Cracked tunnel liner.

By

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George was concerned. He had just been asked to come to the hydro site to inspect the new power tunnel. The hydro facility was in the process of being commissioned, with watering-up of the power tunnel. The concrete lined, 6.8m diameter, 340m long tunnel in horizontally stratified sandstone and shale, paralleling the river had been filled, but the drainage system was discharging at several times the expected flow. The tunnel was being slowly dewatered through the spiral case drain, and an inspection was scheduled in 3 days time.

To reduce the external pressure on the unreinforced concrete tunnel liner, two 10cm drain pipes had been attached to the rock wall on each side, covered with canvas attached to the rock, to prevent entry of concrete, and embedded in the concrete at about the horizontal diameter. The drain pipes were connected at the upstream ends, and were kept free by flushing during concreting of the tunnel. The drain pipes passed through the powerhouse valve gallery, where the flow was measured with a Venturi system. Shortly after tunnel filling started, with water in the tunnel at about the ¾ reservoir level, the flow meter recorded a sudden sharp increase in flow, to beyond the recording ability of the meter. A decision was taken to dewater the tunnel to inspect the concrete liner.

When George arrived at the site, the tunnel was being readied for inspection, with a fan blowing air into the turbine spiral casing manhole to clear any gases out through the intake air vent. George and a few others entered the tunnel with flashlights, and walked upstream. Shortly after the end of the short steel liner, they found a two horizontal cracks in the concrete, at about the horizontal diameter, extending upstream for about 40m. The crack was just a continuous hairline, but the tail of a small fish was observed caught in the crack, and from the size of the fish, it was guessed that the crack had opened by about 2cm.

What had gone wrong? After the phone call, George had his engineers check the tunnel design, but all seemed to be in order, with more than adequate rock cover to counter the internal pressure. However, from the location and extent of the cracks, it was evident that rock cover was inadequate, and the water pressure in the tunnel had lifted the overlying rock. To measure the extent of movement on tunnel pressurization, it was decided to install two scratch plates, one on each side. The scratch plates consisted of a leaf, cut in half, from an old steel rear wheel car spring, attached to the concrete above the crack, terminating in a pointed rod. Below the crack, a lead plate was attached to the concrete, with the point from the spring above pressing down on the plate.

The tunnel was watered up, with the pressure maintained for a few hours. After this, the tunnel was slowly dewatered and the scratch plates inspected. Both showed movements just over 1.7cm. What to do? Extending the steel liner upstream to after the end of the crack was out of the question. Cost would be prohibitive, and commissioning would be delayed by several months. The alternative of adding reinforcing and a thin concrete cover was also discarded for the same reasons. What about accepting the leakage, allowing the tunnel to crack slightly, thus engaging the rock weight. From the few hours of observing the flow at full reservoir pressure, it appeared that flow was steady, even though it was excessive.

However, this option was also discarded, since it was felt that water pressure in the rock mass could slowly increase, and a catastrophic blow-out could occur. Then one of the engineers suddenly had a thought. Why not add a flexible waterstop to the crack, allow the tunnel to crack, but limit the flow into the drains with the waterstop. It was decided to try this option. Two 0.6m wide, 2.5cm thick, 45m lengths of rubber conveyor belting was ordered. On arrival at site, they were clamped to the concrete above the cracks, and covered with a thin steel plate for protection. The steel plate extended down over the bottom of the belting, and was loosely attached to the concrete through oval bolt-holes allowing about 3cm of movement.

To monitor the leakage more closely, two new Venturi meters were installed, one to measure low flows, and the other to measure higher flows. Both had alarms installed to warn of excessive flow. The tunnel was watered up and the drain flows closely monitored. Leakage was initially higher than anticipated, but gradually reduced to well within what had been expected, at only a few liters per second. It was thought that the reduction was due to sealing of the rubber-concrete contact with fine silt in the glacial run-off water. The tunnel has now been operating for several years without further trouble.

Lesson learned.

This appears to be a case of inadequate grouting. When a tunnel is excavated in horizontally stratified rock, the rock above the tunnel tends to relax down into the tunnel. If the rock above the tunnel is not adequately grouted, the tunnel liner will crack and will expand vertically to lift the rock back into place, to engage the overlying rock mass. At this site, high pressure grouting was not used in case the tunnel drains were blocked. In such cases, it is preferable to omit the drains, and ensure that the rock is fully grouted.

It does not appear to be a case of hydrojacking, as the main crack was horizontal, although there was sufficient rock cover to prevent lifting of the overlying rock mass. Had the crack been caused by hydrojacking, it would normally have been near-vertical, reflecting inadequate in-situ stress as a result of yielding of the abutment towards the river.