Seventh Symposium on Salt, Vol. I 285–291 (1993)
Elsevier Science Publishers B.V., Amsterdam

Extension of a Concrete Shaft Lining at the Cote Blanche Mine, Louisiana, USA

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ABSTRACT

Access to the mine workings in the salt domes of Louisiana is provided by means of vertical shafts from surface. The shafts are constructed through an incompetent saturated alluvium in locations adjacent to waterways connecting to the Gulf of Mexico. The key goal in design and construction of the shafts is to achieve a secure seal which will prevent an inflow from the overlying alluvium/waterway. Such an inflow could flood the mine and result in the total loss of all operations. The seal must be located within the salt because there is no cap of insoluble rock or other competent material protecting the salt dome from the saturated alluvium above. The typical shaft is constructed with a circular concrete liner extending through the alluvium and down into the salt for a distance sufficient to achieve a watertight seal at the contact between the concrete and the surrounding salt.

The Service Shaft at the Cote Blanche Mine is designed as described above and is in a location where the alluvium thickness is 142 m. Following construction in 1963, the shaft functioned satisfactorily over a period of 25 years, until September of 1989. At that time a minor leakage was observed seeping through a crack in the salt below the bottom of the concrete liner. An ensuing probe hole drilling and grouting program indicated that an extension of the lining was required to re-establish a seal that would ensure the long term security of the shaft and the Cote Blanche Mine.

This paper describes the water inflow conditions encountered in the probe hole drilling and grouting program which produced the decision to extend the lining. The design requirements for the lining extension are discussed, and the program which permitted construction with no interruptions to the owner's mining operation is described. The paper illustrates how a program of regular inspection and maintenance in an operating salt dome shaft can detect an inflow condition before it becomes a risk to mine security and in time for corrective action to be undertaken to ensure long-term security.

INTRODUCTION

Cote Blanche is one of three operating salt mines on the Louisiana coast of the Gulf of Mexico. Access to the mine workings and production hoisting of dry salt are through vertical shafts. Each mine produces a nominal one and one half to two million tons per year. The majority of the product goes to the mid-western United States to be consumed in the ice control market.

These coastal mines are located in salt domes that are one to three miles in diameter. One dome has a surface outcrop, while others lie as deep as 150 m below surface. The earliest reported dry mining operation consisted of quarrying 10,000–30,000 tonnes of salt from the outcrop during the Civil War (1861–1865). After several unsuccessful attempts, underground mining commenced about 1900. Two mines were put into operation in the 1900s, one in the 1920s, and two more in the early 1960s. Two mines were flooded and permanently lost for further production in the early 1980s. One loss occurred when a surface borehole was inadvertently drilled into the mine, connecting it to an overlying lake and a canal system to the Gulf of Mexico. The second was intentionally flooded during an abandonment program which the owner instituted following the discovery of unsafe structural conditions in the mine. The five mines which existed in the 1960s and 1970s are located in separate domes called the Five Island salt domes. They are not truly islands but areas where the land rises above the marshes. All the domes have the common characteristic of no significant caprock and the salt is directly in contact with the overlying saturated alluvium.

The mines that have been able to sink their shafts in locations where the top of the salt is above the water table have had no significant problems with water leakage into their shafts during construction and during production operations to date. Where the top of the salt is below the water table, the risk of water leakage is a major problem. During construction, excavation through the water-saturated alluvium has, in most cases, involved artificial ground freezing for temporary support. The key mine security item, however, is the construction of a secure seal along the contact of the excavation wall in the salt and the shaft lining. The purpose of the seal is to prevent fluid leakage from the overlying alluvium. Any leakage through the seal area, however minor, creates the risk of catastrophic flooding due to the solubility of the salt. Circular concrete shaft liners have normally been extended through the alluvium and into the salt for a minimum distance of 48 m. Seal materials have been cement and chemical grouts, bitumen, and Dowell chemical seal used in some combination. After construction, a rigid inspection program combined with maintenance grouting has proven to be essential.

At Cote Blanche the depth of alluvium overlying the salt is greater than at any of the other mine locations. The depth at the Service Shaft is 142 m and at the Production Shaft is 152 m. Because the depth is greater, it follows that the hydrostatic pressure in the saturated alluvium at the top of the salt is also greater. The water pressure bears directly on the seal area; therefore, conditions at the Cote Blanche dictate not only that an inspection program be rigidly maintained but also that any water leakage, even quite minor leaks, be dealt with immediately. This type of system was in place in 1989, when a minor leakage in the salt below the concrete wall was observed in the Service Shaft.

DESCRIPTION OF SERVICE SHAFT

Figure 1 is a section through the Service Shaft showing as-built conditions after construction in 1963, when it was used for hoisting development salt while construction of the Production Shaft was being completed. The total shaft depth is 412 m from surface to the mining level. The 2320 mm inside diameter concrete liner extends 180 m from surface to the top of the pump station. This places the liner bottom 38 m below the top of the salt, where the top of the salt reaches to 142 m below surface. Below the pump station, except for a concrete collar at the floor, the shaft is an unlined 2270 mm diameter excavation in the salt. The water table is at sea level, approximately 12 m below surface at the shaft collar. The geological section is simple, showing only alluvium and salt, with the alluvium consisting of saturated sands, silts, and clays.

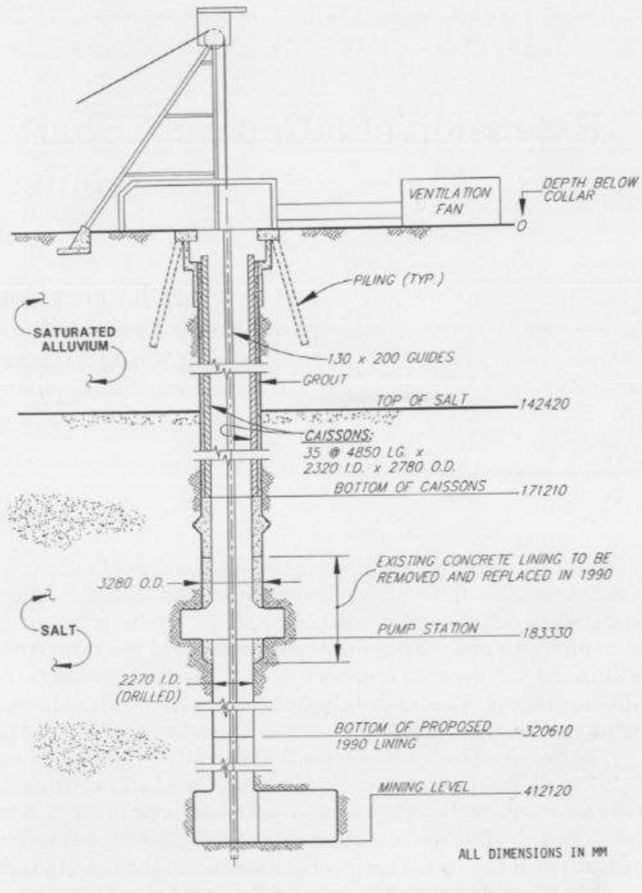

Fig. 1. Section through service shaft as built in 1963.

The Service Shaft is unique in that it is the only one in the coastal area which was constructed using a surface drilling rig. All others were constructed through most of their depth using conventional drill and blast methods. Construction procedure for the Service Shaft commenced with the drilling of a 3280 mm diameter hole from surface to depth of 171 m using drilling mud to support the excavation and flush the cuttings. A liner consisting of reinforced concrete caissons, 2320 mm in diameter and prefabricated in 4850 mm lengths with socket and spigot ends, was lowered into the hole and grouted to full depth. Additional grouting was carried out, using shaft sinking personnel, after the hoist, headframe, conveyance, and partial furnishings were installed. To ensure the security of the shaft structurally and against bypass leakage, 9 m of concrete lining was constructed below the caissons. A bearing hitch (foundation ring) was included in the lining extension and a pump station was constructed immediately below the lining extension. The shaft excavation was then extended to the mining horizon by drilling with a 2270 mm diameter bit.

A surface fan supplies the mine with 5240 m^3/min of fresh air ventilation down the Service Shaft, pressurizing the headframe interior atmosphere to 178 mm, water gauge. Air velocity in the 2320 mm caisson portion of the shaft is, therefore, 1240 m per min. A double door arrangement in the headframe creates an air lock, permitting access when the fan is operating. Personnel and materials are hoisted in a double deck man-cage. The cage travels on 130 mm by 200 mm guides that are held in place by steel brackets which are attached to the shaft wall by anchor bolts in both the lined and unlined portions of the shaft. The single drum hoist has dual 160 KW motors. It operates out of balance to hoist the mancage using a single hoist rope.

SHAFT MAINTENANCE: 1963–1989

During the 26 years following construction, no fluid leakage was observed at the bottom of the concrete wall in the Service Shaft; therefore, the seal created by grouting behind the 38 m of liner from the top of the salt to the liner bottom was effective. However, it was effective only because the maintenance staff made careful and regular inspections of the area, arranging for testing and maintenance grouting to be performed whenever conditions appeared to require it. Inspections included not only looking for leakages in the cracks and joints in the caissons and the concrete wall but also opening valves on rings of "tell-tale" pipes which connected to the contact between the concrete and the salt. On numerous occasions during the inspections, water leakage or increases in flow from minor leakages were observed within the 38 m area. Subsequent test hole drilling through the shaft wall frequently revealed accumulations of fluid in the form of saturated brine that would support flows of several liters per minute over a substantial period of time. These accumulations usually occurred in the upper half of the 38 m area, but on occasion were discovered within 6 m of the bottom of the wall. Maintenance grouting procedures required that brine saturated cement grout be employed to fill any large voids and that a low viscosity brine-based acrylamide grout be injected into all holes to achieve the best possible final seal.

A major contributing factor to the frequent need for remedial grouting was the construction method employed originally in drilling the hole and installing and grouting the caissons. The method required that drill mud be left in the hole for wall support during installation and grouting of the caissons. During the grouting operation cement grout was pumped into the annular space between the outside of the caissons and the surrounding formation, commencing at the bottom, causing the mud to be displaced by the grout as it rose in the annular space. Unfortunately, as proven in subsequent test drilling and grouting operations from within the shaft, a substantial volume of mud was bypassed and not displaced. It remained at random locations within the annular space between the salt and the caissons. Commencing in 1963, numerous attempts were made to displace mud in order to achieve a continuous seal; however, during maintenance grouting in 1989, traces of the mud were still evident.

WATER INFLOW BELOW THE LINING: 1989

During a routine inspection in 1989, a leakage was observed flowing from an unused short drill hole in the salt wall below the concrete collar at the floor of the pump station, i.e. at a depth of 185 m below the surface and 44 m below the top of the salt. Although the leakage volume was only a fraction of one liter per minute, mine management treated the discovery as an emergency condition and engaged Dynatec Mining Corporation to commence immediately on a test hole drilling and maintenance grouting operation. Fortunately, the volume of flow from the leakage remained constant over a period of several weeks while a series of test holes were drilled to assess the conditions associated with the leakage, before sealing it off with a low viscosity chemical grout.

In addition to the localized drilling and grouting in the vicinity of the leak, a further program was carried out over a three month period above and below the leakage horizon and at a greater distance into the salt wall. Horizontal rings of holes were drilled in an eight hole pattern to a depth of 10 m, creating a search area of 24 m in diameter with each ring. The rings were drilled at 1500 mm vertical intervals to a distance of 14 m above the leak. Below the leak, rings were drilled at 3000 mm intervals to a depth of 18 m, as well as rings at 30, 60, and 90 m. Wherever water was encountered in a hole, intermediate holes were drilled on either side to attempt to establish the extent of any flow path. Of the several hundred holes drilled, only four or five intercepted fissures large enough to accept cement grout. Approximately 50% of the holes accepted a low viscosity chemical grout, and in most cases the quantity was less than 110 liters. All holes were abandoned by plugging off several meters of their collars with cement grout.

A major water source encountered during the program was approximately 15 m above the pump station and 7 m from the shaft wall. Flows of 75 l/min were encountered in two holes. 170 sacks of cement were injected into one hole, and the grout coupled to two other holes. No significant water was encountered in this area in subsequent drilling and redrilling. Other flows of up to 40 l/min were encountered in several holes drilled from the pump station, from 9 m above, and from 15 m below the pump station. One hole in each of the three locations was injected with ten to thirty sacks of cement and coupled to two or three adjacent holes.

The drilling and grouting program thus confirmed the information indicated by the leakage flow volume: that there was no well developed system of flow paths connecting the leakage below the pump station to a major water source. However, the program did show that a major water source existed within 15 m of the leakage. The quick action in setting up the program permitted the source to be sealed off before erosion and solutioning caused the flow to develop further and become a risk to mine security.

Assessment of the program results focused on the fact that a major vertical water-bearing anomaly existed within 9 m of the shaft wall. Minor water-bearing anomalies that appeared to be associated with the major one occurred randomly and as close as one-half meter from the unlined shaft wall and to a depth between 30 and 60 m below the pump station, i.e. 70–100 m below the top of the salt and 212–242 m below surface. The static pressures recorded while testing and grouting indicated that all the anomalies connected to the water table. For risk assessment purposes it was assumed that the anomalies connected to the alluvium that directly overlay the top of the salt. In this case a well developed flow path into the shaft could have been a conduit for the saturated alluvium as well as water.

Although the grouting program sealed the leakage and all the anomalies contacted by drill holes were grouted, the presence of water-bearing anomalies in close proximity to the unlined salt wall was deemed to be an unacceptable risk to the long-term security of the mine. Consequently, company management made the decision to extend the concrete lining a distance of 150 m, i.e. 90 m below the deepest suspected water.

LINING EXTENSION DESIGN

The lining extension is shown in Figure 2. It is an unreinforced concrete cylinder with a 2730 mm inside diameter and a 460 mm wall thickness. The concrete has a design strength of 40 MPa and was made up using brine instead of fresh water in order to be compatible and bond with the salt wall. The structural strength of the cylinder is adequate to resist the hydrostatic pressure exerted by a column of brine originating from surface. However, due to the nature of concrete, the wall is not totally water

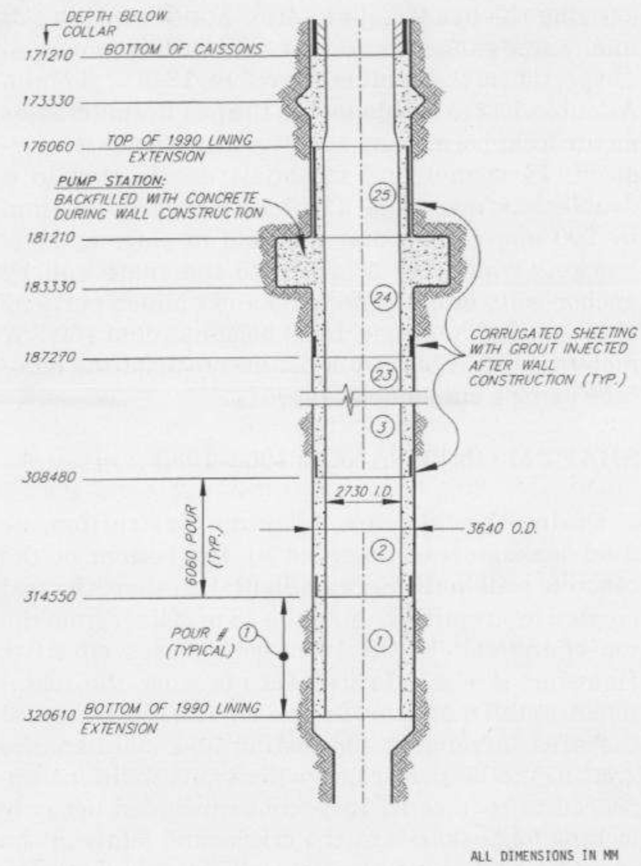

Fig. 2. Section through service shaft showing 1990 lining extension from depth 176,060 mm to 320,610 mm.

right. Shrinkage cracks and other blemishes are potential conduits through the concrete wall for any water which might find its way from a water-bearing anomaly into the contact between the salt and the concrete. Grouting during construction and subsequent maintenance grouting is the method employed to seal or reduce to a damp spot on the wall any of these types of leakage.

The key function of the liner is to prevent any migration of water down the contact between the outside of the concrete cylinder and the surrounding salt. This has been accomplished by the bonding which occurred between brine-saturated concrete and salt, as well as contact grouting of any minor voids caused by concrete shrinkage or cracks, loose material, and other blemishes in the salt wall. A substantial factor of safety has been built into this function by extending the liner 90 m below the lowest horizon where a water-bearing anomaly was suspected, i.e. assuming a hydrostatic pressure of 2.5 MPa at this horizon, the pressure reduction required over the 90 m distance is only 8 KPa per meter. To improve the effectiveness of the contact grouting operation, a ring of 1.5 m high corrugated metal sheeting was fixed to the salt wall at 6 m vertical centers, previous to each concrete pour, over the full height of the lining extension. The function of the sheeting was to provide a continuous void 1.5 m high over the full circumference of the shaft, permitting a non-shrink cement grout to be injected and to form a seal ring.

The existing lining, including the caissons and the underlying reinforced concrete lining including the foundation ring, was deemed to be satisfactory except for the 5 m above the pump station and the collar below, which did not have adequate concrete thickness. This concrete was removed to permit the top of the extension to be a water-tight joint in the lower portion of the foundation ring. The pump station was backfilled with concrete and is now part of the extension.

LINING EXTENSION CONSTRUCTION

The Cote Blanche Mine operates on a 24 h day and 5 day week schedule with frequent weekend work requirements. For the 8 month construction period Dynatec was allotted the uninterrupted use of the Service Shaft for 48 h each weekend and four afternoon shifts of 8 h during the week. This arrangement permitted Dynatec to work two crews for two shifts of 12 h and two of 8 h each week, i.e. a total of 80 h.

Mining regulations require that two means of egress must be available to personnel in the mine. Personnel must be removed from the mine if conditions in either exit do not permit hoisting within a one hour time limit. Since only two shafts service the mine, it was necessary for Dynatec to devise a construction method which would comply with this "one hour requirement". The method is best described under the following headings: 1, Mobilization; 2, Drill Blastholes; 3, Blast and Install Temporary Guide Brackets; 4, Construct Concrete Lining; 5, Grout.

Item 1: Mobilization

The key item during mobilization was the design, procurement, and testing of a concrete form and a 3 deck scaffold. The concrete form, as shown in Fig. 3, was 2730 mm in diameter and 6 m high. It was composed of twelve segments bolted together and with an access door in each segment. A hinged door arrangement permitted the form to be collapsed for breaking off the wall. The unique and essential components of the form were two pair of guide brackets, whose use is described below in Item 4: Construct Concrete Lining. The 3 deck scaffold, as shown in Fig. 4, was designed for suspension under the man-cage and storage on the mine level when not in use. Only ten minutes were required for the storage-to-suspension operation or the reverse.

Item 2: Drill Blastholes

Construction of the lining extension required that the existing opening of approximately 2.5 m diameter be enlarged to 3.5 m. This was accomplished using horizontal rings of blastholes, 0.5 m apart vertically. A pattern of 28 holes was employed in each ring. All the holes were drilled over the full 150 m height before the start of any blasting. Drilling was done simultaneously from all three decks of the scaffold, using templates to ensure accuracy.

Item 3: Blast and Install Temporary Guide Brackets

The major risk in this operation was blasting damage to the wooden guides in the vicinity of the blast and below. The risk was mitigated by the close

Fig. 3. Assembly of concrete form and 3 deck scaffold on surface. Assembly includes a pair of guides and guide brackets to ensure an exact fit of all components and to train crews in their use.

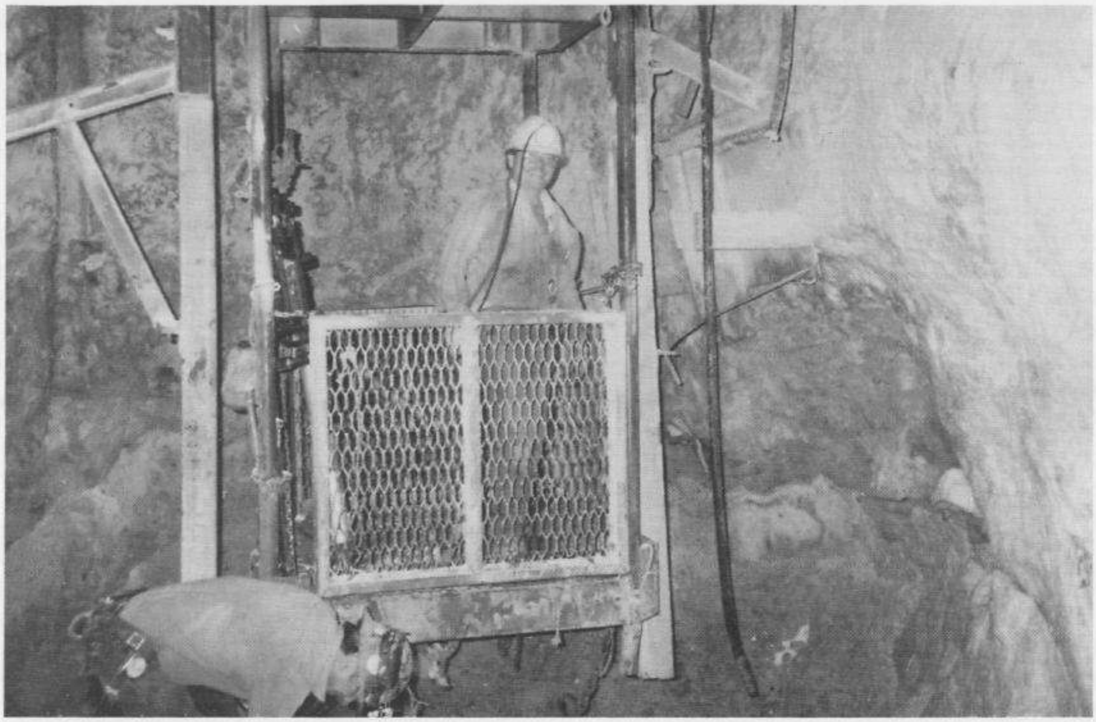

Fig. 4. Mine level shaft station showing bottom deck of the 3 deck scaffold suspending below the man-cage.

spacing of blastholes, millisecond delay blasting caps, low powder factor, removal of adjacent guides during blasting, and a blasting sequence where the open face was always above the blast. The blasting operation commenced below the floor of the pump station where extra holes were drilled and blasted to achieve the initial 3.5 m diameter excavation. Subsequently 15 or 16 rings were usually included in each blast to achieve a 6 m advance. The required excavation above the pump station was not blasted until after completion of concrete wall construction below it.

All blasting was initiated through an electric cable from surface. A single electric blasting cap, primacord, in-hole non-electric millisecond delay detonators, and one stick of emulsion explosive per hole were employed in the blast area. Using this system the blast could be postponed at any time up to the wiring in of the electric blasting cap, if personnel had to be removed from the mine.

During each blasting operation, two pair of guides were removed and slung on the scaffold immediately prior to wiring in the electric blasting cap. The scaffold was then raised to be clear of the blast, secured, and detached from the man-cage. The crew proceeded to surface in the man-cage and initiated the blast. On re-entry the guides were immediately re-attached in order to comply with the "one hour requirement". Splice plates were employed for guide connections where brackets had been removed by the blast. The splice plates gave adequate structural support to permit slow speed hoisting to remove personnel from the mine. Normal hoisting could not be resumed until channel beams, used as temporary guide brackets in the 3.5 m diameter excavation, were installed. Excavation to 3.5 m diameter and installation of temporary guide support was completed to the full depth of the lining extension before the start of the concreting operation.

Item 4: Construct Concrete Lining

The lining was constructed in 6 m lifts from the bottom up. After pouring each lift the 6 m high concrete form was raised, using chain blocks, into position for the subsequent pour. During this operation all guide brackets within the 12 m height involved, had to be disconnected and/or removed to permit the form to slide up between the guides and the wall. Splice plates were used to maintain the guide connections. Fortunately, while the form was in its collapsed mode, during the raising operation, it did not impinge on the guides. It was possible, therefore, to hoist the man-cage through the concrete form at any time during the raising operation and thus comply with the "one hour requirement". When the concrete form was in position for the subsequent pour, the guides were bolted to brackets on the form. At the same time the permanent guide brackets were installed on the previous pour and bolted to the guides. Thus, when the concrete form was in pouring position, normal hoisting conditions existed in the shaft.

Concrete was delivered from ready-mix trucks on surface down the shaft through a 160 mm pipe into a double dash pot and then through two 160 mm material conducting hoses into the form. Tremie tubes were employed behind the form to reduce the risk of segregation. The three deck scaffold was tied off at the same depth as the concrete form for ease of working during the pour, and the man-cage was used for access from surface.

Item 5: Grout

All grout was injected through the 400 holes drilled through the grout pipes installed as two rings of 8 in each of the 25 pours of 6 m, which were made during the concreting operation. The rings were located at the top and bottom of the 1.5 m high corrugated sheets attached to the salt wall at the bottom of each 6 m pour. Grouting was done in two stages. The first was cement grout, and the second was chemical.

Before injecting any grout, all 400 holes were drilled through the concrete wall and the corrugated metal to a minimum distance of 0.5 m into the salt. The cement grout was made up with saturated brine to ensure a bond with the salt as well as non-shrink characteristics. The water/cement ratio was kept low to reduce bleed. Injection started at the bottom of the lining extension and proceeded through to the top. In each pour each of the 8 holes in the bottom ring was injected first, but any hole that coupled was not injected. The procedure was repeated for the top ring. All pours were treated in the same fashion. All holes were pressured to 3 MPa, the maximum permitted by the wall design.

All holes were redrilled to a depth of 0.5 m into the salt before injection with chemical grout. The grout employed was a low viscosity acrylamide made up with saturated brine. Injection procedures and pressures were the same as with the cement grout.

The grout program was completed by cleaning out all grout holes, dry packing, and installing a stainless steel plug with greased threads in the grout pipe.

PERFORMANCE

Dynatec was awarded the contract for the construction of the lining extension on December 1, 1989, for a fixed price of $500,000.00 and completion in nine months. One month was added to the schedule for an owner requested delay in starting the project. The project was completed on August 28, 1990, or ten months after award.

On completion of the project there was no evidence of leakage through the concrete at any location in the liner extension. However, in 1991 a minor seepage was observed through a construction joint in the concrete wall approximately 120 m above the bottom of the lining extension. The leak was sealed by drilling through the adjacent grout pipes and injecting acrylamide grout. Test drilling through grout pipes over the full height of the extension showed no evidence of water flow at any other location.