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Tunnelling Under Great Lakes

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Abstract: Ontario has constructed five large diameters under the Great Lakes (Lake Erie, Lake Huron and Lake Ontario). Tunnels were driven by a drill-blast method through a variety of rock conditions, ranging from high water inflow conditions to highly stressed ground. This combined with the design and operational requirements had a major influence on construction approach, which ranged from continuous grouting to control water seepage to a special excavation and tunnel lining sequence to accommodate time-dependent deformations. The emphasis in this paper will be on the construction approach in completion of cooling water tunnels driven under Lake Erie, Lake Huron and Lake Ontario. Tunnels serve Ontario nuclear generating station.

Keywords: Lake Ontario; tunnel; lining

1. Introduction

The locations of three generating stations (Nanticoke, Bruce and Darlington), subject of this paper, were chosen on the basis of their proximity to the residential and industrial markets of Ontario as well as an abundant supply of cooling water from the adjacent lakes. Tunnels, described in this paper, are needed to convey cooling water from lakes into the generating stations. Currently, Ontario operates three nuclear stations, using CANDU type technology in a partnership with Atomic Energy of Canada Limited (AECL), the Hydro-Electric Power Commission of Ontario, Canadian General Electric, and other companies.

2. Ontario Electricity by Fuel Source

Ontario's electricity system is designed to support the needs of approximately 5.25 million residential and small business customers, 53,000 commercial consumers and 400 industrial consumers. The Province has over 30,000 km of transmission lines and over 260,000 km of distribution lines.

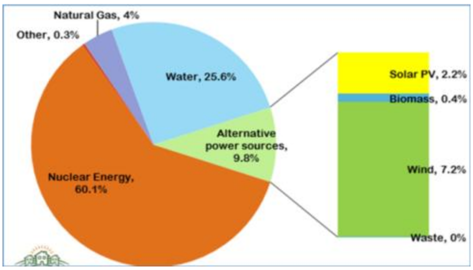

Fig. 1. Ontario electricity by fuel type.

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3. Canadian Reactor (CANDU)

The CANDU (Canada Deuterium Uranium) is a Canadian pressurized heavy-water reactor design used to generate electric power. The acronym refers to its deuterium oxide (heavy water) moderator and its use of (originally, natural) uranium fuel. CANDU reactors were first developed in the late 1950s and 1960s. Fig. 2 is a schematic view of the reactor.

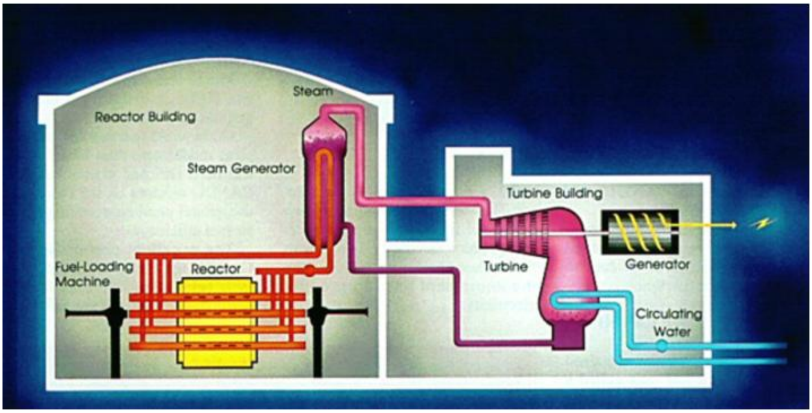

Fig. 2. Schematic view of the CANDU reactor.

4. Waters of the Great Lakes

Fig. 3. Great Lakes geographic layout.

For many years Ontario has used the waters of the Great Lakes for the generation of electricity for the Province; first for the hydro-electric developments on the Niagara River leading from Lake Erie to Lake Ontario and more recently as cooling water in nuclear generating stations. Domestic use for drinking water from Great Lakes has been practiced for many years. The Great Lakes began to form at the end of the Last Glacial Period around 14,000 years ago, as retreating ice sheets exposed the basins they had carved into the land, which then filled with melt-water. The Great Lakes consist of five freshwater interconnected lakes being Lake Superior, Michigan, Huron, Erie and Ontario. They are a critical component of the regional economy on both sides of the border. Great Lakes vary in depth, Lake Superior being the deepest (over 400m) and largest in size (over 82,000 km²).

5. Tunnelling Under Lake Erie

Lake Erie is the fourth-largest lake by surface area of the five Great Lakes in North America and the eleventh largest globally. It is the southernmost, shallowest, and smallest by volume of the Great Lakes. It is situated on the international boundary between Canada and the United States. As per Figure 4, the Nanticoke Generating Station is located on the Northern shore of Lake Erie. It was constructed as a coal-fired power station, in operation from 1972 to 2013. At the time, it was the largest coal-fired station in North America and it provided 3,964 MW of power into the southern Ontario power grid. A few years back, it has been transformed into a 44-megawatt clean energy facility that hosts 192,431 solar panels across 260 acres.

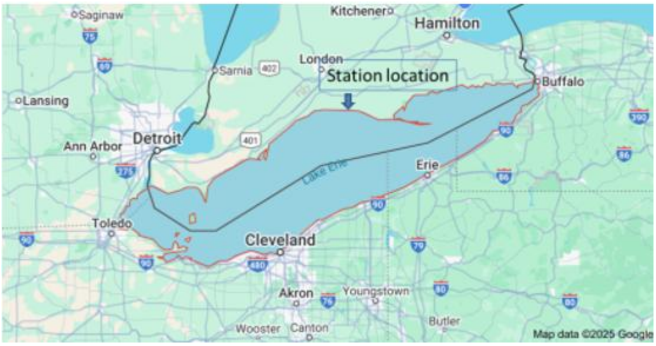

Fig. 4. Lake Erie location

As illustrated in Figure 5, an intake, cooling water tunnel, was constructed under the lake. The geology of the area consists of sedimentary rocks, limestone and shale. His was the first cooling water tunnel constructed for thermal generating station. Since the tunnel was driven through water-tight sedimentary formations there were no challenging risks facing the contractor's works. Conventional drilling, blasting, scaling, rock bolting and concreting were used to construct/excavate the tunnel. Tunnel was excavated with Atlas-Copco ladder drills. A crew of 12 men worked on the drill Jumbo assembly. Total time to drill an 11 feet advance was 3.5 hours. Shotcreting was used to temporarily support the tunnel arch. Concrete lining was installed in a final phase of the construction.

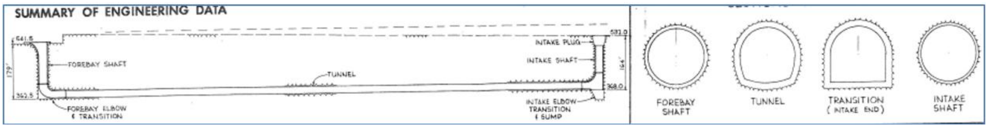

Fig. 5. Tunnel profile and concrete liner sequence.

6. Tunnelling Under Lake Ontario

Figure 6 shows Lake Ontario configuration. The lake is one of the five Great Lakes of North America. It is bounded on the north, west, and southwest by the Canadian province of Ontario and on the south and east by the U.S.

The Canada–United States border spans the centre of the lake. The Canadian cities of Hamilton, Kingston, Mississauga, and Toronto are located on the lake's northern shorelines. Lake Ontario serves as the outlet to the Atlantic Ocean via the Saint Lawrence River, comprising the western end of the Saint Lawrence Seaway.

Fig. 6. Lake Ontario Location.

A 3,512 MW Darlington Generating Station is located on the north shore of Lake Ontario approximately 60 km east of Toronto, Ontario, (see Figure 6 above). The construction cost was $14.4 billion, 1980s CAD ($23.8 billion in 2021approximately). A required cooling water flow is conveyed into the station via a 1,000 meters long intake tunnel and discharged into the lake through a series of vertical diffusers extending 1800 m offshore, see Figure 8, below.

Fig. 7. Layout of the Darlington generating station.

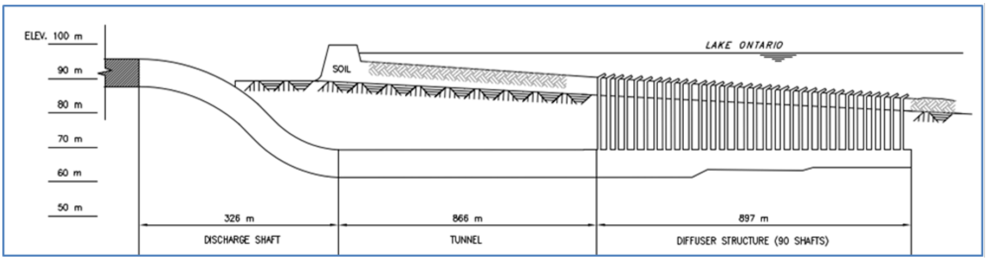

Fig. 8. A profile of the diffuser tunnel at Darlington generating station.

The intake and discharge tunnels were excavated through massive limestone. Due to the presence of high horizontal stress in rock, the rock joints remained closed and as a result, tunnels were dry, not yielding any water inflows. This resulted in high excavation daily rates. A comprehensive rock mechanics program was carried out in both tunnels to address in-situ stress issue and to ermine the time delay required between excavation and installation of concrete lining. A waiting period of 90 days was built into the construction schedule to allow for time-dependent deformation stress relief.

Fig. 9. View of discharge tunnel.

7. Tunnelling Under Lake Huron

Lake Huron is one of the five Great Lakes of North America. It is shared on the north and east by the Canadian province of Ontario and on the south and west by the U.S. state of Michigan, see Figure 10. Lake Huron comprises the eastern portion of Lake Michigan–Huron, having the same surface elevation as Lake Michigan, to which it is connected by the 8.0 km Straits of Mackinac. Combined, Lake Michigan–Huron is the largest freshwater lake by area in the world.

Fig. 10. Location of Lake Huron.

The Bruce nuclear generating station is located on the east shore of Lake Huron, 300 km northwest of the City of Toronto, see Figure 11. Ontario. With eight CANDU pressurized heavy-water reactors and the capacity close to 6000 MW, it is one of the largest energy complexes in the world. An 8:7 m diameter, 900 m long tunnel was excavated beneath the lake. The main portion of the tunnel was positioned within the bedded limestone of the Detroit River Formation. The results of water pressure testing indicated that open wet rock conditions would be encountered at various locations

Fig. 11. Layout of the Bruce generating station.

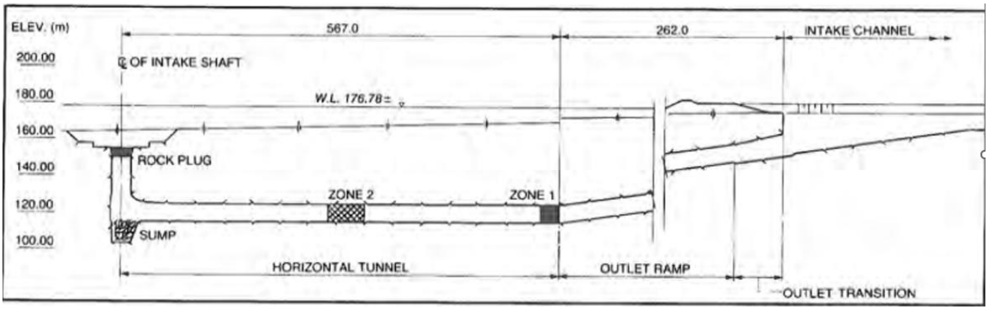

Fig. 12. Bruce intake tunnel profile.

During design phase, it was estimated that one-third of the excavation time would be spent on water control. An 11 m^3/min inflow was estimated for bidding purposes. The tunnel was excavated by full face blasting rounds combined with grouting. Normally the excavation cycle consisted of grouting a minimum of 30 m beyond the tunnel face, to control seepage followed by excavating for 24 m. A total of 49 grout cycles were required to grout the entire tunnel length.

Each grouting cycle consisted of 15 to 46 grout holes, depending on local conditions. This operation resulted in a total of 40,000 m of probe and grout hole drilling and injection of 5,300 m^3 of cement grout. Water seepage was minimized by grouting, while excess water was pumped from the tunnel via a weir box to the ground surface. Progressive estimates of the potential water seepage indicated a cumulative total of 112 cubic metres per minute for the full tunnel length.

Fig. 13. Illustrates large flow under pressure.

8. Conclusion

Tunnelling under Great Lakes poses a challenge of tidal resonance, sometimes preventing conducting any operation from the lake side. The cooling water intake tunnel constructed under Lake Huron exhibited high water pressure acting upon the tunnel floor. Large water inflows have caused stoppage of work and loss of tunnel temporarily. Tunnelling under Lake Ontario mandated special design and construction approach to deal with high in situ rock stresses.

9. Authors

Boro Lukajic is Professional Canadian engineer, since 1968. Fellow Engineering Institute of Canada – inducted in 2000, lifetime achievement award, TAC 2017. Experience covers projects worldwide in hydro power and nuclear energy. In Canada: Labrador, Yukon Territory, Ontario, British Columbia and Manitoba. Internationally: US, Brazil, Hong Kong, Costa Rica, Colombia and United Arab Emirates.

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Acknowledgement

We dedicate this publication to a great individual, father-mentor, Milisav Milojevic, 1924 – 2012.

11. References

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