Research Progress on the Generation and Propagation of Landslide Surge

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***Abstract* — Along with the implementation planning in Hydraulic Engineering project, Landslide surge problem is more and more getting attention. In combination with main research progress of landslide surge in China and the statistics of 9 typical landslide surges in the Yangtze River basin, this paper summarizes three key issues for landslide surge: Initial surge height, Surge propagation and attenuation characteristics, and Influence of Surge hazard bearing body. Last, the paper puts forward the deficiencies and some prospects in these three key issues.**

Keywords - landslide surge; initial surge height; surge propagation and attenuation characteristics; hazard bearing body; review.

I. INTRODUCTION

Reservoir bank landslide slides into the water at high speed, and the energy transfers to the water body to form the surge. Then the huge surge impacts on the other side, and spread along the upstream and downstream. It causes serious immediate impact on two banks and the dam of bank downstream, then It may produce some reservoir crash risk, such as: reservoir dam break or burst and so on. The crash risk is a direct threat to the safety and property of people in the area. The topographic and geologic condition at the dam site are most complex in Yangtze River Basin. Reservoir storage breaks original condition stable, and it easily induces earthquake in reservoir area, leading to bank landslide. For large volume, once the landslide body near the dam downslide, it will arouse the huge surge. The propagation distance of landslide surge across reservoir water is short, so the energy attenuation is small, then huge energy will have a serious impact on the downstream. Along with the implementation planning in Hydraulic Engineering project, this issue is increasingly subject to the attention of the majority of scientific research workers.

At present, the research on the landslide surge is also quite a lot of research workers at home and abroad, but the landslide itself relates to multi factor problem in wave mechanics, dynamics, rock mechanics and other disciplines. So the research is based on certain hypothesis and simplification, to reduce the secondary factors and only consider the key factors. Most of the parameters are selected from the experience, Therefore, the results of the calculation and the actual situation are relatively large different. Mostly landslide research focus on the three key issues: Initial surge height; Surge propagation and attenuation characteristics; Influence of Surge hazard bearing body. This paper summarizes the historical progress of the three aspects, finds out the problems, and discusses the future research directions

II. ENGINEERING EXAMPLE OF LANDSLIDE SUR-GE

Numerous examples of landslide surge occurs, but also to people's lives and property caused huge losses. On August 25, 1933, Diexi, in Minjiang River of the Yangtze River basin occurred a magnitude 7.5 earthquake leading to an average thickness of 170m, a volume of about 2.1×108m3 huge landslide, forming different size of 11 barrier lakes, triggering 7 lakes outburst, 6,865 people dead and injured 1,925. On July 18, 1982, Jipazi in the Yangtze River basin occurred a volume of about 1.5×107m3 huge landslide at a speed of maximum speed 12.5m/s sliding into the Yangtze River, destroying 1,730 houses, industrial and agricultural production 6 million yuan in direct economic losses. According to the historical data analysis of Yangtze River Basin 9 typical landslide accidents[1~2](Table 1), It is very intuitive understanding of the serious harm of landslide surge, so the accelerated research on the landslide surge is very necessary. However, from generation to propagation the landslide surge involves many factors. Technical difficulty is too big to carry out the overall study, so we must scientifically divide some parts, that is more conducive to search the law of landslide surge thoroughly.

TABLE 1. 9 TYPICAL ACCIDENT LANDSLIDE SURGES IN YANGTZE RIVER BASIN

No.	Name	Size/10^6m^3	Time	Damage
1	Dadangzi Landslide	70	1896	Blocking the river, Boats damaged
2	Diexi Landslide	210	1933	6,865 people dead, injured 1,925
3	Tanggudong Landslide	68	1967	Dam-break flood
4	Jipazi Landslide	15	1982	Shipping disruption,

				damaged houses 1,703
5	Xintan Landslide	30	1985	9 people dead, destroyed 60 boats
6	Xikou Landslide	0.18	1889	221 people dead, more than 600 million loss
7	Qianjiangpin Landslide	24~30	2003	24 people missing and dead
8	Dayantang Landslide	3.0	2007	4 people missing and dead
9	Xiluodu Landslide	0.12	2013	12 people missing

III. THE RESEARCH PROGRESS OF LANDSLIDE SURGE

Over the years, there is more and more research on landslide surge, but the in-depth and comprehensive progress is still relatively slow for the complex engineering problems. The key for research is to calculate the height of surge, analyze its propagation, and thus to evaluate the impact of the surge of hazard bearing body[3]. Therefore, the combination at home and abroad research data, the majority of research projects are concentrated in the three key issues: Initial surge height; Surge propagation and attenuation characteristics; Influence of Surge hazard bearing body.

A. Initial surge height

Surge is secondary disasters caused by the landslide, whose energy transfers to the water. So the size of the landslide surge is directly related to the landslide of energy. The energy transfers to the water body, and the water formed surge. It is a prerequisite for research, but also the key part to the height of landslide surge. Throughout the process of researching landslide surge, the history research can be roughly divided into three periods: The first period, from the 1970s until the 1990s, gradually more landslide surge literature appears, but almost all of the researchers for the study of landslide surge are concentrated in the physical model and numerical calculation, from the simplest assumptions began to constantly moving forward and deeply. The second period, to the 90s, with the development of fluid mechanics, numerical model analysis are emerging, then more researchers try to use the numerical model to solve the problem of landslide surge, obtaining more accurate results. So it is widely used in engineering practice to verify. The third period, since the 21 century, The rapid development of computer hardware promotes the most fluid calculation software development and application, and computer numerical simulation can provide complete and systematic information, unlimited space and time, but also no physical space and material cost of the experiment, therefore it is easy to get to any point of the wave height, velocity, cycle. Numerical simulation has flourished, and various finite element software, such as: Ansys, Fluent, Flow3d etc., is used in visualization of landslide surge generation and process.

The first period, in 1970 Noda[4] Edwrad based on the hypothesis of unidirectional flow, semi-infinite water, and declining in elevation greater than the depth of the water. In vertical fall and horizontal sliding two extreme cases, According to the linear gravity surface wave theory, combined with physical testing, the author suggested empirical formula of initial surge height associating with sliding velocity and water depth. However, because the method does not consider the wave reflection or front width of landslide etc. So if the front width of landslide is not big and farther away from the landslide, calculated value of surge somewhat higher[5]. In 1980 on the basis of Noda's research, In vertical fall and horizontal sliding two extreme cases, Pan Jiazheng[6] considered the wave reflection and superposition in the rectangular pool, then suggested empirical formula of landslide surge, and became the first to put forward the calculation of the landslide surge of domestic researchers.

The second period, in 1990 Yuan Yinzhong and Chen Qingsheng [7] from the basic equations of unsteady flow derived calculation equations of landslide surge and established numerical model for one and two dimensional approximation calculation. Finally the surge height from Tangyanguang landslide and Xintan landslide are calculated by using the equations. In 1998, combining disasters of Huanglashi landslide, Yang Xuetang etc.[8] used finite element method to calculatethe maximum surge height that generated by Huanglashi landslide sliding into the river under different water level of the Yangtze River.

The third period, in 2009 Song Xinyuan etc.[9] used dynamic mesh technology to control the movement of the sliding body by UDF (User-Defined Function) Programming, and used VOF method combining with RNG ƙ-Ɛ turbulence model to track nonlinear free surface flow field, and based on FLUENT to simulate the water velocity, the height of the free surface and the flow, which is caused by the sliding body. And the numerical results are compared with the experimental data of Monaghan and Kos. In 2011 from Navier-Stokes equation Xu Bo etc.[10] used VOF method to track the free surface, and based on FLOW3D to simulate the broad waters of landslide surge, then the numerical results were compared with experimental results, and the calculated results were in good agreement with the experimental results. On this basis, the paper study the wave heigh from the position of the measuring point when the surge generated under the same angle but different radius and the same radius but different angles.

B. Surge propagation and attenuation characteristics

After the surge generating, surge propagation and attenuation characteristics determine the extent of the downstream damaged .It reveals the law of surge propagation process and is more conducive to protect downstream facilities. But research directed to the landslide surge propagation is significantly later than the surge height of research. The early twentieth century, based on some results about surge propagation, more and more researchers began to depth of this problem.

In 2004 Li Wei etc.[11] established the mathematical model of landslide surge, introduced the (u, h) curve, and qualitative analysised possible waveform after the sparse wave catching up the shock wave. And in the situation that they meet to produce a reflected wave and the incident wave, the paper conducted research on the quantitative relationship and calculation methods of wave height and velocity. In 2005 Jiangzhi Bing etc.[12] derived DIF equations for simulation of landslide surge, used Non-regular grid finite volume method and explicit MacCormack prediction-correction numerical method to solve the equation, and established the numerical model of landslide surge, then used prototype observation data of the Xintan Landslide to verify the numerical model, and along the path of propagation of the simulation surge is in good agreement with prototype observations. In 2013 Zhou Guiyun etc.[13] applied shallow water equations to numerical simulation of surge. The equations were solved by using the two step Taylor-Galerkin method. Through using numerical examples to verify numerical models, the results showed that after producing the surge continued to decay from entry point to the rapidly advancing around and with the increase of wave propagation distance the wave height declined gradually decreases. The changes of water level and surge height calculation were in good agreement with the measured data, and propagation process of the landslide surge was visual. In 2015, based on the Geo-wave software technology, Wang Shichang etc.[14] did second development to form FAST software. No. 4 slope at Gong Jiafang on Three Gorges Reservoir as the research object, was used to conduct numerical simulation of landslide surge. From experiment datas of the surge propagation simulation, it showed that the characteristics of spatial distribution of maximum wave height at each position was intermediate concave and the wings extending along the slope. Sharp attenuation zone of the surge propagation was basic distribution within near 1 km where surge occured, and the greater wave height, the greater the drop height of unit distance.

C. Influence of surge hazard bearing body

After producing, surge through the water body spread and ultimately transfers energy to the disaster bearing body. The impact of the disaster bearing body is mainly divided into two major types: First, the impact on the other side, that is run-up problems of surge. After the collapse of a large volume of landslides, it forms a huge surge to impact on the other side of the landslide. Due to the limited width of river, the other side of the landslide became the first damage area by the first wave. Second, the impact on downstream areas. Huge water energy of surge is transferred to the downstream area, influences to the ship channel and impacts on the dam that may cause the dam burst, thus the formation of a larger disaster. So the accurate calculation of the surge impac on hazard bearing body directly determines the accuracy of surge disaster forecast.

Run-up problems of surge is a hot issue that researchers focus. In 2005 Liu[15] used VOF method to track the free surface, simulated run-up and fallback of surge after the block downsliding. In this paper, the experimental results are verified by the LES model. In 2008, in a research results, Wang yang[16] based on continuity equation of the canal inconstant flow, momentum equation and theory of head loss, divided the surge process into sharp attenuation part and the slow attenuation part , and obtained the exponential law of sharp attenuation part and the law of the route loss of the canal inconstant flow of the slow attenuation part. In 2010 from the assumed conditions Dai Yunxia[17] summarized existing calculation characteristic of Pan Jiazheng, referenced the influencing factors and the applicability, then modified parameters of the relevant formula from the wave mechanics. Finally, the author used the modified method for run-up of surge at Dayantang Landslide, and the height were in good agreement with the actual wave height.

The surge transfers to the downstream, and the risk analysis and assessment are critical for downstream area(reservoirs, dams, waterways and ships, etc.) forecast. In 2003 Zhou Jianhua[18] applied one-dimensional model, two-dimensional model and hybrid mathematical model to analyze disasters of landslide surge. Based on this study, the author studied two dangerous rock bodies of the Three Gorges Reservoir typical area (Huanglashi landslide and Lianziya). The results showed that if the landslide occured, it would cause serious damage to people's lives and property in the nearby 12km. In 2012 Luo Chao [19] used the numerical simulation method of large eddy to simulate surge caused by wedge slider and surge and marine structures interaction. The calculation results are in agreement with the experimental results. This proved that had a significant influence on the waves of the deck, and sway was the greatest impact in that the top of the pier had dramatic impact. In 2013 Huang Jinlin etc.[20] tested the wave pressure loading on the front of upright dam in different depths of water, and proposed calculation pressure wave model for the upright dam. Then for the condition that E Gongdai landslide surge spread to the Lechang Gorge Dam, he used this model to do the dam of security assessment. In 2014 Luding etc.[21] used Tuokou pier in Wanzhou as the prototype, and designed rock landslide surge physical model, then extrapolated calculation formula for navigation limits of ships in the inland waterways. The formula was checked and verified by the ship model tests. Then he explained the formula for the waterway during the wave flow field.

IV. CONCLUSIONS AND PROSPECTS

In this paper, research history about the three key issues of landslide surge was reviewed. It can be seen also in the deepening of research, from the initial study of the basic

assumptions in the rectangular rigid body about vertical and horizontal two extreme states to multivariate and multistate complex problems, but also closer to landslides surge. Yet there is still no generally accepted systemic solution, and there are many technical problems to landslide surge itself, so in the future studies the researchers can be based on the following aspects of a more in-depth and comprehensive study:

(1) In the initial surge height, it involves many parameters, and most studies are based on sliding velocity and water depth, but the 3D dimension and the different types of landslide(rock landslide, soil landslide, slumped mass) are also important factors to affect landslide surge height. Especially in physics experiments it should be considered to strengthen further study.

(2) Surge propagation and attenuation characteristics. More attention in the rectangular river or semi-infinite water body, but little attention in surge propagation or variation of the characteristic parameters about different river forms(U-type, V-type, folding type, etc.), tributaries of the import and distribution in main stream, morphological changing along the slope(wide variations into the narrow river channel or narrow variations into the wide river channel) .

(3) Surge impact on hazard bearing body. The study of such issues also need further step by step, such as: run-up of surge to the other side of the mountain, the law of run-up of surge to downstream dam, the impact of channel morphology or slope form etc. And through the method of physical experiments or numerical simulation etc., the reseachers further explore different load patterns which surge impact on hazard bearing body and the critical value of hazard bearing body under surge impact energy and other related topics.

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