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Planning and Design of the Second Manapouri Tailrace Tunnel Project, NZ

M. D. Gillon
B.E., M.E., MIPENZ, Reg. Eng.
Hydraulic Structures Manager, Electricity Corporation of New Zealand, NZ
R. J. Essex
B.S., M.S., M.E, P.E., MASCE, MITA
Vice President and Project Manager, Woodward-Clyde, USA

Summary The Manapouri Power Station is a hydroelectric facility located on the South Island of New Zealand. Constructed in the 1960's, it includes an underground power station and a 9.8 km, 9.2 m diameter tailrace tunnel. The output of the power station is currently limited due to excessive head losses in the tailrace tunnel. To remedy this situation, the Electricity Corporation of New Zealand (ECNZ) intends to construct a second tailrace tunnel. ECNZ selected Woodward-Clyde and DesignPower to confirm the feasibility of the project and to prepare Tender Documents for construction. The Project will involve the construction of a 9.8 km, 10 m diameter, TBM-mined tunnel and appurtenant facilities. This paper summarises key planning and design issues addressed during the design, outlines innovative disputes avoidance provisions incorporated in the Contract, and overviews the Interactive Tender Process (ITP) to be implemented.

1. EXISTING FACILITIES

The Manapouri Power Project develops the hydropower potential of the portion of the Waiau River watershed located upstream of Lake Manapouri on the South Island of New Zealand (see Figure 1). Power is developed by diverting water from Lake Manapouri through a surface intake structure and directing it to an underground power station. The water is conveyed through seven vertical penstocks to seven 100 MW (nominal) turbine generators, which are located about 183 m below the level of Lake Manapouri in a rock cavern that measures 111 m long, 18 m wide, and 39 m high. Flow passes through the turbines, through a series of draft tubes and draft tube manifold, and then to the tailrace tunnel (Tunnel No. 1), through which the water is conveyed approximately 9.8 km to Deep Cove. Deep Cove connects to the Tasman Sea through Doubtful Sound.

Tunnel No. 1 is 8.9 m high by 9.1 m wide, and is concrete lined in a horseshoe shape. The tunnel grades downward from an invert elevation of approximately El -3 m at the power station to a low point of El -40 m about 2.2 km from the (downstream) outlet portal, and then grades upward at a 1.67% grade to the portal. The soffit of the outlet portal is at El 2.3 m.

The existing facilities were constructed between 1963 and 1969. Drill and blast methods were used to excavate the underground rock cavern, access tunnel, and tailrace tunnel. The rock encountered during construction was strong metamorphic rock, primarily gneiss, with lesser amounts of intrusive igneous rocks. Groundwater inflows to the tunnel during construction were significant, with measured point source flows as high as 91 l/s, and cumulative inflows measured at the portal of the tunnel as a high as 900 l/s. Separate, detailed records of construction were maintained by the Construction Manager and the Contractor. These records were a valuable contribution during the planning and design of the second tunnel.

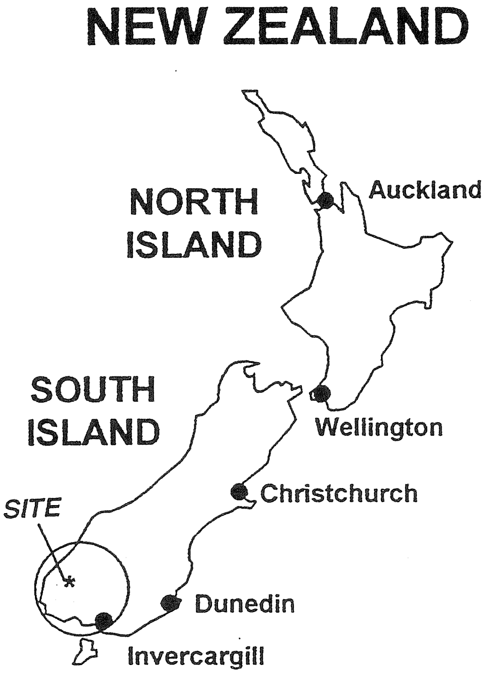

Figure 1. Project site location.

The Project has not been able to operate at its designed capacity because: (1) friction losses in the tailrace tunnel have been greater than anticipated; and (2) the lake level was not subsequently raised an additional 8.2 m, as was contemplated at the time of design.

2. PROPOSED FACILITIES

The new tailrace tunnel (Tunnel No. 2) will be aligned parallel to Tunnel No.1 in plan. The TBM-driven tunnel will have an excavated diameter of 10 m, will be excavated from its downstream portal, and will connect to existing facilities at the existing draft tube manifold.

In addition to Tunnel No. 2, the project includes headworks, outlet works, dewatering facilities, and tailrace channel improvements. The headworks facilities include: a headworks adit excavated from the existing power station access tunnel; a maintenance shaft connecting the headworks adit to the tailrace tunnel; a stop log shaft and structure; and a plug excavation which will connect new construction to the existing draft tube manifold. An isometric of the headworks facilities is shown on Figure 2. The outlet structure will consist of: a concrete structure that will facilitate a smooth hydraulic transition from Tunnel No. 2 to a new tailrace channel; a stop log structure that will seal off waters in Deep Cove from Tunnel No. 2 during inspection and maintenance periods; and an access bridge which will both facilitate installation of the stop logs and provide access to the Tunnel No. 1 portal. The dewatering facilities will consist of a dewatering adit which extends from a portal located to the south of the Tunnel No. 2 portal to the low point of Tunnel No. 2, a dewatering shaft that extends down to tailrace tunnel level, and several core holes that connect the dewatering shaft to Tunnel No. 2. Tailrace channel improvements will include a new channel connecting the outlet portal to the existing tailrace channel, and removal of obstructions that have caused hydraulic losses in the existing channel.

3. KEY PROJECT ISSUES

3.1 Anticipated Construction Conditions

The principal rock types through which Tunnel No. 2 will be excavated are Paleozoic gneiss with varying degrees of intrusion by pegmatites and other granitic rocks, gabbro and diorite, and to a lesser degree, mixed metasediments. The rock mass is characterised by large sections of good quality rock, with foliation and jointing, but with numerous faults and shears. Approximately 75% of the original drill and blast tunnel was supported with rock bolts, with about 25% supported with steel sets. However, the records indicate that many of the steel sets installed were not required, and never carried loads. The faults and shears encountered during the excavation of Tunnel No. 1 were recorded on as-built records. The fault zones or shears were found to vary in width and character, ranging from discrete, narrow discontinuities less than 0.3 m, to wider zones up to 25 m that contained highly fractured and shattered rock. Some reaches of Tunnel No.1, as long as 75 m, contained closely spaced faults and shears. These faults and shears were usually steeply dipping (greater than 60°) and crossed Tunnel No. 1 at angles ranging between 30° and 90°. Clay gouge was typically encountered as thin seams within the fault zones. Crushed zones, commonly associated with pegmatite, were encountered in a few of the more significant faults. Many of the fault and shear zones had parallel joints that were avenues for ground water inflows and weathering to tunnel depth.

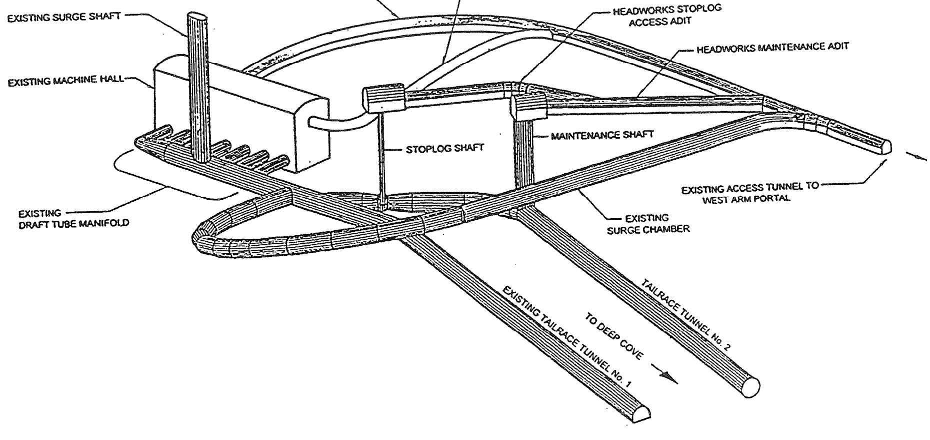

Figure 2. Existing and proposed headworks facilities.

During the excavation of Tunnel No. 1, many of these faults were the source of significant groundwater inflows that impacted the original construction. Flows encountered at the heading ranged up to 91 l/s, and flows measured at the portal ranged up to 910 l/s. These groundwater inflows were particularly problematic for the downgrade drive of the tunnel. The Contractor resorted to extensive formation grouting ahead of the tunnel to reduce these inflows to manageable levels.

Crushed and blocky and seamy zones required steel rib supports, and were associated with occasional blowouts at the heading. In the more competent injection complex rocks toward the power station end of the project, spalling conditions were experience on the sidewalls of the tunnel, indicating vertical overstress conditions.

The tailrace channel and related facilities at Deep Cove will be constructed in late Quaternary unconsolidated deposits and man placed fill. The materials are anticipated to be highly variable in size ranging from silts and clays to large boulders, highly permeable, horizontally stratified, and hydraulically connected to the operating tailrace channel located approximately 30 m to the north. Positive groundwater control measures will be required to protect portal area excavations, and the portal in general, from groundwater inflows through these permeable materials.

The rocks in the headworks area of the project will generally be more competent and less fractured than elsewhere along Tunnel No. 2, except for a narrow zone of joints that will intersect the pillar at the bifurcation of the new tunnel and existing draft tube manifold. This will require carefully controlled blasting.

3.2 Technical Action Team Meeting

A number of key environmental and technical issues impacted the layout of the new facilities. There was also an important scheduling issue that affected the manner in which the design was carried out. To meet internal schedule requirements, ECNZ had originally desired that confirmation of the design and preparation of the construction Drawings and Specifications be completed between November 1994 and June 1995. Woodward-Clyde pursued the design process under a "fast track" mode, which included a Technical Action Team (TAT) Meeting. The TAT brought together 28 key professionals that included Woodward-Clyde Team members, selected outside consultants, and ECNZ personnel. Prior to the meeting, Woodward-Clyde personnel reviewed the as-built geologic logs and reports from the original construction, and interviewed individuals who were directly involved during the construction. Informational packages were provided to participants in advance of the Meeting. Also, based on the information reviewed and conceptual engineering accomplished within the first several weeks of the design effort, a series of 125 "Key Questions" was developed. These key questions guided an intensive, 10-day programme of singular and concurrent workshop sessions. Key issues were discussed, the more critical criteria that would control the design were evaluated, and recommended layouts, configurations, and additional issues to be resolved were identified. As challenging as it was to control these intensive working sessions, all participants knew they had met the Meeting's objectives when answers to all Key Question had been developed. Key design issues addressed during the TAT Meeting and throughout the detailed design were:

- establishing the extensive list of design criteria that would govern the design, including geologic, hydrogeologic, geotechnical, hydraulic, structural, operational, maintenance, environmental, and constructability considerations;
- the vertical profile of Tunnel No. 2, which needed: to maximise the length of up-grade construction to facilitate drainage of inflows away from the heading; and to accommodate upsurge and downsurge conditions during fluctuations of the power station when operating singularly or in combination with Tunnel No. 1;
- characterisation of the ground conditions to be encountered during tunnel excavation, through analysis of project construction records, interviews with personnel involved with the original construction, additional geologic mapping, and the results of limited additional subsurface drilling and laboratory investigations;
- evaluation of tunnel stabilisation measures that will be appropriate to the ground conditions, and compatible with TBM excavation;
- evaluations of the need for a final lining in the tunnel, ranging from an unlined tunnel to a final lining of either shotcrete or cast-in place concrete;
- given the variable rock mass quality and high groundwater inflows anticipated, the feasibility of mining the tailrace tunnel with a 10 m diameter TBM;

- provisions for controlling high groundwater inflows during tunnelling, including the drilling of probe holes to assess ground and groundwater conditions ahead of the excavation, the drilling of drain holes ahead of the TBM, and the ability to carry out formation grouting ahead of the TBM;

- the relative distance, and potential for hydraulic connection, between the new and existing tunnels;

- the layout and design of a dewatering facility that would permit Tunnel No. 2 to be dewatered for inspection and maintenance purposes during its operating lifetime, as well as provide an adequate pumping plant during construction that would handle the high groundwater inflows anticipated during construction;

- the layout and design of the headworks facilities, which needed to be able to isolate and facilitate inspection and maintenance of Tunnel No. 2 while power station operations were maintained, permit inspection of all hoisting facilities during upsurge events of the power station, and minimise downtime of the power station during connection of the new facilities during construction;

- the layout of the outlet works facilities, which needed to provide a smooth hydraulic transition from the tailrace tunnel to the tailrace channel, isolate the new tunnel from Deep Cove waters during inspection and maintenance intervals, and facilitate TBM mining of the tailrace tunnel from the outlet portal; and

- the overall hydraulic performance of Tunnel No. 2, when operating singularly or in combination with Tunnel No. 1, for a range of static and hydrodynamic surge conditions.

3.3 Environmental Controls

In addition to the complex and interrelated design issues surrounding the hydraulic, structural, and operational performance of the new facilities, the pristine environmental setting within which construction will take place needed to be addressed. The project will be constructed within the Fiordland National Park, which is administered by New Zealand's Department of Conservation (DOC). The area is also designated as a World Heritage Area, and is registered with the United Nations. Due to the unique environmental setting, ECNZ worked with an Environmental Liaison Group for several years, and agreed to a number of strict environmental limitations that will be imposed on the construction. These limitations include:

- no labour camp facilities at Deep Cove;

- no staging of non-essential office staff within the Park boundaries;

- stringent limitations on particle sizes, amount of suspended solids, and hydrocarbon content permitted in construction water discharges;

- noise limitations during evening hours;

- limited areas for construction disturbance; and

- the shape of spoil piles to be created as a result of the tunnel excavation.

3.4 Value Engineering

Mid-way through the design process, the accelerated design schedule was relaxed. This afforded ECNZ and Woodward-Clyde the time to conduct a value engineering review of a number of key project components. The principal objectives of the value engineering studies were to improve the hydraulic efficiency of the new facilities, optimise operational performance, reduce the construction cost, reduce the construction schedule, or reduce perceived construction risk. Key project components and considerations that were addressed included:

- the sizing and configuration of the bifurcation, where the new tailrace tunnel will intersect the existing draft tube manifold;

- the cross-sectional size and shape of the tailrace tunnel between the bifurcation and the headworks stop log structure;

- modelling analyses of high insitu stresses encountered during the initial construction, which caused spalling conditions during construction, and review of stabilisation measures intended to address these conditions;

- the operational configuration and shape of underground openings for the dewatering facilities;

- the configuration of the outlet works facilities, to improve construction and operational flexibility, as well as minimise construction risks due to groundwater control problems;

- the prioritisation of desired modifications in the existing tailrace channel, which could only be accomplished when the power station was shut down temporarily to connect the new tailrace tunnel to the existing draft tube manifold; and

- ventilation issues related to staging construction work from within the existing tunnel access road to the power station.

4.0 CONTRACTUAL CONSIDERATIONS

The successful construction of the Project will require a good working relationship among the Contractor, ECNZ, and Woodward-Clyde. A key element of that teamwork will be to build an atmosphere of trust with the Contractor. The project will include a number of proactive steps toward establishing and maintaining a good working relationship with the Contractor; through the incorporation of key risk sharing provisions into the Tender Documents, a form of Contract that will include a flexible system of compensating the Contractor for work performed, and the development of an Interactive Tender Process (ITP) aimed at team-building starting from the introduction of the Project to the construction fraternity.

4.1 Risk Sharing Provisions

Three provisions will be included in the Tender Documents which will provide efficient means for the resolution of disputes that may develop during the construction. These items are:

- Geotechnical Baseline Report (GBR);
- Disputes Review Board; and
- Escrow Bid Documents.

The potential for differing site condition claims is inherent in underground construction. In the past, Tender Documents for tunnel construction projects have provided data gathered from nearby construction and subsurface exploration programs, but have left much of the risk to the tenderers to evaluate and cope with the variable conditions that might be encountered. There has been an increasing trend toward providing tenderers more information upon which to rely in preparing their proposals. The most straightforward means of providing this type of information is in a Geotechnical Baseline Report (GBR). The GBR:

- sets forth the designer's interpretation of the available subsurface data and previous construction records;
- describes how the subsurface conditions might vary from those evidenced in the available information;
- describes how the anticipated subsurface conditions have influenced the construction plans and specifications; and
- describes how the anticipated subsurface conditions will influence the construction.

The GBR is a part of the Contract, and will be utilised as a basis for evaluating differing site conditions claims. The allocation of risk is clearly presented with this approach; the Contractor carries the risks for all conditions consistent with the baseline conditions, and the Owner carries any additional risk associated with conditions beyond the baseline.

The Disputes Review Board (DRB) is a panel of three experts independent from the contracting parties who, during the construction, can be asked to resolve a dispute that cannot otherwise be resolved between the parties. The DRB is established at the start of the work, and is kept apprised of the progress of the work through periodic progress reports and site visits. During the site visits, the DRB has an opportunity to discuss, in an informal and communicative environment, any concerns regarding the work. In the event of a dispute, sessions are convened at or near the jobsite to hear both sides of the dispute, to review records, to view site conditions, and to ask questions of both parties. Following a relatively short period of deliberation among the board members, a set of non-binding recommendations for resolution is offered.

Contractors who have utilised this process indicate that they anticipate fair treatment, moreso than with any other single contractual provision.

Escrow Bid Documents confirm the Contractor's assumptions, calculations, and information used in preparing his tender in a format that can be accessed during the work. The documents are required to be submitted by one or more of the lowest tenderers, within several days following the opening of tenders. Prior to award of the Contract, the documents of the preferred tenderer are briefly reviewed for completeness by selected Owner's representatives in the presence of the Contractor. The documents are then escrowed with a third party, and can be reviewed at the request of either party in the presence of both the Owner and Contractor representatives to assist in resolving a dispute.

While the Geotechnical Baseline Report, Dispute Review Board, and Escrow Bid Documents tend to focus on the *resolution* of disputes if and when they arise during the work, an additional provision, Partnering, has as its objective the creation of an environment for communication to *avoid* disputes. At the time of this writing, ECNZ is considering the option of entering into a Partnering Charter or Agreement with the Contractor. The process consists of a mutually developed formal strategy of commitment and communication. The negotiations are generally conducted between the top level management of the parties, so that involvement and commitment are demonstrated at the highest levels and followed downward through the ranks. Through periodic evaluation, the parties have the opportunity to review the effectiveness of the process, and to take corrective action to ensure that effective and timely communications are maintained.

4.2 Interactive Tender Process (ITP)

The ITP was conceived as a proactive effort on behalf of ECNZ and Woodward-Clyde to provide improved information to prospective contractors during the pre-tendering and tendering stages of the Project, so that they could better understand the project components, project constraints, and project risks, and why certain courses of action were or were not taken in the design. In addition, the ITP provides an opportunity for tenderers to review draft documents and to provide input prior to finalisation and issuance of the Tender Documents. The ITP was developed to include the following key elements:

- The development and issuance of project information in an interactive compact disc format. The compact disc contains an audio/video overview of the project and its components, operational constraints and environmental requirements that will influence the work, and a review of the project site and nearby housing facilities to aid prospective tenderers in assessing the overall project setting. The CDi was intended to assist contractors world-wide in assembling their teams for the project, in completing questionnaire submittals, and in preparing their tenders. Rather than bring the prospective tenderers to the project site, the CDi brings the project to the prospective tenderers.

- Issuance of a Contractor Questionnaire, to be completed and submitted by Principals or Joint Ventures interested in tendering for the Work. Questionnaire submittals were evaluated and ranked, to facilitate the identification of a shortlist of qualified parties who will be invited to continue throughout the remainder of the ITP.

- A site visit and briefing. The shortlisted Parties will be issued a draft of the Tender Documents for their review, following which they will be asked to attend a mandatory site visit and briefing. ECNZ and Woodward-Clyde will provide a briefing of the design, the bases for design, and other design approaches and layouts that were ruled out for various reasons. In this manner, tenderers will gain a better appreciation of which project components are fixed and which are flexible, and where tenderers will be permitted to apply their ingenuity to project components, construction staging, and construction sequencing. Tenderers will be given a tour of the site, will be permitted to review documents assembled during the design related to the previous and proposed construction, and will be permitted to provide feedback, both verbally and in writing, on the draft Tender Documents. This feedback is intended to eliminate, or at least reduce, the number of ambiguities in the Tender Documents, and hopefully, serve to reduce the number of misunderstandings that will occur during the Work. This process is also intended to achieve tenderer "buy-in" of the documents, so that they more fully support the contents and intent of the Documents during the construction.

- Incorporation of Tenderer Comments. ECNZ and Woodward-Clyde will endeavour to incorporate relevant and appropriate comments and suggestions offered by tenderers, prior to finalising the documents for formal issuance and Tendering.

5. CONCLUSIONS

The planning and design of the Second Manapouri Tailrace Tunnel Project has attempted to address numerous environmental, geological, and contractual challenges. The well-documented, difficult conditions encountered during the original tailrace tunnel construction are a forewarning of what is to follow. While efforts have resulted in what is believed to be an efficient and effective design, success of the project will depend on the ideas and abilities of the Contractor. Thus, allowance has been made for Contractor-offered suggestions and modifications. The effectiveness of the design and contractual approach will be demonstrated during the construction. This approach may serve as a template for other heavy and underground construction works projects.