

Rehabilitation at Standley Lake

Christoph Goss, of Deere & Ault Consultants Inc, describes the tunnelling works undertaken to facilitate the Standley Lake Rehabilitation Project, which recently won an Engineering Excellence Award by the American Council of Engineering Companies (Colorado)

Standley Lake Dam and Reservoir, in the north-western greater Denver Metropolitan area, Colorado, is an earth embankment with a height of 33.5m and a crest length of 2,012m. The reservoir stores 51.8Mm³ of raw water that cannot be drained without causing a major interruption to Denver's water service. The dam was constructed in 1908 using soil from railroad

trestles and "puddling" in a clay core on a foundation of weak expansive, and slickensided claystone bedrock.

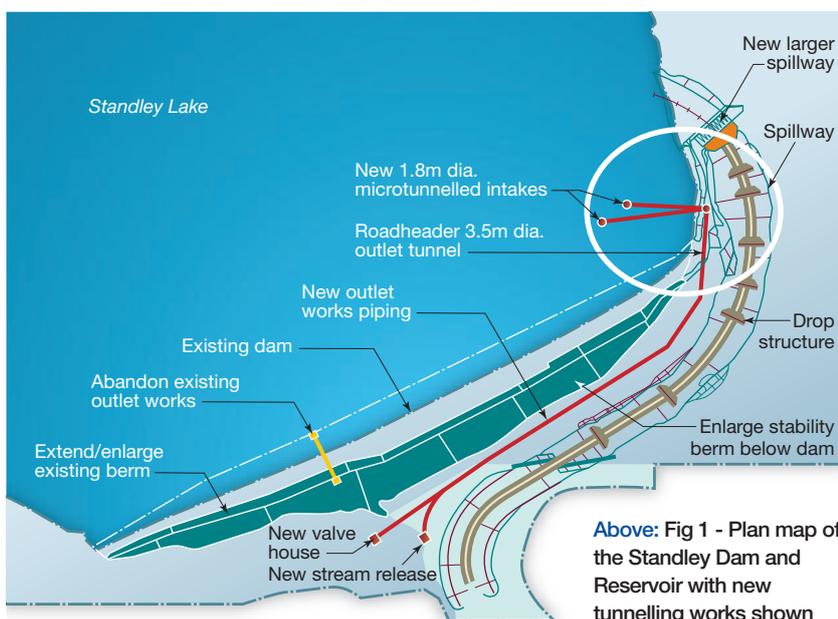
Given these factors, the dam was plagued with slope failures from the beginning. Recently, the old pressurised outlet works constructed through the maximum section of the earth dam, experienced separation problems at the joints due to creep and sliding of the embankment and foundation.

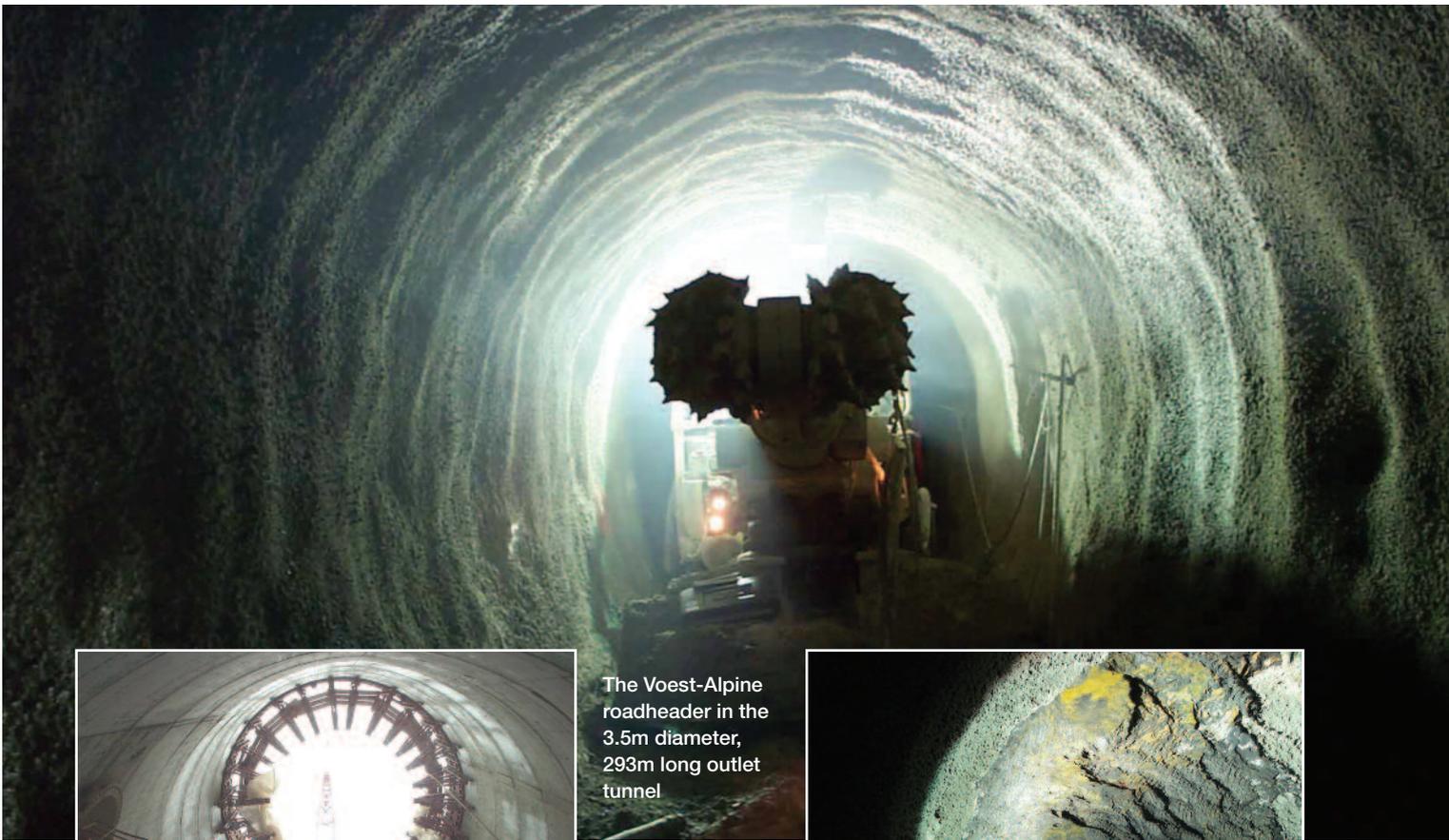
The US\$32.5M renovation carried out in 2002-2004 included constructing outlet works tunnelled in the abutment (separate from the embankment), a new spillway, and placement of additional stability berms. The outlet works replacement required two 1.8m diameter microtunnelled wet lake taps, 380m and 186m long, a permanent valve shaft 12.2m wide x 32m deep, and a 3.5m diameter 293m long roadheader driven outlet tunnel. The contractor was a JV of ASI and RE Monks, of Colorado with microtunnelling by Michels Pipeline Construction.

Geology

The project's near surface bedrock consists of Late Cretaceous/early Tertiary, sedimentary strata of the Laramie Formation, interbedded very low strength sandstones and claystones. The rock contains thin lignite stringers and carbonaceous zones, as well as iron nodules in the sandstone and iron concretions in the claystone. The claystones could be described as highly over-consolidated, stiff, fissured clays. The sandstones are locally very dense, although generally only weakly cemented. Beds of irregular log-shaped features of well-cemented sandstones occur locally.

There is a well-defined weathering profile in the bedrock that tends to follow the





The Voest-Alpine roadheader in the 3.5m diameter, 293m long outlet tunnel

Left: View up the main shaft



Right: Slickensides in the tunnel crown

topography. The bedrock was consolidated under overburden pressures that were well in excess of the existing pressures. The unloading or stress relief of the strata resulted in differential rebound, the opening of joints, and the development of local fissures and numerous slickensides.

The intake tunnels would extend beneath the existing reservoir and therefore below anticipated water levels. Static groundwater levels at the other facilities were encountered well above the base of the structures. At the valve shaft, groundwater was encountered approximately 15.2m above the base of the shaft. Along the outlet tunnel alignment, groundwater levels ranged from 9.1m to 15.2m above the tunnel invert. Downstream of the valve shaft, the groundwater elevation dropped, mirroring the topography.

Shaft construction

Valve shaft excavation began in September 2002 using a trackhoe with a bucket and a trackhoe with a hoe ram. Spoil was placed into a skip and lifted out of the shaft and dumped north of the shaft for eventual use in the random fill east of the existing dam. As shaft excavation proceeded the sides were trimmed to a minimum diameter of 12.2m. Shotcrete, some 250mm-380mm thick, was applied over the exposed bedrock within two to three hours. A second layer of was placed to secure heavy steel rings (ribs) and

complete the shaft wall shotcrete thickness to 750mm. Twenty-four rows of 3m and 2.4m long rock dowels were installed between the steel rings with a percussion drill. After reaching the bottom, steel reinforcement was placed and the final concrete lining was placed using slip forms.

Outlet tunnel construction

Excavation of the 3.5m diameter 293m long modified horseshoe outlet tunnel started in January 2003. The tunnel was driven west, towards the shaft, by a Voest-Alpine ATM-50 roadheader supplied by Antraquip. Muck was removed with an LHD and stockpiled on the north side of the portal area for later incorporation into the toe berm. The tunnel advance rate for 142 working days was approximately 2m per day. The tunnel holed out into the valve shaft in August 2003.

Most of the tunnel, 258m, was supported with 100mm of steel fibre reinforced shotcrete (type I support). The remaining 35m near the portal and at the valve shaft, was supported with a combination of a 150mm thick layer of shotcrete and lattice girders on 1.2m centres (type II support).

Coordinating tunnel support installation with excavation was an initial challenge for the crew. Originally the crew placed shotcrete in the afternoon after the daily advance. A second layer was placed in the morning prior to mining. This procedure

generally left 3m-6m of unsupported ground for six or seven hours. Ravelling with local block fallout resulting in overbreak of the claystone was common, hence the procedure was modified as follows; mine 1.8m, install shotcrete and then mine another 1.8m and install tunnel support. These modifications reduced the air exposure time for the claystone and time the ground was unsupported to three to four hours, resulting in reduced overbreak. In areas of poor ground, the shotcrete thickness was increased to approx 150mm.

The ground was primarily claystone of varying degrees of sandiness. The upper layers tended to be more weathered and were typically lighter coloured with iron-stained joints. As overburden increased, the claystone became more grey and massive. Shears, slickensided joints, and small coal seams and inclusions were common. Towards the shaft, a dark grey bed of carbonaceous claystone was encountered. Bedding plane features typically of thin sandy joints horizontal or dipping gently east were common. Other joints tended to be discontinuous. In several locations, block fallout on slickensided joints in the tunnel crown led to overbreaks of up to 1m.

Throughout the tunnel, the claystone would slake after several hours exposure to air. In most cases the ground was classified as firm to slow ravelling with the rate



Above: The Akkerman MTBM about to be recovered by crane after the successful lake tap

increasing with longer exposure. The ravelling typically consisted of claystone fragments falling from the crown. Only limited groundwater (moist spots and minor weeps) was encountered.

Tunnel convergence was measured regularly with a tape extensometer in arrays consisting of five anchors, short pieces of rebar with eyebolts located in the crown, upper haunches, and lower haunches. The anchors were placed near the face soon after shotcreting was complete. The largest movement was horizontally near the invert where shotcrete placement was delayed for days until the roadheader had passed. The horizontal displacement is logical when one considers that the claystone is heavily over consolidated with horizontal stress likely several times greater than vertical. The displacement stopped as soon as the invert was shotcreted and the full ring of reinforcement was completed.

Lake tap construction

The Upper and Lower Intake tunnels beneath Standley Lake were constructed by subcontractor Michels Pipeline Construction using microtunnelling. This was selected as the most reliable method for tapping into a full reservoir. There were still potential risks with such a long underwater drive, such as sticking of the pipe due to swelling pressure and convergence. Thanks to good fortune and a skilled crew, the upper and lower intake tunnels were successfully installed between April 2003 and October 2003.

The new 250 horsepower Akkerman MTBM was outfitted with carbide tipped picks and scrapers and had a 190mm overcut. The MTBM was advanced using a set of four 400t jacks and jacking frame pushing off of a thrust block on the heavily reinforced concrete shaft wall. Jacking forces were reduced by pumping bentonite through ports into the space between the pipe and ground. The pipe used in the intake tunnels was 1890mm o.d. 190mm thick Permalok steel pipe (type 7), with gasketed joints and a polymer coating on the exterior.

Upper intake conduit

To form a work platform for the MTBM, the shaft was filled with approx 8.5m of sand covered with a 10cm thick concrete slab.

Upper intake excavation began in May 2003. Progress appeared to be controlled by the MTBM's capacity to excavate, process, and transport the plastic claystone cuttings. Faster rates were achieved where the MTBM encountered a less plastic mixture of claystone and sandstone. The MTBM holed out into the upper intake pit, 186m away, in June 2003 and was recovered by a crane supported on a barge. Once the MTBM was recovered, the intake pipe was shoved into final position. Upon drive completion, the space between the pipe and pipe was grouted using a fly ash and cement grout. Pumped volumes were equal to 87% of the theoretical void, indicating that very little of the overcut had collapsed, squeezed, or swollen shut.

Since access to the face was impossible, the geology was determined by cuttings taken from the separation plant. Near the shaft, the ground was mostly grey to dark grey claystone while the remainder of the drive was in locally sandy tan/brown/grey claystone with iron staining. For a short section of the drive, the MTBM mined through iron nodules embedded in the claystone. These were easily cut by the machine and actually increased production by helping to break up the heavy clay. Near the extraction pit, the MTBM mined through a partial face of buff, weakly cemented sandstone. This ground again aided in production by allowing the operator to push harder without plugging up the MTBM.

Lower intake conduit

The MTBM was lowered into the shaft bottom in July 2003 and holed out in September 2003. It was recovered from the lower intake recovery pit at a water depth of more than 24m. The final length of the installed conduit pipe from the intake structure to the valve shaft was 380m

An intermediate jacking station (IJS), a powered short stick of pipe that expands along its axis, was placed into the lower intake pipe string approximately 183m behind the MTBM. The IJS, which can be used to assist the main jacks in the valve

shaft, consisted of eight separate jacks with a total jacking capacity of 800t. However, the main and tailcan jacks provided enough thrust, so the IJS was not used. Once the lower microtunnel was complete the IJS jacks were removed and the sliding coupling was welded shut. Again, the pumped volumes of grout in the overcut annulus were equal to about 80% of the theoretical void.

The geology was interpreted from solid cuttings disgorged by the separation plant and correlated with results from previous exploratory drill holes and lab results. The separation plant solids showed the relative amounts of sand, silt, and clay during that portion of the drive. The largest percentage of material consisted of clay balls 120mm to 50mm in diameter. When pulled apart, these balls showed the intact claystone structure. Towards the extraction pit, the material changed from predominantly grey/dark grey to a mottled tan/brown/grey with iron stains. This appeared to indicate moving from less weathered material into more weathered material. Small sand lenses lead to periods of greater production.

Conclusion

Microtunnelling was a cost effective, safe method to perform a wet lake tap into a fully operational reservoir. The slickensided swelling claystone displayed some poor behaviour, such as falling blocks on slickensides and significant convergence, in the 3.5m diameter modified horseshoe roadheader tunnel, but the microtunnelled 1.8m diameter circular tunnels up to 380m long were bored through the same strata without significant problems and with only moderate jacking pressures.

The new outlet tunnels at Standley Lake are now operational and should allow the reservoir to function as a reliable water storage facility for the next century. In 2005 the Standley Lake Rehabilitation Project was awarded the Engineering Excellence Award (water resource category) by the American Council of Engineering Companies-Colorado.

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