



DESIGN-BUILD DATELINE

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**HIGH-PERFORMANCE CONSTRUCTION MATERIALS —
WHAT ARE THE OPPORTUNITIES FOR DESIGN-BUILDERS?**

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HIGH-PERFORMANCE CONCRETES: CREATIVE APPLICATIONS, NEW OPPORTUNITIES

By Ed Alsamsam, Beatrix Kerckhoff, and Jamie Farny

Concrete's low environmental impact, as well as its versatility, durability, and economy, have made it the world's most abundant construction material. In the United States alone more than 300 million cubic meters (400 million cubic yards) of ready mixed concrete is used each year in airports, highways, streets, bridges, parking lots and garages, stadiums, low- and high-rise buildings, dams, homes, floors, sidewalks, driveways, and numerous other applications.

Concrete is formulated to meet numerous industries' and building needs. There is normal-weight concrete, structural lightweight concrete, high-strength concrete, autoclaved cellular concrete, heavyweight concrete, mass concrete, and decorative concrete, to name a few. During the last several decades, a boom in concrete technology has widened the application and use of this already ubiquitous construction material. Advances in admixture technology and mix proportioning have spawned new types of high-performance concretes.

PART I SELF-CONSOLIDATING CONCRETE

Among the most significant innovations is self-consolidating concrete (SCC). The construction industry has always longed for a concrete that can flow easily into tight and constricted spaces without requiring vibration. Over the years the need for this technology has grown as designers specify more heavily reinforced concrete members and ever more complex formwork.



Self-consolidating concrete is able to flow into almost any shape or form, providing excellent surface characteristics. For the Porthaven Professional Building in Cuyahoga, OH, white concrete was used to present the design of sculptor Harvey Wheeler.

WHAT IS SCC?

Honeycombing or exposed reinforcement in structural walls or columns poses a constant concern. Until recently, the industry used superplasticizing admixtures (also known as high-range water reducers) in conventional mixes in an attempt to achieve flowable concrete and prevent poor consolidation and voids. This allowed the use of concrete having an eight-inch or greater slump; however, some vibration was still required for adequate consolidation. While high doses of superplasticizers create a very fluid concrete that flows readily,

the mortar is too thin to support the weight of the coarse aggregate and segregation becomes a problem. The key to creating SCC, also referred to as self-compacting, self-leveling, or self-placing concrete, is to produce a very flowable mortar that retains a viscosity great enough to support the coarse aggregate. Today, new advances in admixtures and mix proportioning are making SCC a practical reality.¹

SCC AND THE SEWARD POWER PLANT PROJECT

In April of 2002, Fihoff

Concrete, Johnstown, PA., supplied SCC for the construction of a 40-foot x 40-foot turbine foundation at the Seward Power Plant in New Florence, PA. This massive elevated turbine foundation is congested with heavy reinforcement and embedments, has five-foot deep grade beams and was placed in one-foot lifts.

SCC mix proportions are shown in Table 1. "We essentially switched the amount of coarse and fine aggregate that you'd add to a normal concrete mix," said Von Parkins, president of Fihoff.



Main characteristics of self-consolidating concrete include: (1) Ability to fill a mold or form; (2) Resistance to segregation (stability); (3) Ability to flow through reinforcing bars or other obstacles without segregation; and (4) Superior surface quality and finishability.

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The superplasticizer was added at the jobsite. According to Parkins, no special batching sequence was required at the plant. Fihoff delivered the concrete to the jobsite at a one-inch slump, added the superplasticizer, revolved the drum 100 times, then measured the spread of the concrete. The SCC spread, called slump flow, averaged 25 inches.

Rick Huss, quality control manager for Fluor Constructors, Seward, PA, was pleased with the fresh SCC concrete properties. "The concrete traveled like they said it would, and it carried the coarse aggregate with it," he said. Huss also said the concrete pumped well without segregating. The only drawback came at the end of the placement. "Finishing the concrete was tough," said Huss. "The surface was sticky and it set up pretty quickly."

BALANCING FLOWABILITY AND STABILITY

SCC needs to be fluid, but also stable, to prevent segregation. The required level of fluidity is greatly influenced by the particular application under consideration. Obviously the most congested structural members demand the highest fluidity concrete mixes. However, element shape, desired surface finish, and travel distance can also determine the required fluidity.

For producing the desired flowability, a new generation of superplasticizers based on polycarboxylate ethers works best. Developed in the 1990s, they produce better water reduction and slower slump loss than traditional superplasticizers. However, more conventional superplasticizers can be used for SCC as well.

To increase the viscosity of the mortar, self-consolidating concrete contains more fine material — but essentially the same amount of water — as conventional concrete. The total content of fines (cementitious or other materials finer than the No. 100 sieve) must be high, usually about 700 lb/yd³ to 950 lb/yd³. Generally, the higher the required flowability of the SCC mix, the higher the amount of fine material needed. In some cases, a viscosity-modifying admixture (VMA) can be used instead of, or in combination with, an increased fine content to stabilize the concrete mixture.

As in any good concrete mix design, aggregate grading has to be optimized. Well-graded aggregates (including well-graded fine aggregates) make the best SCC. Many locations around the country, however, have neither the equipment nor the aggregate to produce well-graded aggregate mixes. A mixture containing a gap-graded aggregate

will have a tendency to bleed or segregate or both, but this can be corrected by increasing the cementitious content (including pozzolans) and/or using a VMA which also facilitates placement.

SCC provides excellent bond with reinforcement. Because of the higher flowability, however, concrete formwork must be designed to handle a full liquid head, and must not have openings where concrete can leak out during placement. The formwork contractor should be made aware of the SCC application in order to propose suitable formwork type and tie spacing.

FRESH CONCRETE PROPERTIES

SCC is characterized by its unique fresh concrete properties. Therefore, new test methods have been developed to characterize SCC properties. Some common test methods for SCC are listed in Table 2 on the following page.

While the fresh properties of SCC differ significantly from those of conventional concrete, hardened concrete properties of SCC are expected to be similar to those of a comparable conventional concrete mixture.

SCC generally costs more than standard concrete mixtures on per-volume basis. Local material availability dictates the cost for SCC in different regions. Also, the selected SCC performance/mix design, depending upon the application, affects cost. However, looking past the higher initial material cost shows that the 'in-place-cost' of SCC, which includes reduced labor, less equipment, and shorter construction times, will in many cases be lower. SCC has great potential economic benefits to design-build projects by allowing unparalleled speed and moldability with less manpower and equipment.

In 2002, 40 percent of precast concrete manufacturers in the United States used SCC and the number is rising. Some new precast

Table 1 Seward Power Plant, New Florence, PA Self-Consolidating Concrete Mix Proportions




Material	Quantity	
	Portland cement (Type I)	297 kg/m ³
Slag cement	128 kg/m ³	215 lb/yd ³
Coarse aggregate ¹	675 kg/m ³	1,137 lb/yd ³
Fine aggregate	1,026 kg/m ³	1,729 lb/yd ³
Water	170 kg/m ³	286 lb/yd ³
Superplasticizer ²	1.3 L/m ³	35 oz/yd ³
AE admixture	as needed for 6% +/- 1.5% air content	

¹ Size: #8 (AASHTO M 43), 100% passing 12.5-mm (½-in.) sieve.

² ASTM C 494, Type F (Polycarboxylate-based)

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Table 2: Typical SCC Test Methods

Test Method	Description
	<p>Slump Flow</p> <p>Test is performed similar to the conventional slump test (ASTM C 143) using the Abrams cone (use of inverted cone possible). However, instead of measuring the slumping distance vertically, the mean spread of the resulting concrete patty is measured horizontally. This number is recorded as the slump flow. Measured characteristic: Filling ability (deformability) & stability</p>
	<p>J-Ring</p> <p>The J-Ring consists of a ring of reinforcing bar such that it will fit around the base of a standard slump cone. The slump flow with and without J-Ring is measured, and the difference calculated. Measured characteristic: Passing ability</p>
	<p>Column Segregation</p> <p>Test evaluates static stability of a concrete mixture by quantifying aggregate segregation. A column is filled with concrete and allowed to sit for awhile after placement. The column is then separated into three or four pieces. Each section is removed individually and the concrete from that section is washed over a No. 4 sieve and the retained aggregate weighed. A non-segregating mix will have a consistent aggregate mass distribution in each section. A segregating mix will have higher concentrations of aggregate in the lower sections. Measured characteristic: Stability</p>

plants are currently being built around the idea of using SCC technology.² With outstanding benefits, SCC usage in the ready-mix concrete industry is also rapidly increasing in the United States. From a production of 130,000 yd³ (100,000 m³) in 2002 to 2.8 million yd³ in 2004, it is estimated that 6 million yd³ will be used in 2006.^{3 and 4}

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BENEFITS OF SCC

Properly proportioned and cast SCC can result in economic and technological benefits for both the designer and the builder.

1. Reduced labor and optimized resource management:
 - a. Little or no need for concrete vibration reducing manpower and coordination needs
 - b. Little or no finishing operations to ensure flat surfaces (self-leveling characteristic) further reducing project manpower
 - c. Less equipment and power costs
 - d. Lower in-place cost
2. Accelerated speed of construction:
 - a. Higher rate of concrete placement
 - b. Faster form filling
 - c. Faster completion and shorter construction time
3. Noise reduction on the job site:
 - a. With the use of "noise-free or silent concrete" construction hours in urban areas might be extended to what would otherwise be curfew periods
4. Durable concrete members:
 - a. Smooth finish with low potential for surface defects
 - b. Improved appearance and consistency in architectural applications
 - c. Excellent bond to steel reinforcing
 - d. Low permeability

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Poor flowability and rebar congestion led to exposed steel bars in the lower end of this manhole wall. SCC could have flowed easily to the bottom of the forms to prevent this situation.

PART II : SELF-CONSOLIDATING GROUT ENHANCES SECURITY ON PRISON PROJECT

Reinforced masonry can be used beneficially on many types of building projects. Perhaps one major limitation to more widespread acceptance has been the sometimes difficult task of grouting cells, especially small/tight cores that contain heavy reinforcement. With conventional grouts, this can be a slow process, as they wend their way through numerous zig-zag paths. Ensuring that grout spaces are properly filled requires thorough inspection plus consolidation and reconsolidation, but the process can be time consuming and costly.

New superplasticizing admixtures (polycarboxylates) have the potential to change that process.¹ These materials coat cement particles and prevent the stickiness associated with particle flocking. But they do not lead to segregation. Simply stated, self-consolidating grouts (SCGs) are free flowing and cohesive, two characteristics necessary to completely fill the long, small, absorptive spaces that you have within or between masonry units (see right, above). The recent Justice Center expansion project for Douglas County, CO, is instructive. Easy material placement is emerging as

the real hero, leading to increased security and safety, cost savings, and better quality of construction.

SECURITY

County officials stressed the importance of 100% solid grouting for the prisoner housing areas (see right, below). SCGs have high fluidity and they maintain flow during placement better than the grout with water alone. As a result, SCGs have a superior capacity for filling cores. Grouting contractor Central Masonry's Dennis Jasken said "The self-consolidating grout worked just like they said it would. But don't put it where you don't want solid grouting, because it's going to find its way everywhere." The SCG formulation provided good assurance that there would be no voids in any of the walls, pleasing designers, builders, and the owner.

COST SAVINGS

With the county watching its budget, it wasn't obvious that SCGs would be cost effective. In addition to the costly admixtures, these grouts are frequently formulated with higher cementitious materials contents. In the Denver market, the grout mix itself commands a premium of 8 percent to 11 percent. But off-loading trucks and getting the grout in place has been faster: production numbers on Central Masonry's jobs in the Denver area are averaging one-half the time it takes to place conventional grouts. This allows the ready-mix producer to keep his fleet productive. Otherwise, the extra time would have to be built into the cost of grouting the masonry wall.

The contractor saves in two ways. If walls contain reinforcement, it's cheaper to use a little more grout and grout everything than to pick out certain cells and increase labor costs. Also, there's no need for an extra laborer on top of the wall to run the vibrator. That person can be assigned to other duties on the job,



As seen through the clear plastic face on this demonstration panel, self-consolidating grout moves freely in tight spaces.



This close-up of the panel in the previous photo shows the leading front of the grout as it travels over a projection into the core, flowing around obstructions to fill the cells completely.



Reinforced masonry with fully grouted cells creates solid confinement for prisoners.

HIGH-PERFORMANCE CONCRETES: CREATIVE APPLICATIONS, NEW OPPORTUNITIES



Cleanouts are used to assure that grout spaces are clean and free of debris prior to grouting.

speeding up the construction project and further decreasing the cost of putting the grout in place.

IMPROVED QUALITY WITH REDUCED SURVEILLANCE

Ultimately, where the technology is paying the biggest dividends for the county is in the quality of the finished walls. Because the SC grout moves virtually unrestricted, there is much less likelihood of developing voids or partially filled cores. Grout flows well, even around wide mortar fins. In fact, the grout supplier cautioned the contractor that he'd better strongly brace the cleanouts if he wanted grout to remain in the wall during placement. Holes or openings will be quickly located if present, because this type of grout will find them and keep flowing. Small openings like unmortared cross webs may be able to prevent excessive grout loss across units, but it's better to fully mortar them if you want to keep grout out of adjoining cores.

Reinforced masonry has the strength to resist impact. For the prison, that was an important design constraint. Lab testing for this SCG mix showed compressive strength averaged 5,020 psi, well above the minimum of 2,000 psi at 28 days required by ASTM C 476, Standard Specification for Grout for Masonry. These tests were done on cored specimens drilled from the grouted wall, according to a variation permit-

ted by ASTM C 1019, the Standard Test Method for Sampling and Testing Grout.

THE LEARNING CURVE

Designers were not familiar with SCGs and were reluctant to specify them, but the contractor saw the benefit of faster, easier placement and the potential for making his job easier. A demo panel was arranged to teach the testing agency how to test this material. Flow, not slump, is checked by measuring the spread of material placed into a standard slump cone. Grout spread was about 26 inches without any segregation of materials, meaning no bleed water and no poorly distributed aggregates. This indicated that the grout was properly designed and mixed to do the job.²

CRIMINALS ARE THE ONLY LOSERS

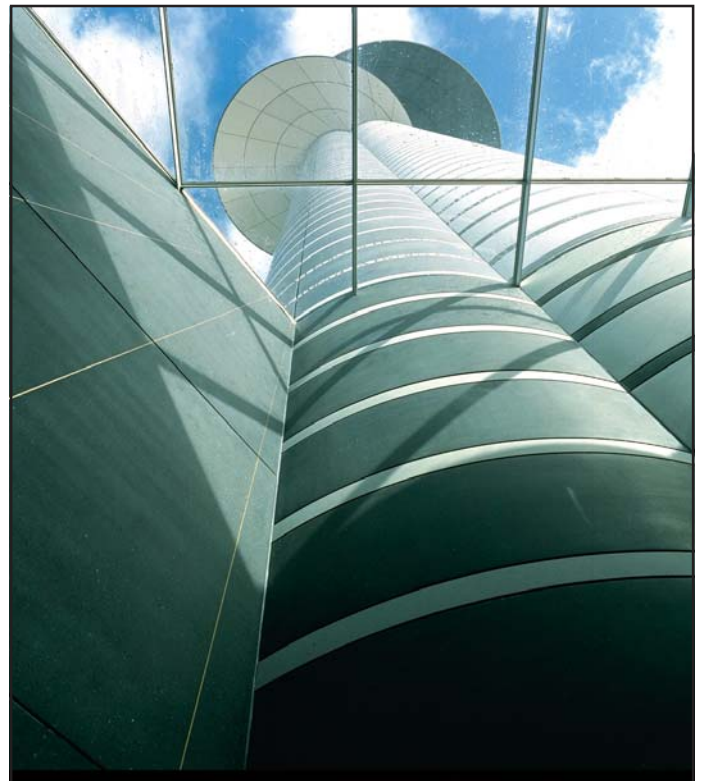
Self-consolidating grouts offer a win-win-win option for designers, builders, and owners of this prison. Designers were assured that their grout walls would be strong and completely filled. Builders are saving time and increasing productivity, making their job easier. The owner is pleased to see his project moving forward ahead of schedule, with excellent results.

During construction, there may be an occasional breach here and there because this type of grout is very fluid and can leak through any opening. The intended occupants, however, won't be so lucky. Once this job

is finished, there won't be any breakouts.

CONCLUSION

Are concrete and masonry structures getting more complex? Definitely, they are. Architects and engineers are creating ever more unique shapes and building accents with this fabulous and moldable material. With SCC and SCG increasing in popularity we are seeing more exposed concrete with curved faces, intricate designs and thin elements. SCC and SCG is not a niche market for precast producers and savvy masonry contractors, it is a mainstream building material. The strong economy, steady residential construction and strong growth in non-residential construction coupled with labor shortages make SCC and SCG ideal candidates to speed up your construction and make the best use of limited project budgets and resources. ♦



Slim and accurate constructions are much easier to realize with SCC, such as this 83-meter high Stockholm Airport tower, which is decorated with excerpts from the work of Antoine de Saint Exupéry. Reduced noise levels made construction during nighttime hours possible. (Photo courtesy of HeidelbergCement)

SELF-CONSOLIDATING GROUT SPECIFICATION AND MIX DESIGN

Grout is a fluid cementitious mixture used to bond together adjacent masonry units or wythes, to bond steel reinforcement positioned in the grout space between adjacent wythes, to bond steel reinforcement in the cores of masonry units to the masonry, or to fill reinforced bond beams.

Conventional grouts contain large amounts of water to provide flowability so that the grouts can be placed. Self-consolidating grouts (SCGs) generally have lower water contents and instead contain a new type of superplasticizing admixture (polycarboxylates) to impart a high degree of workability. SCGs are virtually the same material as self-consolidating concrete, except they have a slightly smaller coarse aggregate size. SCGs can be fine or coarse grouts, but are generally coarse.

Although these mixes are already well accepted in several markets — Maryland, Louisiana, Washington, Colorado, and Florida — many designers and builders have never even heard of SCGs. Specifiers may be reluctant to call for them, and instead, the contractor might propose to use them to save time and money. No matter which party suggests SCGs, success depends on correctly specifying important aspects of the mix.

ASTM C 476, Standard Specification for Grout for Masonry, allows for both proportion and strength requirements. With SCGs, you want to quantify the fresh and hardened properties. Grout spread should be 22 inches to 30 inches (see “Testing SCGs” below). Grout strength should be 2,000 psi minimum at 28 days. Shear-bond strength or pullout strength of grout have also been tested and could be specified if needed for certain projects.

TESTING AND INSPECTING SCGs

As an example of the properties of self consolidating grout, several physical parameters of a specific formulation are shown in Table 1.¹

Table 1. Properties of an Example Self Consolidating Grout Formulation

Property*	Results (averages)
Slump flow, (within 10 minutes), in.	26
Temperature, °F	60.7
Water loss (w/c at 5 minutes and beyond)	stabilized at 0.5 with little subsequent change
Compressive strength, psi	5020
Grout-unit shear-bond strength, psi	498
Reinforcement pullout strength, psi	67,600

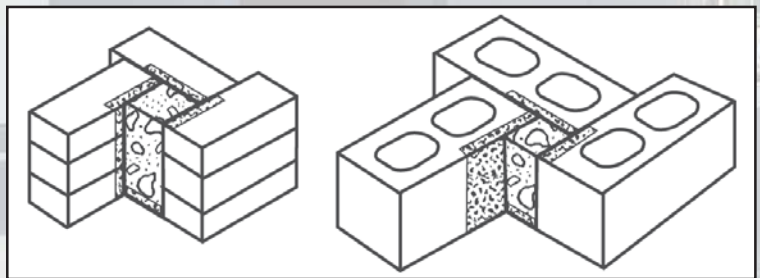
* Measured after the truck arrives at the job site.

Ready mix producers will check the slump flow (spread) on this material before sending it out to a site, similar to sampling the slump of concrete. (Flow may be checked again at the site, but workability retention is high and retesting isn't mandatory.) On a stable, flat surface, a slump cone is filled, then removed, resulting in a large pat of material. Pat diameter is measured at two places (at right angles to each other) and the average is recorded as the result. SCGs should have a spread of anywhere from 22 in. to 30 in. At the same time, there should be no evidence of segregation: no bleed water forming around the edges of the pat and no clumps of aggregate. If either condition is occurring, it indicates non-cohesive behavior. That could lead to poor

grout quality in place.

Compressive strength specimens should be made. ASTM C 1019 is the Standard Test Method for Sampling and Testing Grout. This

standard calls for a mold composed of a “pinwheel” of sets of four masonry units forming a square of 3 inches by 3 inches and a height of at least twice the width (four bricks won't be tall enough to meet the height criteria, so multiple layers are necessary). Note 6 of C 1019 indicates that alternate methods of forming specimens may be used provided that they are first verified by comparative testing with the standard “pinwheels.” One compressive sample that has become popular for fluid grout mixes in the Denver market is a core drilled from a regular concrete masonry unit that has been grouted with SCG. Three-in. diameter cores can be obtained



Grout molds are made from a “pinwheel” of masonry units. Alternately, compressive strength specimens can be drilled from cores of grouted units.

SELF-CONSOLIDATING GROUT SPECIFICATION AND MIX DESIGN

TESTING AND INSPECTING SCGs, continued



The slump flow test is done on a flat surface using a standard slump cone. After filling, the cone is lifted and the diameter of the resulting pat is measured.

from grouted standard size concrete masonry units (8x8x16 in. nominal dimensions) and cores will meet the required height-to-diameter aspect ratio.

Building Code Requirements for Masonry Structures permits the use of grouting procedures that exceed the limitation on maximum pour heights if a grout demonstration panel is constructed to verify that the proposed grouting will adequately fill the spaces.² The inspecting agency should be made aware of the test panels prior to the job pour. This affords inspectors the opportunity to view the demonstration so they can compare the actual construction to it. The most important aspect of grouting will be making sure that the cells that are intended to be filled are actually and adequately filled. Characteristics of the hardened grout should have already been verified by lab testing. Specifiers can accept test results from the grout supplier. The building code

requires cleanout openings to verify that cores are not obstructed with debris.

Self-consolidating and conventional grouts have similar hardened properties but differ in their fresh properties. Testing fresh SCG requires a different method than the slump test. The slump flow is a simple yet effective quality control method developed for assessing workability and cohesiveness of SCG. As more specifiers and builders become aware of the material's performance, it is likely that flowing grouts will be used with more regularity.

SIDEBAR REFERENCES

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- ² For more information on the prison project, contact Tom Cummings, New Products Commercialization Manager, at Tom.Cummings@lafarge-na.com

The Portland Cement Association (PCA) is an organization of cement companies to improve and extend the uses of cement and concrete through market development, engineering, research, education, and public affairs work. PCA was founded in 1916 and is headquartered in Skokie, Illinois. Visit www.cement.org for technical information, publications, and resources on cement and concrete technology.

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