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Study on Optimization of Flood Discharge Types in MHSJ Stilling Basin

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Abstract: *At the beginning of the operation of a Hydropower Station adopted a new type of stilling basin with multi-horizontal submerged jets (MHSJ), it was found there was a phenomenon of roller shutter door and window vibration in some local area of the downstream region during the flood discharging process. The prototype observation indicated that the flow induced vibration is greatly influenced by flood discharging types with different open combination of the sluice gates. Flow fluctuating pressure is a main load that frequently causes damages to flood discharge structures, which is a crucial incentive that caused flow induced vibration of the downstream region of the hydropower station. In this paper, from the perspective of hydraulics, the flood discharging types with different open combination of the sluice gates under same flood discharge were simulated through a series of hydraulic model experiments. Judged by the values of fluctuating pressure on the bottom plate of stilling basin, it was found the joint discharging type of surface outlets and middle outlets is better than surface outlets discharging type or middle outlets discharging type. The response law between discharge allocation proportion of each outlet and fluctuating pressure characteristics in the still basin was preliminary revealed. The optimal flood discharge types were obtained. The research results can provide technical support for the operation and management of the Hydropower Station. The reduction of vibration intensity from the source is expected.*

Keywords: *Fluctuating pressure, multi-horizontal submerged jets (MHSJ), experimental model, flood discharge type*

1. Introduction

The natural river located at the dam site of a Hydropower Station had the characteristics of "high water head, large unit discharge, frequently flood discharging and high sediment laden", so the way of the flood discharge and energy dissipation was mainly affected by atomization, navigation, desilting and geological conditions. The study of Lian JJ et al. (2009) and Efimenko A (1995) showed that the traditional bottom-flow energy dissipater will cause high close-to-bed velocity in the stilling basin which usually interacts with the structure and brings severe damage to the bottom plate. In order to overcome those limitations, a new type of stilling basin with multi-horizontal submerged jets (MHSJ) had been proposed and adopted. MHSJ had been investigated by many researchers. Huang et al. (2008) pointed out the drop height and the height-differences between surface and middle outlets of MHSJ affect the close-to-bed velocity and flow performances in the stilling basin. Yang et al. (2004) and Li et al. (2004) (2006) conducted studies on the energy dissipation mechanism of MHSJ, found that several strong shear flows were formed in the stilling basin and the effect of energy dissipation was enhanced. Zhang et al. (2005) studied the hydraulic characteristics and dissipated energy ratio in a stilling basin of MHSJ, the formula to calculate the conjugate water depth and energy dissipated ratio were obtained.

After the power station was completed, through prototype monitoring, it was detected that by using the new type of energy dissipater, the problems of flood discharge and energy dissipation were conquered. The flow pattern in the stilling basin, the energy dissipation rate, the dam safety and other hydraulic characteristics showed good properties. The effects of weak atomization, high energy dissipation ratio, low close-to-bed velocity, stable flow pattern, flexible flood discharge mode, and suspended sediment passing in security was achieved. But during the flood discharging process, it was found there was a phenomenon of roller shutter door vibration, furniture fibrillation, and chandelier swing in some local area of the downstream region.

As is known, dam body and discharge structure vibration induced by high-speed flow is a common problem that most high dam projects must face. Flow fluctuating pressure is a main load that frequently causes damages to flood discharge structures. The fluctuating load in turbulent flow has a great impact on the time-averaged movement and the vibration of hydraulic structure, which was the incentive that caused roller shutter door vibration, furniture fibrillation, and chandelier swing in some local area of the downstream region of the hydropower station. In this paper, from the perspective of hydraulics, the flood discharging types under different open combination of the sluice gates were simulated through a series of hydraulic model experiments. The relationship between the operational schemes of the sluice gates and the fluctuating pressure in the stilling basin was explored, which possessed great significance for the basic theories research and the solutions for the doors and windows vibration problem in the local area of the downstream region.

2. Experimental Set-up

The experimental model was designed based on a hydropower station. The experimental layout was shown schematically in Fig.1. The model of the project includes upstream reservoir, flood discharging section, stilling basin and downstream reach. The MHSJ energy dissipater was also contained in the model. The flood discharging section consists of 6 surface outlets and 5 middle outlets, which were disposed alternately. The width of the surface outlet and the middle outlet was 8.0 m and 6.0 m, respectively. The elevation of the surface outlet and the middle outlet was 261.0 m and 253.0 m, respectively. The stilling basin was 228.0 m long and 108.0 m wide. The elevation of stilling basin slab was 245.0 m. The experimental model was established according with Froude similitude (tested in a 1:80 scale physical model). The upstream reservoir was built by concrete structure, and the flood discharging section, stilling basin and downstream reach were made of transparent PMMA (polymethyl methacrylate). The test section settled in a rectangular flume was 14.0 m long, 1.0 m wide and 0.8 m high. Water supplying facility with the capacity of 200 L/s was placed in front of the upstream reservoir. The discharge was measured by a rectangular measuring weir. The water level in the upstream reservoir was measured by testing probe. The water level downstream was adjusted by a gate. DJ800 multifunctional monitoring system was used for data acquisition and data processing of fluctuating pressure, then the characteristics of the experimentally measured fluctuating pressure on the bottom floor and guide wall of the stilling basin was focused. 31 measuring points were set on the center part of the stilling basin slab. 20 measuring points were set on the right guide wall of the stilling basin, since the stilling basin is symmetrical in the model. The arrangement of the measurement region and the numbering of measuring points were shown in figure 1.

The field monitoring result indicated that even under an identical flood discharge, some flood discharging patterns caused ambient door or window vibration while others didn’t. In consideration that the fluctuating pressure characteristics were always affected by the flow patterns, therefore, it is necessary to conduct several groups of experiments with different open combination of the sluice gates under same flood discharge. Under this principle a total of 10 experimental work conditions were designed. The 10 experimental work conditions were divided into three categories according to the open combination of the sluice gates, that is: flood discharging through surface gates only, flood discharging through middle gates only, flood discharging through joint operations on surface gates and middle gates.

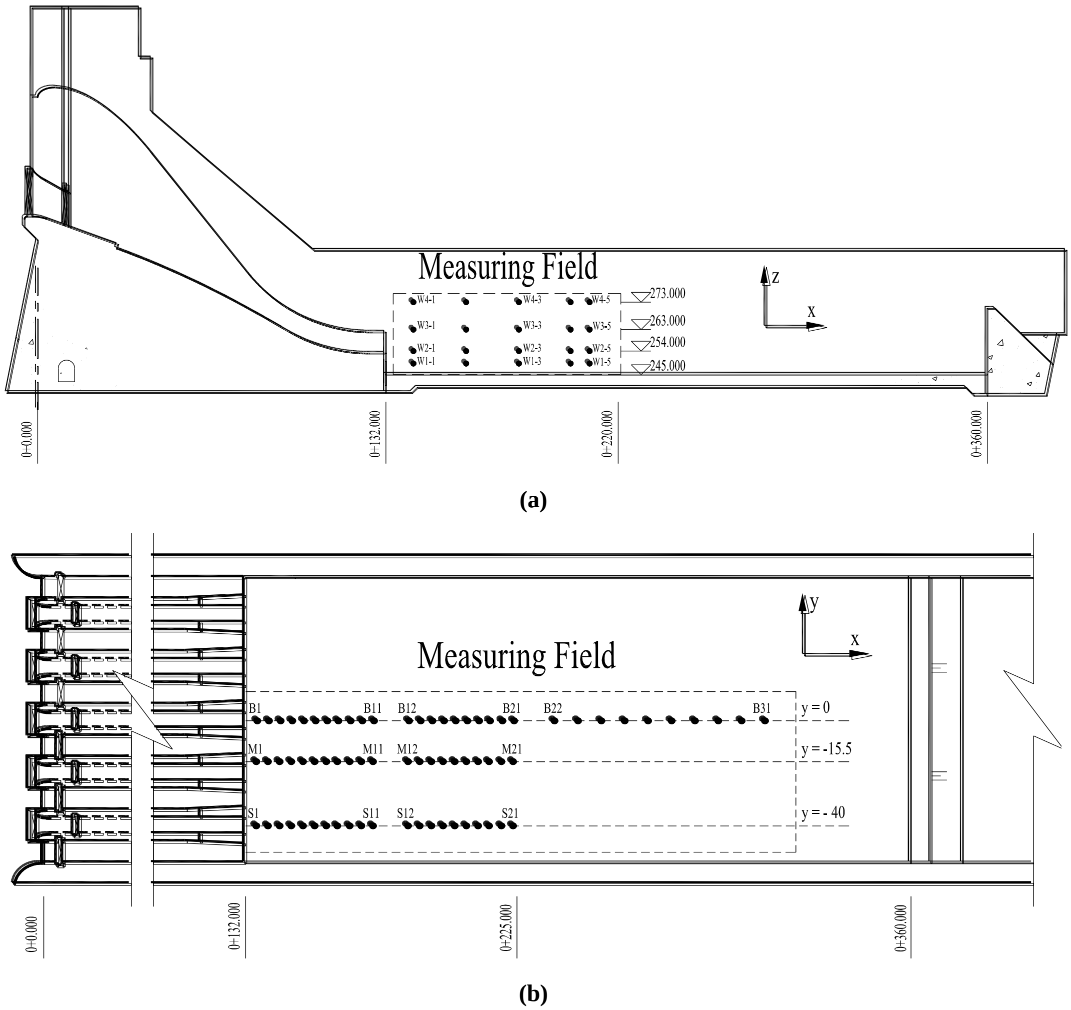

Figure 1. Experimental setup and the layout of the measuring points

3. Comparative Analysis and Optimal Selection of Different Flood Discharging Types

When flood discharged through a single stilling basin under a certain value, the fluctuating pressure characteristics under the condition of different operational schemes of the sluice gates were investigated through comparative analysis. The operational schemes of the sluice gates contained: discharging through middle outlets only ("middle outlets discharging" for short), discharging through surface outlets only ("surface outlets discharging" for short) and discharging by joint operations of surface outlets and middle outlets ("joint discharging" for short). Fluctuating pressure values on the bottom plate and the guild wall of the stilling basin were treated as the comprehensive judgment standard to evaluate the advantages and disadvantages of the three-different flood discharging types. The smaller fluctuating pressure values reflected the better flood discharging type.

According to the judgment standard mentioned above, 3000 m^3/s flood discharging through a single stilling basin (equals to 6000 m^3/s flood discharge through both stilling basins) was taken as an example to conduct comparative analysis and optimal selection of different flood discharging types. 10 experimental conditions were carried out at 3000 m^3/s flood discharge. Details of the 10 experimental conditions were shown in table 1. Among them, middle outlets discharging includes case 1 and case 2, surface outlets discharging includes case 3, case 4 and case 5, joint discharging includes case 6, case 7, case 8, case 9 and case 10. Fluctuating pressure values of the stilling basin were shown in figure 2. Thereinto, the fluctuating pressures on the bottom plate were shown in figure 2(a), 2(b) and 2(c), the fluctuating pressures on the guild wall were shown in figure 2(d), 2(e) and 2(f).

Table 1. Details of experiments under 3000 m^3/s flood discharge

Condition No.	Flood discharge type (outlets not mentioned below were closed)	Total discharge (m^3/s)	Upstream water level (m)	Downstream water level (m)
Case 1	1# and 5# middle outlets partly opened uniformly	3000	370	273
Case 2	2# and 4# middle outlets partly opened uniformly	3000	370	273
Case 3	1#, 2#, 5# and 6# surface outlets partly opened uniformly	3000	370	273
Case 4	2#, 3#, 4# and 5# surface outlets partly opened uniformly	3000	370	273
Case 5	1#~6# surface outlets partly opened uniformly	3000	370	273
Case 6	1#, 5# middle outlets partly opened uniformly and 2#, 5# surface outlets partly opened uniformly	3000	370	272.1
Case 7	1#, 5# middle outlets partly opened uniformly and 3#, 4# surface outlets partly opened uniformly	3000	370	272.1
Case 8	2#, 4# middle outlets partly opened uniformly and 3#, 4# surface outlets partly opened uniformly	3000	370	272.1
Case 9	1#~5# middle outlets partly opened uniformly with 1000 m^3/s discharge and 1#~6# surface outlets partly opened uniformly with 2000 m^3/s discharge	3000	370	272.1
Case 10	1#~5# middle outlets partly opened uniformly with 2000 m^3/s discharge and 1#~6# surface outlets partly opened uniformly with 1000 m^3/s discharge	3000	370	272.1

Assessed by the judgment standard, it can be found from figure 2 that the joint discharging condition was better than the middle outlets discharging or surface outlets discharging condition. It can also be found the middle outlets discharging condition and surface outlets discharging condition had their advantages and disadvantages respectively. As shown in figure 2(a), 2(b), 2(c) and 2(d), the surface outlets discharging condition was better than the middle outlets discharging condition. As shown in figure 2(e) and 2(f), the middle outlets discharging condition was better than the surface outlets discharging condition. To the realistic situation, many bottom plates of stilling basin were severely damaged due to flood release and energy dissipation. Through overall consideration, the sequence of flood discharging types from advantage to disadvantage can be listed as: joint discharging, surface outlets discharging and middle outlets discharging.

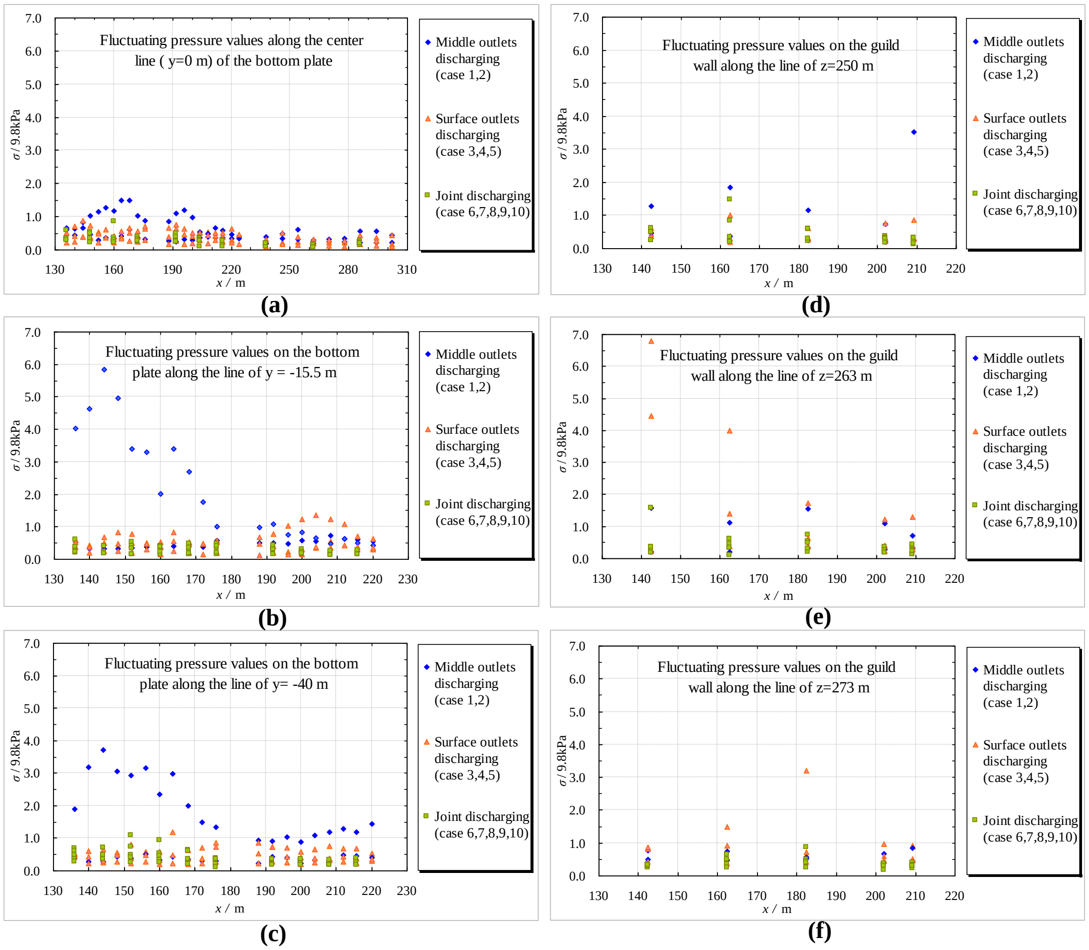

Figure 2. The fluctuating pressure values in the stilling basin caused by three different flood discharging types under 3000 m^3/s flow rate

As mentioned above that the joint discharging condition was better than middle outlets discharging or surface outlets discharging conditions, furthermore, there were some discharging conditions more favorable inside the joint discharging conditions. In order to find out the optimal operational schemes of the sluice gates on a more granular level, the joint discharging experimental conditions (case 6, 7, 8, 9 and 10) were analyzed particularly. On the whole, the fluctuating pressures of case 6, 7, 8, 9 and 10 were compared in figure 3. Thereinto, the bottom plate fluctuating pressure was shown in figure 3(a), 3(b) and 3(c), the guild wall fluctuating pressure was shown in figure 3(d), 3(e) and 3(f). Out of those figures as a whole, it can be found that case 9 and case 10 were the optimal operational schemes under 3000 m^3/s discharge of a single stilling basin. Judged from the fluctuating load on the bottom plate or the guild wall, the advantages and disadvantages of case 9 and case 10 were determined by the ratio between middle outlets discharging volume and surface outlets discharging volume. Seen from figure 3, it can be found the fluctuating load of discharging trough surface outlets was larger than that of discharging trough middle outlets, the bottom plate fluctuating load in case 9 was smaller than that of case 10, but the guild wall fluctuating load in case 9 was larger than that of case 10. Therefore, on the basis of comprehensive consideration, when considering more of the frequent damage of bottom plate, the case 9 was the best; when considering more of the guild wall fluctuating load, the case 10 was the best. In consideration of the reality that many bottom plates of stilling basin were severely damaged, in this paper, fluctuating load on the bottom plate were taken as the first reference to evaluate the discharging types. Through contrastive analysis of Figure 3, the sequence from advantage to disadvantage of the five flood discharging conditions under the joint discharging types with the discharge of 3000m^3/s can be listed in table 2.

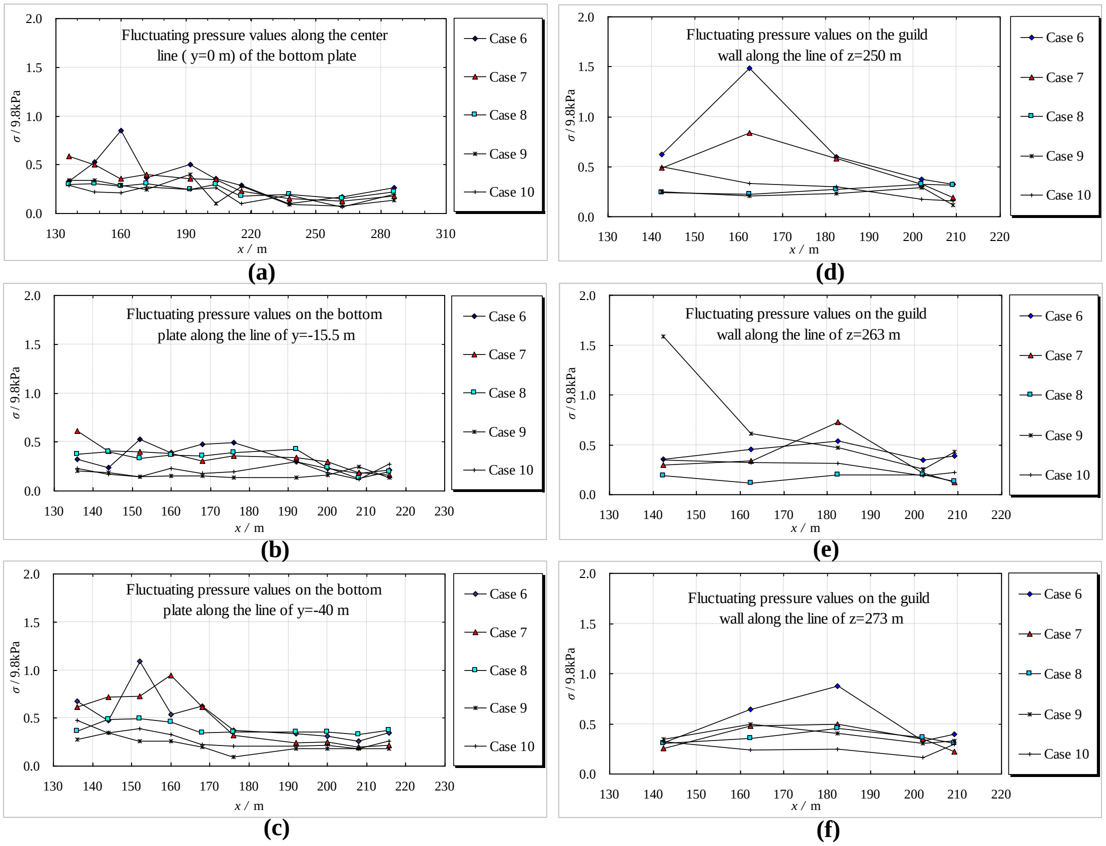

Figure 3. Comparison chart of five different cases through joint discharging under the condition of 3000 m^3/s flow rate

Table 2. The sequence of the five flood discharging conditions under the joint discharging types with the discharge of 3000m^3/s

Ranking form advantage to disadvantage	Condition No.
1	Case 9
2	Case 10
3	Case 8
4	Case 6
5	Case 7

Among the experimental conditions carried out in the experimental program, except the 10 experimental conditions analyzed in this paper, other experimental conditions under different flood discharge were also compared respectively when the work conditions at a same discharge value. The comparative analysis method was the same as what was conducted under the condition of 3000 m^3/s flood discharge above, and the conclusions were similar with that got from the 3000 m^3/s flood discharge experimental conditions. The details of the full-scale analysis of all the other experimental conditions were not described in this paper.

4. Conclusions

Based on a practical hydropower station with the energy dissipation pattern of MHSJ, a series of systematic hydraulic physical model experiments were carried out in this paper. Under the experimental conditions with different open combination of the sluice gates, the characteristics of fluctuating load on the bottom plate and guide wall of the stilling basin was observed and investigated. The relationship among fluctuating load and open combination of the sluice gates was obtained through deep analysis and the following conclusions were drawn:

1. The fluctuating load on the bottom plate and the guide wall of the stilling basin was closely related to the operational schemes of the sluice gates and the flood discharge type. Obvious differences of the fluctuating pressure characteristics were shown under a same flood discharge with different flood discharge type. The sequence of the fluctuating load under the three flood discharging types from small to big was as follows: joint discharging, surface outlets discharging and middle outlets discharging. Judged from the fluctuating load, in general, the sequence of flood discharging types from advantage to disadvantage also was: joint discharging, surface outlets discharging and middle outlets discharging.

2. Through further analysis of the joint discharging cases, the optimal operating conditions of the sluice gates were selected out. On the whole, in terms of reducing fluctuating load, the work conditions of symmetrically opening all the gates were more effective than those of asymmetrically opening the gates, which also ameliorated the flow patterns in the stilling basin, then could significantly reduce the influence that lead to peripheral ground vibration.

5. Acknowledgements

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