Natural Fit

By Bill Drakeley

As I sat through a seminar highlighting contemporary organic architecture, the realization occurred that shotcrete construction is a seamless fit to this design philosophy. The principal of design of America's most famous architect, Frank Lloyd Wright, was that of organic architecture. These concepts were based on what nature creates. Wright's designs were to be site-appropriate with respect to their materials and surroundings. Form was to have function. It was not only to be functional but also efficient. John Lautner, a disciple of Wright, used this design principal as his foundation. Real architecture in Lautner's practice was that it is as it looks—real materials, real settings. The structural assemblies were not fake or made to look like something else. They were natural solutions to reduce the amount of energy needed or used (that is, stone, wood, wind, solar, glass, and so on). The shapes of structures were either straight or curved, based on client wants and needs. The architecture was a living space meant to fit within its natural surroundings.

Now, the question you may be asking yourself as you read this architectural rambling is, "What does this have to do with swimming pool shotcrete?" Frank Lloyd Wright, John Lautner, and Helena Arahuete (Lautner's apprentice and now head of Lautner Associates) all consider concrete to be a symbiotic and natural component of their structural designs. Concrete is an organic design material made with natural ingredients. Using the advanced technologies of shotcrete, architects and designers have almost unlimited freedom in the creative aesthetics of their concrete structures. Without the need of heavily reinforced two-sided forms, shotcrete completely removes many barriers on shape and thickness imposed by casting concrete members. Many of the evolving living space concepts created by innovative architects now use shotcrete as a means of placing materials, not only for structure but also for architectural looks. The first vanishing-edge swimming pool was built in the late 1950s and designed by John Lautner. The vanishing edge origin or concept, as described by Lautner, was a simple "continuation of space." Keeping this design concept prominently in mind, our company helped the design team on a current project realize a pool's potential with significant enhancements in overall scope. This article will describe the job evolution.

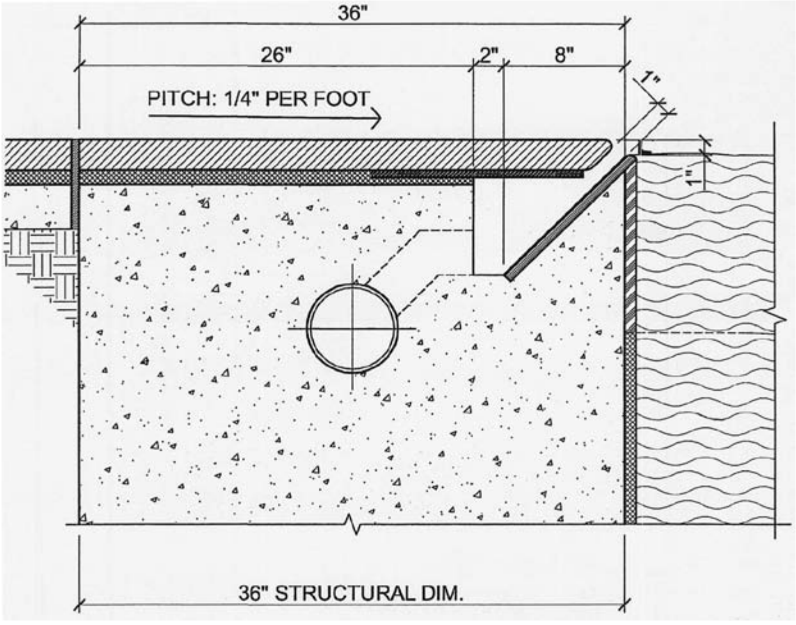


Fig. 1: Lautner edge section. Scale: 1.5 in. (38 mm) = 1 ft (0.3 m)

Redesign

This "continuation of space" premise is where the pool project shines. Drakeley Swimming Pool Company was chosen to build a perimeter edge overflow pool for a contemporary, artistic design firm in the New York countryside. The original plans showed an overflow pool with the idea of water elevation being near or equal to the deck height. Acknowledging the look that the design team was going for, we redesigned the original pool plan by removing a bulky underwater coping stone that visually highlighted the lower water elevation and pool perimeter to a new "Lautner Edge" (refer to Fig. 1). This edge detail is a knife-point gutter system allowing the coping to virtually touch the edge point with a small slot, allowing water to flow into a recessed channel. Having the water near deck level, without seeing an unsightly underwater coping and trough, is the continuation of space that the clients envisioned. Shotcrete was the only solution that allowed us to create this detail. Shotcrete, with its in-place compaction and inherently high strength, needed to be watertight not only for the pool vessel but also for the Lautner overflow design. Having variable thicknesses in a durable vertical edge element with consistent water flows simply would not have been possible with conventional concrete and hand casting.

Excavation

The general contractor informed us that they had blasted to a 9 ft (2.7 m) depth for the pool area over 10 years ago because of ledge rock. Our questions for the general contractor were:

- Did you remove the blasted material?
- Did you backfill the excavation with a quality fill?
- Was the backfill compacted in lifts?

The answers were "No, No, and um, er, ah, No." The parameters of the pool were 60 x 20 ft (18 x 6 m), with a deep end of 8 ft (2.4 m). Our excavation crews encountered unsuitable materials as we dug through the previously placed fill. It was all shot rock surrounded by clay/silt/fines that would not support a pool structure. We needed to find the bottom of the previously filled material and start from there. After 15 ft (4.6 m) of digging from form height, we finally found hard ledge rock (Fig. 2). A problem with this was that the overblast excavation area undermined an 8 ft (2.4 m) wall running along the pool side, as well as its footing, both of which were built prior to the pool construction. Our crews dug, then placed and compacted stone as we went from deep end to shallow (Fig. 3). This sequence allowed continued support for the freestanding wall as we progressed through the excavation. The compacted stone gave us a stable base on which to support the pool shell without movement or differential settlement. This is critical in any concrete/shotcrete construction, but is especially important when the subgrade is loaded with a high weight like water.

Plumbing

The perimeter slot overflow is an atmospheric condition, meaning gravity flow is through large-diameter piping. When using polyvinyl chloride (PVC) piping, the pipe must be rigidly plumbed and then completely encased with proper shotcrete cover. The pool wall bond beam was to be 3 ft (0.9 m) thick. The backside, after a vertical depth of 2 ft (0.6 m), transitioned into a 12 in. (300 mm) wall, which connected to a 12 in. (300 mm) thick floor. Our plumbing was 4 in. (100 mm) in diameter for each long wall side of overflow collection and then expanded up to a 6 in. (150 mm) trunk line. Our return was a 4 in. (100 mm) pipe around the perimeter. Both lines used tees and bushings down to 2 in. (50 mm) fitting connections (Fig. 4). The bond beam was thick enough to fully encase all the piping. The reinforcing steel, however, would have been less uniform and required more freeform bending to get around certain locations. To avoid these problems, we placed the long wall open-side collection pipe outside of the bond beam with only 2 in. (50 mm) fitting stubs through the wall (Fig. 5). All other piping was either fully encased in the wall by shotcrete or in the stone layer under the pool shell.

Forming and Steel

Because the slot overflow was part of a 3 ft (0.9 m) wide bond beam, we constructed it with

Fig. 2: Bottom of excavation to solid, undisturbed soils/rock

Fig. 3: Drainage stone layer, retaining stone bags, and compaction

Fig. 4: Reinforcing bar installation, retaining stone bags, and piping

a two-stage shotcrete process. Our reinforcing steel configuration used three cages for the bond beam with No. 5 (No. 16M), No. 4 (No. 13M), and Grade 60 (420) deformed bar. Its grid pattern was offset using 12 x 12 in. (300 x 300 mm) spacing. The first shoot left the top of the pool with a 2 ft (0.6 m) haunch detail (meaning the backside was higher than the front.) This raised haunch had each of the 2 in. (50 mm) diameter piping overflow dropouts properly encased with the surrounding steel in shotcrete. Using Grade 60 (420) reinforcing steel requires an automatic/hydraulic bending machine. The lower walls had No. 4 (No. 13M) bars with a double-cage offset. This offset is a 6 in. (150 mm) grid pattern in plan or cross-sectional view. Our forming was with rigid plywood, 2 x 4 in. (50 x 100 mm), and 1 x 6 in. (25 x 150 mm) rough-sawn lumber. This allows very good rigidity to accept the impact of the shotcrete without breaks or voids. The long wall adjacent to the raised decorative stone wall was shot next to its concrete footing. Tolerance of the edge design is critical in all phases of pool construction but especially in our second stage of shooting. To get the knife edge, we were to drill in new steel reinforcing bar with connecting and horizontal bars and form an inverted angle bracing to shape the runoff of the backside of the edge into the hidden trough. This edge angle was to match the cut angle of the future coping stone keeping a parallel 1 in. (25 mm) slot. Our flow of water in gal./minute (L/minute) depends on the levelness of the edge. Because the concrete material was going to be shot to a point, it was important that we over-shoot by approximately 1 in. (25 mm) and then grind down the installed material, forming a more rounded edge. The forming was installed for this technique. This edge is the essential design piece, melding the pool water level with the deck elevation and exemplifying the pool's organic architecture. Our forming and steel installations always had that end goal in mind.

Fig. 5: Beam profile of first stage of shooting process

Shotcrete

Shotcreting took 3 days. Because the walls and floors were thick, we used (including surge tank) a total of 160 yd^3 (122 m^3) of in-place materials. Our concrete specifications required a 4000 psi (27.6 MPa) compressive strength after a 28-day wet cure as a bare minimum. The actual concrete strengths after 7 days were 4820 psi (33.2 MPa) and above, according to independent lab testing by the general contractor (refer to Table 1). Our mixture design was rich portland cement with a maximum water-cement ratio (*w/c*) of 0.45. This mixture provides more than enough paste binder to cover 100% of the aggregate gradation in terms of total surface square feet. Most shotcrete appli-

Table 1: Shotcrete Compression Test Report PT471CL-01B-10-10

Laboratory Data (ASTM C39, C42, C511, and C1231)

Core ID	Date of test	Age, days	Drilled core length, in. (mm)	Uncapped core length, in. (mm)	Capped core length, in. (mm)	Capped core diameter, in. (mm)	Core area, in.^{2} (mm^2)	Total load, lb (kg)	Strength correction factor	Unit load, psi (MPa)	Core location
01	10/12/10	8	3.87 (98.3)	3.12 (79.2)	3.66 (93.0)	2.72 (69)	5.80 (3742)	27,960 (12,682)	1	4820 (33.2)	Test panel 1
02	10/12/10	8	3.92 (99.6)	3.11 (79.0)	3.64 (92.5)	2.71 (69)	5.76 (3716)	29,770 (13,503)	1	5170 (35.6)	
03	11/01/10	28	3.91 (99.3)	3.53 (89.7)	4.01 (101.5)	2.72 (69)	5.80 (3742)	40,640 (18,434)	1	7010 (48.3)	
04	11/01/10	28	3.83 (97.3)	3.44 (87.4)	3.93 (99.8)	2.72 (69)	5.80 (3742)	34,850 (15,808)	1	6010 (41.4)	
05	11/01/10	28	3.83 (97.3)	3.09 (78.5)	3.76 (95.5)	2.72 (69)	5.80 (3742)	40,880 (18,543)	1	7050 (48.6)	

Note: Unit weights are approximate and are calculated based on cylinder weights and volumes determined in the laboratory. *Table courtesy Atlantic Testing Laboratories* cators or designers are unaware of this crucial aspect of the concrete mixture design (refer to Table 2). The shotcrete method of placement uses the wet process (Fig. 6). The wet-mix pump (Allentown PC 20) was coupled with an Ingersoll Rand air compressor with a capacity of 375 ft^3/minute (175 L/s). We used a secondary air compressor (185 ft^3/minute [86 L/s]) primarily to run the air lance. The air volume and velocity is important to properly compact shotcrete materials especially (as in our case) when there is more than one layer of steel reinforcement. Our output was 10 yd^3/h (7.6 m^3/h) with a truck every hour. We reduced the steel pipe from 5 in. (125 mm) at the pump discharge to 3 in. (75 mm) steel pipe at the pool edge. At the pool edge, we reduced with a 3 x 2 in. (75 x 50 mm) reducer into a 2 in. (50 mm) flexible hose connected to our nozzle. Our crews began shooting the entire floor first, and then proceeded with the walls. With wet mix, we had very minor aggregate rejection, which produced no significant rebound. An important aspect of the shooting process was cleaning overspray from the reinforcing steel adjacent to the shotcrete placement. We used air from a nozzle (minus concrete) and an air lance to clean the reinforcing steel. This waste material collected on the previously shot floor, was collected, and then shoveled out. After each application, we prepped all construction joints to a roughened surface at a 45-degree angle and made sure they were in a saturated surface-dry (SSD) condition prior to receiving more material. Even though the shoot was over a period of 3 days, this pool shell, with no expansion joints, is still considered monolithic concrete. Once the pool was completed and reached final set (well over the specified 500 psi [3.4 MPa] minimum), the general contractor slowly started to fill the pool to over 3/4 full with water to: a) satisfy the project specifications that required watertight concrete prior to subsequent surface applications; and b) cure and keep concrete in a moist condition to help minimize any concrete shrinkage (Fig. 7). The concrete ready mix plant was local and used local materials for the sand and aggregate, keeping in step with our organic objective.

Finished Materials

After all plumbing and fitting installations, our last work before startup was applying the finished surface materials. The overflow slot was lined with a slate/stone tile and a gray plaster to seal fitting connections and dropouts. The pool interior was given a typical gray plaster to match its surroundings. Because the pool shell was required to be watertight and compressive values were indicative of good shotcrete, we needed no additional waterproofing (technically "dampproofing"). The general contractor applied a New

Table 2: Batch Weights Per Cubic Yard

Cement (ASTM C150 Type I/II)	800 lb (363 kg)
Sand (ASTM C33) SSD	2325 lb (1055 kg)
ASTM No. 8 stone (3/8 in. [9.5 mm])	300 lb (136 kg)
Water	43 gal. (163 L)
Air Mix 200	1.0 ± 0.5 oz/cwt (0.62 ± 0.31 g/kg)
WR 91	2.0 oz/cwt (1.25 g/kg)
Air content	8 to 10%
Slump	3 in. (76 mm)

Admixtures: all The Euclid Chemical Company, Cleveland, OH
Air entraining agent: Air Mix 200; water reducer: WR-91

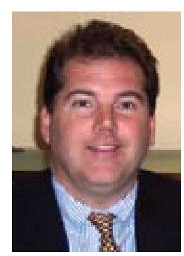
Fig. 6: Wet-mix shotcrete process, ACI Nozzleman shooting base of walls

Fig. 7: Lautner edge in place, tank testing for water tightness

England marble stone for the pool coping and cover of the trough. The design details (refer to the cross section) require a 1 in. (25 mm) gap between all edges. One-hundred-percent of the perimeter is near deck level and 100% of water (during secondary edge flow pump mode) flows over the edge in a skimming capacity. Specialty water edges such as that produced on this project require durability, water tightness, and precise installation techniques to be successful. Hand-packing or casting materials without the high-velocity impact inherent in shotcrete just won't give you the performance that these water edges demand. Tight finished tolerances allow this project to enjoy significant energy savings by use of a variable speed, energy-saving pump for the edge flow. The pool sanitation is primarily organic through ozone generation, and the heating system uses a high-efficiency heater unit. The finished product (Fig. 8) is a seamless, durable shotcrete structure (perhaps better considered a shotcrete artwork) that perfectly embodies the architectural philosophy.

To make this contemporary concept a reality, we relied on the many benefits inherent in shotcrete. Over-blasted conditions, strength, water tightness requirements, and gutter detailing to a point all required our knowledge and experience in sophisticated, high-tech concrete placement with shotcrete. As a builder, it's intuitive to try and simplify designs. This thought process makes the job easier for the field construction team and yields faster completion dates with less hassle. However, as a firm believer in always raising the bar (strength, applications, and so on), I believe we as pool shotcrete builders have a responsibility to see the project through the eyes of the architect or designer. Imagine the "wow" factor of a client if we were to bring different architectural designs into our pool construction presentations. As an industry, we must climb the credibility ladder. Being in tune with an established and accepted form of architecture (such as Wright and Lautner) brings all of us to a level of opportunity in all things shotcrete that we would have never reached before. Couple this with future credibility from the American Concrete Institute or ASA, and I seriously doubt any of us would ever run out of work.


Fig. 8: Finished pool


Bill Drakeley *is President of Drakeley Industries and W. Drakeley Swimming Pool Company. Drakeley Industries is a shotcrete consulting firm that is dedicated to the training and implementation of the shotcrete process in regards to building water-retaining structures, ground support, and underground shotcrete application. Drakeley Pool Company is a design/build construction and service firm specializing in in-ground, high-end commercial and residential pools. Drakeley is an active member of ACI Committee 506, Shotcreting. He is the first ACI Certified Shotcrete Examiner from the pool industry nationwide. Drakeley is also an ACI Certified Nozzleman, ASA Board of Direction member, ASA Technical Advisor, and Chair of the ASA Pool & Recreational Shotcrete Committee. His writings have been published in national and international trade magazines, including* Shotcrete*,* Watershapes*,* Pool and Spa*, and* Luxury Pools *magazines. In addition, Drakeley is a Platinum Member of the Genesis 3 Group, a licensed member of the Society of Water Shape Designers, and a member of the Association of Pool and Spa Professionals (APSP). He is also the concrete/shotcrete instructor at the Genesis 3 Pool Construction Schools and NESPA Region 1 Show in Atlantic City. As an instructor/trainer, Drakeley has given lectures on shotcrete applications for various pool trade shows and for World of Concrete. Drakeley is an Expert Witness regarding shotcrete applications for the swimming pool industry.*