1.0 INTRODUCTION

The paper describes the inlet works for the 9 MW Tyson Creek Hydroelectric Project. The facility is located about 40 km north of Sechelt on the west coast of British Columbia (Figure 1). The reservoir is a natural lake with an active storage of 1.2 million cubic meters, and the total head of 874 m makes Tyson Creek the highest head run-of-river project in North America. The inlet works comprise a 455 m long, 3.5 m diameter pressure tunnel driven by drill and blast methods in very strong granite, with a 10 m long concrete tunnel plug constructed at the lower end of the tunnel. The pressure tunnel is connected to the lake with a lake tap located at a depth of 40 m below the maximum lake elevation. A benefit of this arrangement is that the intake structures are entirely underground with zero surface exposure.

Bathymetry and an ROV (remotely operated mini submarine) were used to locate the break out of the tunnel into the lake bed. The components of the lake tap include a rock trap, diamond drill holes to the surface for the blasting lines, pump controls, and water level gauges, as well as air pressure venin. Also described are procedures to grout, support and blast the final tunnel rounds, and to protect the tunnel plug from shock waves generated by the final blast.

The success of the lake tap breakout, with complete protection of the inlet infrastructure, required the implementation of a carefully planned sequence of tasks. The overall approach used for the lake tap closely followed the procedures developed in Norway on many previous similar projects.

2.0 INTAKE CONFIGURATION

The configuration of the pressure tunnel was governed by the requirement to locate the intake at as low an elevation as possible to maximize the live storage of the reservoir, and the only feasible location for the tunnel portal. The conditions at the portal comprised a steep rock face in strong granite where the portal cut could be made with minimal rock support, an adequate lay down area and reasonable ease of construction for the access road (Figure 2). The elevation of the portal is 956 m.

2.1 Pressure Tunnel

When the location and elevation of the lake tap were finalized (see Section 3, Investigation below), the tunnel was laid out in three straight segments with two 45 degree bends, a total length of 455 m and at a uniform upward grade of 12 per cent. The 12 per cent grade was close to the maximum that could be accommodated by rubber tired mining equipment, and would also provide good drainage at the face.
The tunnel was driven by drill and blast methods with a 3.5 m square cross section to suit a sub-horizontal joint set that occurred frequently in the roof. The tunnel dimensions were selected to suit the mining equipment comprising a 2.2 cu. m scoop tram and a single boom drill jumbo. The tunnel was driven entirely in very strong, massive granite and rock support was limited to about 20 fully cement grouted, 1.5 m long rock bolts mainly located at intersections with the re-muck bays. No shotcrete was required.

2.2 Tunnel Plug and Rock Traps

The intake structure comprised a 10 m long concrete tunnel plug to control the flow of water from the tunnel into the steel penstock. The plug was located towards the lower end of the tunnel to minimize the length of steel penstock. The plug was also positioned so that the minimum rock cover of 60 m provided the required confinement to withstand the maximum head of 70 m of water. Construction of the plug involved using careful blasting to strip out the tunnel to a height of 6.5 m and to create a wedge-shaped opening. The combination of the shape of the opening and the irregular rock surface provided the required shear strength for the concrete plug to resist the water force on the upstream face. Two consolidation grouting curtains were injected near the upstream face of the plug. Contact grouting was undertaken, once the concrete had been cast and cured, from ports extending out from the DN1500 penstock inlet piece that traverses the plug.

Another component of the headworks is a 5 m wide by 9 m long pump chamber located just downstream of the tunnel plug. This facility pumps the minimum instream flow release back to the natural lake outlet in order to meet fisheries requirements. This chamber is supported with pattern bolts on 2 m centres and galvanized wire mesh.

The tunnel incorporates two rock traps. The lower trap is just upstream of the tunnel plug and is 30 m long with the base at a depth of 4.5 m below the level of the tunnel floor; the trap is designed to contain falls from the tunnel roof that may be washed down the tunnel during power generation operations. The upper trap is just downstream of the Lake tap and is designed to contain the rock generated by the final blast (see Section 4 below).
3.0 LAKE TAP INVESTIGATION

The focus of the investigation to locate the lake tap was to find a steep face in sound rock free of lake sediments, boulders and logs. This would allow a clean cut to be made into the lake bed with no risk of debris being drawn into the tunnel.

The first step in the investigation was to examine the bathymetry that had been collected to determine the volume of the lake reservoir. Although this data was on a course grid of about 10 m, it indicated the presence of a steep face in an area that would produce a suitable tunnel alignment. A remotely operated mini submarine (ROV) was then used to inspect the lake bed using high intensity lights and a video camera that transmitted images to a display unit on the shore. The ROV provided a continuous display of its depth, heading and speed, but it was necessary to reference its position by installing three, precisely located weighted cables spaced at 20 m along the lake shore, with markers on 10 m intervals, on the lake bed. The ROV survey clearly identified the mudline at the base of a steep, clean rock face that extended to the surface. The video images were sufficiently clear that it was possible to identify the geological structure in the face and to correlate this with mapping of the cliff face above the water level.

After locating the rock face, a further set of detailed bathymetry measurements were made, with the intention of fixing the position and angle of the face and tie this into the site survey. However, it proved difficult to interpret the data from the near vertical rock face, and it was found that the ROV video provided the most useful data on lake bed conditions.
An earlier ROV investigation of the lake bed closer to the outlet of the lake found continuous sediments on the lake bed with no rock exposures; this location was not suitable for the lake tap.

The geological investigation comprised mapping rock outcrops along the tunnel alignment and in the lake bed, and drilling a 427 m long, NQTT diamond core hole from the portal area to the lake. The hole was drilled along the shortest tunnel alignment and before the alignment was changed to suit the revised lake tap location. Although it was intended that the drill hole would be at the same grade as the tunnel, the actual grade was horizontal and the end of the hole was about 40 m below the lake bed. The core showed the rock to be fresh, very strong, massive granite with no areas of seepage except for the last 40 m that was somewhat fractured with RQD values in the range of 40 to 80 per cent. Water flow at 400 l/m, at the pressure of the water level in the lake, occurred over the last 25 m of the hole.

Based on these investigation results, the elevation of the floor of the tunnel at the lake tap was finalized at 1008 m and the alignment was finalized as shown on Figures 2 and 3.

4.0 LAKE TAP PROCEDURE

The configuration of the lake tap is shown in Figure 4. The advantages of maintaining the 12 per cent grade of the tunnel were that the elevation of the inlet was just above the mud line in the lake bed, and that access to the face for drilling and mucking was facilitated. However, the disadvantage was that ejection of the rock in the final blast into the rock trap would have to depend on the water pressure acting on the rock face in the lakebed, with no assistance from gravity.
The sequence of activities in the lake tap was as follows:

- When the tunnel was at a nominal distance of 21 m from the lake bed, a single probe hole was drilled to check the distance to the lake bed.
- The tunnel was then driven in 2 m long advances to a distance of 8 m from the lake bed. After each blast, two arrays of three, 1.5 m long rock bolts were installed in the roof. Then four probe holes, one in each corner, were drilled to further confirm the thickness of the remaining rock. The probe holes were sealed with a mechanical plug and then grouted with cement.
- A 100 mm thick layer of steel fibre reinforced shotcrete was then applied to the face, and to the walls for a distance of 8 m along the tunnel. At this point, the tunnel was in sound rock with minimal seepage and no instability of the roof or walls; it was not necessary to grout the rock ahead of the face.
- The rock trap was drilled and blasted, but the muck was left in place to allow access to the face for the final blasts.
- The tunnel was left in this condition for a six month period from December 2008 to May 2009 because heavy snow accumulation at this elevation prevented access during the winter.
- When work re-commenced in 2009, the tunnel was advanced with rounds 2 m and 1 m long. Arrays of rock bolts were installed in the roof on 1 m centres as the tunnel advanced.
- A total of 12 probe holes were drilled into the lake to confirm the precise shape and thickness of the rock pillar (Figure 5).
- The tunnel was then advanced by a further 1 m, at which time the thickness of the pillar varied from a minimum of 3.4 m to a maximum of 4.8 m in one corner.
- An array of spiles, 25 mm diameter fully cement grouted galvanized steel bars, were installed in the roof and walls of the tunnel as shown in Figure 4. This reinforcement was required to maintain the stability of the rock above and prevent rock falls in the lake bed from blocking the opening into the lake.
- Two HQ diamond core holes were drilled from the tunnel just downstream of the upper rock trap to the ground surface. The function of the holes was first to allow the air trapped in the upper part of the tunnel to vent to the atmosphere when the final blast was detonated. Also, the blast lead wires, the power cable for the submersible pump in the upper rock trap and the cables for the water level gauges were run up the holes from the tunnel to the surface.

At this time the face was stable and seepage was limited to dampness of the rock and dripping on some joints over the final 8 m length approximately of the tunnel.

5.0 BLASTING OF LAKE TAP

The two essential requirements of the final blast were as follows. First, the final blast had to shatter the remaining plug of rock in the lake bed and ensure that the debris was ejected by the water pressure, acting on the lake bed, along the horizontal tunnel into the rock trap. Second, the headworks infrastructure in the lower end of the tunnel had to be protected from the shock wave generated by the blast and the in rush of rock and water into the tunnel.

Figure 5 shows the layout of the blast holes in the final round. Drilling the final round, mucking the rock traps, machine cleaning the tunnel floor and removing all tunnelling equipment was carried out before the concrete tunnel plug was started. Construction of the plug and the intake infrastructure took about three months to complete. During this time, the final tunnel face was inspected regularly but there was no significant increase in the seepage rate despite the 3 m by 3 m face being perforated with 65 drill holes.

The blast holes were drilled to within 500 mm of the lake bed and were loaded to a 150 mm collar with 32 mm diameter Dyno Unimax explosive and double primed. The collars of the blast holes were sealed with a plastic sleeve to retain the explosive in the holes.

The procedure to protect the head works from the shock wave of the blast was to fill the tunnel with water to the level of the concrete dam formed by the base of the trash rack to create an air cushion in the upstream end of the tunnel (Figure 4). The water was pumped into the tunnel
through the tunnel plug and the air ahead of the water was vented to the atmosphere through the two diamond core holes drilled from the tunnel to the ground surface. The water level in the tunnel was monitored by two water level gauges mounted on the concrete base of the trash rack.

It was also necessary to keep the upper rock trap dry during the blast so there would be little resistance to the blasted rock falling into the trap. A submersible pump was installed in the rock trap, for which the power cable ran down one of the HQ diamond drill holes.

Once construction of the concrete tunnel plug was complete, the final round of blast holes was loaded, the tunnel was filled with water to the level of the trash rack and the final blast was detonated. The day after the blast, the ROV was returned to the site to inspect the lake tap. Although visibility was limited by glacial rock flour in the water, it was evident that a clean break in the lake bed had been achieved with little instability of the roof or lake bed, and that most of the rock had been ejected into the rock trap.

6.0 CONCLUSIONS

The success of the Tyson Creek lake tap was due in part to the excellent rock throughout the length of the pressure tunnel. That is, ground support was limited to spot rock bolts with no need for shotcrete. Furthermore, the low permeability of the rock meant that no grouting was required ahead of the face and the minimal seepage rate made for favourable working conditions.

The other aspect of the work that contributed to the success was the application of experience on similar projects in Norway, and carrying out a detailed plan of work tasks in which no short cuts were taken.

![Figure 5 Layout of Blast Holes in Lake Tap](image)
7.0 ACKNOWLEDGEMENTS

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