Analysis of Self-Consolidating Concrete in Architectural Shear Wall Applications: Case Study

Peter Finocchio
California Polytechnic State University
San Luis Obispo

Architectural concrete surfaces have always been a point of focus for concrete contractors, architects, and owners, especially when consolidation poses risks due to a high density of reinforcement. Contractors have begun using self-consolidating concrete (SCC) in exposed vertical applications to combat the risk of poor consolidation. This paper investigates the characteristics of SCC and evaluates a case study of a recent project that was completed on the Central Coast of California. The study examines the cost variance between using SCC mix and a standard mix in architectural shear walls. The analysis is done by evaluating a multi-story Type 1A structure containing three floors of architectural shear walls. These findings are useful to contractors, owners, and architects undergoing an analysis of whether to SCC on their project.

Key Words: Self-Consolidating Concrete, Thixotropy, Hydrostatic Pressure, Full-Liquid Head, Reinforcement

Introduction

Self-Consolidating Concrete (SCC) is a highly fluid mixture designed to flow and consolidate under its own weight instead of mechanical consolidation (vibration). The mixtures characteristics allow it to fill spaces without segregation, even in structural elements with high rebar congestion. Proper consolidation of an architectural wall can significantly benefit the walls finish (Cemex). SCC is a more viscous mixture and is commonly poured full-liquid head, meaning the concrete is placed full form height within the period required for its initial set. Typically, this results in the formwork to be engineered for full hydrostatic pressure. Standard mix concrete needs mechanical vibration to properly consolidate and is typically poured in lifts. Lifts vary within 3-5’ depending on wall dimensions and is not typically designed for full hydrostatic pressure. Contractors tend to debate whether to use SCC or standard mixes for architectural shear wall applications because of the finish, as well as the different formwork requirements and methods of placing.

The American Institute of Concrete (ACI) has produced extensive research regarding the structural properties of self-consolidating concrete. Thus, contractors can use this data to understand the means and methods of building with it. However, research regarding the cost variance between the use of

SCC and standard concrete mixes has not been heavily researched, to date. This research will cover a portion of existing information on SCC and then perform a case study on a past project comparing the cost data to help close the knowledge gap.

Background

Factors Affecting Form Pressure

Multiple factors affect the hydrostatic pressure exerted when placing concrete in a wall form. These factors include: casting rate, fluidity level, coarse aggregate volume, binder content and type, temperature of fresh concrete, minimum dimension of formwork, degree of vibration, and thixotropy (ACI). According to Kamal H. Khayat (2021), a professor of Civil Engineering and specialist in development of high-performance cement-based materials, thixotropic factors play a large factor in determining the hydrostatic pressure of SCC. Thixotropy is defined as the increase in yield stress and viscosity with time (ACI). Thixotropy can be assessed by structural breakdown and structural build-up approaches. A high thixotropy mix will be able to support its own weight and exert less pressure on formwork. Understanding the thixotropic characteristics of a mix will help determine the necessary formwork required based on hydrostatic pressure. Two pieces of equipment are used when monitoring hydrostatic pressure within a form, pressure cells and load cells.

Workability & Testing of Self-Consolidating Concrete

Self-Consolidating concrete is a high-performance concrete that is used to improve casting in congested sections and to insure proper filling of restricted areas with little to no mechanical consolidation. Khayat (1999) concluded, the workability of mixture to successfully place SCC require excellent deformability and ability to flow under its own weight through congested reinforcement. Ensuring high stability is important to achieving proper bonding to reinforcement and the securing uniform properties of cured concrete.

Testing of workability varies significantly within Standard and SCC mixes due to different viscosities. For example, workability of a standard mix is determined off a slump test. Slump test protocol can be found within ASTM C143. Workability of a self-consolidating concrete mix is determined based on a Slump Flow Test and the test procedures can be found in ASTM C1611/C1611M standards. To summarize a slump flow test, a cone is filled with SCC and is not mechanically vibrated, the cone is lifted, and the spread of concrete is measured. For an SCC mix, the spread ranges from 18-32 inches and the viscosity can be estimated by measuring the time taken for concrete to reach a spread of 20 inches. Figure 1 displays the measuring of viscosity of an SCC mix with a slump flow test.

Figure 1. Slump Flow Test (Testing – Self-Consolidating Concrete)

Effect of Material and Mixture Composition of SCC on Form Pressure

K.H. Khayat and Kavya Vallurupalli (2021) conducted tests to determine the effects on formwork pressure and decay when varying multiple mixture parameters of a Self-Consolidating Concrete Mix. The results are displayed in Table 1 below.

Table 1

Effect of Material and Mixture Composition of SCC on Form Pressure

Increase in Parameter	**Initial Pressure**	**Decay**	**Reason**
Set retarding admixtures	Increased/limited effect	Slower	Retarding rate of cohesion development
Set accelerating admixtures	Decrease/limited effect	Faster	Accelerates rate of hydration
HRWRA content (fixed w/cm)	Increase	Faster, slower, no change	Varies with workability retention characteristics of HRWRA and its dosage
Binder Content (fixed w/cm and slump flow)	Increase	Faster	Increase in thixotropy
Water Content (fixed slump flow)	Increase	Faster, slower, no change	Decrease in shear depends on

			workability retention characteristics of
Coarse aggregate content	Decrease	Faster	Increase in internal friction amplified by coarse aggregate
Concrete Temperature	Decrease/Limited effect	Faster	Accelerated rate of hydration
Rate of casting	Increase	No effect	No stiffening allowed at higher rates
Formwork width	Increase	Slower	Reduction in arching action
Formwork roughness	Decrease	No effect	Increase of friction between formwork and concrete
Reinforcement percentage	Decrease	No effect	Partial support from reinforcement reduces lateral pressure
VMA (Viscosity modifying admix): Fixed slump flow	No change/ Increase	Slower	Depending on VMA and HRWRA dosage slower decay if HRWRA improves slump retention
VMA (Fixed HRWRA)	Decrease	Faster	Addition of VMA typically increases the degree of thixotropy

As shown in the table, the initial hydrostatic pressure and hydrostatic pressure decay with time varies regarding multiple parameters. A faster pressure decay indicates a faster structural build up and an increased initial pressure would require increased formwork support.

Methodology

Research on structural properties of SCC had to be evaluated prior to examining the cost variance between placing architectural shear walls with SCC in comparison to a standard mix. Research began with a jobsite visit to a Central Coast project where there were multiple architectural shear walls placed using SCC. A meeting was conducted with the lead concrete Superintendent to walk the site and to hear his experience with SCC, in general and on this specific project that was completed in December 2020. This superintendent was extremely knowledgeable about the structural properties of SCC and gave me insight on the different tactics he used when placing SCC. The most prominent aspect the Superintendent mentioned was the finish of the SCC mix. SCC was able to meet the required finish specified by the architect without little to no patching. He also mentioned when using a standard mix, hundreds of patching manhours would've been allocated to meet the specified finish. In addition, the high viscosity of the SCC mix meant that the formwork had to be engineered for "full-liquid head," and the formwork had to be substantially increased to contain the increased hydrostatic pressure at the bottom of the form. This increased the overall formwork cost for this specific project, as well as additional labor was required to form these walls.

Following the site visit, I continued research through the American Concrete Institute (ACI) where I was able to attend a virtual convention. The virtual convention included a panel dedicated to research of form pressure exerted by Self-Consolidating Concrete. This panel included topics such as the thixotropy of SCC, effect of material and mixture composition of SCC on form pressure, methods of and monitoring In-situ form pressure. Following this convention, I had gathered enough data to begin the case study on the cost variance.

To conduct this case study, meetings were conducted with a Project Manager for the structural concrete contractor on this specific project to help identify the main areas of cost variance. After discussing, it was determined that the areas of greatest cost variance that should be focused on included: concrete cost per cubic yard, formwork material costs, formwork fabrication costs, patching labor costs, and placing labor costs. Project documents were provided for an educational facility, Type 1A structure that included 3 stories of architectural shear walls. A cost analysis was to be examined if 1) those walls were placed using SCC and 2) as standard mix was to be used.

First, a quantity take-off (QTO) of the total cubic yardage of concrete and contact square footage of the shear walls was performed. Next, the project schedule was evaluated to determine the duration of formwork rental and number of shear wall pours. Concrete material quotes for both the SCC mix and standard shear wall mix were acquired from a local ready-mix supplier. The formwork supplier provided proposals for these walls engineered for an SCC mix and as well as engineered for a standard mix. Lastly, a composite crew size and rates were determined for formwork fabrication and concrete placing, as well as price per contact square foot of patching. All of this information was consolidated, and an estimate was created and organized in an excel document to plug in pricing data in conjunction with the QTO to finalize the cost analysis for the project.

Discussion & Results

Labor Variation

After the estimate was complete, it was evaluated by the concrete contractor's project manager and estimator to verify the information and overall costs. In summary, labor costs varied for formwork fabrication, patching, and placing. For a standard mix, formwork fabrication was calculated using 1 week duration and a 6-man journeyman carpenter composite crew rate of $44 (not full burden). For SCC a 2 week 7-man journey carpenter composite rate of $44 (not full burden) was used. The SCC walls had a longer fabrication duration and longer crew size because the formwork was 20-30% more reinforced due to the expected increased hydrostatic pressure. Patching for walls using a standard mix was calculated based off a contact square footage takeoff of 19037 csf and a unit price of $2.77 per csf was used. Patching for SCC walls was based off the same 19037 csf takeoff but used a unit price of $1.75 per csf, per input received from the concrete contractor based on historical data. SCC used a lower patching unit price because the finish product of a SCC wall requires significantly less patching. Placing of the standard mix walls was calculated using a 4-man crew with a journeyman composite rate of $37.90 (not full burden). Placing of SCC walls was calculated using a 2-man crew with a composite rate of $37.90 (not full burden). The SCC placing crew was smaller, because the use of labor on the vibrator is not needed. Both crews were quantified into 12 hour pour days per schedule provided in project documents.

Material Variation

Material costs varied within price per cubic yard of concrete and formwork rental fees. For a standard 5000 psi mix with Type 2 cement, concrete pricing was calculated using a price per cubic yard of $112. For a 5000 psi SCC mix with Type 2 cement, concrete pricing was calculated using a price per cubic yard of $130. Both unit prices were based on previous quotes from concrete suppliers and total cost was calculated using a shear wall takeoff of 478 CY. Formwork rental fees were calculated using information from a formwork supplier and a provided project schedule. A quote for both formwork utilizing a standard mix and SCC mix were provided by the formwork supplier and was broken into monthly rental fees. The duration for formwork rental was 6 months. For a standard mix the formwork was quoted at $2,500 per month. For an SCC mix, formwork was quoted at $3,354 per month. The SCC formwork cost was more expensive because the increased hydrostatic pressure exerted from the SCC required 25%-30% more equipment.

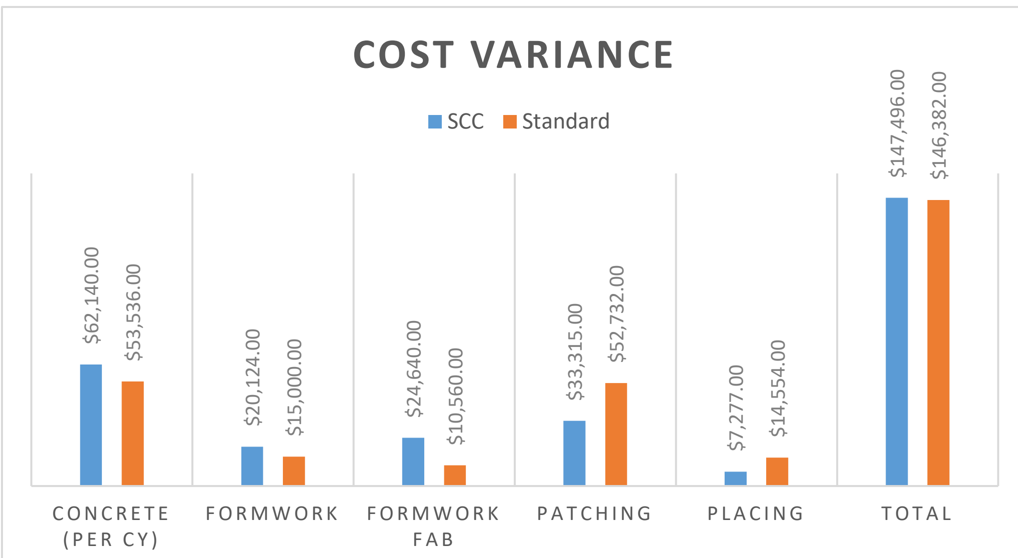

Figure 1 – Cost Variance Analysis

Total cost for formwork fabrication using a standard mix was calculated to be $10,560. Total cost for formwork fabrication using SCC was calculated to be $24,640. SCC carried $14,080 more in cost for formwork fabrication. Total cost for patching using a standard mix was calculated to be $52,732. Total cost for patching using SCC was calculated to be $33,315. SCC incurred a $19,418 savings for concrete patching. Total cost for placing using a standard mix was calculated to be $14,554. Total cost for placing using SCC was calculated to be $7,277. SCC incurred a $7,277 saving for concrete placing. Total cost for concrete using a standard mix was calculated to be $53,526. Total cost for concrete using SCC was calculated to be $62,140. SCC carried $8,604 more in cost. Total cost for formwork rental using a standard mix was calculated to be $15,000. Total cost for formwork rental using SCC was calculated to be $20,124. SCC carried $5,124 more in cost. Overall using SCC on this project would result in $1,113 more in cost.

Conclusion

The use of Self-Consolidating concrete is appealing to contractors working on architectural shear walls, because of the improved ability to be cast within congested sections while insuring proper consolidation. However, building with SCC is different than a standard mix due to varying structural properties. These structural variances incur different costs throughout construction. This case study analyzed a 3-story education facility to determine the cost variance between using a standard mix and SCC mix within the architectural shear walls.

After analyzing a project that included 3 stories or architectural shear walls totaling 472 cubic yards of concrete, SCC proved to be $1,113 more expensive. This data in conjunction with non-monetary factors will help contractors determine whether the use of SCC is right for their project. Even though this case study focuses on a 3-story educational facility, the cost variance methodology can be utilized on any project where the use of Self-Consolidating Concrete is being considered for architectural shear walls.

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