Quality Inspection and Evaluation of Lining of Flood Discharge Tunnel in Nam Lik 1-2 Power Station

Meng Li¹, Heran Wang², Minghui Feng¹ and Xiulin Li¹*  
¹China Institute of Water Resources and Hydropower Research, Beijing, 100038, China  
²Beijing Liangshui River Management, Beijing Water Authority, Beijing, 100038, China  
*Corresponding author’s e-mail: lixl@iwhr.com

Abstract. In 2015, Laos Nam Lik 1-2 power station once dealt with the defect of the flood discharge tunnel. After the flood discharge hole was emptied in 2018, it was found that the concrete was peeled off and exposed. After on-site census, radar detection, rebound and core strength testing, it is judged that the tunnel has apparent defects but does not affect the flood season operation. In order to prevent the surface concrete from being washed by the water flow and continue to expand the shedding surface, it can be repaired and strengthened after the flood season, which provides a favorable scientific basis for the operator.

1. Introduction
Laos Nam Lik 1-2 hydropower station has a designed installed capacity of 100MW and an average annual power generation of 435 million kW•h. Before the arrival of the local flood season in 2018, the flood discharge and diversion tunnel was emptied. It was found that the right side of the D0+018.969 top plate of the rear part of the inspection lock chamber, the right-side arch of D0+031.469 in the 1# import transition section and the D0+031.969 arch of the 1# import transition section have concrete falling off and exposed steel bars. Special inspections of concrete quality are urgently needed to ensure safety.

2. Inspection content
This test focused on the roof area where concrete was found to fall off. At the same time, it also carried out general surveys and radar scans on the pressurized tunnel sections. The main test contents include lining defect survey, concrete internal quality inspection, concrete strength, carbonization depth, thickness of steel protective layer and reinforcement condition detection. According to the results of the on-site test, the concrete quality inspection in the water area was added. Because there was no pile number in the cave, all the piles were detected with the inspection gate as the starting point. The detection range started from the inspection gate to the working arc gate, and the corresponding station number is 0+000~0+365.

3. Defect census
Firstly, a comprehensive inspection of the pressure hole was carried out, without the gradient section, to the overall appearance of the tunnel. In the gradient section, by using scaffold, the inspection personnel were close to the top panel and carried out detailed inspection.
After the inspection, 17 defects were found, involving 6 types of defects, including structural joint seepage, new whitening after grouting, cracks, concrete falling off, watering, and unblocked drainage holes. There are 2 seepage waters, 2 white deposits, 4 cracks, 1 concrete shedding area of 3.75m², 6 watering area (Fig. 1), and 1 unblocked drain hole.

In the gradual section, there were a crack flow, a water seepage point and five cracks (17.8m in length in total), 2 concrete voids (9.1m² in total), and 3 falling concrete area and exposed steel bars (29.2m² in total). Typical defects are shown in Figure 2.

4. Carbonization depth inspection
In this inspection, there are 5 measuring points on the left wall of the left hole and the right wall of the right hole, and 27 measuring points on the top plate, the carbonization depth is less than 0.5mm, which indicates that the concrete in the tunnel is not carbonized, which is related to the filling operation of the pressure tunnel in the flood discharge tunnel.

5. Concrete strength testing
This project adopts the integrated method of core drilling and rebound method to test the strength of lining concrete. The second stage concrete below the hole section EL240 is wear-resistant and impact-resistant concrete, and the number is not lower than C35. Three cores were taken on site, and no steel bars were touched. The core sample looked good. No obvious stones and voids were found, and the concrete was poured tightly. The minimum compressive strength of the left wall of the left hole and the core of the right side of the right hole is 42.3 MPa, which is much higher than the design strength. Only one piece of the standard core sample of the left invert arch has a compressive strength slightly less than the design strength, which is 32.9 MPa, and the other three pieces are all larger than 35 MPa, which satisfies the design strength requirements as a whole. The rebound method is used to detect the strength of the roof concrete. The minimum value is 37.5MPa and the highest value is 69.9MPa. The large dispersion indicates that the concrete quality is not uniform and still meets the C35 design requirements.

6. Geological radar detection of lining quality

6.1. Inspection plan
Geological radar detection uses the SIR-4000 geological radar of US GSSI company. According to the site conditions, 4 sets of typical survey lines and 2 concrete fall-off areas are arranged in the key inspection area of the roof. The position of 1~4 line is shown in Figure 6.
The title is set 17 point Times Bold, flush left, unjustified. The first letter of the title should be capitalized with the rest in lower case. It should not be indented. Leave 28 mm of space above the title and 10 mm after the title.

Figure 3. Radar line (looking up the top).

The measuring line ① is in the intact area of concrete. The 200M antenna is used to measure the lining and the surrounding fall-off rock. The 400M antenna measures the internal quality of the concrete. The measuring line ② is also in the concrete intact area. The 2600M antenna is used to measure the distribution of the steel in the direction of the flow and the thickness of the protective layer of the steel. The measuring line ③ is transitioned from the concrete intact area to the void area. The internal mass of the concrete is measured with a 400M antenna, and the 2600M antenna measures the distribution of the steel along the vertical direction of the water flow and the thickness of the protective layer of the steel. The measuring line ④ is close to the concrete falling off area, and the internal quality of the concrete around the falling area is measured with a 400M antenna to judge whether the falling off has an expanding trend. 2#, 11# concrete falling off area, using 200M antenna to detect the contact between the lining and the surrounding rock.

The entire pressure-bearing section is tilted to the left and right of each line, and the 400M antenna is used to measure the internal quality and the steel section. Although the detection side of different frequency antennas in the same measurement area is different, the radar scan pattern may also overlap, and the various results can be mutually verified.

6.2. The contact of lining and surrounding rock
The internal quality inspection of the lining is mainly based on 400M antenna. The detection object has a gradient section of the roof concrete falling edge area, the roof emptying area, the left hole of the left-side wall, the middle pier right side surface, the right hole of the right-side wall and the entire pressure hole section. The key detection area of the gradual section: no abnormality in the lining of the falling edge of the roof, indicating that the concrete around the detached part is not at risk of falling off. The radar scanning map of the top row voiding area (line number ③) is shown in Figure 4. The front 3m lining has no abnormality, indicating that the lining surface is of good quality, and there is significant voiding occurred between the lining surface and the inner reinforcement in the last 1 m range. This is consistent with the census results, indicating that the void occurs between the lining and the inner reinforcement and is close to the steel. There is no obvious abnormality in the concrete inside the left wall of the left hole, the right façade of the middle pier, and the concrete of the right wall of the right hole.

There is a pressure section in the downstream of the gradual section: the radar scan results of the left arch line discovered that, a total of two linings and surrounding rocks are found to contain water, one lining peripheral rock is not dense, and one lining is not dense (census water area), one protective
layer of steel is thick. The results of the radar scanning of the right-inverted arch line showed that one lining was not dense (the watering area), and the three protective layers of the steel were thick.

The title is set 17 point Times Bold, flush left, unjustified. The first letter of the title should be capitalized with the rest in lower case. It should not be indented. Leave 28 mm of space above the title and 10 mm after the title.

6.3. The lining quality inspection of the watering area
The inspection found that there were 2 watering areas near the right invert arch of 0+342.5, and there was a possibility that the internal concrete could be emptied, which would affect the safe operation of the tunnel. Using 200M and 400M antennas to re-examine 0+340.5~0+344.5, it is found that the internal concrete is not dense near 0+342.5 and 0+343.5. Figure 10 demonstrates that concrete has been emptied by brushing.

7. Geological radar measures the thickness and spacing of the protective layer of steel
Geological radar detects the thickness of the protective layer. First, the concrete dielectric constant is calibrated in the exposed area of the concrete falling steel. According to the measured thickness of the protective layer, the electric constant is deduced, and the radar data is time-depth converted according to this standard, and the thickness of the protective layer of the steel is obtained. The radar inversion diagram shows that the thickness of the protective layer of the vertical flow direction is 16cm (Fig. 5), and the thickness of the protective layer of the rebar in the direction of the flow is about 20cm, which is greater than the design thickness of 10cm. The spacing of the steel between the water flow and the vertical flow direction is 200mm, and it meets the design requirements.
8. Conclusion
The inspection shows that the concrete lining of the flood discharge tunnel mainly has appearance defects such as falling off concrete, exposed steel bars, and multiple cracks and water seepage. The strength of the lining concrete, the spacing of the steel bars and the thickness of the protective layer all meet the design requirements. The internal inspection of the geological radar lining showed that no obvious anomalies were found in the lining and surrounding rock, and the contact was good. For the key detection area of the roof, the quality of the concrete at the edge of the roof is good, and there is no risk of falling off at present. The void mainly occurs between the lining and the inner steel bars, close to the steel bars. The concrete in the watering area of the inverted arch is emptied by brushing. According to the comprehensive judgment of the inspection results, although the tunnel has obvious defects, it does not affect the flood season operation. In order to prevent the surface concrete from being washed by the water flow and continue to expand the shedding surface, it can be repaired and strengthened after the flood season, which provides a favorable scientific basis for the operator.

Acknowledgments
This research was funded by the National Key R&D Program of China (No.2018YFC0407102), the IWHR Basic Research Fund (SM0145B442016, SM0145B632017, SM0145B952017, SM0145C102018), and the Open Research Fund of State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, IWHR (Grant No.SM0145B252018, SM0112B242018).

References
[1] Pan, D., & Liu, C. (2014). Preliminary study on feasibility of capacity expansion for nam lik 1-2 hydropower station. Hydropower & New Energy.
[2] Nam Lik 1-2 Hydropower Project. https://cdm.unfccc.int/Projects/DB/Germanischer1335441117.9/view
[3] Lalaghe, A., Lebens, M. A., Hoff, I., & Grov, E. (2016). Detection of Rockfall on a Tunnel Concrete Lining with Ground-Penetrating Radar (GPR). Rock Mechanics and Rock Engineering, 49(7), 2811-2823.
[4] Zhang, M. M., & Zhang, X. D. (2014). Application of Ground Penetrating Radar in Tunnel Concrete Lining Quality Detection. Advanced Materials Research., 358-363.
[5] Baryshnikov, V. D., Khmelin, A. P., & Denisova, E. V. (2014). GPR detection of inhomogeneities in concrete lining of underground tunnels. Journal of Mining Science, 50(1), 25-32.
[6] Liu, Y. H., Wu, D. Y., & Wang, J. X. (2010). Ground-Penetrating Radar Detection of the Defects in Tunnel Lining. Advanced Materials Research., 3794-3797.
[7] Pan, J. S., Yang, L., Leng, Y. B., & Lv, Z. Q. (2011). Application of the Ground Penetrating Radar in the Quality Detection of Tunnel Lining. Advanced Materials Research, 5381-5385.
[8] Li, X., Lu, X., Li, M., Hao, J., & Xu, Y. (2018). Numerical Study on Evaluating the Concrete-Bedrock Interface Condition for Hydraulic Tunnel Linings Using the SASW Method. Applied Sciences, 8(12).