Art, Animals, and Architecture: Shotcrete Builds the National Aquarium in Baltimore

by Dave Knipe

It has been widely known for several decades that shotcrete is an ideal material for constructing naturalistic habitats for animals. When fresh concrete is freed from the constraining requirements of a rigid form, it can be shaped and carved in much the same way a sculptor handles clay or a piece of marble, but on a dimensional scale that is only limited by money or imagination. Shotcrete is also an incredibly versatile building material, which means it can serve many purposes on a project that ambitiously demands the blending of architecture, engineering, and aesthetic innovation.

America's National Aquarium is located in Baltimore, MD. The designers for the recent Pier 3 Expansion project aspired to replicate the watershed forest of rural Maryland and, in contrast, the dramatic canyons of eastern Australia to showcase the diversity of aquatic species in its extensive collection. This required building a structure that included 50-ft-tall waterfalls and rock cliffs that rose more than 80 ft from the lobby floor. This artificial wilderness was constructed from reinforced concrete clad with sculpted shotcrete, and it is housed inside a strikingly modern, 10-story glass-walled cube. Inside the cube, crocodiles, kookaburras, and monitor lizards coexist well in exhibit habitats comprised of shotcrete rocks with shapes and colors so realistic to their intended geology that they confound the uninformed visitor as to how they came to be placed inside a glimmering glass tower with foundations firmly planted below the Inner Harbor of downtown Baltimore.

NAIB's exhibit buildings are built on piers below the Inner Harbor of downtown Baltimore

The National Aquarium in Baltimore's recent expansion included creating monumental shotcrete mountains inside a contempory glass building

The logistical nature of the construction of large public aquarium building projects is tremendously complex, requiring the interfacing of most conventional building trades with the added disciplines of animal husbandry, life-support plumbing and filtration, waterproofing for tanks and pools, massive interior plantscapes, and the replication of natural forms through the innovative use of shotcrete and composite materials such as fiberglass and epoxy resin. But aquariums like the one in Baltimore are consistently popular choices for American communities as focal points for urban rebuilding programs, such as those recently constructed in Pittsburgh; Miami; Atlanta; Camden, NJ; and Long Beach, CA. This was the motivation behind the concept that the expansion of the National Aquarium should be both spectacular and unique in scope.

The National Aquarium in Baltimore (NAIB), contracted in 2002 with Aqua Venture (a local joint venture between two large general contractors, Whiting-Turner and Barton Malow) to manage the construction of the building, was budgeted originally at over $50 million. A specialty subcontractor with headquarters in Tucson, AZ, Cemrock Landscapes, Inc., was contracted for the habitat construction, which included approximately 60,000 ft^2 of hand-carved shotcrete artificial rockwork and dozens of large artificial trees and plants. Cemrock was involved as a consultant during the design development phase to assist in feasibility planning, budgeting, and scheduling. It was clear that the shotcrete work for the project would be critical because Cemrock would be responsible for the final appearance of a majority of the finished surfaces.

Cemrock had extensive experience in the construction of numerous previous zoological

Shotcrete rockwork is directly adjacent to delicate exterior glass walls. Massive pockets in the rock formations will accommodate plants and trees

Shotcrete rockwork formations rising to a level of over 80 ft above finish floors also camouflage mechanical ducts and vent openings

projects, but the challenge of the Pier 3 Expansion was unprecedented. The shotcrete rockwork would house or conceal all of the structural building core, the sophisticated and cumbersome heating, ventilating, and air conditioning (HVAC) ducting, life-support plumbing, and electrical raceways and conduits. The work of placing structural concrete is an invasive process that necessitates the protection of vast areas of adjacent work, but this project would be built inside the footprint of a multi-story building, in places within inches of delicate glass panels supported by expensive stainless steel tension systems.

Elaborate scaffolding and temporary stair systems were erected inside the building as staging for the shotcrete operation. These assemblies had to be constantly maintained, deconstructed, and moved repeatedly to access the evolving, complex shapes of the rockwork cliffs. Shotcrete rock formations were manipulated to camouflage air conditioning vents, plumbing penetrations, and air-handling units as well as zookeeper doors and hatches within the animal exhibits that had to appear as natural parts of the synthetic geology.

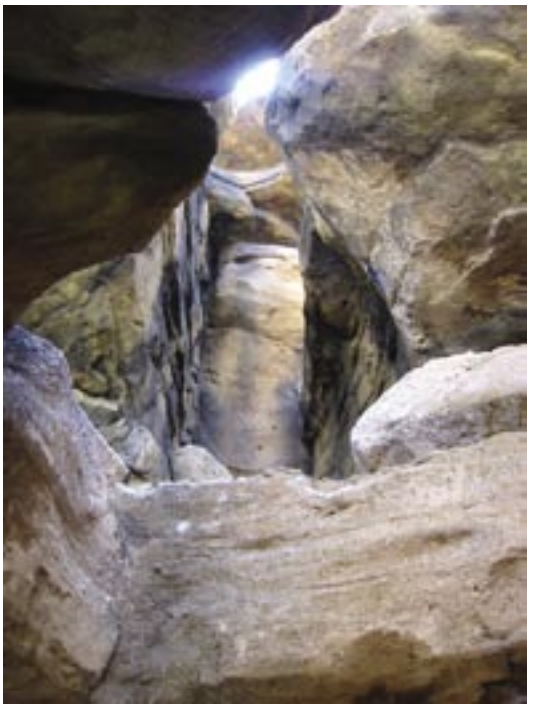
It was decided that the best documentation for the intended shape of the shotcrete rockwork would be a 3/8 in. = 1 ft scale model, which was created by the Aquarium staff using artist's oil clay, which itself weighed nearly 200 lb. The shotcrete work was extensively reviewed by Cemrock's structural engineer prior to construction. Over 1500 yd^3 (1150 m^3) of shotcrete rockwork had to be constructed so as to carry structural loads evenly over the building walls and foundations. Complicated armatures of reinforcing bar were epoxy-anchored to cast walls then bent by hand to create the rough shape of the rocks. Expanded metal lath was used as a backing for the shotcrete, which had an average thickness of 6 in. (150 mm). The rock shapes were governed

Shotcrete is applied over hand-bent reinforcing bar shapes then "carved" and painted to resemble the desired geology

by the scale model, which had to be reviewed many times each day for fidelity to the design, which meant hundreds of trips up and down the scaffolding for Cemrock's artistic supervisors. The rough structural form was covered with concrete plaster that was carved, trowelled, brushed, and raked into uncanny replications of natural rock. The shotcrete rock was colored with the use of integral colors and multiple, thin layers of acrylic latex paints. Special attention had to be given to large planter areas in the rock cliffs, maintaining and augmenting the waterproofing for the structures, and the construction of extraordinary features such as rock bridges, ledges, and heaped boulders.

The shotcrete work began in December 2003 and was completed in August 2005. The project schedule was compressed, working backward from an end date that had to accommodate several months for water quality testing, air balance, plant growth, and acclimatization for sensitive animal

Shotcrete artificial rockwork cliffs combined with artificial vines and roots resemble water-worn canyons of Australia



Masterful craftsmanship in shaping shotcrete formations is evident in a synthesized overhead crevasse

species to their newly-synthesized environments. All exhibits were continuously attended to from start to finish, despite delays due to winter weather and the inevitable changes to the design.

NAIB is already beginning phased openings of the Pier 3 Expansion Project, with a grand opening scheduled for December 2005. Once inside, the exceptional efforts of the shotcrete contractor are evident to the visitor. Exotic parrots and other birds are enveloped by a nearly invisible series of nets with anchors disguised inside the artificial rock.

Artificial rockwork creates a realistic backdrop for a future waterfall in the Maryland exhibit area

Lungfish and turtles bask under heat lamps cleverly secreted from public view by cantilevered boulders. The top margin of one large reptile tank runs alongside a keeper pathway that is shrouded by the curving trunk of an artificial tree over forty feet in length. An artificial fir tree juts from a vine-encrusted cliff that springs up from a pool filled with game fish indigenous to Maryland waterways.

The arduous task has resulted in an edifice that will stand as an architectural phenomenon, one of the most original and overwhelming zoological habitats ever created.

Dave Knipe *resides in Tucson, AZ. He has developed technological programs for numerous companies that use concrete and composite materials. Knipe is an accomplished writer and musician, an amateur auto mechanic, and a paralegal assistant. He currently is the Assistant Director of Cemrock Landscapes, Inc., an award-winning builder of naturalistic environments, where his responsibilities include estimating and job costing. Knipe also provides consulting services to other private clients.*