Seven Mile Dam: Dam Stability Improvements

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Summary

The stability of the Seven Mile Dam was improved using corrosion protected, load-testable, restressable 92-strand anchors. This paper discusses the design, construction and installation of these 57 post-tensioned anchors, which currently have the largest capacity of any such anchors in the world.

Background

BC Hydro's Seven Mile Dam and Powerplant is located on the Pend d'Oreille River near Trail in southeastern British Columbia, approximately 6 miles upstream from its confluence with the Columbia River (Figure 1).

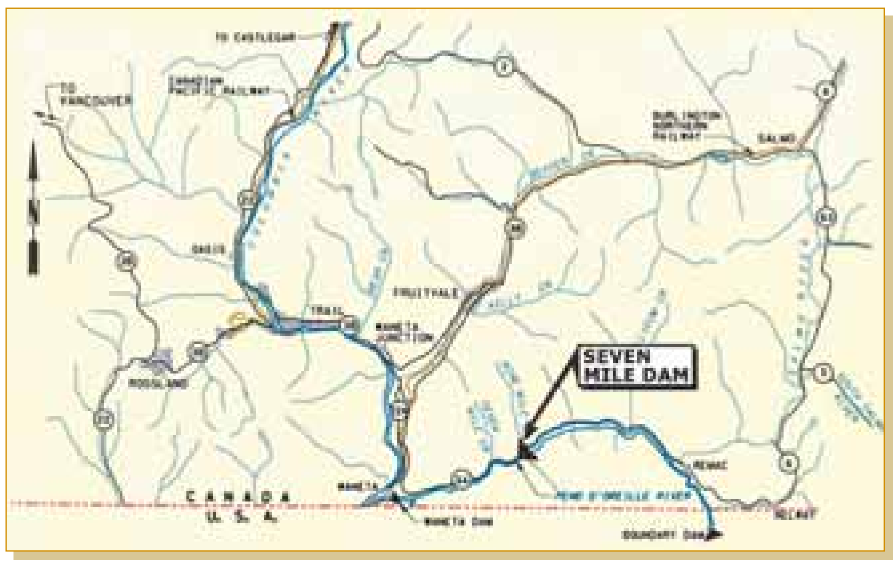

Figure 1

The Seven Mile Dam is a 347 m (1138 ft) long concrete gravity structure with a maximum height of 80 m (262.5 ft). From right to left the dam consists of a 107 m (350 ft) long north gravity section, a 102 m (336 ft) long power intake section, a 98 m (322 ft) long five-bay spillway section and a 40 m (130 ft) long south gravity section. With a top-of-dam elevation of 530 m (1740 ft) and a maximum normal reservoir level of 527 m (1730 ft) above a centreline-of-distributor elevation of 459 m (1506 ft), the powerplant has just over 61 m (200 ft) of head, and generates over 800 MW. The power-intake section has four operating gates and four embedded 8 m (25 ft) diameter steel penstocks. These lead to a concrete powerhouse located immediately downstream of the dam (Figure 2).

The dam and powerhouse were completed in 1980 and operated with a maximum reservoir elevation of 523 m (1715 ft) for eight years. In 1988 an agreement was reached which permitted the reservoir to be raised to maximum elevation of 527 m (1730 ft), and hence extend into the United States. Due to the raising of the reservoir and changes to dam performance criteria, it became necessary to upgrade the dam. This was accomplished by the installation of anchors and improvements to the spillway gates.

These safety improvements help the dam meet current dam safety requirements. A contract for the supply and installation of the post-tensioned anchors was awarded to the low bidder Peter Kiewit Sons Co. in July 2002 for approximately $13 million. The supply of the anchors themselves was sub-contracted to Con-Tech Systems Ltd. BC Hydro Engineering Ltd. prepared the contract, completed the design, and administered the construction work.

Anchoring

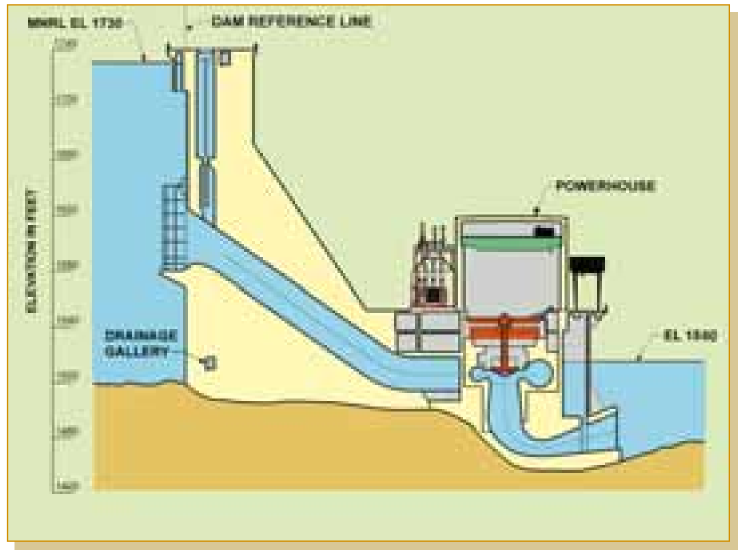

Figure 2, **Power Intake (elevation)**

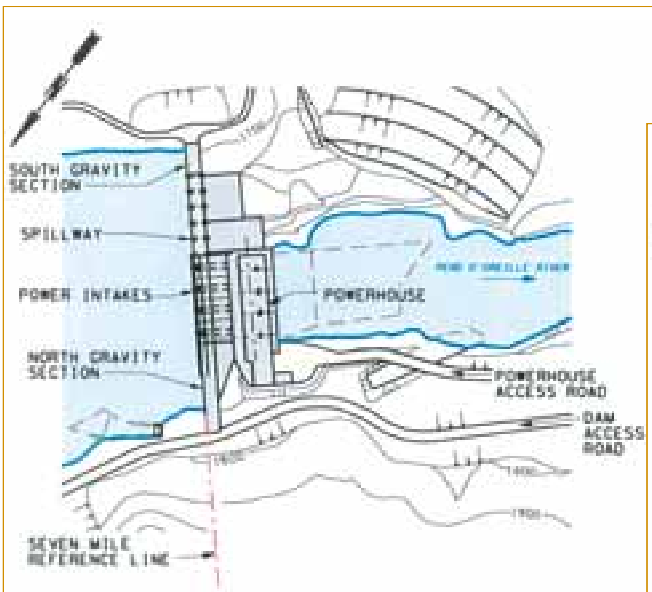

Figure 2, **Plan**

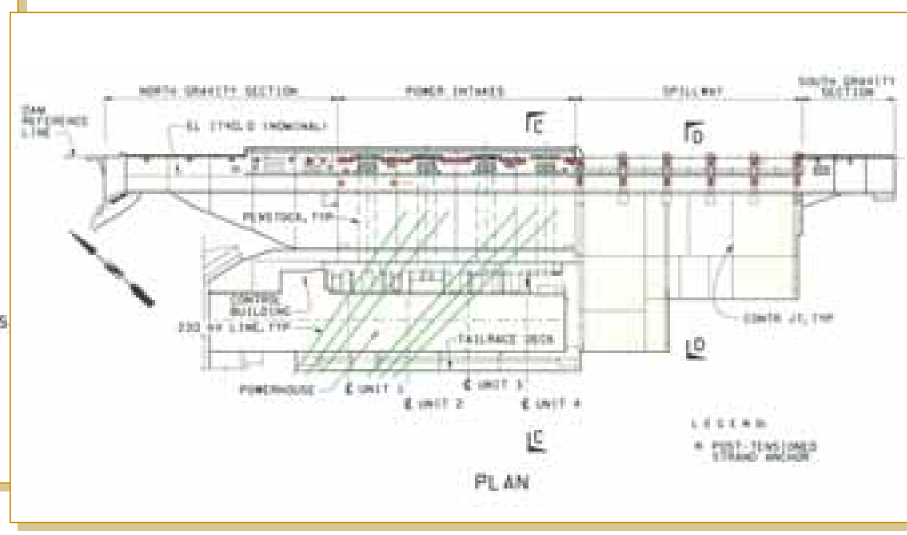

Figure 3, **Anchor Locations**

Anchor Layout

The post-tensioned anchors were installed from the dam deck in a vertical orientation near the upstream face in order to provide the maximum effectiveness. The locations of the anchors are shown in Figure 3 and the orientation in Figure 4.

Anchor Hole Drilling

The drill holes for the anchors were 400 mm (15.75 inches) in diameter, up to 126 m (415 ft) in length and required an alignment tolerance of 1 in 300. The alignment of the holes was surveyed at 6 m (20 foot) intervals using a digital magnetic inclinometer which provided azimuth and inclination

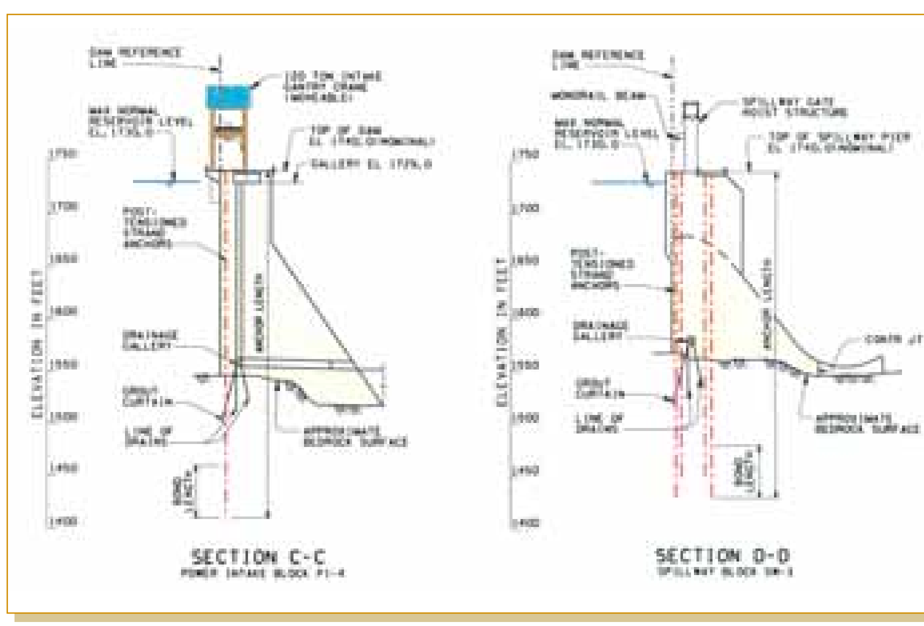

Figure 4, **Anchor Orientation**

to a hand-held recorder. A section of stainless steel drill string located above the drill bit was used to facilitate measurement of the azimuth. An average alignment tolerance of 1 in 800 was achieved with a range of 1 in 300 to 1 in 5000.

For the drilling of the holes, a down the hole hammer rotary percussion drill with button head bit was used as specified in the contract. A 6 m (20 foot) long stabilizer and heavy walled drill string was used to achieve the required alignment tolerance (Figure 5).

Anchor Hole Drilling

After the hole was drilled to its full depth, water pressure testing was performed and the water in the hole was evacuated to permit an inspection using BC Hydro's drill hole video camera. Based on the results of the water testing and drill hole camera inspection, the extent of consolidation grouting

Figure 5, **Anchor Hole Drilling**

was determined and the hole was consolidation grouted, re-drilled and re-tested. A total of 8,534 m (28,000 ft) of drilling and re-drilling was performed.

Prior to installation of the anchors, a water-tight HDPE outer sheathing was installed to provide an additional layer of corrosion protection in addition to three external grout tubes. The outer sheathing consisted of an 18 m (60 ft) long 254 mm (10 inch) nominal diameter corrugated section (3 mm or 0.12 inch thick) over the anchor bond length and a 305 mm (12 inch) nominal diameter smooth wall section (10 mm or 0.4 inch thick) over the free-stressing length.

During the anchoring work, an Enhanced Surveillance and Response Plan was implemented, with continuous staffing and increased monitoring of the dam instrumentation to provide additional information regarding the foundation conditions. For each anchor hole, instrumentation which could be influenced by the construction activities, such as drilling, water testing and grouting of holes, were identified. The reading frequency for these instruments was increased and monitored on a real time basis. In addition, instrumentation and drain holes in the drainage gallery were continuously flushed in the immediate vicinity of anchor holes that were being grouted.

Anchor Assembly and Installation

The required anchor force and limited amount of space available on the top of the dam necessitated the use of large capacity anchors. The final anchor design incorporated 92 - 15 mm (0.6 inch) diameter strands with a guaranteed ultimate tensile strength (GUTS) of 23,972 kN (5,390 kips).

The high strength strands were encapsulated in wax corrosion protection which was applied to the strand after the strand was "opened" to ensure complete encapsulation of each of the seven wires. The coated strand was then sheathed with a 2 mm (0.07 inch) nominal thickness extruded HDPE sheathing. White sheathing was chosen to reduce heat build-up and to facilitate inspection and detection of any sheathing damage. The HDPE sheathing was extruded over the waxed strand in one continuous length to ensure complete encapsulation and maintain corrosion protection of the strand until the anchor could be assembled. The wax was turned on and off during the extrusion process to avoid contamination of the bond length and provide the lengths of bare strand for the bond length and jacking length. The anchor strand was supplied to the site in 2621 m (8600 ft) reels, each custom made for a particular anchor. Over 457,200 m (1,500,000 ft) of strand was used in the fabrication of the 57 anchors. Anchor details are shown on Figure 6.

Anchors were fabricated inside a tent that provided environmental protection for anchors during assembly. Anchors were fabricated as required, although the assembly beds allowed for some storage of anchors awaiting installation.

The anchors were transported from the assembly area to the dam (a 1.6 km or 1 mile trip) on a series of bogies and installed into the outer sheathing in the hole using a roller type installation frame (Figure 7). Internal grout tubes were added as the anchor was installed and final cleaning and quality control inspections were performed during the installation.

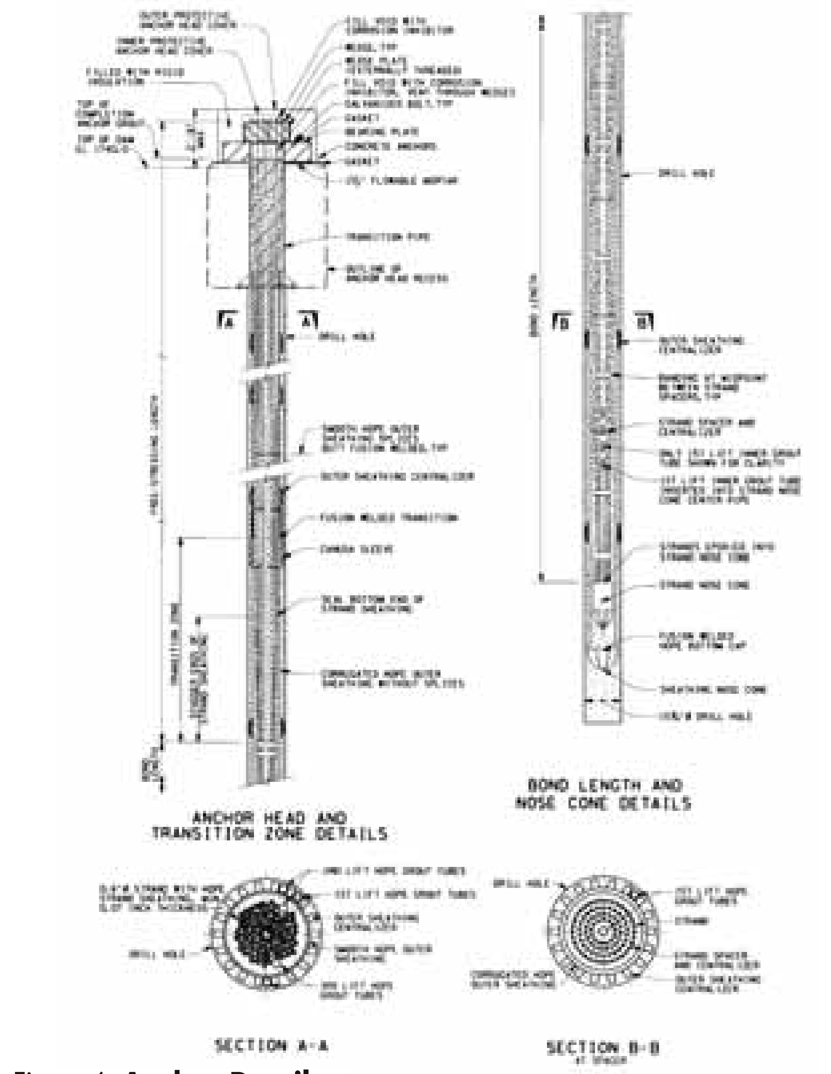

Figure 6, **Anchor Details**

Figure 7, **Anchor Installation**

Figure 7, **Anchor Transport**

Once installed, the anchors were suspended on a frame until they could be grouted. Grouting was performed using Type 10 cement in one stage with three lifts of grout tubes on both the inside and outside of the outer sheathing. Flyash was added (20 per cent of cementitious materials by weight) in the bond length to assist migration of the grout into the bare strand in the bond length.

Anchor Stressing

Anchors were stressed generally following the Post Tensioning Institute guidelines using jacking systems specifically designed and fabricated for the project. The anchors were proof loaded to 80 per cent GUTS and locked off at 72 per cent GUTS with a typical transfer loss of about 2 per cent of GUTS.

The project required that the stressing jack be able to fully stress and de-stress the anchors without re-gripping on the strands. Anchor elongation at the proof load of 19,177 kN (4,312 kips) (80 per cent GUTS) for the longest anchor was over 838 mm (33 inches), hence a 19,569 kN (4,400 kip) 36 inch stroke custom fabricated stressing jack complete with stressing chair and power pack was used to meet the contract requirements (Figure 8).

Figure 8, **Installation Jack System Stressing**

The stressing jack was fully calibrated at the University of California at Berkley.

Since the load in the anchors must be verified in the future in order to ensure the long term performance of the anchors, the wedge plates were externally threaded to allow for future load verification of the anchor. Load verification was carried out using a restressing system employing 4 - 5,026 kN (1,130 kip) jacks linked by a summing plate and attached to the wedge plate by a sleeve coupling. In addition, a 152 mm (6 inch) length of strand was provided above the wedge plate in order to allow for single strand restressing of the strands if required in the future.

Both the installation stressing jack and load-testing/restressing systems were supplied by Kiewit's anchor supplier, Con-Tech Systems Ltd. and designed/fabricated by Janox Fluid Power Ltd. The equipment performed well given their unique design and high load capacity requirements.

Once an anchor was stressed and locked-off, completion grouting was performed and the upper portion of the bearing plate and the interior of the wedge plate were filled with wax corrosion protection. An inner protective steel anchor-head cover was then installed over the wedge plate and filled with wax in order to protect it and the exposed strands. An outer protective steel anchor-head cover was then installed to provide protection from damage.

Conclusion

All of the post-tensioned anchors were successfully installed and stressed by November 2003. Four of the anchors installed early in the program were load-tested at the end of the program and found to have maintained their initial lock-off loads with negligible losses.

These 92-strand anchors have the largest capacity of any in the world, and as recognized by the Project Manager Peter Calder P. Eng., were fabricated, installed, stressed and tested with ease. This achievement, by Peter Kiewit Sons Co., Con-Tech Systems Ltd., Janox Fluid Power Ltd. and BC Hydro Engineering, is truly outstanding. ■