Steel stress monitoring analysis for water pressure test of spiral case

Hao Wu1, Xueyi Wu1,* and Zhaohui Zhu1

1China Institute of Water Resources and Hydropower Research, Beijing, China

*Corresponding author e-mail: wxy52168@126.com

Abstract. Taking the water pressure test of Hohhot Pumped Storage Power Station as the research object, the steel stress was analyzed by monitoring data of 3# spiral case. It could be found that the change of steel case stress was closely related to the change of water pressure, multi-correlation coefficients were between 0.993 and 1.000. The largest steel stress (194.65MPa) was less than steel yield strength (610MPa) when the spiral case was faced to the largest inner water pressure. When the inner water pressure was up to holding pressure (3.24MPa), stress of spiral case was 20.73MPa. Under same water pressure, the stresses of up and down socket ring were 1.1~1.8 times as much as others in same section. When the largest inner water pressure was transmitted to the spiral case, 3.24MPa internal water pressure was endured by spiral case and 3.36MPa pressure was shared by spiral case and unit concrete. The results show that stress change of 3# spiral case is normal and steel is worked in the elastic range.

1. Introduction
The concreting method of spiral case is usually divided into three types: preloading spiral case, cushion bedding spiral case and direct burying spiral case [1, 2]. Different concreting methods may lead to large differences in the mechanical characteristics of spiral case and structure [3].

Preloading spiral case is widely used in High-HD hydropower station of China, the United States, Canada, Brazil and Europe countries. Water pressure test is an important step in the preloading spiral case concreting process. It can not only test the welding quality of the spiral case and seat ring welds, but also eliminate the welding stress to a certain extent, and can also obtain monitoring date. It provides a certain data reference for the calculation of the volute and unit water pressure model and the optimization of the reinforced concrete reinforcement. At present, the steel stress research for water pressure test of spiral case is mostly simulated by the finite element method [4, 5], and lacks the monitoring data. In this paper, 3# spiral case of Hohhot Pumped Storage Power Station with the largest HD value in hydropower project is taken as the research object, and the analysis on results of stress monitoring of it is carried out in the water pressure test.

The Hohhot Pumped Storage Power Station is the first pumped storage power station in Inner Mongolia. The total installed capacity of the power station is 1200MW, the unit capacity is 300MW, the maximum head of the power station is 585m, the design head is 521m, and the HD value of the steel tube is as high as 4140mm. It is concreting method is preloading spiral case.
2. Research method

2.1. Measuring point
In order to monitor the hoop steel stress of the spiral case during the water pressure test, two monitoring sections are arranged along the direction of the upstream and downstream and the direction of the factory axis (see Figure 1 for the layout of 3# spiral case). Five DI-10 type differential resistance steel plate strain meters are installed separately on the top, bottom, outer side, and on the upper and lower sides of spiral case (see Figure 2 for the layout of steel plate strain meter). The steel plate strain meter is fixed at the monitoring part with the matching fixture, and digital electric bridge is used to test the resistance ratio and the resistance to obtain the strain meter monitoring data.

Figure 1. Layout of 3# spiral case

![Figure 1. Layout of 3# spiral case](image)

Figure 2. Layout of steel plate strain meter

![Figure 2. Layout of steel plate strain meter](image)

2.2. Pressing process
After filling with water, the water pressure test of spiral case is carried out with a 5-stage pressure. The pressures are 2.8 MPa, 6.5 MPa, 8.83 MPa, 11 MPa, and 13.25 MPa. During the pressurization process, each stage is kept for 5 minutes. When it is pressurized to the maximum pressure, it is kept for 30 minutes, then the pressure is reduced. The depressurization is carried out in two stages. The two stages are from the maximum pressure to the design pressure and from the design pressure to the concreting pressure. When it drops to 3.235MPa, it remains stable and prepares for concreting. The water pressure test process diagram is shown in Figure 3.
2.3. Calculation formula

Differential resistance monitoring instrument directly output resistance ratio and resistance value. Steel stress $\sigma$ is calculated by the formula (1).

$$\sigma = E[f(Z - Z_0) + a(b - a_c)(R - R_0)]$$

(1)

Where $\sigma$ is the steel stress; $E$ is the steel plate elastic modulus; $f$ is the instrument coefficient; $Z$ is the current resistance ratio; $Z_0$ is the reference value resistance ratio; $a$ is the temperature coefficient; $b$ is the temperature compensation coefficient; $a_c$ is the instrument temperature coefficient; $R$ is the current resistance value; $R_0$ is the reference value resistance value. Where $E$, $f$, $a$, $b$, and $a_c$ are given values, and $Z$ and $R$ are measured values.

3. Monitoring results and analysis

During the water pressure test, the steel stress was monitored for each stage. The stress monitoring results of the 3# spiral case are shown in Table 1~2 (the elastic modulus of the steel plate is 205GPa), timing process line of stress of spiral case in section 1 & 2 is shown in Figure 4, and Relationship graphics of stress and water pressure in section 1 & 2 is shown in Figure 5.

| Time       | Water Pressure | B3-5 | B3-6 | B3-7 | B3-8 | B3-9 | unit |
|------------|----------------|------|------|------|------|------|------|
| 2013-5-6 7:56 | 0.00           | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | MPa  |
| 2013-5-6 8:22 | 2.80           | 40.17| 22.27| 37.46| 34.93| 40.59| MPa  |
| 2013-5-6 9:44 | 6.50           | 93.33| 55.08| 89.40| 77.99| 97.35| MPa  |
| 2013-5-7 8:22 | 8.83           | 125.23| 73.81| 115.92| 101.23| 130.94| MPa  |
| 2013-5-7 9:44 | 11.00          | 142.89| 113.64| 149.77| 130.32| 159.90| MPa  |
| 2013-5-7 11:40| 13.25          | 178.33| 132.36| 179.93| 159.41| 194.65| MPa  |
| 2013-5-7 12:40| 8.83           | 125.23| 73.81| 115.92| 101.23| 130.94| MPa  |
| 2013-5-7 13:40| 3.24           | 1.97 | 20.73| 14.14| 5.50 | 19.37| MPa  |

It can be seen from Table 1 and Table 2 that when the internal water pressure is 13.25 MPa, the maximum stress of the spiral case is 194.65 MPa, which is lower than the yield strength of the steel (610 MPa); when the internal water pressure is 3.24 MPa (concreting pressure, 49% of the maximum internal water pressure), and the maximum stress of the spiral case is 20.73 MPa.

If the influence of concrete shrinkage and the outer concrete structure is neglected, when the water pressure in the spiral case is 3.24 MPa, the hydraulic load can be independently borne by spiral case. When the internal water pressure reaches the designed maximum value (6.6 MPa), the spiral case can independently carry 3.24 MPa hydraulic load, and the outer concrete share a 3.36 MPa hydraulic load.
Table 2. The stress of spiral case in section 2

| Time         | Water Pressure | B3-10 | B3-11 | B3-12 | B3-13 | B3-14 | unit |
|--------------|----------------|-------|-------|-------|-------|-------|------|
| 2013-5-6 7:56 | 0.00           | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00 |
| 2013-5-6 8:22 | 2.80           | 35.89 | 31.86 | 38.02 | 30.54 | 37.93 | MPa  |
| 2013-5-6 9:44 | 6.50           | 37.93 | 31.86 | 38.02 | 30.54 | 37.93 | MPa  |
| 2013-5-7 8:22 | 8.83           | 106.48| 97.99 | 109.40| 96.28 | 119.69| MPa  |
| 2013-5-7 9:44 | 11.00          | 131.57| 115.64| 130.14| 108.02| 146.92| MPa  |
| 2013-5-7 11:40| 13.25          | 160.30| 142.75| 162.40| 131.50| 180.10| MPa  |
| 2013-5-7 12:40| 8.83           | 80.41 | 70.54 | 109.51| 97.61 | 61.53 | MPa  |
| 2013-5-7 13:40| 3.24           | 12.77 | 11.39 | 13.33 | 3.26  | 19.82 | MPa  |

Figure 4. Hydrograph of stress of spiral case in section 1 & 2

Figure 5. Relationship graphics of stress and water pressure in section 1 & 2

It can be seen from Fig. 4 that the stress variation of steel plate conforms to the law of step-up and pressure reduction, and the stress changes with the change of water pressure. It has a good correlation. The complex correlation coefficient between the stress change of the steel plate and the internal water pressure is between 0.993 and 1.000. The relationship between internal water pressure and steel stress is shown in Figure 5, and the correlation coefficient is shown in Table 3.

Table 3. Complex correlation between stress and water pressure.

| Measuring point | B3-5 | B3-6 | B3-7 | B3-8 | B3-9 | B3-10 | B3-11 | B3-12 | B3-13 | B3-14 |
|----------------|------|------|------|------|------|-------|-------|-------|-------|-------|
| Complex correlation | 0.997 | 0.977 | 0.993 | 0.998 | 0.997 | 1.000 | 0.998 | 0.999 | 0.997 | 0.993 |

Since the seat ring stiffness is larger than the volute casing, the deformation of the volute will be affected by the seat ring under the action of internal water pressure. From Figure 6 (the inner ring design
water pressure is 8.83 MPa, the outer ring design water pressure is 13.25 MPa) It can be seen that the stress of the steel plate near the butterfly edge (B3-9, B3-14) and the lower butterfly edge (B3-5, B3-10) on the same monitoring section is greater than the stress of the remaining part. Compared with the rest of the steel plate stress, the upper and lower butterfly steel plate stresses accounted for 70.2% of the ratio of 1.1~1.4, and 1.5~1.8 accounted for 13.1% of all ratios.

![Distribution graphics of stress in section 1](image1) ![Distribution graphics of stress in section 2](image2)

Figure 6. Distribution graphics of stress

4. Conclusion

Through this test and monitoring data, we can get the following conclusions:

(1) The steel stress variation of the 3# spiral case of the Hohhot Pumped Storage Power Station is in accordance with the law of pressure rise and pressure reduction. The stress has a good correlation with the water pressure change, and the complex correlation coefficient is between 0.993 and 1.000.

(2) When the internal water pressure of spiral case is maximum (13.25 MPa), the maximum steel stress is 194.65 MPa, which is lower than the yield strength of the steel. Under the influence of the seat ring constraint, the upper and lower butterfly edge stresses are greater than the rest of the same monitoring section, and the stress ratio is generally between 1.1 and 1.8.

(3) When the internal water pressure is the designed maximum internal water pressure, the water pressure within 3.24 MPa can be borne by the spiral case, and 3.36 MPa can be shared by the outer concrete structure.

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