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# Study on Structural Characteristics of Siphon Well Design in a Power Plant

Shen Dongmei<sup>[1]</sup>, Yu Cairui<sup>[1]</sup>, Wu Shaoyang<sup>[2]</sup>

<sup>1</sup> Architecture and Civil Engineering Department of West Anhui University, 237012

<sup>2</sup> Central Southern China Electric Power Design Institute (CSEPD) of China Power Engineering Consulting Group Corporation, 430071

Email of all the authors:

Corresponding Author: shendongmei; email:shdm9832@163.com;  
phone:15855269832; fax:0564-3307059 ; yucairui; email:yucr\_2000@163.com;  
phone:13865643150; fax:0564-3307059:wushaoyang; email:285010685@163.com;  
phone:15827222355; fax: 027-87811992

**Abstract:** The structural characteristics of siphon wells are important parameters to determine the good operation of siphon wells. Based on the engineering data of a power plant and combined with the physical model test of hydraulic characteristics, considering the hydraulic characteristics, the foam pollution and the engineering cost, this design can avoid the defects of simple theoretical calculation and has a strong reference value.

## 1.Introduction

The structural characteristics of siphon wells are important parameters to determine the good operation of siphon wells. Siphon well could be deemed an important hydraulic structure in cooling water drainage system of power plants, the rationality of its structure is not only closely related to the realization of its own function, but also directly affects the safe and efficient operation of the whole system. The weir crest elevation and cross-sectional area of siphon wells are the main structural parameters affecting their own functions. If the weir crest elevation is too high, the siphon effect will be weak, the operation and maintenance cost will increase. Besides, the serious foam pollution will be produced. If it's too low, it is easy to cause the negative pressure to be too low and even the water hammer will be destroyed. If the cross-sectional area is too large, the construction cost will be increased, and if it's too small, the negative pressure water hammer will probably appear if the water pump is cut off suddenly <sup>[1-5]</sup>.

At present, the siphon well structure design is obtained by referring to the relevant design manual, and the design calculation is only analyzed unilaterally from the economic benefit. However, for specific projects, due to the differences of specific sites conditions, the structural design parameters may not be consistent with the actual engineering when they are initially determined. At the same time, due to the serious foam pollution caused by the improper design of structural parameters, the environment will be greatly damaged.

The physical model is based on the principle of similarity, and scaling down the prototype. Through hydraulic tests, the defects of relying solely on theoretical calculation can be overcome, which can not only verify the rationality of theoretical calculation parameters, but also observe its



hydraulic characteristic. Water flow patterns and foam pollution. Therefore, in the actual engineering design, the structural parameters of siphon wells can be determined by the physical model test of hydraulic characteristics, which not only considers the economy, but also gives considerations to the environmental protection and safety, and has the irreplaceable advantage of other methods.

## 2. Methods: engineering information and design

### 2.1 Basic engineering information

A coal-fired power plant, near the Yangtze River, is located in a northern subtropical monsoon humid climate, where the average annual temperature is  $16.1^{\circ}\text{C}$ - $18.3^{\circ}\text{C}$ . What is more, there is abundant rainfall, ample sunshine, hot summer and cold winter. Installed capacity is 600 MW, set up two groups. Taking the main plant of the power plant as zero meter floor and the relative elevation at the top of the condenser is 5.50m. The circulating water quantity of a unit is  $17.04\text{ m}^3/\text{s}$  summer and  $12.26\text{ m}^3/\text{s}$  in winter. The water level at the outlet of cooling water near the river is about 56.58 m in summer and 55.66m in winter.

### 2.2 Engineering design analysis

#### 2.2.1 Hydraulic characteristic physical model test

##### (1) Choice of intersection

The section area of siphon well is an important parameter in structural design, it is affected greatly by site limitations in actual engineering. The circulating water quantity of this project was relatively small, therefore, the siphon well size was also smaller. Considering the small occupation of thin-walled Weir, it was determined that thin-walled Weir was used as overwater structure. There are three kinds of common thin-walled Weir: orthogonal Weir, skew Weir and folded Weir. For the project was limited by the site, consideration was given to the use of skew Weir. Due to the intersection angle of skew Weir is a main factor affecting its flood discharge capacity, determining a suitable intersection angle is the key of Siphon Well design. In order to determine the suitable intersection angle, a thin wall weir flow model was established in the laboratory (see Figure 1 below). The discharge experiment of skew Weir at the intersection angle of  $15^{\circ}$ ,  $30^{\circ}$ ,  $45^{\circ}$ ,  $60^{\circ}$  was studied experimentally. By measuring the water head of the Weir under different working conditions, the water surface profile of various condition was shown in Figure 2 below.

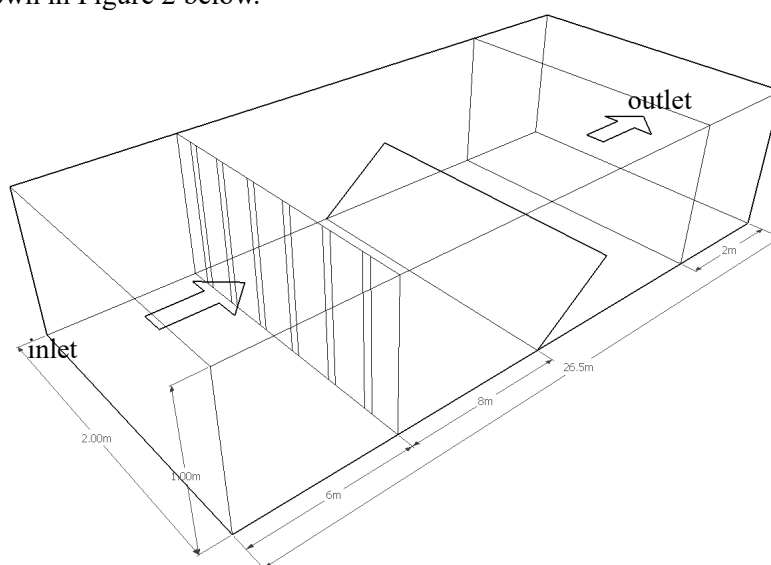


Fig 1. Discharge test plan of thin-walled weir

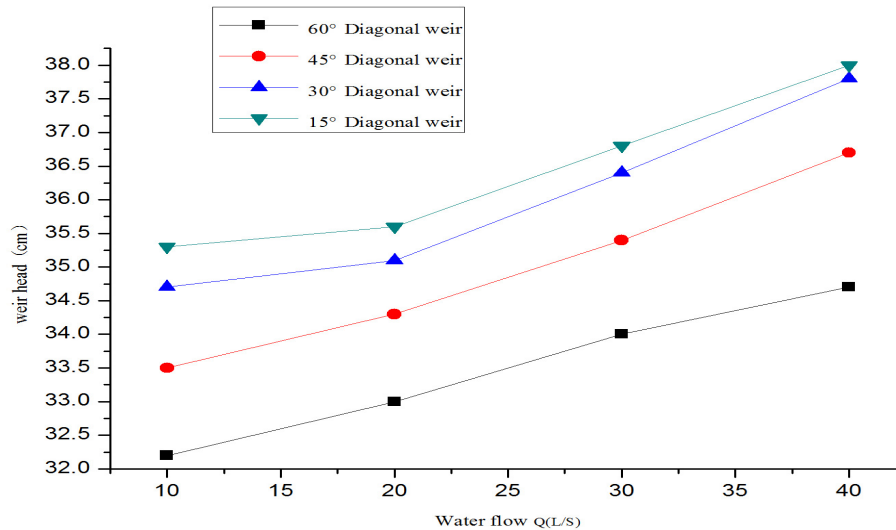


Fig 2. Relationship between water flow at different angles and head of weir

It can be seen from Fig.2 that under the same flow rate, with the increase of intersection angle, the head of Weir decreases and the discharge capacity of weir becomes stronger. However, is the bigger the angle, the better. When the flow rate increases, the water head on the weir increases more slowly, but what about the downstream water flow pattern and whether there will be foam pollution or not should be further combined with the downstream water flow pattern analysis.

#### (2) Analysis of water flow pattern

If Weir crest elevation is high, a large amount of gas will be doped in the water flow behind the siphon well, forming a large amount of foam which has a great impact on the environment<sup>[5]</sup>. In response to the above problems, based on the discharge test plan of thin-walled weir, the flow pattern and foam transport in siphon wells were analyzed, and the hydraulic performance of siphon wells was optimized.

The experimental results show that in the case of free discharge, when the angle of intersection of skew Weir increases from 30° to 60°, the current scour tended to be intense, the turbulence of downstream flow enhanced, and the amount of foam is increased. Combined with the flow-head curve, considering the discharge capacity and foam pollution, a skew Weir with an intersection angle slightly greater than 30° was preliminary determined.

#### 2.2.2 Design calculation

The discharge of submerged Weir is

$$q_v = \sigma m_0' \cdot b \sqrt{2gH}^{1.5} \quad (1)$$

where parameter are expressed as:

$b$ ——the width of overflow Weir, m

$\sigma$ ——Submergence coefficient, According to table 1

$q$ ——rate of flow, m<sup>3</sup>/s

$g$ ——acceleration of gravity,

it can be concluded that the Weir is a non-submerged Weir, and the flow coefficient of Weir can be obtained by calculating  $C_H \geq 0.5H$ ,  $H \geq 0.1m$  ( $C_H$  - Weir height,  $H$  - weir head), then

$$m_0' = 0.402 + 0.054 H/C_H \quad (2)$$

Table 1 Submergence coefficient  $\sigma$ 

| Condition                           | computational formula                                         |
|-------------------------------------|---------------------------------------------------------------|
| $0.15 \leq \frac{H}{C_H} \leq 1.90$ | $\sigma = 1.05(1 + 0.2 \frac{h'}{C_H})^3 \sqrt{\frac{Z}{H}}$  |
| $0.15 \leq \frac{H}{C_H} \leq 0.25$ | $\sigma = 1.008(1 + 0.2 \frac{h'}{C_H})^3 \sqrt{\frac{Z}{H}}$ |

calculation. Finally, determining the angel of skew Weir was  $\phi = 34^0$ , the width of overflow Weir was 21.633m, the length of siphon well was 20m and the width of siphonc was 9m. Siphon horizontal profile was presented in figure 3 as below.

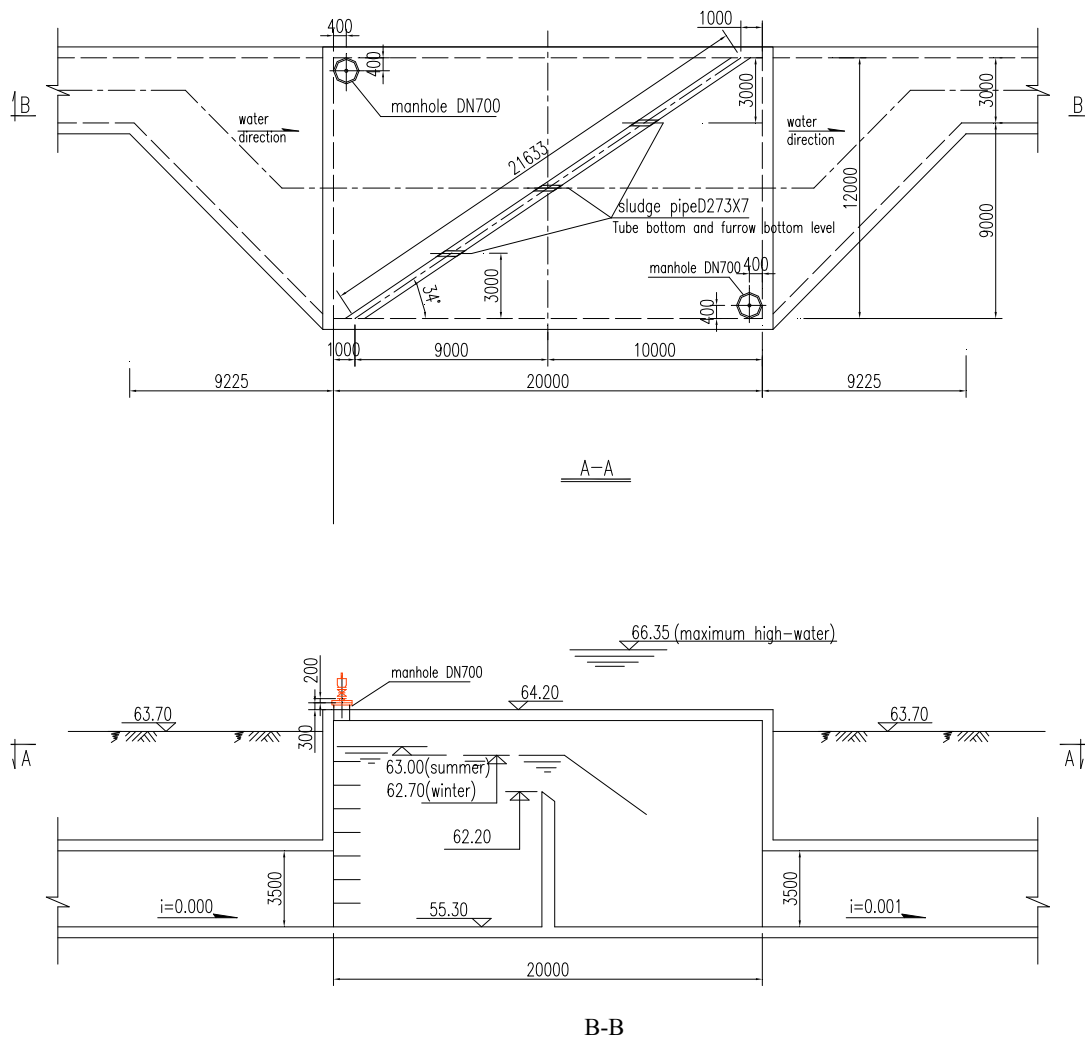


Fig. 3 Siphon profile of a power plant

### 3.Results and discussion

### 3.1 Design optimization analysis

### (1) Economic optimization analysis

Affected by the actual site, the well width was too large, the siphon well occupied too much space, the construction quantity and the cost increased. so it is not suitable to adopt the large-angle Skew Weir in the view of the engineering economy.

### (2) Optimization analysis of environmental protection

During the free discharge of siphon wells, severe water vapor adulteration was produced, and the foam pollution of drainage outlet was serious. From the physical model test of hydraulic characteristics, it can be seen that when the intersection angle of skew Weir increases gradually, the turbulence of flow enhanced, the distance of return to normal gradually increased, and the amount of foam produced increased. In order to eliminate sensory pollution caused by foam, many power plants often add defoamer to the drainage system. This will not only increase the operating cost of the power plant, but also defoamer will cause secondary pollution to the receiving water environment<sup>[6]</sup>. From the aspect of environmental protection, the angle of siphon well should not be too big.

### (3) Security optimization analysis

The higher the siphon utilization is, the more significant the economic benefits are. If the other dimensions of siphon wells are invariant and the siphon utilization height of the siphon well in the power plant is increased by 2m, the pump head will be reduced by 2m.

If the number of hours used per year is calculated at 5000, the factory electricity price is 0.4 yuan / kW\*h, the annual operating cost of the water pumps of the two units will be reduced as follows:

Pump shaft power increase×number of hours used per year × electricity price =  $(K\gamma QH/102/\eta) \times 5000 \times 0.4 = 1.05 \times 1000 \times ((17.04 \times 7 + 12.26 \times 5)/12) \times 2 \times 2 \times 5000 \times 0.4 / (102 \times 0.85) = 145.80$  (Ten thousand yuan)

It can be seen from the above formula that when the siphon height was increased by 1 m, the annual operating cost of the power plant could be saved by about 730000 yuan. But in terms of safety, siphon utilization is not the higher the better. Due to the circulating water pipe is a closed space, if the distance from the circulating water outlet to the condenser outlet is more than 10 meters (a column of water at atmospheric pressure), it will lead to the cut off of the circulating water backwater pipeline, and the consequences will be very serious. In order to make the backwater flow smoothly, the circulating water pump will do more work, thus consuming more electricity, the effect is counterproductive. According to the practical results of previous projects, from the point of view of safety analysis, the siphon utilization height is generally used 7 m.

Synthesis of the above three aspects of optimization analysis, the angle of skew Weir  $\varphi = 34^\circ$  and the siphon height of 7 m is reasonable.

## 3.2 Engineering validation

The design has completed construction and operation, after a period of observation, the system ran smoothly and produced little foam pollution. When the siphon wells were adopted, the annual operating cost could be reduced by about 10million yuan during two years, which shows that the method of determining the structural parameters of siphon wells combined with the physical model test of hydraulic characteristics is reasonable and feasible.

## 4. Conclusion

The structural characteristics of siphon wells are important parameters to determine the good operation of siphon wells. The rationality of its structure is not only closely related to the realization of its own function, but also directly affects the safe and efficient operation of the whole system. The structural parameters derived from the design manual are often inconsistent with the actual site. And the power plants are mostly close to the river. The foam pollution caused by cooling water will cause great damage to the environment. In this study, the physical model test of hydraulic characteristics is carried out in the laboratory. Considering the discharge capacity and hydraulic flow pattern, the oblique weir with an angle of slightly more than  $30^\circ$  is preliminarily drawn up. In the design process, the design parameters are optimized and analyzed from three aspects to determine the siphon well size. Finally,

through engineering verification, the comprehensive design layout is reasonable. The structural characteristics of siphon wells are studied by combining theoretical derivation with laboratory physical model, which provides a new idea for engineering design.

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