Experimental Research on Fluctuating Pressure Characteristics of “Revetment-Protected and Non-Bottom-Protected Plunge Pool” of High Arch Dam

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Abstract. In the construction progress of hydropower project, the energy dissipation security was always the focus of design and research. When the river overburden and water cushion was deep enough, the deep water cushion can be used for the energy dissipation design, and a new type - “Revetment-Protected and Non-Bottom-Protected Plunge Pool” was studied and proposed, whose stabilization was directly effected by the fluctuating pressure on the plate surface and back. The experimental research of fluctuating pressure was carried out on the 1:50 hydraulic model, and characteristic of fluctuating pressure was studied and summarized in this paper.

1. Introduction
In the construction progress of hydropower project, the energy dissipation security was always the focus of design and research. Particularly, most of the high arch dams have the characteristics of “High water head, Large discharge and Narrow river valley”, which can bring lots of difficulties in energy dissipation design. The trajectory type energy dissipation is the most widely used in dam body, and the water plunge poor was set downstream the dam body for the project safety, as shown in Table 1[1], which is mostly total protected by concrete lining[2]. However, in the last several years, the river overburden and water cushion was deep enough in the dam site, which is becoming a new characteristic of these hydro-projects. Accordingly, the deep water cushion can be used for the energy dissipation design, and a new type - “Revetment-Protected and Non-Bottom-Protected Plunge Pool” was studied and proposed, which is successfully used in Wudongde Hydro-project, as shown in Figure 1[3]. The “Revetment-Protected and Non-Bottom-Protected Plunge Pool” was unprotected in the bottom, so the revetment protect lining is also permeable with the installing of drain-pipe.

Table 1. The characteristics of built/building high arch dam in China.

| Name  | Height(m) | Dam body Discharge(m³/s) | Water Head (m) | Type of Plunge Pool                  |
|-------|-----------|--------------------------|----------------|-------------------------------------|
| Xiaowan | 292     | 16889                    | 225.9          | Flat-bottom plunge pool             |
| Xiluodu | 278     | 31496                    | 189.5          | Flat-bottom plunge pool             |
| Laxiwa  | 250     | 6000                     | 213            | Invert-arch plunge pool             |
| Ertan   | 242     | 16300                    | 166.3          | Flat-bottom plunge pool             |
The flood discharge into the plunge pool is always considered as the submerged impinging jet flow, which can cause violent turbulence in the plunge pool, so as to energy dissipation[4]. The turbulence can force the fluctuating pressure on the revetment lining, espesially the permeable “Revetment-Protected and Non-Bottom-Protected Plunge Pool”[5].

In order to study the effect of fluctuating pressure on the revetment lining stabilization, we analysed and calculated the fluctuating pressure data by the model test in this paper. And then the characteristic of fluctuating pressure was studied and summarized.

2. Model Test Design
The experimental study was carried out on the 1:50 hydraulic model. There are 5 crest outlets and 6 middle outlets setting on the dam body of Wudongde Hydropower Project, and 3 spillway tunnels were arranged on the left bank[6]. The experimental model is as shown in Figure 2.

![Figure 2. 1:50 Hydraulic Model](image)
by pressure sensors, where four measuring points are set in each plate, as shown in Figure 3. Pulsating pressure tests were carried out synchronously on the plate surface and back.

![Figure 3. Layout sketch of the test plates and measuring points](image)

3. Analysis of model test results

3.1. The experiment conditions
The experiment conditions of 1:50 hydraulic model is shown in Table 2.

| No. | Condition | Upstream water level (m) | Operation | Discharge(m³/s) | Downstream water level (m) |
|-----|-----------|--------------------------|-----------|----------------|---------------------------|
|     |           |                          |           | Dam body       | Plant                     | Total                     |
| 1   | P=0.1%    | 979.38                   | Crest+Middle+Tunnel | 30198         | 3500                      | 33698                     | 849.73                    |
| 2   | P=0.5%    | 975.00                   | Crest+Middle+Tunnel | 25300         | 5600                      | 30900                     | 847.86                    |
| 3   | P=1%      | 975.00                   | Crest+Middle+Tunnel | 22400         | 5600                      | 28800                     | 846.36                    |
| 4   | -----     | 975.00                   | Crest      | 7270           | 5600                      | 12870                     | 833.61                    |

3.2. Fluctuating Pressure Process Line
The typical fluctuating pressure process lines were shown in Figure 4~ Figure 7 under different experiment conditions without significantly different. The turbulence of process line is obvious, where the dominant frequency range is between 0.001 and 5 Hz, and the main frequency is generally below 0.1 Hz.

![Figure 4. Fluctuating pressure process line of measuring point V of 3# plate under the condition No.4.](image)

![Figure 5. Fluctuating pressure process line of measuring point V of 5# plate under the condition No.4.](image)
3.3. Comparison of Pulsating Pressure at Different Measuring Points

There were 6 test plates and 4 pulsating pressure measuring points set on each plate surface and back in this experiment. The pulsating pressure measuring was carried out synchronously. The pulsating pressure results were statistical analyzed at different measuring points, as shown in Figure 8–Figure 11. The root-mean-square of fluctuating pressure is between 0.70×9.81 kPa and 1.71×9.81 kPa, and there is no obvious regularity difference.

3.4. Comparison of Pulsating Pressure on the plate surface and back

The average root-mean-square of fluctuating pressure is shown in Figure 12~Figure 15. It is shown that the root-mean-square on the plate surface is larger than the plate back, which indicates that fluctuating pressure decreases in varying degrees as it passes into the plate back surface through the plate permeable hole, and the decreasing rate is 7.12%~22.61%.
4. Conclusion

The stabilization of permeable “Revetment-Protected and Non-Bottom-Protected Plunge Pool” was directly affected by the fluctuating pressure on the plate surface and back, which is caused by the turbulence of flood discharge. The experimental research of fluctuating pressure was carried out on the 1:50 hydraulic model, and characteristic of fluctuating pressure was studied and summarized.

(1) In this experimental research, there were 6 test plates and 4 pulsating pressure measuring points set on each plate surface and back in this experiment, and the pulsating pressure measuring was carried out synchronously.

(2) Under different experiment conditions, the turbulence of pulsating pressure process line is obvious, with the dominant frequency range 0.001Hz ~ 5Hz, and the main frequency below 0.1Hz.

(3) The root-mean-square of fluctuating pressure on the plate surface and back is between 0.70×9.81kPa and 1.71×9.81kPa with no obvious regularity difference.

(4) The average root-mean-square of fluctuating pressure on the plate surface is larger than the plate back, indicating the fluctuating pressure decreases as it passes into the plate back, and the decreasing rate is 7.12%~22.61%.

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