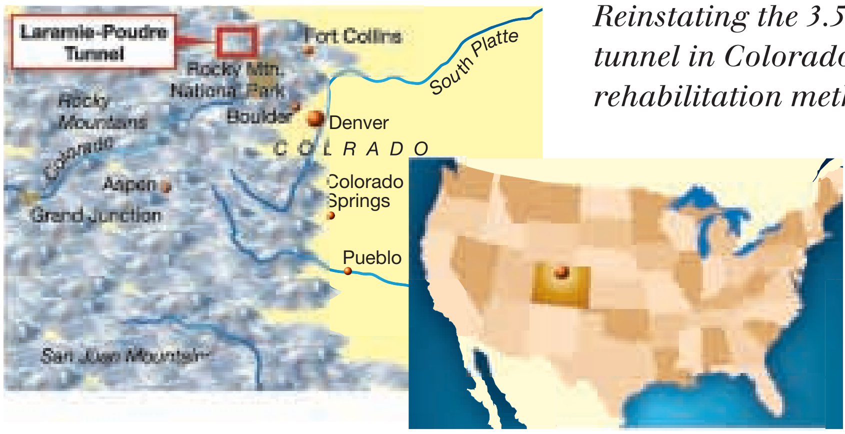
Rehabilitation in the Rocky Mountains



Reinstating the 3.5km long Laramie-Poudre irrigation tunnel in Colorado, US, involved a wide variety of rehabilitation methods. Restricted access to the site and tunnel works combined with strict environmental constraints also created major logistical challenges. Dr Christoph Goss, resident engineer for Rocky Mountain Consultants, describes the history of the tunnel and the recent works carried out

Below: Fig 1 - Location of the Laramie-Poudre irrigation tunnel in the Rocky Mountains, near to the northern edge of Colorado's Front Range in the US

The 3.5km long Laramie-Poudre Tunnel is located about 87km northwest of Fort Collins in northern Colorado, 72km up the narrow Poudre Canyon. The tunnel was driven from 1909 to 1911 at the narrowest point between the Laramie River in the west and the Cache La Poudre River in the east. The tunnel provides valuable irrigation water for agricultural, domestic, and industrial uses along Colorado's northern Front Range. In May 2000, the centre of the tunnel collapsed, flooding the upstream area and slowing the water to the Poudre River to a trickle.

Tunnel History

Construction work on the tunnel started on Christmas Day, 1909. On the east side, a large camp was built. It had an office, black smith, bunk house, mess hall, shop, hospital and power plant (Case 1995). To provide the site with power and compressed air, a dam was built 3km upstream, at Poudre Falls. Water was piped to the site in a wood pipeline and used to run a generator and compressor. On the west side, a smaller camp was built and power poles were run over from the east side.

Below: Mining out the last of the caved rubble in the cavern

On the east side, the tunnel was driven with a rough rectangular cross section 3m wide and 2.4m tall. Leyner No. 7 water drills were initially used, but the hard ground required the development of a more robust drill, which later became the Leyner No. 8 (Brunton 1911). For explosives, a blasting gelatin having 60% the strength of pure nitroglycerine was used for most of the drive. To aid mucking, steel plates were placed on the invert in front of the face. These provided a surface from which to shovel. Mules were then used to haul the muck cars.

On the west side, tunnelling proved to be more challenging, mostly because it required mining downgrade (1.7%). To avoid a massive flood from the Laramie River, a temporary portal was made 20m above the eventual inlet. This kept the tunnel safe, but the steep decline of 25% (Brunton, 1911) to the tunnel alignment created a serious muck hauling problem. While the tunnel kept clear of the river, groundwater percolating through fissures collected at the face and made work difficult. In October 1910, when advance rates in the east proved to be good enough to make the schedule, work on the west side was stopped.

The tunnel was completed on July 27, 1911. However, court battles between the states of Colorado and Wyoming over water rights prevented operation until 1914 (Case 1995). Since then the tunnel has run water every year, but at a court mandated maximum of 9.9m^3/s instead of the original design of 22.7m^3/s. Sections of the tunnel were rehabilitated periodically with major operations in the 1940s and 1970s.

Geology

The tunnel runs through a massive complex of Precambrian granites and gneisses, part of the Front Range of the Rocky Mountains. Locally, nodules and seams of strongly altered biotite schist are encountered. The strong granites and gneisses provide excellent ground conditions, allowing over 80% of the tunnel to remain unsupported. However, areas with soft, sand like biotite invariably require support.

Two main joint sets are found throughout the tunnel.

The first is near vertical and perpendicular to the tunnel axis. Where encountered individually, these joints just exhibit local overbreak. Where several joints are grouped together, short sections of support are required. The second joint set is almost parallel to the tunnel and at a shallow angle. In numerous places a joint can be seen slowly coming up from below springline, defiantly making its way to the crown. Full support, often for more than 40m, is required where the joint moves across the crown. Locally, the joints are healed with calcium carbonate. Areas where the two joint sets met typically had very high crowns and required significant support. The caved section featured both joint sets with close spacing, along with biotite schist pockets.

Investigation

Rocky Mountain Consultants Inc. was contacted by the Tunnel Water Company in the summer of 2000 to investigate the collapse, recommend a solution, develop specifications and provide construction oversight. Engineers and geologists examined both sides of the tunnel from the portals to the caved area. Near the centre, on the west side, a timbered section gave way to a nearly vertical face of collapsed rock. On the east side, debris from the collapse was visible several hundred metres downstream. As one approached the caved area, the debris built up like a ramp until the tunnel became impassable.

The accessible areas of the tunnel revealed almost every support type known in tunnelling. The most common was square timber sets with rock back packing. In some areas the timbers were edge to edge, making a rectangular wooden flume. In other areas timbers had 5-15cm gaps between them. Some of the timbers appeared to be from the original construction, while others were certainly put in later. Another common support type was the concrete arch. The arches appeared to have been formed around existing, probably failing, timbers. Reinforcing steel was found exposed in the concrete in some instances. In two areas liner plate with concrete backfill provided support.

Above: Steel pipe being expanded inside the timbered section. Note the grout hoses reaching above the timbers

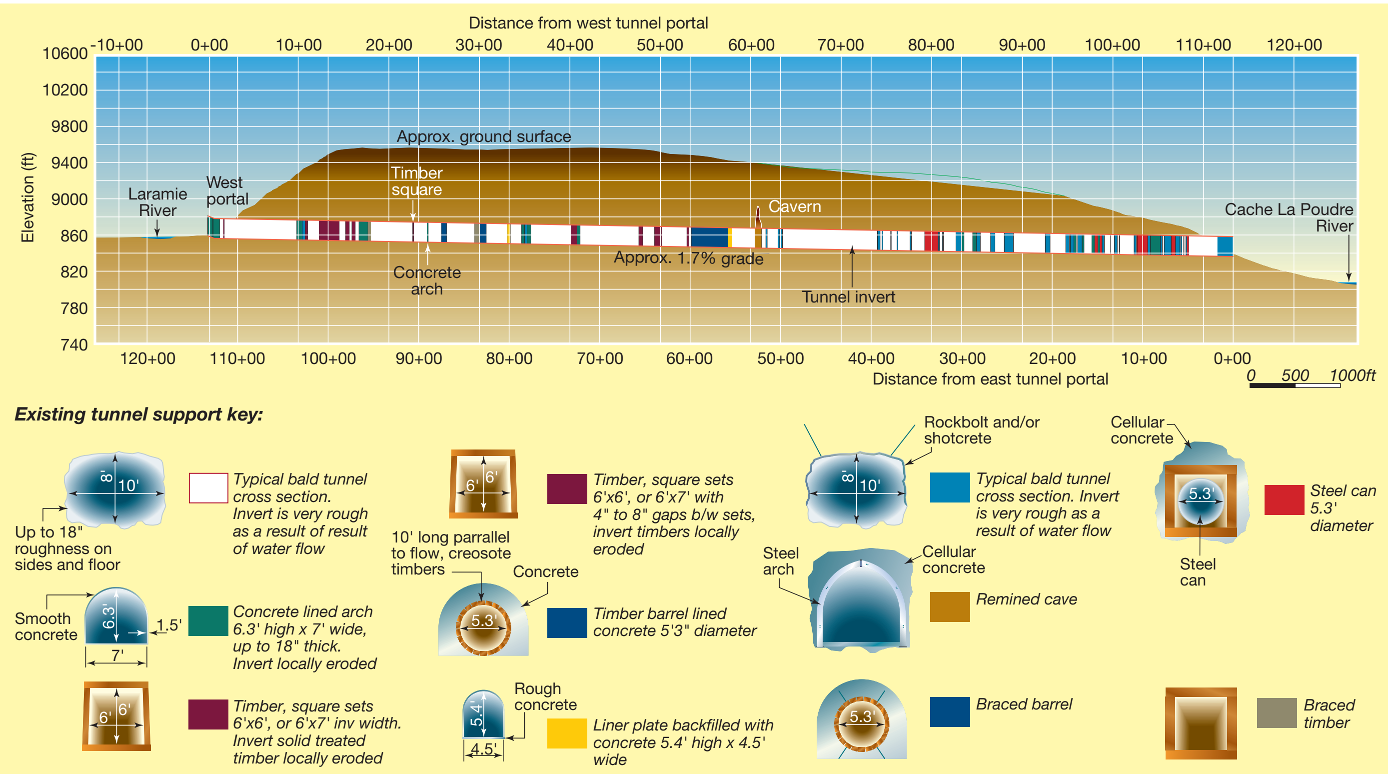
These areas (1.2m by 1.4m) proved to be restrictive to both the engineers and the water. Calculations showed that when the tunnel was running at maximum capacity, the liner plate sections had pressurised flow. This was seen in the field where the upstream side of each section had rubble piled up and the downstream side had holes, eroded in the invert, more than 1m deep, 10m long and as wide as the tunnel.

The most unusual support was a timber "barrel". 3m long timbers were laid end-to-end, parallel to the flow, and arranged in a circle like the staves of a barrel. Behind the timber barrel was cast in place concrete. The ends of the barrel sections had attractive transition areas made of stones cast within the concrete.

Design

Designing the rehabilitation was the next major challenge. To be successful, the following criteria had to be met:

- Clear the blockage;
- Support potentially weak areas;



Below: Fig 2 - Cross section of the Laramie-Poudre irrigation tunnel, showing th e various types of support at the completion of Phase 2

Above: View of the face while mining through the caved area. The timber set is clearly visible within the muck

- Keep the tunnel capable of flowing its legal volume of 9.9m^3 per second;
- Have the tunnel active for the 2001 irrigation season;
- Keep total costs below US$4M.

To achieve these goals, the project was split into three phases. Phase one consisted of re-mining through the caved section, supporting areas with failing supports and making permanent repairs to areas in the middle of the tunnel. Phase two consisted of placing permanent support in the entire eastern half of the tunnel. Since access to the east side of the tunnel would be difficult in the future, attention was focused on repairing that side. Phase three, which is scheduled for future work, will consist of replacing interim supports on the west side with permanent structures. Phase three would also likely include a new intake structure on the west side.

Mobilisation

When Robinson Construction Inc (RCI), of Sumner, Washington, mobilised on site in November of 2000, they had to deal not just with a challenging tunnel repair, but also with major logistical obstacles. The tunnel location, 72km up a narrow canyon and 87km away from the nearest city, made equipment procurement and servicing more difficult and time consuming.

The actual site access road was a four wheel drive/hiking trail that had been widened by a small amount. The road size and eventual tunnel restrictions severely limited the size of equipment that could be used. The remote location also yielded very limited housing for the crews.

The cave-in

The critical task in the tunnel was to clear and support the caved-in section. The task was greatly complicated by the size restrictions enroute to the caved area. The narrow timber sets allowed only the smallest equipment through. All mucking was accomplished with Eimco 12B and 22B pneumatic overshot muckers loading 2m^3 cars, invoking many fond memories of mining in the 1950s. The muckers, locomotives, and muck cars were provided by Mining Equipment Inc.

As the face slowly advanced, W6x25 arched steel sets from American Commercial Inc. were stood every 1.2m for support. Heavy ship channel was used as crown bars to provide a canopy ahead of the face. The muck was a mixture of sand, clay, gravel and boulders ranging in size from a hat to a large bus. During the advance, the old timber sets appeared in the face. They leaned a bit to the left, but were otherwise intact within the field of muck.

When the crews broke through on March 6, 2001, they looked back on an 18m long, 875m^3 cave.

Above the tunnel, the cave reached up 15m, but to the north the cave reached at least 24m before pinching out in the darkness.

The cave was too large to be filled, given the budget, equipment size and time constraints. Hence, a 2.5m thick cushion of cellular concrete grout was pumped above the fully lagged steel sets to absorb the impact of any future rockfall. The grout mixing equipment was a custom built ChemGrout CG3L6 supplied by Surecrete, Inc, while Pacific International Grout provided the foaming agent, mixing equipment, and on-site training.

Timbered Sections

The same type of timber sets that had failed in the cave had to be rehabilitated in other areas to assure a long lifespan for the tunnel. Some of the shorter sections in relatively good ground were removed and replaced by 2m long grouted Williams rockbolts, mine straps and shotcrete. The shotcrete was a dry mix applied with a Aliva 246.2 pump.

The longer timbered sections had to be repaired in place with an expandable steel pipe, placed inside the sets and grouted into place. The expandable "squash pipe" was an innovative value engineering proposal by RCI. It allowed the pipe to fit through tunnel constrictions instead of having to locally remove support and re-mine. The pipe was made of 1cm thick steel that was split longitudinally rolled together so that the ends overlapped. This compressed pipe was able to navigate tight spots within the tunnel while being moved into place with the locomotive. Once the pipe was in place, the overlapping joints were expanded to 1.6m, filling the inside of the timbers. After all the joints were welded, the ends were sealed with shotcrete bulkheads. Next, cellular concrete grout was pumped though grout ports in the upper haunches of the pipe. The grout filled both the annular space between the pipe and timber as well as the voids in the crown. 126m of tunnel was repaired in this manner.

Other Repairs

During the last 90 years, various sections of the tunnel had been repaired with a cast in place concrete arch. In most sections this appeared to be over existing timber sets. Most of the concrete arches had visible voids and punky areas where the concrete had decayed and now showed the remains of corroded rebar. These concrete arched sections were repaired in three steps. First, steel c-channel arches were bolted into place on 1.2m centres. Next the steel arches and concrete (including the invert) were covered with 8cm of shotcrete. Finally the voids behind the concrete were filled with cellular concrete grout.

Most of the remainder of the tunnel was in good ground and required no further support. Blocky areas were locally bolted. The more sheared areas were supported with a combination of rockbolts, mine straps, and shotcrete.

Success

Water flowed on May 16, 2001. Much of the credit for successfully completing the Laramie-Poudre Tunnel Rehabilitation goes to close cooperation between all parties. The contract, with most items in per unit quantities, assured simple and fair cost adjustments as the scope of work was modified in various areas. In closing, the cooperation, creativity, and skill of everyone on the project allowed the design challenges to be met, a feat that everyone can be proud of. T&T

Acknowledgements
I would like to thank Mr Fred Walker and the Tunnel Water Company for providing most of the historical documentation of the tunnel and allowing this story to be printed. I also thank Roy Spitzer of RMC for his editing and advice on this article. Finally I wish to thank Bill Austell, Bob Ward, John Dempsey, Bill Quick and others on the RCI team for their hard work and dedication to this project.

REFERENCES

Brunton, David W. Notes on the Laramie Tunnel. American Institute of Mining Engineers Transactions Vol. XLIII. 1911. p99-118.
Case, Stanley R. The Poudre: A Photo History. Published by Stanley R. Case, Bellvue CO. 1995. p252-266.