# Study on Reventment-Protected and Non-Bottom-Protected Plunge Pool of High Arch Dam

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**Abstract.** Lots of high arch dam have the characteristics of "High head, Large discharge and Narrow river valley", therefore, the security researches of energy dissipation were always the focus in these hydro-projects. Statistically, the trajectory type energy dissipation is the most widely used in the built high arch dams, and the water plunge poor were always set downstream the dam body. However, the widely used protected plunge poor need large investment with the disadvantage of complicated operation and maintenance. Along with the construction of concrete high arch dam in the Southwest China, the river overburden and water cushion were deep in 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, such as the "Reventment-Protected and Non-Bottom-Protected Plunge Pool", which has the advantage of more simplified project design and more economy investment.

## 1. Introduction

Lots of built and building dams, especially the high arch dams, were located in the Southwest China with abundant hydro-power resources. Most of these dams have the characteristics of "High water head, Large discharge and Narrow river valley", which can bring lots of difficulties in form choice, entire layout and structure design. The security of energy dissipation not only can influent the project investment and benefit, and also have direct influence on the safety operation of the hydro-project. So the researches were always the focus in these hydro-projects, especially in high arch dam projects [1].

The trajectory type energy dissipation is the most widely used in dam body, and the water plunge poor were set downstream the dam body for the project safety, as shown in Table 1. However, the widely used protected plunge poor need large investment with the disadvantage of complicated operation and maintenance [2].

Along with the construction of concrete high arch dam in the Southwest China, the river overburden and water cushion were deep in 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 then the plunge poor patterns were summarized in combined with the engineering practice. A new type - "Reventment-Protected and Non-Bottom-Protected Plunge Pool" was studied and proposed.

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 |
| Goupitan | 232.5 | 28900 | 148.1 | Flat-bottom plunge pool |
| Jingping-I | 305 | 10074 | 225 | Flat-bottom plunge pool |
| Baihetan | 289 | 30200 | 200.7 | Flat-bottom plunge pool |
| Wudongde | 270 | 27184 | 134.1 | Reventment-Protected and Non-Bottom-Protected plunge pool |

## 2. Research progress of plunge pool

The flood discharge into the plunge pool is always considered as the submerged impinging jet flow, and that's why the research is studied based on the submerged impinging jet theory. Turbulent impinging jet is the most popular jet flow, so the mechanisms of inside energy transfer, momentum transport, fluid entrainment, mixing and diffusion are closely related with the vortex structure caused by the jet velocity gradient [3,4].

In the engineering practice, the flood discharge flow into the plunge pool of high arch dam will become the submerged impinging jet flow. The flow pattern, velocity distribution, bottom impact pressure, erosion distribution and structure vibration of the plunge pool were studied based on the model experimental and original observation [5,6]. Based on the research works, different type of plunge pool were studied and proposed.

### 2.1. Totally protected plunge pool

Because of the large discharge and flood discharge capacity, the manual plunge pool under the high arch dam is totally protected by concrete, which has two most common structure type: flat-bottom plunge pool and invert-arch plunge fool, such as Figure 1.



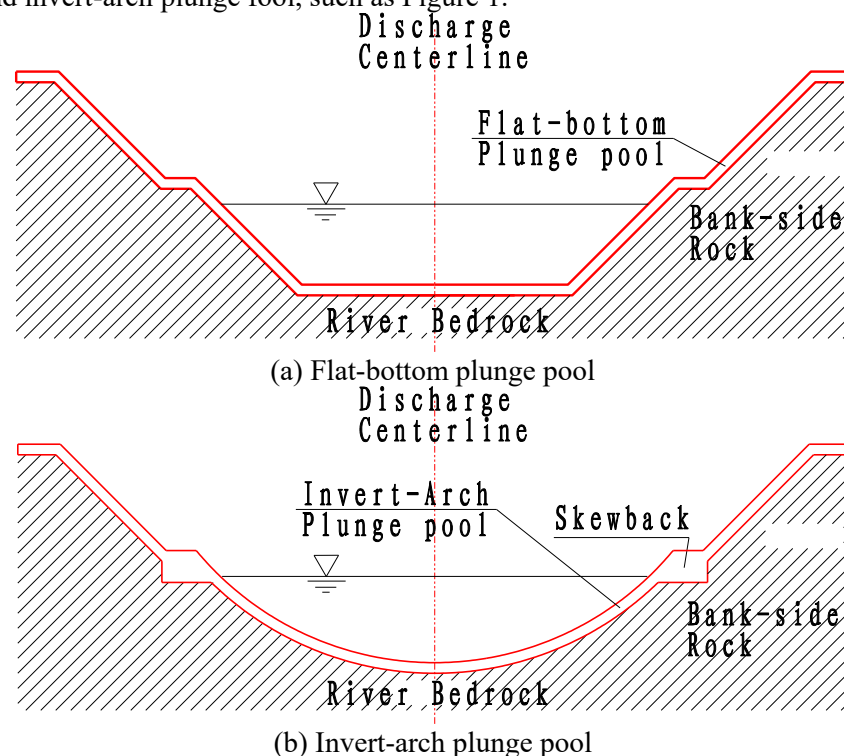(a) Flat-bottom plunge pool



(b) Invert-arch plunge pool
Fig. 1 Sketch of total protected plunge pool

The flat-bottom plunge pool has concrete floor laid in the middle of river bed, which is mostly very thick to resist the huge buoyancy with the measures of pump drainage and anchorage et al. The invert-arch plunge pool is designed according with the river nature shape, which is arch style concrete bottom instead of flat-bottom. The stability's controlling conditions of invert-arch plunge pool is based on the arch ring stability.

*2.2. Reventment-Protected and Non-Bottom-Protected Plunge Pool*
Reventment-Protected and Non-Bottom-Protected Plunge Pool can use the deep water cushion for energy dissipation, and the bottom was not peotected by concrete plate, as shown in Figure 2.
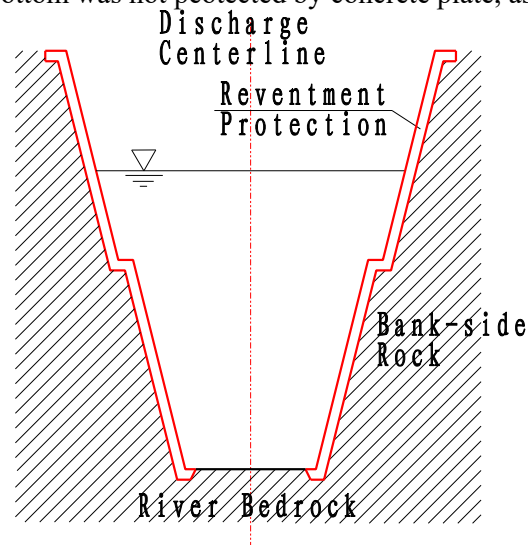


Fig. 2 Sketch of Reventment-Protected and Non-Bottom-Protected plunge pool

The design of Reventment-Protected and Non-Bottom-Protected Plunge Pool is a new type in the high arch dams. However, it has obvious advantage in some special engineering conditions. There are some high arch dams in building with deep river overburden and water cushion, and it is possible to take the design of Reventment-Protected and Non-Bottom-Protected Plunge Pool with advantage of deep water cushion.

## 3. Study of Reventment-Protected and Non-Bottom-Protected plunge pool
The most important characteristic of the Reventment-Protected and Non-Bottom-Protected Plunge Pool is deep water cushion, which should be the focus of the research works.

*3.1. Scour depth*
There must be enough water cushion depth in the scour pit when the flood discharges from the high arch dam, which can be calculated as following:

$$t_k = \alpha q^{0.5} H^{0.25} \tag{1}$$

Where:
$t_k$— maximum water cushion depth in the scour pit, from water surface to bottom, m;
$q$— discharge per unit width at the bucket lip;
$H$— difference between the upstream and downstream water levels, m;
$\alpha$— erosion coefficient, Hardly erodible bedrock as 0.7~1.1; erodible or moderately erodible bedrock as 1.1~1.4; highly erodible bedrock as 1.4~1.8.

Wudongde high arch dam, as the only project with Reventment-Protected and Non-Bottom-Protected Plunge Pool, the bedrock is thick limestone and marble with well-integrity, and so $\alpha=1.2$. The calculate results of water cushion depth in plunge pool as shown in Table 2.

Table 2. The calculate results of water cushion depth in plunge pool.

| Location | Bank side | Middle side | Bank side | Middle side |
|---|---|---|---|---|
| Discharge conditions | 5 surface outlets | 1 surface outlet | 6 medium outlets | 2 medium outlets |
| Downstream water level (m) | 836.03 | 828.82 | 836.31 | 830.41 |
| Calculated water cushion depth (m) | 44.68 | 41.3 | 65.66 | 66.35 |
| Actual water cushion depth (m) | 54.46 | 96.82 | 77.44 | 98.41 |

The results showed that, the calculated water cushion depth is smaller than the actual water depth, which can meet the requirement of related design specification.

*3.2. Impact dynamic pressure*

Based on the turbulent jet theory, the flood discharge from high arch dam will form submerged impinging jet flow, and there will be a submerged impinging area. The early research and engineering practice showed that: the maximum of pulsating pressure and impact dynamic pressure appear in the submerged impinging area; the maximum impact dynamic pressure should be no more than $15\times9.81kPa$ for the totally protected plunge pool, and thus the pressure should be keep in a small range for the Reventment-Protected and Non-Bottom-Protected plunge pool, which also should be verified by the hydraulic model experiments.

The flow pattern in the plunge pool and dynamic pressure distribution were observed by the model experiment of Wudongde Hydro-project, as shown in Figure 3.
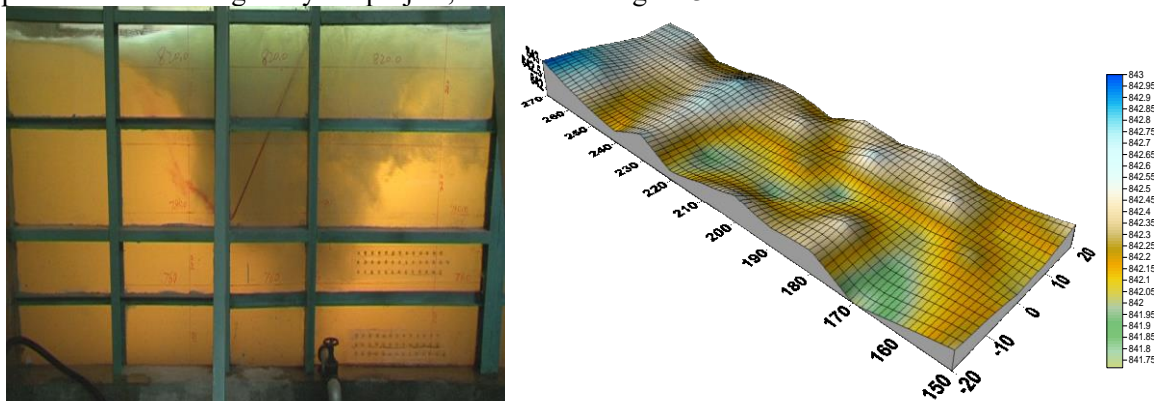


Figure 3 Flow pattern and dynamic pressure distribution on the bottom of plunge pool

The experimental results showed that, the main jet flow which discharge from the dam body did not touch the bottom of plunge pool and did not have obvious scouring to the bank side. The dynamic pressure distribution doesn't have obvious pressure peak and gradient. It can be considered that the bottom of plunge pool doesn't scoured by the flood discharge flow and the impact dynamic pressure is almost zero.

From the discusses above, the design of "Reventment-Protected and Non-Bottom-Protected" plunge pool can be used in Wudongde high arch dam project.

## 4. Formatting the title, authors and affiliations

Due to the huge flood discharge capacity, the trajectory type energy dissipation is the most widely used in dam body with manual totally protect plunge pool. When the water cushion is very deep in the high arch dam site, the deep water cushion can be considered to dissipation the energy, which can

simple the concrete-protected design. Based on Wudongde hydro-project, the water cushion depths were calculated and the impact dynamic pressure was observed, and the results showed that the design of "Reventment-Protected and Non-Bottom-Protected" plunge pool can be proposed in Wudongde high arch dam project.

**Acknowledgments**

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