THE TUNNEL SEALING EXPERIMENT: AN *IN SITU* DEMONSTRATION OF TECHNOLOGIES FOR VAULT SEALING

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ABSTRACT: A major international experiment, demonstrating technologies for tunnel sealing at full-scale, is being conducted at Canada's Underground Research Laboratory (URL) with participation by organizations from Canada, Japan, France and the U.S.A. Two bulkheads, one composed of high performance concrete and the other of highly compacted sand-bentonite material, have been be constructed in a tunnel in unfractured granitic rock at the URL. The Tunnel Sealing Experiment will characterize the performance of the two bulkheads under applied hydraulic pressures. The chamber between the two bulkheads will be pressurized to approximately 4 MPa, a value representative of the ambient pore pressures in the rock at a depth of 420 m. Instrumentation in the experiment monitors the seepage through and around each bulkhead as well as the changes to the pore water pressures, and hence changes to the flow directions, in the intact rock. Stresses and displacements in each bulkhead are also monitored. The objective of the experiment is to demonstrate technologies for construction of bentonite and concrete bulkheads and to quantify the performance of each bulkhead.

Introduction

The Underground Research Laboratory (URL) is a geotechnical research and development facility constructed by Atomic Energy of Canada Ltd. (AECL) as part of Canada's Nuclear Fuel Waste Management Program. The URL, located in southeastern Manitoba, is constructed in the Lac du Bonnet granite batholith and provides a representative geological environment in which to conduct large-scale multidisciplinary experiments. Results from research at the URL are being used in the assessment of the feasibility and safety of deep geological disposal of nuclear fuel waste.

Many countries (Canada, Japan, France and the United States among them) are each developing concepts for the deep geological disposal of radioactive waste materials. The safety of the respective disposal systems relies on the combined performance of the natural barriers (host rock) and engineered barriers (the waste form, the waste container, the buffer barrier, the room, tunnel and shaft backfill material). Concepts for deep underground disposal of radioactive waste, as advanced by many international organizations, include bulkheads or plugs in the shaft, or at the entrances to disposal rooms, or both. One requirement of the bulkheads is to act as a barrier to the flow of water, and hence the potential advective transport of radionuclides, through the backfill or near-field Excavation Damaged Zone (EDZ) in the rock.

The Tunnel Sealing Experiment has been designed to characterize the sealing potential of well-constructed bulkheads from the perspectives of both engineering performance and safety assessment. One bulkhead is composed of highly compacted sand-bentonite blocks, while the second has been constructed using Low-Heat High-Performance Concrete (LHHPC). The region between the bulkheads was filled with sand and water, which will be pressurized to a magnitude of pressure similar to the ambient pore pressure in the far-field rock. The experiment has been constructed at a depth of 420 metres below the surface in an unfractured rock mass, where the ambient pore pressure is approximately 4 MPa.

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The objectives of the experiment are to assess the applicability of technologies for construction of practicable concrete and bentonite bulkheads; to evaluate the performance of each bulkhead; and to identify and document the parameters that affect that performance. The experiment was designed to characterize an achievable bulkhead performance using currently available technologies. In this context, performance of the Tunnel Sealing Experiment bulkheads is defined as the ability of the bulkheads to restrict the flow of water in the axial direction of the tunnel. In a repository, however, the ability of a seal to limit the transport of radionuclides is of greater importance than simply limiting the flow of water. In the Tunnel Sealing Experiment, therefore, a tracer solution will be injected into the water supply to aide in determining relevant transport properties of the bulkhead-rock sealing systems. Information gained from this experiment can be used to set performance criteria for seals for safety assessment analyses of repositories. The end product of the experiment will be information that can be used in engineering design and safety assessment of sealing systems for used fuel waste, non-heat generating radioactive waste and low-level radioactive waste repositories.

The design and construction of the experiment itself has equal importance as the measurements taken during experiment operation. Elements of the experiment design include not only the construction of the clay and concrete bulkheads but also the excavation of the tunnel and bulkhead keys. Currently, the construction of the experiment is complete. The water injected into the region between the two bulkheads will be pressurized slowly over a five month period and operation of the experiment at full pressure will last for approximately one year. This paper summarizes the design and construction of the experiment and the plans for experiment operation.

Conceptual Design

The configuration for the Tunnel Sealing Experiment is presented in Figure 1. In this experiment a sand-filled pressure chamber (the test tunnel) is confined by the rock and two outer bulkheads. One bulkhead has been constructed of highly compacted bentonite-based material. The swelling of this bulkhead is confined by the sand in the test chamber on one side and by a structural steel restraint on the other. The second bulkhead has been constructed of concrete. The concrete developed at AECL over the past seven years has the properties of high strength, low heat of hydration, low shrinkage and low pH, all of which are desirable for use in nuclear waste disposal. It is generally referred to as Low-Heat High-Performance Concrete. The test chamber dimensions are representative of a full-scale excavation in a repository. The shape and width-to-height ratio of the tunnel was selected to limit the EDZ under known *in situ* rock stresses. The concrete and bentonite bulkheads were keyed into the rock to cut off flow through the EDZ, and a bentonite-based grout has been injected into the EDZ near the clay bulkhead (Masumoto et al. prep). A cement-based grout will be injected into the concrete bulkhead-rock interface should there be evidence of leakage along this interface.

Excavation and Rock Engineering

Rock engineering is an integral component in the design of a bulkhead-rock sealing system. Designing an excavation to limit the amount of fracturing occurring in the rock as a consequence of the tunnel (or shaft) excavation, will have the beneficial effect of reducing the number of the potential pathways for contaminant transport. The Excavation Damaged Zone is generally defined as the region of rock adjacent to an excavation which has undergone irreversible changes to the basic properties of strength or deformation moduli. In brittle, crystalline rock, such as granite, these changes can only be brought about by cracking. The cracking could be microscopic, by inducing new microcracks or lengthening existing ones. In

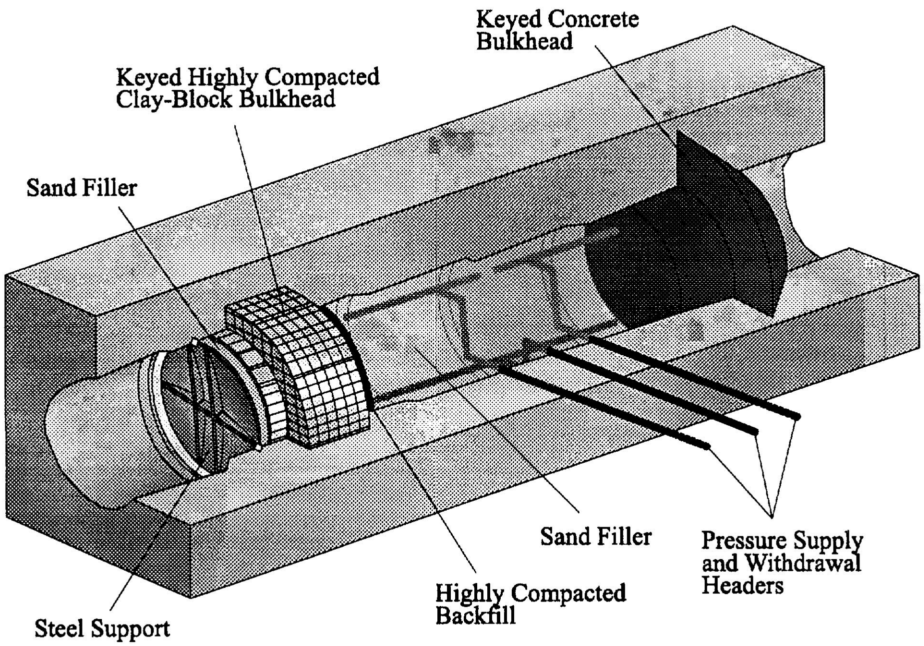

Figure 1: Configuration of the Tunnel Sealing Experiment

the other extreme, the damage may be in the form of new macroscopic fractures tens of cm in length, induced by stress redistribution or as an end result of blasting. If occurring in sufficient density, the microcracks will have an effect on the long-term strength of the rock; however, a much greater crack density is required to affect the rock's hydraulic properties.

Tests on the connectivity of excavation-induced fractures have been conducted in the floor of tunnels excavated using drill-and-blast and mechanical techniques (Chandler et al. 1996). These tests have shown that damage from high compressive stress concentrations or from blasting will provide pathways for the flow of water. In the extreme case, the excavation of tunnels in a highly stressed rock mass may result in the creation of zones of intensely fractured rock near the tunnel surface (Read 1996). Although these zones can be relatively small in cross-sectional area, less than 0.1 m^2, the hydraulic conductivity can be increased by more than 6 orders of magnitude. If the tunnel shape and alignment is optimized to reduce the compressive stress concentration below a magnitude indicative of the rock's *in situ* strength, visible fracturing caused by stress redistribution, and the associated effect on hydraulic conductivity, can be greatly reduced or eliminated.

The alignment of the Tunnel Sealing Experiment test tunnel is parallel to the direction of the maximum principal stress in the rock. Orienting the test tunnel in this direction induces lower compressive stress concentrations at the tunnel periphery than aligning the tunnel perpendicular to the maximum principal stress azimuth. Experience at the URL shows that stable tunnel geometries can be excavated regardless of the tunnel alignment. However, a tunnel aligned parallel to the maximum stress direction will require a smaller aspect ratio (width to height) to ensure the maximum compressive rock stresses in the roof and floor is below the magnitude which causes unstable failure.

The test chamber has a 3.5-m-high by 4.375-m-wide elliptical cross section, and an aspect ratio of 1.25. The peak compressive boundary stress around this room is 105 MPa, and the minimum boundary stress is about -0.5 MPa (tension) in the walls. The cross-sectional dimensions of the test chamber are large enough to be representative of a repository room, allowing the sealing technologies to be tested at full-scale. It is interesting to note that if the tunnel were aligned perpendicular to the maximum principal *in situ* stress, the width-to-height ratio for a stable elliptical opening would have been 2.25 or greater. The test chamber was excavated using a full-face drill-and-blast technique, using blast patterns and sequencing that was optimized during excavation of tunnels which accessed the Tunnel Sealing Experiment area. No special construction methods were employed beyond the controlled blasting techniques used for any of the excavations at the URL.

Keyed Bulkheads

A preliminary investigation of blast-induced fractures observed on the walls of a few excavations at the URL concluded that visible blast-induced fracturing was more apparent where the stresses in the rock were tensile, or in very low compression. A small number of blast-induced fractures were over-cored to measure fracture length. The longest fracture trace was approximately 0.8 m, however all other overcored fracture traces were less than 0.5 m. No tests have been conducted to assess the transmissivity of blast-induced fractures, however, hydraulic tests in the floors of tunnels excavated using drill-and-blast techniques measured increases of hydraulic conductivity of up to three orders of magnitude within 0.5 m of the stable floor. Beyond 0.5 m the measured hydraulic conductivities were similar to the conductivities measured for intact rock several metres away from an excavation.

A 1 m deep excavation key, therefore, can interrupt virtually all the stress-induced and blast-induced damaged rock zones around the tunnel (Martin et al. 1996). However, there are potential difficulties in placing material (either concrete or clay blocks) tightly against the excavation surfaces and up to the top of the keyed excavation. Also, it has been argued that the process of excavating the key could create a new damaged rock zone outside the key. All issues considered, it is believed that the alternative of having no key has a much greater potential for measurable flows of water through blasting-induced fractures, than if the tunnel bulkheads were keyed through the EDZ. In the Tunnel Sealing Experiment new damage around keys was minimized by avoiding drill-and-blast excavation during key construction. The keys were excavated by first drilling overlapping boreholes around the perimeter of the key, and then breaking the rock out from between the lines of boreholes using hydraulic rock splitters.

Considerable numerical modelling was conducted to evaluate the optimum shape for the two bulkhead keys (Billaux 1997). In the end it was decided that best shape for the keys would be different for the two different bulkhead materials. Numerical model results suggested that a combination of steeply angled (45° to 60°) and vertical faces on the keys were optimum for interrupting zones of both shear induced and tensile stress induced damage in the rock. It was also believed that the rigid concrete bulkhead would be better able to transfer some of the load from the pressure chamber onto the rock using a conical shaped bulkhead and key (Figure 2). This transfer of stress was not as apparent for the less rigid clay bulkhead. For rotational stability, it was decided that the concrete bulkhead should be at least as long as it is high. A cylindrical shaped-key for the clay bulkhead would better facilitate maintenance of a level construction surface for placement of the rectangular-shaped pre-compacted clay blocks (Figures 2 and 3). The two bulkheads, therefore, have both different shaped keys, and different lengths.

Clay Bulkhead

The clay bulkhead material is a mixture composed of 70% Kunigel V1 bentonite clay and 30% graded silica sand. The same composition of Kunigel V1 and sand was previously used in a large scale experiment at the Big-Bentonite (BIG-BEN) facility in Japan (Fujita et al. 1996). An important element of the Tunnel Sealing Experiment is to investigate the practicality of emplacing massive clay-based tunnel seals in a full-scale excavation. The tunnel seal involved

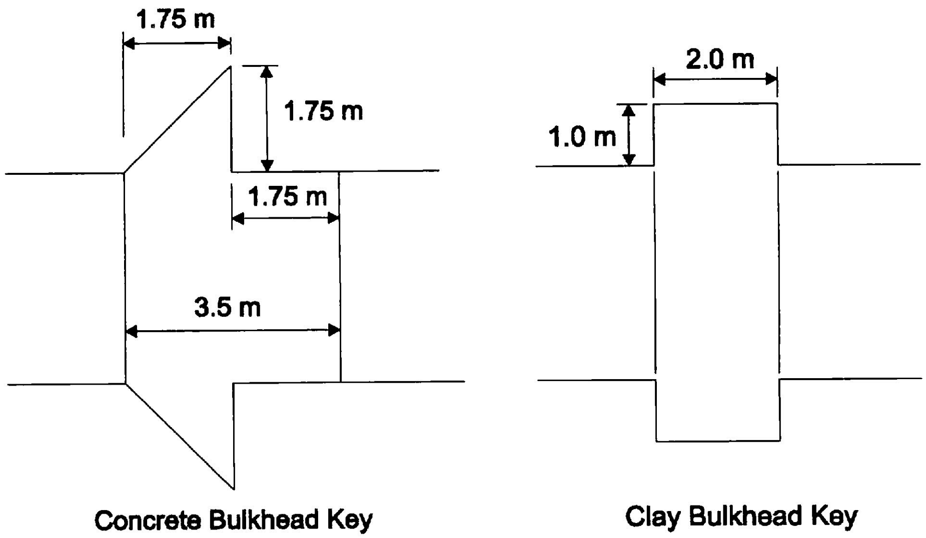

Figure 2: Shape of Concrete and Clay Bulkhead Keys

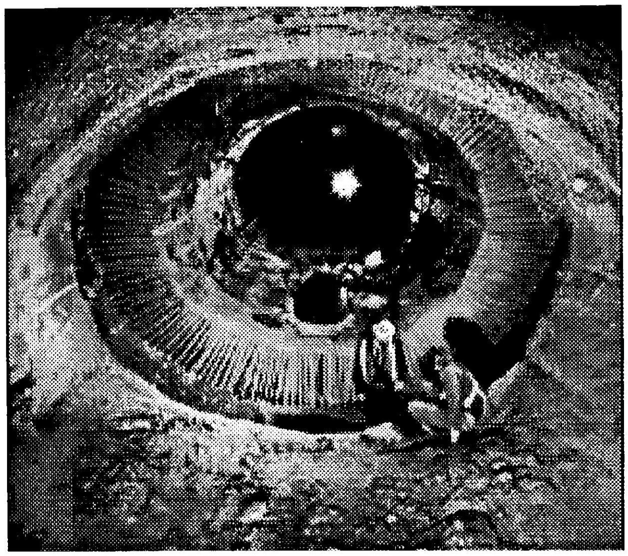

Figure 3: Photograph showing the excavation of the test tunnel and the clay bulkhead key

placement of 61 m^3 of densely compacted sand-bentonite material under conditions of constrained geometry. Three techniques were possible for bulkhead construction: *in situ* compaction of the sand-bentonite material; placement of precompacted blocks; and pneumatic placement of granulated bentonite or bentonite-sand mixtures. In the Tunnel Sealing Experiment the primary technique for material placement was the use of pre-compacted blocks, however a pneumatic placement technique was used to provide a thin cover of the clay material on the surface of the rock. The uniformity of material density and moisture content in the pre-compacted blocks and the quality control of the final product was better than for any *in situ* compaction techniques that were tested. Blocks which did not meet quality control specifications could simply be discarded before installation whereas the removal of lifts of compacted material would have had a damaging effect on the experiment bulkhead. Also, since there are 235 instruments within the clay bulkhead, it was deemed that *in situ* compaction would have a greater potential for damaging the sensors or their leads during construction.

The blocks installed in the clay bulkhead have nominal dimensions of 0.1 m by 0.36 m by 0.17 m. Approximately 9000 blocks were used in the construction of the bulkhead. The target dry density for the material was 1.9 Mg/m^3. At this density, the pressure exerted by the bentonite when it becomes saturated and swells is about 1 MPa, and the material will have a hydraulic conductivity of about 10^{-12} m/s. The clay and sand components were blended in 2 Mg batches and moisture conditioned to a gravimetric moisture content of 14.5%. The blocks were fabricated in a modified Adobe block compactor (Figure 4). The compaction machine was previously used to fabricate compacted blocks for the small-scale sealing tests at the Waste Isolation Pilot Plant (WIPP) (Finley and Tillerson 1992). The compactor produced the blocks by static compression of the loose material. The compaction machine produced blocks having very uniform distributions of density and moisture content, with smooth planar surfaces. The blocks themselves were rugged; the edges or corners did not readily break when dropped. A total of almost 14,000 blocks were produced for use in the experiment and in construction trials and simulations. Although the block making machine was designed for faster operation, good quality blocks were produced at a rate of approximately 2 blocks per minute.

The excavated surface of the rock was rough in the vicinity of the clay bulkhead (Figure 3), and a shot-clay material was applied to this surface to facilitate making a smooth contact between the blocks and the rock. The shot clay material was fabricated by first air-drying and crushing compacted clay blocks into particles of 10 mm diameter or smaller, and then returning the material to the mixing machine to "round" off the corners of the particles. This material was then pneumatically sprayed into place using conventional shotcrete equipment. The operator added water to the shot-clay at the nozzle of the sprayer to produce a material that would stick to the walls and have consistent and relatively compact characteristics. The applied dry density was approximately 1.3 Mg/m^3 at a moisture content of 22% and the thickness of the shot-clay varied from 5 to 60 mm depending upon the roughness of the rock surface. The shot-clay was applied pneumatically at a rate of approximately 100 kg/min.

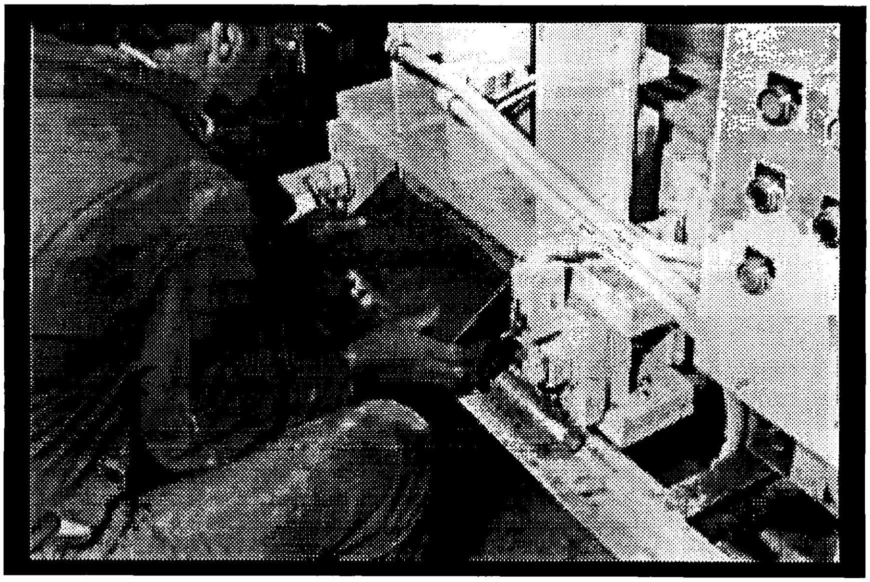

Figure 4: Photograph showing block fabrication

The blocks were placed in the bulkhead by hand (Figure 5). The pattern of block placement is shown in Figure 6. Most of the instrumentation was installed on or near the surface of the rock or in 7 major horizontal layers. In this arrangement, large volumes of the bulkhead were free of instrumentation or their cables, and the rate of block placement in these regions was approximately 30 blocks per hour. If gaps were visible between adjacent blocks, no matter how small, a powdered bentonite-sand mixture was applied into the gap. During fabrication of the blocks, every tenth block was tested to determine dry density with the average block dry density being 1.92 Mg/m^3. The estimated dry density of the assembled bulkhead, based on the weight of blocks used less the weight of cuttings and scrap material, was 1.89 Mg/m^3. In the final stage, an assembly of 80 blocks (approximately 1 Mg mass) was pushed up into the remaining open space at the top of the clay bulkhead key using forklift-style forks on an underground scooptram.

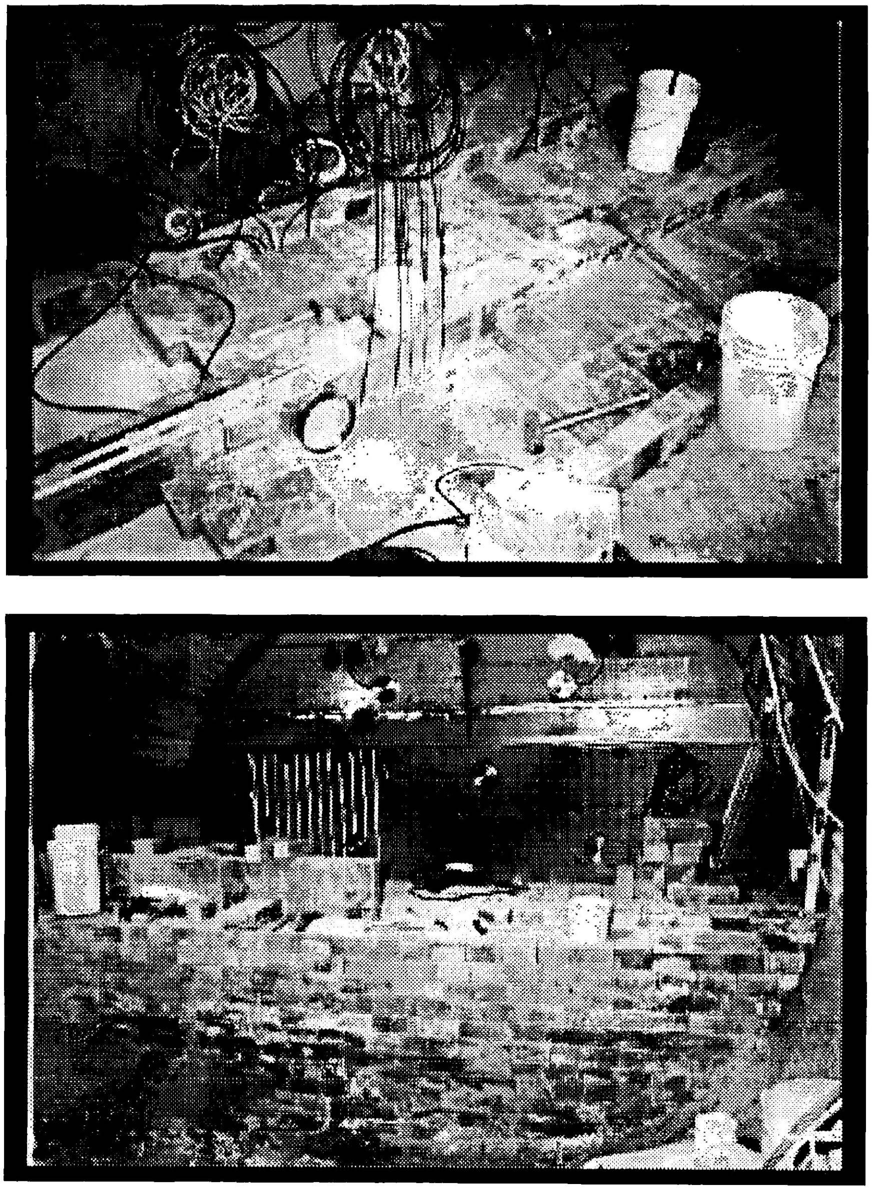

Figure 5: Photographs showing clay bulkhead construction

Clay Bulkhead Restraint

In order for the clay blocks to generate swelling pressure upon saturation, the material must be constrained against volume expansion. Towards the inside of the experiment the bulkhead is constrained by the sand fill in the pressure chamber. This sand was compacted in 150 mm lifts using a vibratory plate compactor. In the top third of the excavation, where there was insufficient room for the compactor to be used, the sand was placed pneumatically. For the material immediately adjacent to the bulkhead, a proportion of 10% bentonite by mass was added to the sand to allow it to be placed at higher densities, therefore having a greater resistance to swelling. Also, inclusion of the clay inhibits the extrusion of the bentonite from the bulkhead into the sand. The 10% bentonite material was placed using both dynamic compaction in layers and pneumatic emplacement.

Towards the outside of the experiment the resistance to the clay bulkhead expansion is provided by a rigid steel restraint system. The restraint system was designed to resist the combined loading of 4 MPa of hydraulic pressure and 1 MPa of swelling pressure. The restraint system was essentially an elongated hemispherical steel shell, with a minimum plate thickness of 25 mm, that transferred the load outward onto a high strength concrete bearing pad (Figure 6). The concrete bearing pad, in turn, was recessed into the rock and secured to its surface by rock bolts. A stainless steel plate and sand fill was used to transfer the load uniformly from the clay bulkhead to the steel shell.

Concrete Bulkhead

Portland cement based concretes are one of the most widely used construction materials, and are particularly suitable for the construction of water retaining structures. Concrete possesses the highly desirable properties of high compressive strength, ease of construction, rigidity, and low permeability. It is the material of choice for hydraulic applications such as water storage tanks, water and sewer pipes, tunnel linings, massive dams, and countless other applications. However, there are some concerns regarding the long term chemical interactions between

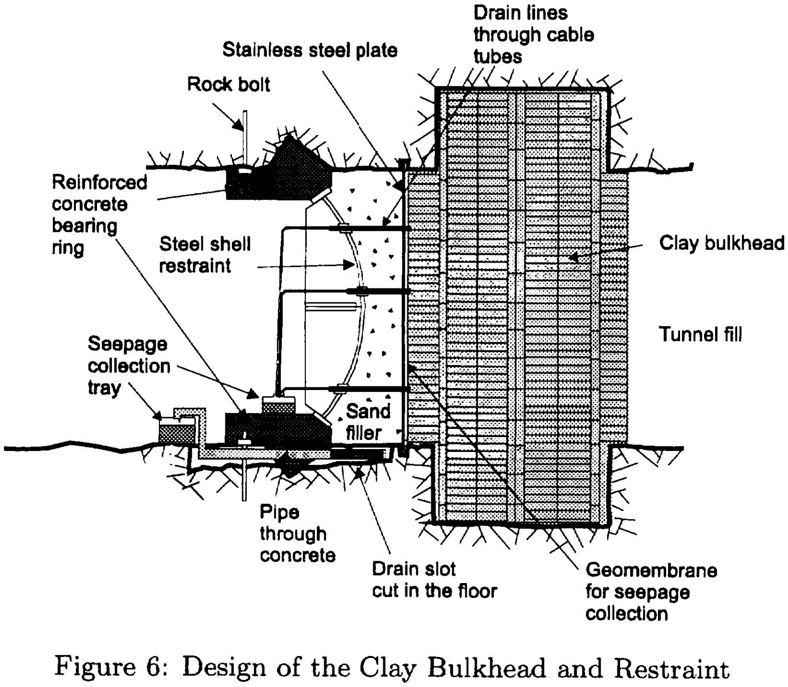

Figure 6: Design of the Clay Bulkhead and Restraint

clay-based and cement-based sealants. The concerns relate to the potential reduction in swelling pressure of the bentonite-based sealants when penetrated by alkaline water, such as that which might be released from submerged conventional Portland cement based concretes.

The concrete material proposed for the Tunnel Sealing Experiment falls into a category known as high-performance concrete (Gray and Shenton 1998). Typically, these materials are characterized by a 28-day unconfined compressive strength greater than 70 MPa. Due to the characteristics of the cementing pastes, these materials tend to have lower hydraulic conductivity and better durability characteristics than conventional Portland cement-based concretes. Normally, high performance concretes contain more portland cement than, and are at least as likely as conventional concrete to release alkaline waters which may affect the sealing properties of bentonite-based clay sealants. The new high-performance concrete being used in the Tunnel Sealing Experiment and proposed for use in a disposal vault for radioactive wastes does not contain these high cement contents.

The new concrete was originally developed for its low-heat of hydration. Accordingly, the material is named Low-Heat High-Performance Concrete (LHHPC). The low heat of hydration was needed to facilitate manufacture and placing of the materials in high-mass structures, such as the bulkheads. Consequently, special precautions would not be required to limit the maximum temperature in the concrete and to minimize the effects of high curing temperatures on the performance of the bulkheads, the host rock, the clay barriers and interactions between these components. The LHHPC is produced by the replacement, in substantial part, of Portland cement by pozzolanic silica fume and non-pozzolanic silica flour. The workability of the product is provided by the introduction of a naphthalene based superplasticizer. Coarse and fine aggregates can be the same as those used in conventional concretes. With the low cement content, the LHHPC has a pH of less than 10, while the pH of conventional concrete is 12.4 or higher. The LHHPC has little or no free lime (calcium hydroxide portlandite) and hence, will not have adverse chemical reactions with bentonite clays. The hydraulic conductivity of the concrete is 10^{-12} m/s or less. The high strength, low hydraulic conductivity, low heat of hydration, and low pH, make the LHHPC an ideal material for use in repository design, particularly when the concrete is to be used in close proximity to swelling clays.

Prior to placement in the concrete bulkhead, the LHHPC was tested extensively in the laboratory and in the casting of a 20 m^3 block. The tests examined, among other properties, the strength, durability, and shrinkage characteristics of the concrete. At 28 days, the strength of LHHPC exceeds 70 MPa and continues to increase with time. Of high importance to the experiment, are the shrinkage properties of the concrete. If the concrete-rock interface was to break as a consequence of shrinkage, apertures between the concrete and the rock will have a large effect on potential flow past the bulkhead. It is recognized that all Portland-cement based concretes have a tendency to shrink during setting and hardening. To investigate the shrinkage of LHHPC tests were conducted in which the concrete was immersed and cured continuously in water; immersed in water for 7 days then dried in air, and wrapped in foil and sealed from the atmosphere. The tests show that when LHHPC is placed in water 1 day after casting, the concrete initially and rapidly expands, and this expansion was greater than for the normal or standard high performance concretes that were tested.

The concrete bulkhead was constructed in two stages. First, a 250 mm thick wall of LHHPC was cast to provide an inner wall against which the larger concrete bulkhead could be poured. The wall included an opening large enough to facilitate completion of the placement of sand fill between the bulkheads and removal of the forms for the wall itself. Later the opening was filled with a second placement of concrete. A steel and timber outer form was constructed which allowed the concrete to be pumped up into the upper regions of the keyed bulkhead with an overpressure of about 100 kPa, which was sustained until the concrete set. To further limit the effects of shrinkage, the form included a geotextile lining on its inner face to provide a continuous supply of water during curing of the concrete bulkhead. No structural reinforcement of the concrete bulkhead was required. Cast within the bulkhead are about 130 sensors detecting deformations, temperatures, pore water suctions, interface displacements, and acoustic properties. These sensors and their cables were secured during placement using a minimal quantity of rigid glass fibre rods.

The cement was blended, batched and bagged for use in pre-weighed quantities. The dry aggregates were similarly and separately prepared. Both the fine and coarse aggregates were derived from a glacial deposit and were mostly of granite origin. The coarse aggregate had a maximum particle size of 10 mm. The concrete was mixed in batches of 1.6 m^3 in a static drum, rotating blade mixer, with a maximum capacity of 2 m^3 (Figure 7). The mixer was located within the surface facilities of the URL, and the concrete was discharged directly into a rail car which was used to transport the material underground via the URL shaft hoist. Underground, the contents of the rail car were emptied into a pump which delivered the concrete the last 10 m horizontally to the concrete bulkhead. The volume of the concrete bulkhead is estimated at 68 m^3.

Experiment Instrumentation

The primary measure of bulkhead performance is the rate of water seepage past either bulkhead. To monitor this flow, the volume of water flowing into water collection reservoirs located immediately downstream of the two bulkheads will be measured. In addition to these measurements, instrumentation has been installed in the rock, the clay and concrete bulkheads, as well as in the sand fill between the two bulkheads. In all, over 700 sensors have been installed in the experiment. Instrumentation includes boreholes fitted with packer systems which isolate a volume of rock and monitor the pressure of the pore water, and sensors used to monitor acoustic emissions and acoustic velocities in the rock and in the concrete bulkhead. In the clay bulkhead there are sensors which estimate the amount of water in the pore space of the clay blocks, the pressure exerted by the swelling clay against the rock surface, and the displacement of the clay blocks themselves. The hydraulic pressure of the water between the two bulkheads is monitored, and electrical conductivity sensors have been

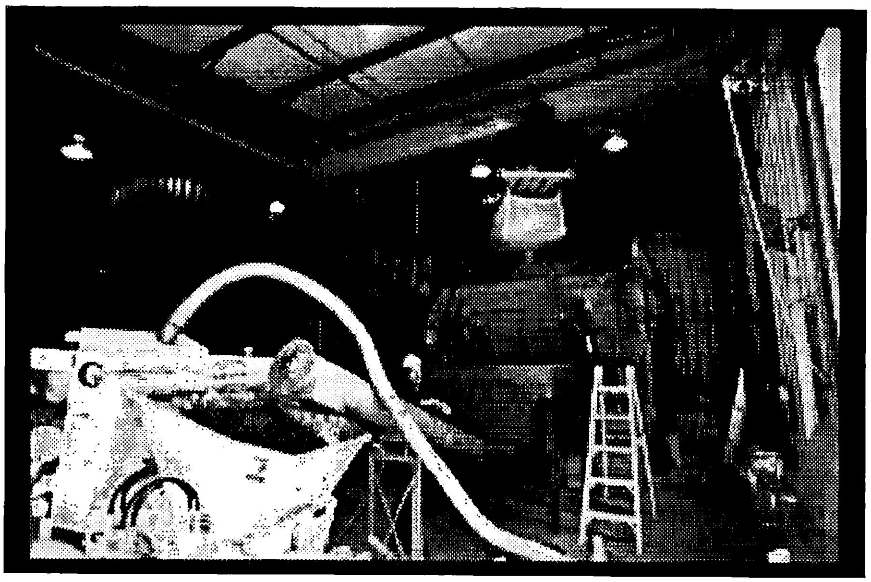

Figure 7: Photograph showing concrete mixer auger and pump as used in large block trials

installed to monitor the concentration of tracer ions in the supplied water. The movement of the tracer will be monitored in an effort to determine the properties of the bulkhead that affect the transport of contaminants. The measurement of strain in hardening concrete is more problematic than first envisaged and different types of strain gauges (vibrating wire, fibre optic and laser) have been included in the design for the purpose of sensor comparison.

The data acquisition units are located underground, in the rooms adjacent to the two bulkheads. Data from the large majority of instruments are being recorded hourly, although the rate of data acquisition for many instruments will be reduced as the experiment progresses. The data is transferred to a main database, which resides on the surface of the URL, and this database is backed-up on a daily basis.

The routing of the cables for this instrumentation was not trivial since every cable could create a potential pathway for water movement through the bulkhead seal. To limit the potential impact of the cables on the measured flow, no cables were run completely through either bulkhead. Cables from the sensors within the chamber between the bulkheads, and water supply headers, were run through boreholes drilled in the rock to adjacent excavations. In the clay bulkhead, there are 235 instruments installed, however, no two cables were run through the clay together, and grooves were carved in the clay blocks for each cable route. Every instrument was sealed and pressure tested to 4 MPa to prevent the cables themselves from acting as conduits and at least one seal was placed on the outside of every cable to prevent fluid flow between the clay block and the cable lead. All the cables in either the concrete or clay bulkhead were run through the interior of the bulkhead to minimize the potential effect on interface flow. Considering the low porosity and low permeability properties of LHHPC, the concrete itself was believed to provide optimum sealing for the instruments and cables installed within the concrete bulkhead, and no additional seals were included.

Experiment Operation

The plan is to conduct the experiment in two phases. The first phase being the pressure test, and the second phase referred to as the thermal test. In the pressure test, water will be supplied to the chamber between the two bulkheads at a pressure of 4 MPa. In the thermal test, the pressurized water will be further heated to 85°C to simulate the heat generated by the radioactive decay of the waste. It is expected that the temperature increase will affect the stability of the rock surrounding the bulkheads, and also will increase the pore pressure in the warmer regions of the rock. The solid components of the concrete and sand-bentonite bulkheads will undergo thermal expansion with corresponding increases in stress, and the effect of this stress increase on bulkhead performance will be monitored.

The pressure test, which will continue until 2000, will also include two stages: the first being a condition of transient flow through the zone of damaged rock, and the second being a tracer test during conditions of near steady flow. There is a concern with respect to immediate pressurization of the clay bulkhead to 4 MPa. Experience from similar tests on clay suggest that if the clay were hydraulically loaded before any of the bentonite was allowed to saturate, swell and provide a seal against flow, then a possibility exists for high flows and possible erosion of the compacted clay blocks. A trial has been conducted in which an approximately one-quarter scale clay bulkhead was successfully pressurized incrementally over a 22-week period. The same pressure increments will be applied to the Tunnel Sealing Experiment. It is also expected that another three or four months will be required before near-steady flow conditions exist in the zone of damaged rock near the tunnel and around each bulkhead. Modelling suggests that saturation of either the clay or concrete bulkhead will not occur for a number of years, hence flow through the bulkheads is not a requirement of the experiment. In the tracer test, water having a distinct chemical signature will be injected into the pressurization system and this test is expected to last for six months or more. Water will be sampled downstream of the bulkheads and at a few locations around the two bulkheads. The water samples will be tested for tracer concentrations with the end result being a measure of tracer travel times. The tracer test results will provide a measure of the ability of the tunnel seals to inhibit the transport of water borne contaminants.

Summary

The Tunnel Sealing Experiment has been constructed at the Underground Research Laboratory. The experiment will test the performance of a concrete and a bentonite-based tunnel seal under the applied water pressure of 4 MPa. The design and construction of the two bulkheads, which is now complete, has equal importance in the experiment as the measurement of flow past the bulkhead and the response of the experiment's instrumentation. Although it is expected to be several decades before a nuclear waste disposal facility will be closed and sealed, this experiment has already provided a demonstration of the technologies that can be applied to repository sealing.

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