose of this experiment and site condition, the major design parameters of the conceptual model experiment are: adjusting range of water depth h is 0.4m to 0.7m, landslide length l is 0.2m-0.4m, the thickness s of the landslide is 0.05m-0.15m, landslide width w is 0.15m-0.25m, landslide head y is 0.5m-0.7m, water entry angle α is 30°-60°. Depending on orthogonal test method, each factor select three levels through analyzing the actual landslide data and the measuring range of this physical model experiment. Ultimately choosing L18 (37) orthogonal table to make experiment plan. There, we did 18 experiments groups and 108 times orthogonal experiment means done six times in each group. Then take the six data values as experiment analysis data after processing. In addition, we targeted conducted a series of 36 groups 156 times additional experiments according to sensitivity analysis results of the orthogonal experiment [8]. And the 6 data values will also be treated as experimental data analysis. The orthogonal experiment table is shown in table 1.

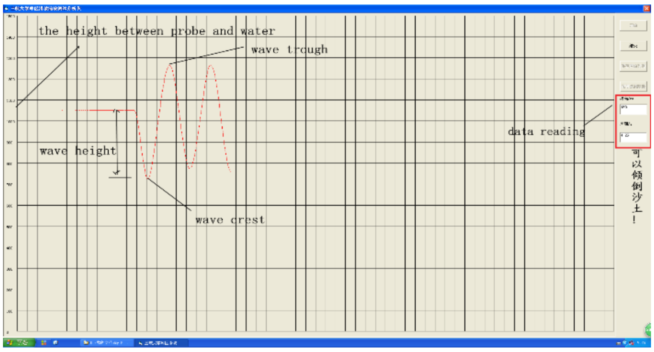
TABLE 1
THE ORTHOGONAL EXPERIMENT TABLE

Group	*l*	*w*	*s*	*α*	*h*	*y*
	(m)	*(m)*	*(m)*	*(°)*	*(m)*	*(m)*
1	0.2	0.15	0.05	0.4	0.5	0.5
2	0.2	0.2	0.1	0.5	0.6	0.6
3	0.2	0.25	0.15	0.6	0.7	0.7
4	0.3	0.15	0.05	0.5	0.6	0.7
5	0.3	0.2	0.1	0.6	0.7	0.5
6	0.3	0.25	0.15	0.4	0.5	0.6
7	0.4	0.15	0.1	0.4	0.7	0.6
8	0.4	0.2	0.15	0.5	0.5	0.7
9	0.4	0.25	0.05	0.6	0.6	0.5
10	0.2	0.15	0.15	0.6	0.6	0.6
11	0.2	0.2	0.05	0.4	0.7	0.7
12	0.2	0.25	0.1	0.5	0.5	0.5
13	0.3	0.15	0.1	0.6	0.5	0.7
14	0.3	0.2	0.15	0.4	0.6	0.5
15	0.3	0.25	0.05	0.5	0.7	0.6
16	0.4	0.15	0.15	0.5	0.7	0.5
17	0.4	0.2	0.05	0.6	0.5	0.6
18	0.4	0.25	0.1	0.4	0.6	0.7

III. MEASUREMENT SYSTEM

Measurement system at the request of topic and actual measurement needs, purchasing pool wave measurement system—SBY2-1 type acoustic wave recorder, it can monitor the fluctuations of the water in each location. The system hardware is mainly composed of intelligent acoustic sensor and host records (as shown in figure 2). The sensor was vertically mounted on above 20m-150m range, real-time monitoring the distance between probe and the surface of wave, and the measurement accuracy is 1mm (as shown in figure 3a). Every 1/16s sensor reads a data, and transfer the data back to the host, then the host application will paint wave images in the form through the record, and the system will automatically read the wave height and period (as shown in figure 3b).

FIGURE 2: MEASUREMENT SYSTEM



(A) MONITORING PROBE PLACEMENT **(B) WORKSPACE OF THE PRIMARY WAVE HEIGHT**

FIGURE 3: HOST OPERATING SYSTEM

IV. RESULTS AND DISCUSSION

The formation of the landslide surge must have three conditions: (1) landslide must have a certain size; (2) landslide must have a high speed when it slides into water; (3) landslide has certain impact face area. The landslide that Satisfy this three conditions will impact the contact surface of water and extrusion the landslide volume of water when it slide into water. Therefore, the landslide surge can be thinked consists of two parts: Shock wave and volume weight. The shock wave is a wave that not considers drainage conditions and has certain impact face area to meet the water at a certain speed. And volume surge is a wave that not considers pushing water conditions and lined with a certain volume rate to drainage water. In the process of integral landslide surge formation, the tail water appeared first and then appeared surge. Here, we defined the primary wave height mainly depend on the energy of water and surge formation stage.

Although the spray formed by landslide tail slide into the cavity of water is heigher, but the carried energy and the extent of the disaster are relatively small, and obviously does not have the characteristics of wave, therefore, we does not consider them in the primary wave range.

4.1 The Primary Wave Height Sensitivity Analysis

According to the scheme of the orthogonal experiment, repeated experiments and preceded the original data from orthogonal experiment results. Obtain the experiment results as shown below:

TABLE 2
THE RESULTS OF ORTHOGONAL EXPERIMENT

l	*w*	*s*	*α*	*h*	*y*	*Wave height*
(m)	*(m)*	*(m)*	*(°)*	*(m)*	*(m)*	*(m)*
0.2	0.15	0.05	40	0.5	0.5	13
0.2	0.2	0.1	50	0.6	0.6	27
0.2	0.25	0.15	60	0.7	0.7	33
0.3	0.15	0.05	50	0.6	0.7	17
0.3	0.2	0.1	60	0.7	0.5	26
0.3	0.25	0.15	40	0.5	0.6	20
0.4	0.15	0.1	40	0.7	0.6	43
0.4	0.2	0.15	50	0.5	0.7	28
0.4	0.25	0.05	60	0.6	0.5	22
0.2	0.15	0.15	60	0.6	0.6	28
0.2	0.2	0.05	40	0.7	0.7	39
0.2	0.25	0.1	50	0.5	0.5	24
0.3	0.15	0.1	60	0.5	0.7	16
0.3	0.2	0.15	40	0.6	0.5	37
0.3	0.25	0.05	50	0.7	0.6	22
0.4	0.15	0.15	50	0.7	0.5	33
0.4	0.2	0.05	60	0.5	0.6	13
0.4	0.25	0.1	40	0.6	0.7	26

Take variance analysis of the orthogonal experiment results, get the variance analysis as shown as table 3.

TABLE 3
THE RESULTS ORTHOGONAL EXPERIMENT

Factor	Quadratic sum	Degrees of freedom	Mean square	F-value	Significance level
l	78.166	2	39.083	4.029	opposite sex influence
w	52.166	2	26.083	2.689	no significant influence
s	244.166	2	122.083	12.585	remarkable influence
a	138.833	2	69.416	7.156	remarkable influence
h	560.833	2	280.416	28.908	specially significant influence
y	3.166	2	1.583	0.163	no significant influence

Through the results of variance analysis we can draw the following conclusion:

(1)The depth of the water(h) has the greatest effect in the primary wave height, the rest according to the influence degree by order are the thickness of the landslide(s), water entry angle(α), length of the landslide(l), width of landslide(w).

(2)The landslide head(y) has minimal influence on primary wave height, so in this study, the factors in addition to the landslide outside the rest of the paper in the primary wave height should be given priority consideration.

4.2 Theoretical Analysis

In this experiment, the landslide is free on the slide into the water, and landslide material external use woven bag package, friction coefficient (f) are the same. Therefore, according to the velocity formula of landslide body into the water:

$$v = \sqrt{1 - \frac{f}{mg\sin\alpha}} \times \sqrt{2gy} \tag{1}$$

We know that speed (v) is closely related to water entry angle(α) in this experiment, so it can be incorporated into the water angle and landslide height(y) in consideration. But the landslide head(y) has no significant effect on the result. The reason for this might be that the speed determined by the landslide head had has influence to the primary wave height but in this experiment the variation range is small due to the range of landslide head is 50cm-70cm. So it can be ignored.

In the sensitivity analysis in the table as we can see, the length and thickness of the landslide have certain effect on the height of the primary wave, but they are lower than the depth of the water. Analysis the reason, it may be that the the length and thickness used in the experiment are smaller than the depth of the water. And in this case, the landslide is submerged by water after into the water. If the length of the landslide is greater than the depth of water, there may be secondary sliding into the water by landslide and cause the superposition of the wave. In addition, if the thickness increases, it will also increase the meet face between the landslide and water and impact the shock wave.

V. CONCLUSION

This article is based on the method of orthogonal experiments aiming at Northwest China channel morphology, carried on the integral landslide wave experiment with the conceptual physical model. We measured the results of variance analysis, it is concluded that the influencing factors which have significant impact on the primary wave height in the order: water depth, thickness of the landslide, water entry angle, length of landslide, width of landslide and landslide head. We analysis the variation trend of the primary wave height with the influence factors and has carried on the theoretical analysis, the analysis results are consistent with experimental results. In addition, the landslide section deformation's influence on the landslide surge needs further research.

ACKNOWLEDGEMENTS

This research was supported by NSFC (National Natural Science Foundation of China) (Granted No.: 51379108).

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