Analysis of causes for slippage of concrete impermeable cover plate of an adjustable reservoir

Shufeng Zhen 1,2*, Rong Li 3
1 Shandong Yellow River Engineering Group Corporation Ltd., Jinan, Shandong, 250013, China
2 Xinjiang Ili River Basin Development & Construction Administrative Bureau, Urumqi, Xinjiang, 830000, China
3 China Institute of Water Resources and Hydropower Research (IWHR), Beijing, 100038, China
*Corresponding author’s e-mail: 516733923@qq.com

Abstract. After the construction of the cover plate in a four-dike adjustable injection reservoir in western China, it was first found that the cover plate near the top of the dam slipped in the filling area, resulting in the tearing of the geomembrane. At present, the impermeable layer has been destroyed in the reservoir without water storage, so it is necessary to evaluate the causes of slippage and the damage degree of geomembrane.

1. Introduction
In western China, a four-dike adjustable injection reservoir (Figure 1) consists mainly of dam body, inlet structure and outlet structure. The normal storage height of the reservoir is 546.00m, the maximum surface area is 0.21 km², and the adjustable capacity of the reservoir is 1.5 million m³. In the construction of impermeable system of reservoir, first, 30mm-thick mortar is poured to form a cushion layer, then 3mm-thick one geotextile with one membrane type geomembrane is laid. The cloth surface of geomembrane is facing up while the plastic film surface is down, then 30mm-thick mortar is poured on the film. After about half a month, when the mortar solidifies, the 20cm-thick plain concrete cover plate is poured, mainly using geomembrane as the impermeable material.

Figure 1. Reservoir overview.
2. Description of defect
After the cover plate is poured, it is first found that the cover plate near the dam top slips in the filling area, resulting in the tearing of geomembrane, as shown in Figure 2. It is preliminarily suspected that the settlement of the dam body causes it, but later, the same phenomenon of the slippage of the cover plate appears in the excavation area, which shows that the settlement is not the main reason for the slippage of the cover plate. At present, the impermeable layer has been destroyed in the reservoir without water storage, so it is necessary to evaluate the causes of slippage and the damage degree of geomembrane.

The fundamental reason for the slippage of the cover plate is that the downward sliding force is greater than the upward friction force along the slope direction of the reservoir basin. From the stable state of the cover plate after pouring to the downward slippage of the cover plate, how the friction force gradually decreases in this process has become the focus of research. According to the on-site inspection, the combination of the cover plate and the upper mortar of geomembrane is well, and the relative displacement occurs between the geomembrane and the lower mortar. It can be seen that the void between the geomembrane and the lower mortar reduces the effective contact area, which is one of the reasons leading to the slippage of the cover plate. In addition, the conventional geomembrane is a two geotextiles with one membrane structure, and the friction coefficient of the one geotextile with one membrane structure used in this project is obviously low, which will also cause the cover plate to slip.

3. On-site inspection

3.1. Inspection equipment
Ground penetrating radar (GPR) is a nondestructive testing method, which can detect the internal cavities, voids and depths of panel defects. GPR transmits high-frequency electromagnetic pulse wave to the measured body by transmitting antenna. Using the difference of electromagnetic properties of underground medium, reflection and transmission will occur at different electrical interfaces, i.e. interfaces with different dielectric constants. The receiving antenna receives reflected electromagnetic wave and records reflection time. According to the characteristics of amplitude, waveform, frequency and in-phase axial shape of reflected electromagnetic wave, the structure and physical properties of medium are analyzed and inferred, or the defects in medium structure are judged.

GSSI SIR-4000 ground penetrating radar, equipped with 2600M high frequency antenna, is used in this test, and adopts distance mode for measurement. At present, most of the 20 cm thick cover plates of the reservoir basin have been poured. It is necessary to ensure the detection depth and improve the detection accuracy as much as possible. The antenna time windows are selected as 10ns, 7ns and 5ns to detect whether the film is void or not.

3.2. Inspection scheme
In order to fully understand the impact of filling on the slippage of cover plate, GPR scans the filling area and excavation area. The antenna traveling route of the filling area is shown in Figure 3. The statistical table of radar survey line is shown in Table 1, with 12 survey lines laid out.
Figure 2. Geomembrane tear due to slippage of the cover.

Figure 3. Radar antenna travel route of the filling area.

Table 1. Radar line statistics

| No. | survey area    | stake number | time window (ns) | line direction | Starting cover | End cover | Remarks       |
|-----|----------------|--------------|------------------|----------------|----------------|----------|---------------|
| 1   | filling area   | 1+482.6      | 10               | From bottom to top | ①             | ⑦        | green Line    |
| 2   | filling area   | 1+479.6      | 10               | From bottom to top | ①             | ⑦        | red Line      |
| 3   | filling area   | 1+482.6      | 7                | From bottom to top | ⑤             | ⑦        | green Line    |
| 4   | filling area   | 1+479.6      | 7                | From bottom to top | ⑤             | ⑦        | red Line      |
| 5   | filling area   | 1+482.6      | 5                | From bottom to top | ⑤             | ⑦        | green Line    |
| 6   | filling area   | 1+479.6      | 5                | From bottom to top | ⑤             | ⑦        | red Line      |
| 7   | excavation area | South side   | 10               | From bottom to top | Near the bottom of the reservoir |
| 8   | excavation area | South side   | 7                | From bottom to top | Near the bottom of the reservoir |
| 9   | excavation area | South side   | 5                | From bottom to top | Near the bottom of the reservoir |

4. Radar scanning analysis

4.1. Radar survey line of the cover plate in the filling area

There are six survey lines tested in the filling body, all passing through the middle of the cover plate. There are two lines from bottom to top. The length of a single survey line is 27m and the time window is 10ns. When the time window decreases, the depth information obtained decreases, but the detection accuracy will be improved. From cover plate ⑤ to cover plate ⑦, there are 11m. The green and red survey lines are tested twice, and the time windows are 7ns and 5ns, respectively. The detection accuracy under different time windows is compared, and their radar survey lines are shown in figure 4- figure 6.
The test results show that 10ns is suitable. The mortar cushion is not obvious within the range of 2m from the top of the dam to pile No. 1+482.6 survey line cover plate ⑥, which tells that its integrity is damaged.
4.2. Radar survey line of cover plate in excavation area

In the southwest corner of the reservoir area, a cover plate is selected for radar and surface wave comparative test, and the cover plate is close to the bottom of the reservoir. 10 ns, 7 ns and 5 ns are used for each test. Radar scans are shown in figure 7-figure 9.

![Figure 7. Line 7 radar scanning profile (10ns).](image)

The detection of survey line in excavation area shows that the cover plate and mortar cushion can be clearly seen in the time window of 10ns, and no obvious void is observed.

5. Conclusion

Through radar detection of dam filling area, excavation area and uncovered area, the following conclusions are drawn:

The boundary line between the cover plate and mortar, mortar and filling body can be clearly seen by selecting 10ns detection time window of the cover area, but the 6cm mortar on top and bottom is the same band in radar image, which cannot distinguish whether the bottom mortar is void or not.
With 7ns time window, mortar layer is not obvious, and the detection depth of 5ns is limited to the cover plate, so it is appropriate to select 10ns for the detection time window of the cover plate.

The mortar cushion is not obvious within the range of 2 m from the top of the dam to pile No. 1+482.6 survey line cover plate ⑥. It can be judged that the integrity of the mortar layer has been damaged. It is the obvious slippage area of the cover plate observed on the spot, which shows that the radar detection accuracy is consistent with the actual situation.

Excluding the situation of the bottom of the cover plate being void, it can be seen that the slippage of cover plate of reservoir is caused by the relatively small friction coefficient of geomembrane.

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