Rebuilding a Landmark

Self-Consolidating Concrete Helps Construction Team Win the Battle of Concrete Placement

By Richard Morrow and Godwin Amekuedi, P.E.

Established in 1842, The Citadel – The Military College of South Carolina, is an academy rich in history and tradition. Located on 176 acres on the banks of the Ashley River in Charleston, South Carolina, the picturesque campus has 24 major buildings, where students pursue studies in 19 different degree programs.

Self-consolidating concrete insured superior finish and clean block outs.

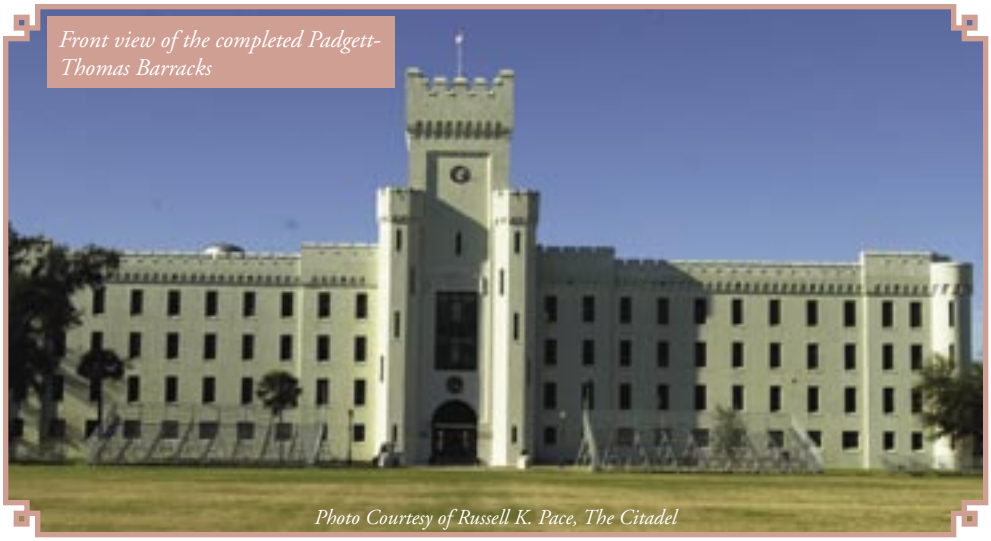
Padgett-Thomas Barracks Clock Tower
Photo Courtesy of Russell K. Pace, The Citadel

At The Citadel, "*students*" are called "*cadets*" and the word "*barracks*" is used in place of "*dormitories*". Four barracks house roughly 1900 cadets who attend the college.

Constructed in 1922, the Padgett-Thomas Barracks was the oldest building and the largest student housing facility on campus. For eighty years, it served as perhaps the best-known symbol of the military college and a model for all other barracks on the campus. An imposing, brilliant white un-reinforced masonry structure complete with turrets and a large clock tower over-looking the parade ground to the east, the center of the Padgett-Thomas Barracks was designed as a quadrangle onto which each room opened, and spiral stairways graced each of the four corners.

By 2000, the venerable structure – with its narrow dorm rooms with high ceilings and hardwood floors – was declared a safety hazard with collapsed ceilings, fallen concrete, backed-up sewer lines and structural instability. In the early part of 2000, the decision was made to demolish and replace the Padgett-Thomas Barracks.

Architect Davis & Floyd, Inc. of Charleston, South Carolina, began work on the design of the new Padgett-Thomas Barracks. The goal: design a new structure, identical in appearance to the landmark building but incorporating modern conveniences, and strong enough to withstand hurricane-force winds and meet seismic requirements of the International Building Code, due to the fact that Charleston is located on top of an ancient fault line.



Front view of the completed Padgett-Thomas Barracks

Photo Courtesy of Russell K. Pace, The Citadel

They delivered a plan for a four-story building that is a work of art and a showcase of excellence. Almost an exact replica of the original, it features a classic fortress design with precast concrete battlements and reconstruction of the magnificent eight-story tower, complete with the original clock, wrought iron gates, and brass seal.

General Contractor EllisDon was awarded the project in June of 2002. Immediately, Project Manager Bill Guedell knew that this would be a challenging job requiring innovation and skill. The 112,000 square foot building was to be constructed entirely of cast-in-place concrete walls and slabs. And not simple walls and slabs – nearly half of the construction would be 6-inch thick, 12-foot high walls requiring intricate forming to create nearly 1000 doorways, window casings, archways, and blockouts for utilities. Because of the new seismic code requirements, the 6-inch thick shear walls were designed with two mats of reinforcement, leaving no room for pump hoses or vibrators. The cadet room walls would be exposed, receiving only a finish coat of paint; therefore a better than normal surface finish was required.

More than 10,000 cubic yards of concrete were required for the construction of the new Padgett-Thomas barracks, so developing a high-performance concrete mixture was critical to the success of the project. On previous campus construction projects on buildings with a similar design, contractors battled severe placement challenges and unacceptable finished appearance that required patching and, ultimately, led to cost overruns. According to Mac Nigels, Project Engineer for Davis & Floyd, Inc, "We realized with the amount of steel in these walls, conventional concrete would not work."

EllisDon Superintendents Les Taylor and Lloyd Keller wanted to avoid the problems associated with conventional wall pours, so they convened a team of experts to begin developing solutions. Together with representatives from Ready Mixed Concrete Company of Charleston, South Carolina, and innovative chemical admixture supplier Degussa Admixtures, Inc. (formerly Master Builders, Inc.), the group developed a mixture that would greatly increase concrete placement efficiency and ensure a superior as-cast finish.

The first criterion was ease of placement, so the group knew right away that a higher slump mix design was required for this project. Specifications called for 4000 psi concrete to be placed at a 4-inch slump with minimal air entrainment, due to Charleston's mild climate. The group agreed on the use of a high-range water reducer (HRWR), but during the pre-placement meetings Degussa Admixtures, Inc. introduced the concept of self-consolidating concrete (SCC). It became apparent to the team that this concrete would be the ideal. The question that remained was how to get it involved in the project. A decision was made to begin wall construction using a 7-inch slump, HRWR-treated concrete while the ready-mix supplier developed an appropriate SCC mixture. Variables considered in proportioning the SCC mixture included aggregate gradation, sand-aggregate ratio, mixture viscosity, and temperature effects.

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Work on the Padgett-Thomas Barracks construction began in August 2002. The 7-inch slump concrete was easy to pump into the thin walls, but after stripping the forms it was clear that coarse aggregate was trapping on the steel and causing sections of rock without paste on the finished surface. These blemishes were unacceptable, and Ready Mixed Concrete and Degussa Admixtures, Inc. responded to a next-day call for help from the construction team to address the challenges.

Ready Mixed Concrete Company and Degussa Admixtures, Inc. poured a demonstration mix using a ¾-inch nominal size coarse aggregate and Glenium 3030 admixture, a polycarboxylate-based HRWR, to achieve a stable concrete with a 20-inch spread. When the 7-day breaks of the concrete achieved 4500 psi, Mr. Nigels initiated a trial pour on an elevator pit wall at The Citadel to justify the use of SCC. The forms were similar, although smaller, to the walls at the Padgett-Thomas Barracks, and the SCC mixture flowed beautifully. When the forms from the elevator shaft were stripped, Mr. Taylor commented, "If you can do that on the walls, we really have something." Early strengths were near the specified 28-day value of 4,000 psi and with that, engineer Mac Nigels approved the use of the SCC mixture for the next wall pour on the barracks.

Workers easily place self-consolidating concrete in forms.

"The spread of the SCC mixture was critical. In most cases the concrete needed to be pumped up into very narrow, intricate forms, filled with reinforcement, that were 12 feet high and up to 80 feet long," explained Mr. Taylor. "On previous barracks projects, contractors struggled to get the 4-inch slump concrete mixture bucketed into the forms, then labored with vibrators that wouldn't fit in the form to ensure proper compaction. Even then, when the forms were stripped the finished wall surface didn't exhibit the sharp edges required and they were laden with honeycombs. Those were the catastrophes we needed to avoid."

"We regularly use technological advancements to help our contractor customers. Maxie Pruitt, who has since retired, spearheaded our efforts in developing a mixture proportion that consistently yielded a spread of 24 to 27 inches," remarked Roy Spivey, Regional Manager for RMCC in Charleston, SC. "The Citadel presented some unique challenges, but we knew we had the expertise and the industry contacts to come up with a solution."

On the first site placements with the SCC, slump flows were less than the designed 27-

inch spread, and although it was a drastic improvement over the previous concrete mixture, there was some fine tuning to do. "We listened to what the contractor really wanted and needed, a mixture that could be placed and consolidated easily with minimal surface blemishes, and we worked to fine tune the mixture, adjusting sand and stone, to come up with the SCC mixture that was poured for the remainder of the project," remarked Brandon Bailey, Sales Specialist for Degussa Admixtures, Inc. in North Carolina.

..."placement time and labor requirements were significantly reduced"...

The final SCC mixture for the project was developed after thorough evaluations of various combinations of aggregates, sand-aggregate ratios, and viscosity parameters with respect to slump flow (spread) using the U-Flow box, compressive strength, set time, and finished appearance. To increase fines in the mixture cost-effectively, Class F fly ash was incorporated, and the sand aggregate ratio was reduced slightly. A computer generated optimum blend of a ¾-inch and ⅜-inch nominal size coarse aggregate aided the resistance of the mixture to segregation. Pozzolith 80 water-reducing admixture and Glenium 3030 polycarboxylate-based high-range water reducer were used in combination with Rheomac VMA 358 organic viscosity-modifying admixture (VMA). These ingredients produced a highly stable 27-inch spread SCC mixture that created finished surfaces resembling glass, without vibration. "We had a vibrator on site for every pour, just in case we got pockets that wouldn't flow, but we never needed to intercede on this project," Les Taylor remarked.

It took about three SCC placements for the contractor to get used to placing a 27-inch spread concrete, but once the crew adjusted the real benefits began to show. There was less movement of the pump hose because of the excellent flowability of the SCC mixture and, consequently, placement time and labor requirements were significantly reduced. The finished surfaces were even better than had been anticipated – with no vibration – ready to accept paint with little or no rubbing.

Getting the pump set up properly for wall placements was another challenge that required innovation by the team. "The forms were so small and full of steel that initially we tried to pump concrete from the top of the wall. The SCC mixture did not segregate, but occasionally aggregate would trap between the wall form and steel mat, causing a build-up of aggregate as it was dropped on top," explained Mr. Nigels from Davis & Floyd. "We made a slight design modification by removing the extra six inches of unattached horizontal bar on the end of the reinforcement mat to create a single place on the end of the shear wall where the pump hose could be inserted the height of the wall."

To avoid segregation in the pump line as the concrete essentially traveled straight up and back down again, a 'ram's horn' or 360 degree hard loop was inserted just above the rubber hose. This ensured a constant and solid flow from the hose, even when pumping slowly. With this set up, concrete was placed from a single point and the SCC mixture flowed into place without segregating, transporting the aggregate around reinforcement, utilities, and blockouts.

From September 2002 until September 2003, more than 6500 cubic yards of SCC were used to construct the 112,000 square foot Padgett-Thomas barracks facility. Everyone involved with the project – engineers, contractors, and the owner – was impressed by the SCC and how it has improved construction, durability and aesthetics. Pour times for 40 to 80 cubic yard wall placements were cut in half, and labor on the wall construction was reduced from six to two employees. Because of the excellent properties of the concrete mixture, not a single vibrator was used. Throughout the project, strengths of nearly 4000 psi at 7 days and 5600 psi at 28 days were consistently achieved. The high flow and spread, increased workability, and excellent placing characteristics of the SCC mixture resulted in consistent quality. All tested mixes met or exceeded the specified strength for the project.

"We achieved everything with this SCC mixture," summarized Mr. Taylor. "We facilitated production of a highly-fluid concrete mixture that enhanced pumping and finishing operations while at the same time ensuring that the plastic concrete maintained its shape on slopes and arches without sagging. We reduced water content and improved viscosity to maintain resistance to segregation while ensuring flowability and controlled setting characteristics. We increased the compressive strength of the concrete, provided resistance to damage from freezing and thawing through air entrainment, and delivered a superior surface appearance upon removal of the forms. The extra effort you have to put forth in forming for an architectural project such as this with SCC is well worth it. I don't think you could produce this kind of quality final product without the advanced SCC mixture."

"This project is a testament to what you can accomplish with a team that is focused on innovation, and communicates early and often to work through challenges to achieve very specific performance benefits," concluded Roy Spivey, of RMCC. "It is clear that the use of SCC provided a winning solution for the entire construction team on the Citadel project. Improved engineering properties, ease of placement, and faster pour times mean a better finished structure – and ultimately a better place for the cadets to live."

Interior finish work on the Padgett-Thomas Barracks is complete, and the new structure was opened to cadets at the start of the 2004-2005 academic year.▪

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Completed Padgett-Thomas Barracks Quadrangle

Photo Courtesy of Russell K. Pace, The Citadel