EcoSmart™ Concrete Project
A Concrete Contribution to the Environment™

COURTYARD ON BEAR & CAVE AVENUE HOUSING – BANFF, AB
CASE STUDY
End of Construction Follow-Up Report

USING ECOSMART™ CONCRETE
IN COLD WEATHER CONSTRUCTION

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1.0 EXECUTIVE SUMMARY

During the construction of the Courtyard on Bear and the Cave Avenue Housing projects in Banff AB, a study was done to report the challenges encountered using EcoSmart™ concrete during cold weather construction, and to provide possible solutions to those challenges. This study included the concrete construction done on the project up to February 2004, however the suspended slabs on the Courtyard on Bear project were poured between March and May of 2004, and therefore could not be included in the report. Some of the long-term strength gain results of the walls and columns poured shortly before February 2004 were also not yet available at the time of the original study. In addition, there was some concern about the strength gain capabilities and long-term durability of several of the mix designs (including the suspended slab mixes) due to their high water-to-cementing materials ratios (W/CM).

This follow up study is intended to report on the additional information collected over the remainder of the construction period. The concrete construction of the two housing projects was completed over a similar timeline, however the additional testing for the latter part of the projects was focused on the Courtyard on Bear site, as it contained a much larger area of suspended slab. In addition, the stripping times for the suspended slabs on this project were not of great concern, so the slower strength gain potentially experienced by EcoSmart concrete would not delay the schedule.

Lab-cured cylinders were used to determine the long-term strength gain of the walls, columns, and suspended slabs, while "cast-in-place punch-out-cylinders" or "CIPPOC" tests were used to gauge the in-situ early strength gain of the suspended slabs.

This report should be read in conjunction with the original report completed in March of 2004, which provides a project description, the project goals with respect to EcoSmart concrete, the concrete mixes and fly ash contents used, and other such information that is not contained herein (http://www.ecosmart.ca/kbase/filedocs/csrbanff.pdf).

2.0 BRIEF PROJECT OVERVIEW

Courtyard on Bear is a three-storey mixed-use building (with underground parking) housing residential and commercial uses, and is the larger of the two projects. The foundations, main floor, second floor, and portions of the third floor are constructed in cast-in-place concrete. The remainder of the building is framed in wood.

The smaller project, Cave Avenue Housing, is a three-storey wood-framed residential complex with cast-in-place concrete foundations and parkade.

This follow up study documents only the concrete test results for the Courtyard on Bear project. Although similar testing was done on both projects during the initial concrete pours (i.e., those documented in the original report), concrete testing on the subsequent pours focused on the Courtyard on Bear project.

3.0 USE OF ECOSMART™ CONCRETE

3.1 Concrete Mix Design

At the outset of the project it was decided that the suspended slabs would use 30% fly ash in the winter temperatures, and 35% fly ash in warmer weather. For the last slab pour, which took place in the warm month of May, it was suggested by the contractor to try a 40% fly ash mix. This decision was based on the positive results found in the previous suspended slab pours, and the fact the stripping times would not be an issue for this pour. All agreed to this suggestion, and a 40% fly ash suspended slab mix was designed. The new mix used a maximum slump of 75 mm, a 20 mm maximum aggregate size, and no air entrainment, similar to the other two mixes. Additional information about the mixes is contained in Table 1. It should be noted that on this project, fly ash was used to partially replace Portland cement without increasing the total cementing materials content.

Element	Strength at 56 days (MPa)	%Fly Ash/Total Cementitious Material and Total Cementitious Material (kg/m^3)			W/CM
		Mix 1	Mix 2	Mix 3	
Slabs, Slab Bands, & Beams	30	30% 271 kg/m^3	35% 271 kg/m^3	40% 270 kg/m^3	0.60

Table 1: Concrete mix designs

An accelerator had been used earlier in the project in the footings, walls, and columns, and was found to be a successful means of improving the initial strength gain of the various high volume fly ash (HVFA) mixes. However, it was decided by the contractor that accelerators would not be used in the suspended slabs. Since the batching plant was almost an hour drive from the site, the concern was that the accelerator may cause the concrete to begin setting too quickly after being placed, and finishing the slab could become more difficult.

3.2 Concrete Use in Structure

Out of the 2720 m^3 of concrete used on the Courtyard on Bear project, the suspended slabs comprised 1470 m^3 of concrete, or 54% of the total concrete volume. Therefore, increasing the use of fly ash in the suspended slabs (and thereby reducing the Portland cement content) had a significant impact on the total fly ash use and Portland cement reduction in the project. The following table summarizes the various quantities of each suspended slab mix used.

Suspended Slab Mix Type	Volume Used	Percentage of Total Suspended Slab Volume	Percentage of Total Concrete Volume
30% fly ash	902 m^3	61%	33%
35% fly ash	436 m^3	30%	16%
40% fly ash	132 m^3	9%	5%
Total	1470 m^3	100%	54%

Table 2: Concrete volumes

3.2 Findings

Initial Strength Gain

The initial strength gain of the suspended slabs was measured with CIPPOC tests. This method of testing involves placing an adjustable plastic sleeve in the slab where drains or other openings are required in the finished slab, and placing a cup or cylinder inside the sleeve. The cylinder is filled with concrete when the slab is poured, and left in place allowing it to gain strength in-situ. The cylinders are later pulled out of the slab for testing, leaving the plastic sleeve in place. This is a more accurate measure of actual strength gain than traditional field-cured cylinders, which are placed on top of the slab and within the hoarding to cure. The traditional field-cured cylinders do not benefit from the heat contained in the mass of the slab, generally yielding more conservative results than CIPPOC tests, which are cured right in the slab.

Traditional field cured cylinders were used to measure the in-situ strength of the footings, walls, and columns, however a more accurate level of measurement was desired for the suspended slabs. Therefore, no traditional field cure cylinders were used for the suspended slab pours, only the CIPPOC tests for initial strength testing, and lab cured tests for long-term testing. To compare the CIPPOC tests to the lab-cured tests, Figure 1 shows the early strength gain results of both types of testing. It can be seen that the CIPPOC test results appear to be in line with the 7-day lab-cured tests, and that the CIPPOC test were even at times higher than the lab-cured cylinders.

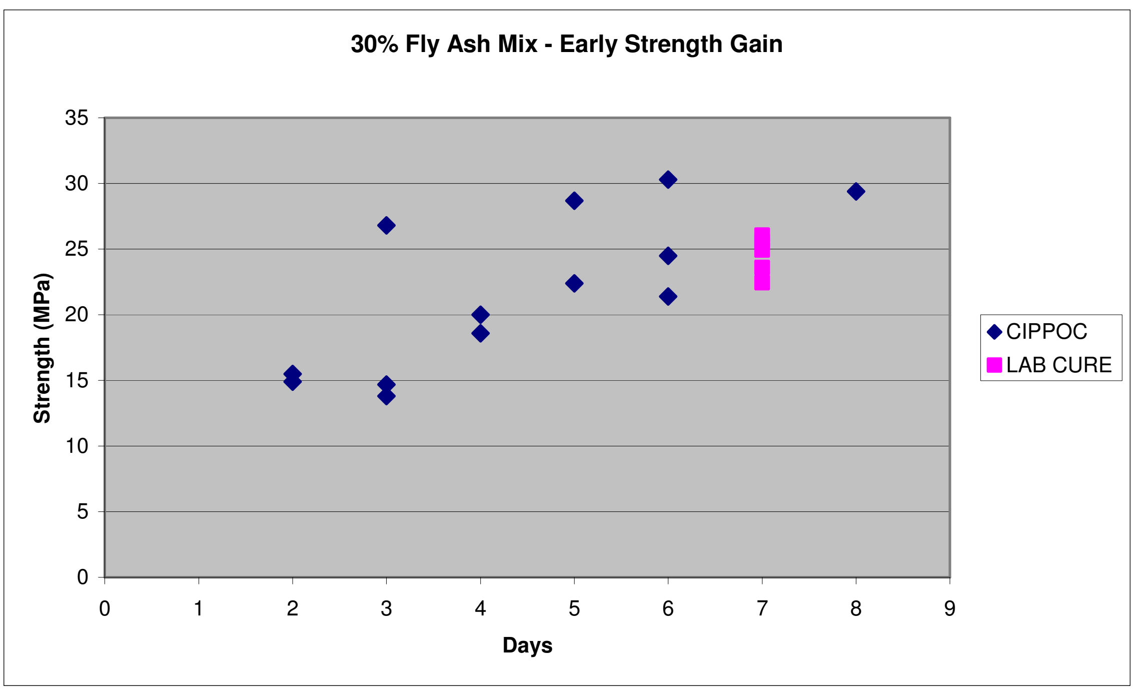

Figure 1: CIPPOC tests versus lab-cured tests

The temperatures recorded during the curing period varied, and are summarized in Table 3. Note that the actual ambient temperature for the 40% fly ash pour was much lower than some of the pours using 35% fly ash, however this drop in temperature did not deter the contractor from using the higher fly ash mix. Also, all pours were hoarded and maintained at an average temperature of 20°C, regardless of the ambient temperature. The hoarding was deemed necessary due to the uncertainty of the variant mountain weather, and due to the possibility of the temperatures dropping significantly overnight.

	30% Fly Ash Mix	35% Fly Ash Mix	40% Fly Ash Mix
Temperature Range	–10°C to +5°C	+2°C to +19°C	+2°C to +5°C

Table 3: Ambient temperature range

A total of 22 CIPPOC tests were done over the course of the 10 major concrete pours, 13 in the 30% fly ash mix pours, 7 in the 35% fly ash mix pour, and 2 in the 40% fly ash mix pour. The results are summarized in Figure 2.

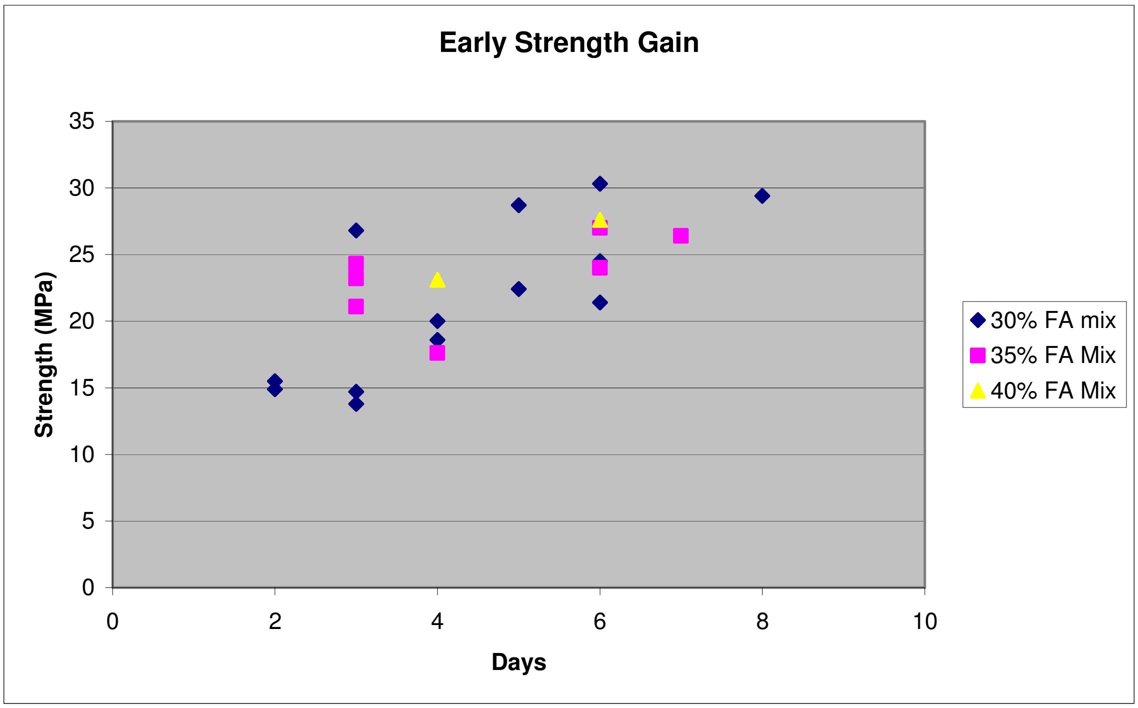

Figure 2: Early strength gain of suspended slabs

These results indicate that in cooler temperatures a 40% fly ash mix can achieve comparable strength gain results to the lower volume fly ash mixes, given that an adequate level of heating and hoarding is provided to the slab over the curing period.

On this project, a slab strength of 17 MPa was required prior to stripping the forms. The results in Figure 2 show that most slabs could be stripped by the third day, which was more than acceptable for this project.

56 Day Concrete Strengths

The suspended slabs showed impressive 56-day strengths, reaching between 31.3 MPa and 39.2 MPa at 28 days, and between 36.7 MPa and 44.7 MPa at 56 days, even though the design strength was 30 MPa at 56 days. Figure 3 shows the long-term strength gains for all three suspended slab mix designs.

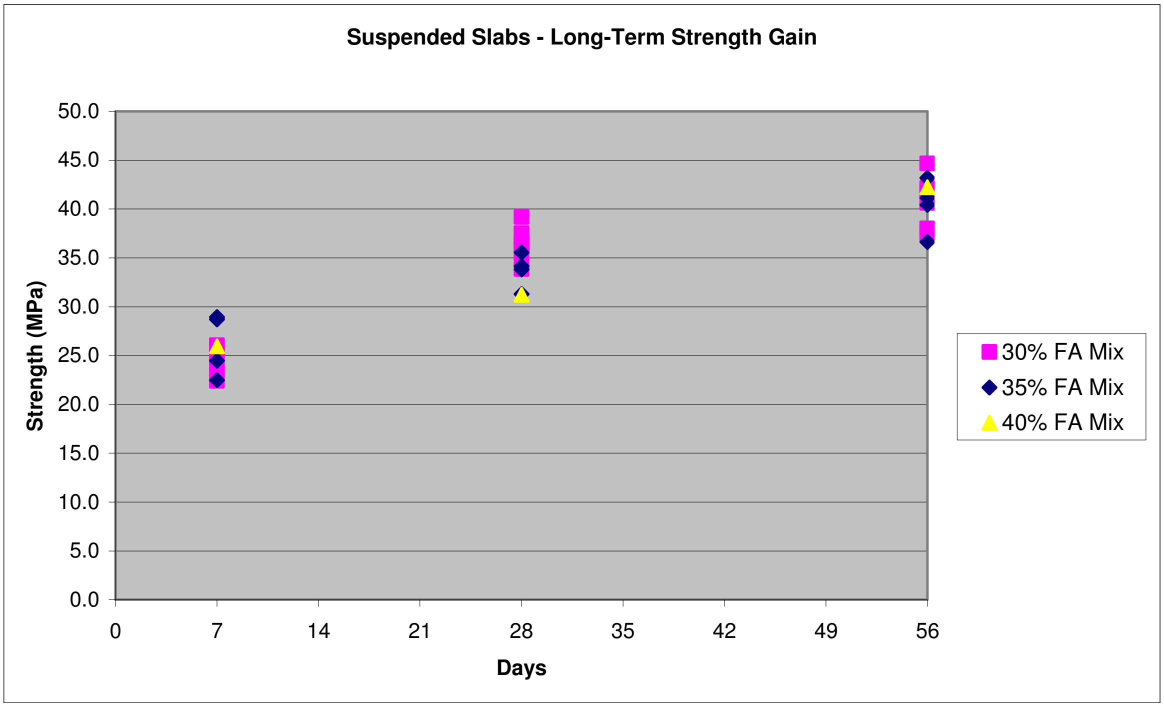

Figure 3: Suspended slab long-term strengths

These high long-term results are common for EcoSmart concrete, particularly in suspended slab mixes, as the total cementitious material content of the mix is often determined by the early strength gain requirements, and not by the minimum design strength. Since adjusting the total cementitious materials content can increase both the initial strength gain and the long-term strength of the concrete, suspended slab mixes with short stripping time requirements often result in slabs with ultimate strengths much higher than their design strengths.

The wall and column long-term strength gains were also notably higher than their design strengths. The wall concrete used a 30 MPa, 40% fly ash mix, while the columns used a 30 MPa, 35% fly ash mix. Both elements required the design strength at 56 days rather than 28 days, however both elements tested at over 30 MPa at 28 days, and over 45 MPa at 56 days using lab-cured cylinders. A sample of test results for walls and columns are shown in Figures 4 and 5 respectively.

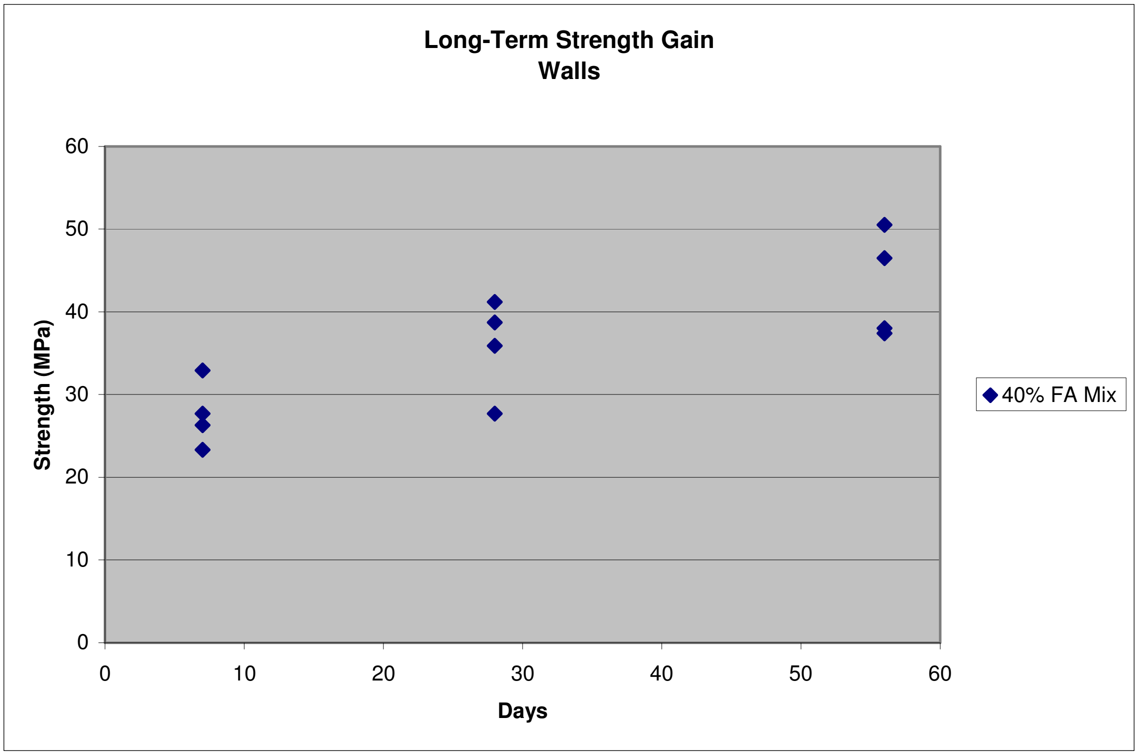

Figure 4: Wall mix strength gains

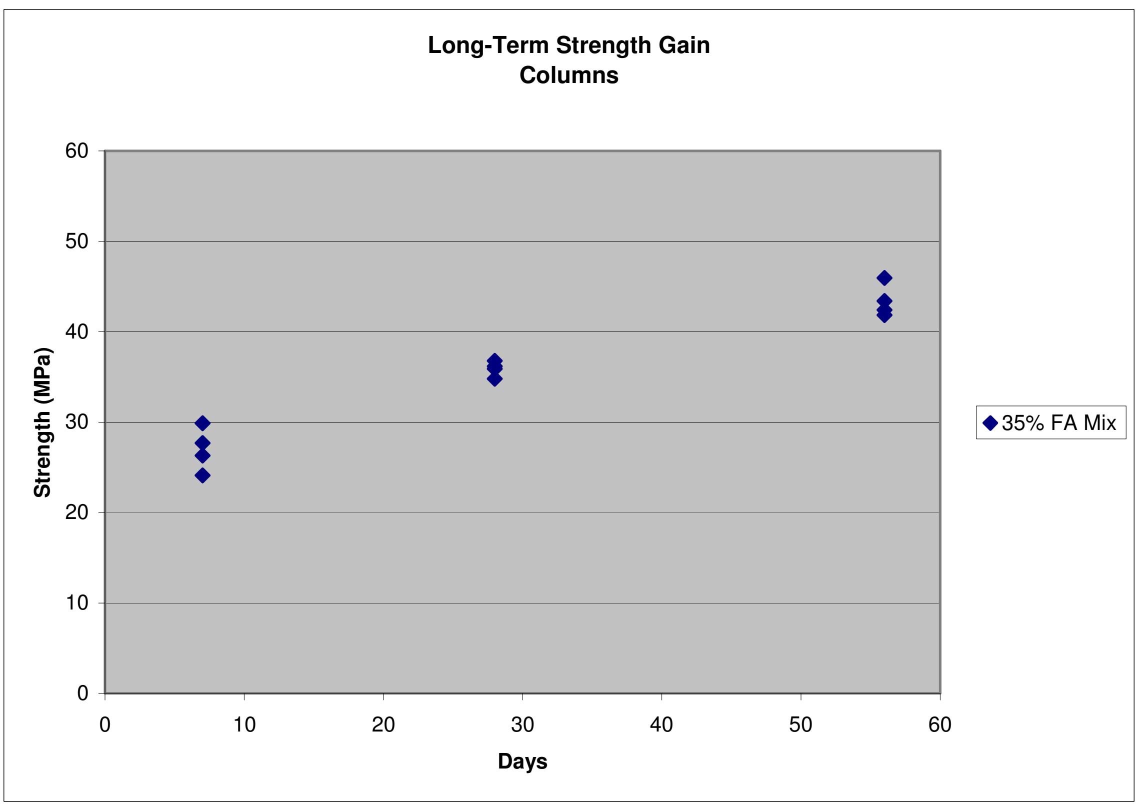

Figure 5: Column mix strength gains

Cement Content versus Strength

As a rule of thumb, the total cementitious materials in a concrete mix (in kg) is generally 10 times the design strength of the mix for non-air-entrained concrete, and 12.5 times the design strength of the mix for air-entrained concrete. For example, a mix with 300 kg of cementitious material (cement plus fly ash) would generally yield a 30 MPa design strength at 28 days[1]. This formula is used in the *LEED® Canada – NC Version 1.0 Reference Guide* to calculate the total cement to be expected in a standard, non-fly ash mix, so that a common comparison of cement reduction can be made.

In addition, the early strength gain of a concrete mix is proportional to the cement content. This is because in the first few days after pouring concrete, the concrete gains strength as the cement reacts with water in a process called hydration. After hydration has begun to take place, the fly ash reacts with one of the by-products of hydration to provide additional strength to the concrete. However, since the fly ash is not very active in the first few days, the early concrete strength gain is based largely on the cement portion of the concrete.

In mixing a high volume fly ash concrete that has an early strength gain requirement, concrete suppliers will often increase the total cementitious material content of a mix as they increase the fly ash content in order to maintain a certain level of cement. This helps to assure a high early strength, and may also lead to higher ultimate strengths than those achieved with comparable standard mixes. As a result, the percentage of cement replaced in a HVFA mix may be less than the percentage of fly ash in that mix, particularly when a high early strength has been specified for the mix design.

However, on this project the slab formwork could be left in place as long as necessary to achieve stripping strength, and as such the early strength gain properties of the concrete did not control the mix design. In fact, Lafarge commented that they were able to reduce the total cementitious materials for the HVFA mix compared to their standard mix since the design strength was required at 56 days rather than 28 days or earlier. As a result, the total cementitious material content was generally lower than both the "rule of thumb" mix and the standard mixes submitted by Lafarge.

Table 4 compares the total cementitious material contents of the suspended slab, wall, and column mix designs used on this project to Lafarge's own standard mixes, and to the "rule of thumb" mixes.

[1] Design strength = 300 kg / 10 = 30 MPa

Element	Total CM for HVFA Mix Used (for 56-day strength)	Total CM for Lafarge Standard Mix (for 28-day strength)	Total CM for "Rule of Thumb" Mix
Suspended Slabs (30 MPa, no air)	271 kg	285 kg	300 kg
Walls (30 MPa, air)	311 kg	328 kg	375 kg
Columns (30 MPa, no air)	271 kg	285 kg	300 kg

Table 4: Comparison of total cementitious materials

Therefore, it is apparent that the HVFA concrete used on this project used less cementitious materials (and therefore less cement) than both measures of a standard concrete mix, while achieving much higher long-term strengths than the design strength. This result proves that the high long-term strengths of the concrete mixes used on this project cannot be attributed to an increased volume of cementitious materials, and that with proper curing, a good mix design, and a flexible schedule with respect to stripping forms, a HVFA concrete does not require an increase in total cementitious materials to achieve the design strength.

<u>W/CM Ratio, Strength, and Durability</u>

The concrete mixes used on this project used relatively high W/CM ratios, which was a concern at the outset of the project. In theory, a HVFA mix with a high W/CM ratio has the potential to have poor durability if the concrete is not properly cured, and may have further decreased initial and ultimate strength gains. For that reason it is generally recommended to keep the W/CM ratio of HVFA mixes as low as possible, preferably less than about 0.45, depending on the class of exposure. This is not always well received by the concrete suppliers and finishers, as lower W/CM ratios, unless higher cementitious materials contents are used, tend to result in less water in the mix and less bleed water on the surface of the placed concrete, creating the perception that the concrete is more difficult to finish.

Many elements on this project used W/CM ratios of 0.60, including the suspended slabs and interior columns discussed in this report. Given Lafarge's confidence in their mixes, which was primarily based on their past experiences, it was decided to use the concrete mix designs as they were submitted, and closely monitor the concrete for signs of decreased initial strength gain. In addition, the contractor used very good curing techniques, including keeping the concrete covered, heated, and damp for 7 days.

With respect to strength gain, the slabs were ready for stripping in three to four days, which does not indicate a decreased strength gain as a result of a high W/CM ratio. Although it was thought at the outset of the project that the W/CM ratios would have to be adjusted during construction to help correct slow initial strength gain, this proved not to be the case.

The durability of concrete is most closely related to its permeability, because permeable concretes allow water and water-borne chemicals to penetrate the surface and damage the rebar and concrete. Concrete mixes with high W/CM ratios are generally more permeable than those with low W/CM ratios, and therefore can be less durable. However, this is primarily a concern for concretes exposed to freeze/thaw, chlorides, sulphates, and other attacking agents. This is reflected in the CSA A23.1-04 code, which imposes a limit on the W/CM ratio in for all classes of exposure other than Class N (or non-exposed). Since the W/CM were kept to these CSA limits for all exposed concretes, and the higher W/CM ratios were used in only those elements considered to be interior elements that will be kept in a dry environment, the durability of the high W/CM mixes is not an issue.

Winter Construction

All winter concrete construction has an environmental cost over summer construction, in that the energy required for maintaining adequate curing temperatures (typically requiring the use of propane fueled heaters that emit greenhouse gases) is solely a winter requirement. It was noted on these projects that the amount of heating used for the EcoSmart concrete was not significantly different than that of standard concrete, and therefore there was little additional environmental cost associated with the HVFA concrete over and above standard concrete in winter construction.

However, the EcoSmart concrete may have benefited from the heating and hoarding in the winter compared to concreting in the summer, because in the winter the temperatures were held constant around 20°C to 25°C for the entire curing period, day and night. In Calgary, the summer daytime to nighttime temperatures will fluctuate; for example in June the average daytime high averages 21°C while the average overnight low averages 7°C [2]. This fluctuation would tend to slow the concrete strength gain overnight in the summer, while the heating and hoarding used in the winter can maintain a 24-hour temperature at whatever level is desired by the contractor. Such summertime fluctuations in temperature tend to have less of an impact on the strength gain of standard concrete than that of EcoSmart concrete.

Therefore, on winter construction projects with concerns about stripping time of formwork, an investment in good, efficient hoarding with adequate heating could serve to reduce the effects of cold weather on initial strength gain and stripping times – for both EcoSmart and standard concrete.

Assessment of Cement “Savings” on the Projects

In the previous report the anticipated cement savings were based on the assumption that the projects would pour half of the suspended slabs with the cold weather mix, and half with the higher fly ash summer mix. The actual cement savings can now be calculated based on the mixes used on the remainder of the projects. The results are summarized in Table 5. The actual cement savings were within 1% of the original prediction.

[2] Taken from internet site *http://calgary.rezrez.com/whattoexpect/weatherstats/index.htm*

Project	Cement Use Based on Lafarge's Mix A (25% Fly Ash)	Cement Use Based on "Rule of Thumb" Mix	Actual Cement Use
Courtyard on Bear	599 tonnes	844 tonnes	504 tonnes
Cave Avenue Housing	300 tonnes	397 tonnes	254 tonnes

Table 5: Cement "savings" on the projects

For the two projects combined, this means a total cement savings of 483 tonnes of cement over the "rule of thumb" method that assumes no fly ash replacement. This is equivalent to a 38.9% reduction in cement over the baseline case[3]. It is estimated that each tonne of cement releases 0.9 tonnes of CO_2 into the atmosphere[4]. Therefore, the use of EcoSmart concrete on these projects released 435 tonnes less CO_2 into the atmosphere than would have otherwise been the case if the projects were constructed with the baseline, all-cement concrete.

4.0 CONCLUSIONS

One of the most important lessons learned from the experiences on the Banff projects was that proper curing is essential with all concrete, and especially so with EcoSmart concrete. On these projects it was shown that good curing practices are achievable, even in the winter, and can result in exceptional concrete quality. The EcoSmart concrete used on these projects used significantly less cement than traditional mixes and, with proper curing, resulted in concrete that is stronger and more durable than traditional concrete, with little impact on schedule and costs.

5.0 RECOMMENDATIONS

As noted in the original report, in construction using EcoSmart concrete the pour sequence should be arranged to allow forms to stay in place as long as possible whenever it is an option. This is more realistic for low-rise, large footprint structures than for high-rise structures that reuse forms from floor to floor. When considering the scheduling of wall, column, and slab pours, additional formwork could be provided to prevent schedule delays related to slower stripping times. If the schedule allows the formwork to be left in place longer, the mix designs should be carefully reviewed to ensure that the total cementitious materials content of a mix has not been based on an early strength requirement, as this may cause an unnecessary increase in the total cementitious materials.

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[3] 483 tonnes / (844 tonnes + 397 tonnes) * 100 = 38.9%

[4] Neil Cumming and Phil Seabrook, "The Role of Concrete in Sustainability", High Volume Fly Ash Concrete. Presentation – AGM APEGBC 2000

For in-situ testing, the CIPPOC tests were very useful in gauging the actual concrete strength of the slabs in cold weather. In a project with tight stripping times, they can serve as a more accurate measure of the actual slab strength than field-cured cylinders, and are worth the small additional cost. Lok tests are an alternative to CIPPOC tests as an accurate measure of in-situ strength, and could be used in place of CIPPOC tests when more appropriate (such as for walls and columns, where the sleeves required by CIPPOC test are not acceptable).

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