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Awarded as one of the American Public Works Association's (APWA) Public Works Projects of the Year for 2016, Chicago's Thornton Composite Reservoir is critical to a comprehensive tunnel and reservoir plan to manage combined sewer overflows and protect water quality. **Kevin Fitzpatrick**, **Lou Storino**, and **Bipin Patel** of the Metropolitan Water Reclamation District of Greater Chicago and Mohammad Djavid, Brian Kazyak, and Vito DiCosola of MWH, now part of Stantec, explain the technical details of this ambitious engineering project.

Limestone quarry transformed into world's largest CSO storage facility

When it comes to the challenge of managing combined sewer overflow (CSO) through the use of existing resources, the Metropolitan Water Reclamation District of Greater Chicago (MWRD) in the US state of Illinois has set a new standard. In November 2015, the MWRD completed the US$429-million conversion of a limestone quarry in the south suburbs of Chicago into the largest CSO storage facility in the world. With a capacity of 29.9 million cubic meters (m^3), the Thornton Composite Reservoir (TCR) provides flood protection benefits to more than 500,000 people in 14 communities and is a critical element of the District's comprehensive Tunnel and Reservoir Plan (TARP) for managing CSOs and protecting water quality throughout its service area.

The 36.4-hectare (ha) portion of the quarry used for the TCR project is the north lobe of a surface quarry complex located on both sides of the Tri-State Tollway in southern Cook County. A main lobe of the complex located immediately south of the reservoir site remains an active quarry, while the third western lobe has served for 13 years as a storage facility for floodwaters from the nearby Thorn Creek and will continue for the next five years until this floodwater is also rerouted to the TCR.

The project site is located in the villages of Thornton and South Holland in southern Cook County, Illinois. The required improvements consisted mainly of preparing the north lobe for combined sewage storage, plugging construction haul roads, and connecting the existing Calumet Tunnel System to the north lobe quarry via a system of redundant tunnels and gates.

MWH, now part of Stantec, was selected by MWRD to perform detailed design work for this project including geotechnical investigations and reports, preparation of construction drawings and technical specifications, and provision of engineering services during construction of the gap dam, tunnel plugs, and connecting tunnels and gates elements of the project. Other elements of north lobe preparation, including the perimeter grout curtain, were designed by other consultants under contract to the MWRD.

To make the north lobe suitable for use as a CSO storage facility, three constructed haul tunnel penetrations between the north lobe and the main lobe complex had to be plugged. The main penetration was a gap in the rock measuring about 35.4 meters (m) high and 61 m wide at its widest point. As quarrying progressed to deeper levels, two tunnel penetrations measuring about 146 m and 183 m in length were excavated for use by mining equipment and haul trucks to transport quarry rock from the north lobe to the main crusher in the main lobe. The tunnels each measure about 7.6 m high and 10.7 m wide.

In addition to physically plugging the gaps, seepage that flows through the open fractures in the rock rib, in the rock surrounding the haul tunnels, and through open joints and bedding plans elsewhere around the perimeter of the facility had to be controlled. No improvement to the bottom of the reservoir was needed, as an impermeable layer of shale approximately 152 m below ground serves as a natural barrier below the facility.

The main elements of this project included a roller-compacted concrete dam (gap dam) 61-m-long (at the crest) and 35.4-m-high; two 8-m by 11-m haul tunnel plugs; 2,743 m of

As quarrying progressed to deeper levels, two tunnel penetrations measuring about 146 m and 183 m in length were excavated for use by mining equipment.

Left: Steel liner in tunnel. Photo by MWH

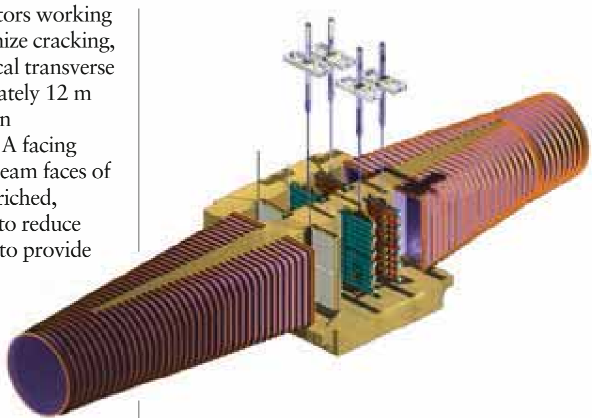
double row grout curtain installed to a depth of 168 m; and a new network of 9-m diameter rock tunnel with four wheel gates 4-m-wide by 9-m-high to control flows into and out of the reservoir.

The gap dam was constructed atop and within the rock rib, bridging across the existing gap between the north and main lobes at bench Level 1, located at an elevation of -33 m Chicago City Datum (CCD). CCD is used to measure inland elevation using Lake Michigan as the base point of 0.

The existing gap has a roughly trapezoidal configuration with a width of approximately 18 m at the bottom and approximately 64 m at the top (elevation: 0.0 CCD). The Tri-State Tollway spans the gap with a twin span bridge, 112 m in length. The gap dam was founded on rock at elevation 35.4 m CCD and was constructed using roller-compacted concrete (RCC). RCC mixing, placement, and compaction followed the general guidelines and recommendations for roller-compacted concrete as defined by the American Concrete Institute in ACI 207.5R. To complete the gap dam, 168 lifts were placed, comprising 26,400 m^3 of RCC, over the course of 46 days of placement with operators working one 12-hour shift per day. To minimize cracking, the dam was constructed with vertical transverse contraction joints spaced approximately 12 m apart and oriented in a radial pattern perpendicular to the upstream face. A facing system for both the up and downstream faces of the gap dam, consisting of grout-enriched, vibratable RCC (GEVR), was used to reduce seepage through the dam as well as to provide a surface more durable against the freeze-thaw cycles and resistant to the potential aggressive action of the CSO.

In addition to the main penetration, which was closed with the gap dam, there were two haul tunnels aligned in the north-south direction, which provided access through the rock rib at an approximate elevation of -55 m and -91 m CCD. The geometry of the haul tunnels are as follows:

- The Level 2 haul tunnel is approximately 8-m-high by 11-m-wide and 146-m-long. At the upstream face of the plug, the tunnel invert is approximately elevation -55.8 m CCD.
- The Level 3 haul tunnel is approximately 7-m



Top: Thornton Composite Reservoir and adjacent quarry complex (courtesy of MWRD)
Above: Three-dimensional view of bifurcated tunnel, steel-lined tunnel, and gate bays. Photo by MWH
Opposite page: Steel-liner installation in tunnel. Photo by MWH

Tunnel plugs were constructed in each of the two existing haul tunnels using cast-in-place reinforced concrete.

high by 10-m-wide and 183-m-long. At the upstream face of the plug, the tunnel invert is approximately elevation -91.7 m CCD.

Tunnel plugs were constructed in each of the two existing haul tunnels using cast-in-place reinforced concrete. Consolidation grouting was performed to improve the strength and deformation characteristics of the rock mass and to seal potential seepage pathways near the concrete-rock interface.

A grout curtain was constructed along the axis of the rock rib to lower the permeability of the rock mass so that the water stored in the reservoir does not migrate to the operational main lobe or into the surrounding groundwater aquifer. The grout curtain generally contained two rows (a-line and b-line) approximately 6 m apart around the entire 2,743-m-long perimeter. Each row of the grout curtain required a minimum installation of initial primary, primary, and secondary holes angled 15 degrees vertically and spaced approximately 6 m from each other at the surface. A split-spaced methodology was implemented to install higher-order holes, when previously grouted holes exceeded the prescribed closure criterion. Additionally, an instrumentation monitoring system (including inclinometers, piezometers, and survey monuments/targets) was installed for monitoring the performance of the rock rib, gap dam and grout curtain during reservoir operation.

The other major element of the overall project is the connecting tunnels and gates (CTG) system that connects the existing Indiana Avenue leg tunnel of the Calumet Tunnel System to the TCR. The CTG system consists of 318 m of 9-m finished diameter conduit and a system of four 4-m-wide by 9-m-high gates that convey and control flows into and out of the CSO reservoir. The new section of tunnel was connected to the 9-m diameter concrete-lined Indiana Avenue tunnel through the demolition of an existing concrete bulkhead wall and weir, construction of temporary bulkheads, excavation and removal of a rock tunnel plug, connection of a new concrete lining, installation of recessed rock anchors in the existing concrete liner, and repair of concrete surfaces in an existing shaft and liner.

The gates installed to control flows in the connecting tunnel are housed in bays located along parallel steel-lined conduit sections within a 19-m excavated diameter, 104-m-deep wet well shaft. The parallel gate systems provide a redundant flow control system. Chambers excavated in rock at the upstream and downstream sides of the wet well shaft house steel-lined tunnel bifurcations integrated with the steel lined gate bays. The upstream bifurcation section is 27-m-long while the downstream section is 36-m-long. Both sections include a seepage collar, the obround transition, the pier nose, and the D bifurcation transitions. The sections are lined with steel that is 38-millimeters (mm) thick and with T stiffeners spaced every 1 m on center. The gate bays are lined with 13-mm-thick steel plates composited to the reinforced concrete conduits running through the bottom of the wet well shaft.

The primary flow control gates for the connecting tunnel are hydraulically operated, 4-m-wide by 9-m-high wheel gates with built-in 813-mm in diameter jet flow gates designed to allow for equalization of water levels between the reservoir and the tunnel system. Each gate bay also includes a redundant secondary wheel gate and space for a maintenance bulkhead. All of the gates are designed to seal against flow in either direction at an operating head of 114 m. Hydraulic power units (HPUs) with embedded parts heating units are provided for operations of the gate hydraulic cylinders.

Control of seepage within the tunnel and chamber excavations is critical for the connecting tunnel system. Seepage control measures include three 8-m-long grout curtain rings at each of the two ends of the steel lined conduits and three 14-m-long grout curtain rings at the intersection of the tunnel with the perimeter reservoir grout curtain. A seepage control grout curtain was used for shaft excavations, and contact and skin grouting were used to fill any voids beneath the concrete or steel liners.

The connecting tunnel discharges into the TCR through a 9-m diameter portal in the 102-m-high rock wall at the northeastern corner of the TCR. A concrete-reinforced diffuser apron is anchored to the bottom of TCR at the discharge point to provide for energy dissipation and minimize the potential for scour.

Since November 2015, upon completion of the conversion of the north lobe of the Thornton limestone quarry into the Thornton Composite Reservoir, the facility has captured more than 7.6 million m^3 of combined wastewater in 8 months. This facility, as part of the District's comprehensive tunnel and reservoir plan, now provides flood protection resulting from combined sewage overflows to more than 500,000 residents in 14 Chicago-area communities combined.