HIGH VOLUME FLYASH CONCRETE USAGE
For High Rise Construction

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Executive Summary

In order to increase fly ash usage in as many construction sectors as possible, the GVRD's Air 2000 program commissioned Fast + Epp to review the potential use of High Volume Fly Ash (HVFA) in highrise construction. The benefits of HVFA include increased durability, increased density and greater long-term strength gain. Most significant however is the reduction of greenhouse gas production that can be realized through its usage.

The program goal was to introduce HVFA to the highrise market in a way that introduced no cost premiums to the existing construction process. From the outset, all team members recognized that this goal was challenging. Highrise construction is schedule driven. Its highly repetitive sequences have been developed and optimized over the years to take full advantage of fast-setting concrete. There are very few lag periods to take advantage of, thus the slower set and cure rates of HVFA concrete are difficult to absorb into the process.

To begin the study, a building that was already designed and whose owner and architect were reasonably disposed towards the material – was reviewed to determine in which elements the bulk of the concrete lay, and hence where the greatest amount of HVFA usage could be realized. The podium and parkade areas looked the most promising after this exercise.

Next, the study team explored the possibility of somehow modifying the concrete mix, without increasing total cementitious contents, in order to produce a mix that was almost as quick setting as cement only mixes. A test program was developed to identify the effect, if any, of accelerators and decreased water contents. The program had the necessary control mixes and also included effects of temperature. The program revealed that current accelerators have almost no effect on HVFA mixes. Likewise reducing the water content, which also required the addition of superplasticiser, did not have the desired effect. The test program also confirmed that, like all uses of HVFA that are sensitive to cure rate, the percentages of flyash require downward adjustment in cold weather to achieve consistent setting times. Thus a transparent HVFA mix (ie: a mix with no differences in cure rate compared to normal cement concrete) remains, for now, an unrealized possibility.

Nevertheless the test program provided useful information. The podium and parkade area, identified in the value-engineering portion of the study, remained the most promising candidate for HVFA usage. The slower production rate and less demanding set times in these areas make them more amenable to HVFA. The potential material savings of the mix will easily offset the costs of any increased shoring required in this area. Furthermore, the HVFA mix produces more durable concrete which is most beneficial in these areas, as they are the only building components exposed to de- icing salts.

In the tower area, the slabs have the longest cure times and thus appear to have the greatest potential for increased fly ash usage. There are still slab-related challenges to overcome. The increased slab set times would make finishing shifts longer, particularly in cold weather. The reluctance of designers to lower stripping strengths and possibly deal with cracking is also a concern. However both of these are surmountable with some modification in procedure. The primary current difficulty is that the cost savings currently available through the use of HVFA, which is essentially an inexpensive mix, are not substantial enough to warrant large-scale procedural changes.

Thus increased fly ash levels in highrise construction will likely be achieved one element at a time. Once the material properties are explored and benefits are realized in podium and parkade construction, the material's inherent benefits and lower cost will be incorporated into other areas.

The earlier HVFA is incorporated in the design and development process, the more its benefits, like high long-term strength, can be employed resulting in smaller sections and less reinforcing steel. Likewise HVFA should be considered for medium rise buildings with large floor plates which often employ similar construction techniques to the parkade and podium areas.

Scope

This report was commissioned by the GVRD Air 2000 program in the context of a Climate Change Action Fund (CCAF) TEAM (Technology Early Action Measure) project initiated by the GVRD in partnership with Environment Canada and Industry Canada. The scope of this study is to investigate the implications of using High Volume Fly Ash (HVFA) concrete in high-rise residential/commercial construction.

Many agencies are currently investigating increased volumes of fly ash as a replacement for cement in concrete. This is primarily driven by the realization that worldwide production of cement accounts for almost 7% of the total world CO_2 production. Increased fly ash usage would support Canada’s commitment to reduce greenhouse gas emissions. It not only reduces the amount of cement produced, but it also results in utilization of an otherwise unwanted byproduct.

The specific building considered is proposed for 1529 W. Pender St. in Vancouver and is being developed by Fine Line International Developments. The building is currently approaching commencement of construction.

The report team is lead by structural engineers Fast + Epp, supported by Levelton Engineering Ltd., who provide their material engineering expertise. Also included on the team are the building architects, Busby + Associates Architects.

Building Specifics

Great West Life will own the proposed building. Ledcor Industries Ltd. is the prime contractor and will manage the construction process and select subcontractors as necessary.

The building consists of three floors of underground parkade supporting 3 floors of commercial / residential floor area on the same large footprint. Above this rises 25 floors of residential space on a smaller footprint. The tower is uniform from the fourth floor up and features an elevator core, exterior rectangular columns and 200mm thick non-post-tensioned concrete slabs. The total building floor area is 17,800 sq. metres.

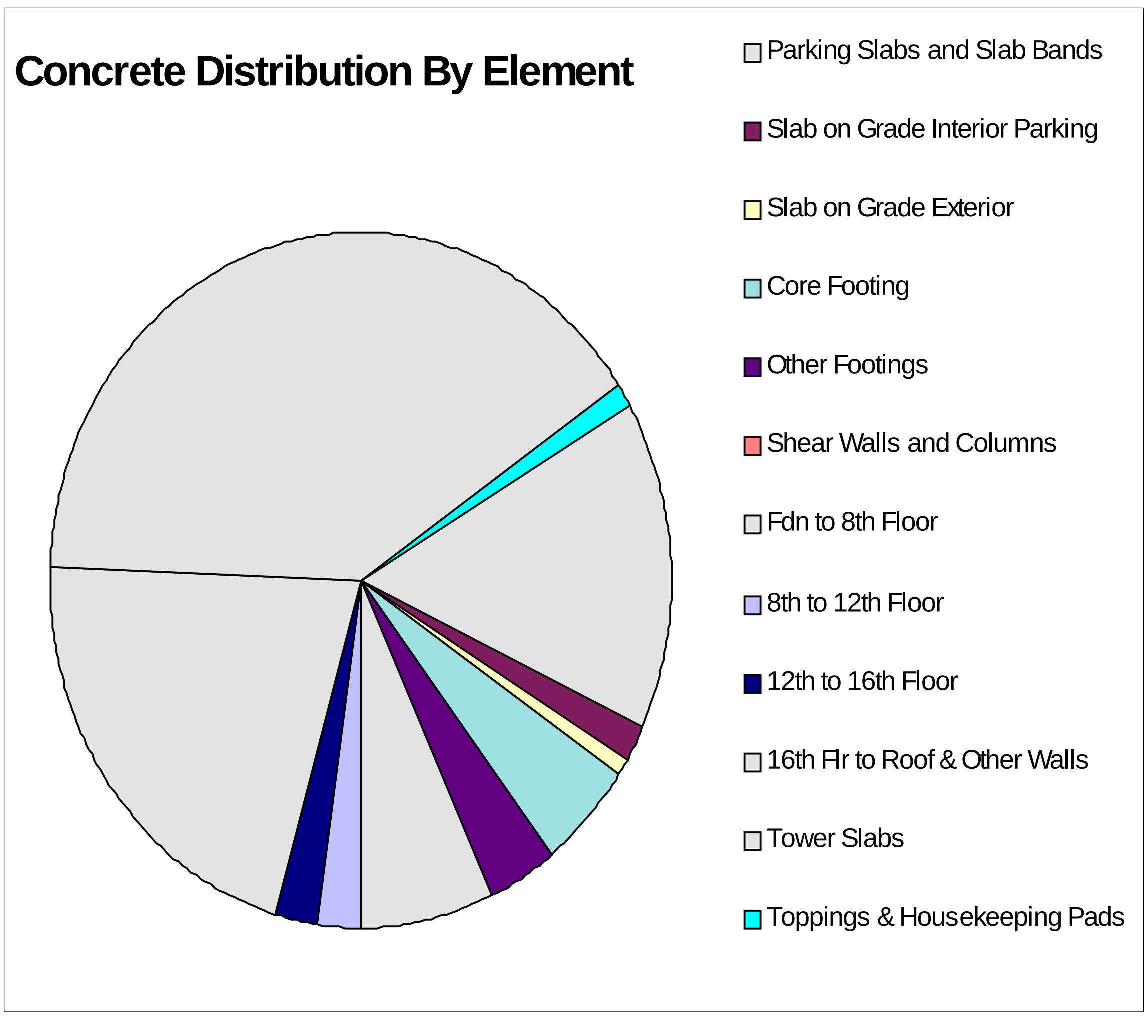
As increased fly ash usage can potentially achieve concrete cost savings, it is useful to review the building's concrete quantities and proportions. Table 1 shows that one third of the building's concrete is contained in the parkade and commercial floors and two thirds is in the tower. Breaking down the concrete by elements reveals that 2/3 of all building concrete comprises horizontal elements (slabs and footings) and 1/3 finds its way into vertical elements (walls and columns). Table 2 gives specific distribution of concrete per element.

Table 1 - Global Distribution of Concrete

Area / Element Group	Estimated Volume (cu.m.)	% of Total Vol.
Parkade and Commercial.	3890	33%
Tower (floors 4-28)	7740	67%
Total	**11630**	**100%**
Slabs and Footings	7840	67%
Columns and Walls	3790	33%
Total	**11630**	**100%**

Table 2 - Specific Distribution of Concrete

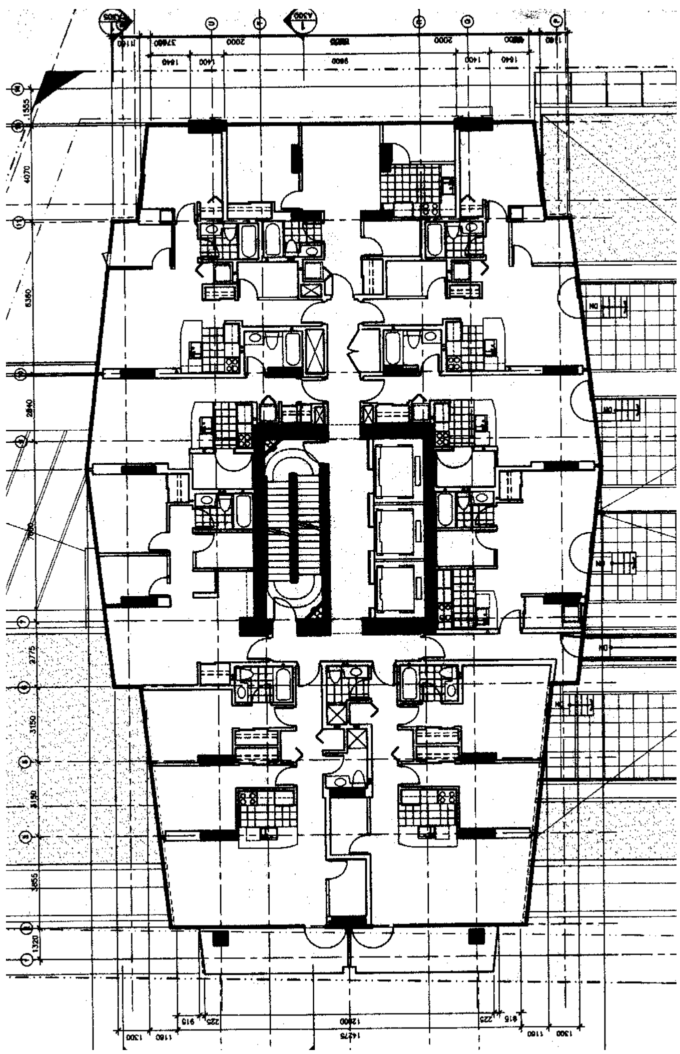
Element	Estimated Volume (cu.m.)	% of Total Vol.
Parking Slabs and Slab Bands	1770	15%
Slab on Grade Interior Parking	210	2%
Slab on Grade Exterior	90	1%
Core Footing	570	5%
Other Footings	430	4%
Shear Walls and Columns		
Fdn to 8th Floor	830	7%
8th to 12th Floor	250	2%
12th to 16th Floor	250	2%
16th Flr to Roof & Other Walls	2460	21%
Tower Slabs	4630	40%
Toppings & Housekeeping Pads	140	1%
Totals	**11630**	**100%**



The construction sequence differs between the lower floors and the tower floors. The lower commercial and parkade floors have little repetition and are formed and shored by conventional means. Plywood forms with aluminum beams and timber or steel shores at specific intervals support the concrete while it cures. The shores usually continue three floors below the floor being poured. Due to the lack of repetition and large volumes of concrete, new loads are not placed on previously placed concrete for 5 to 7 days. Ledcor expects to be out of the ground - finished the parkade - in two months.

The tower by contrast is extremely repetitious and thus formed with fly forms that are flown into place with the crane, supported by jacks on the floor below and removed in as little as 16 hours after concrete placement - leaving the slab unsupported. To achieve the four day cycle time per storey, the next floor slab pour is poured 96 hours after the floor below. Re-shoring, as in the parkade, extends two floors below the fly forms or three floors below the slab being poured.

Figure 1 – Typical Tower Floor Plan



Goals

HVFA concrete will provide owners with numerous benefits as outlined in literature addressing this subject. The benefits of HVFA concrete can be summarized as follows:

- Better or Increased Compressive Strength (over the long term)
- Decreased Permeability
- Increased Durability
- Reduced Heat of Hydration
- Improved Resistance to Sulfate Attack
- Decreased Bleeding and Segregation (due to low water content of mix)
- Reduced Shrinkage
- Reduced Creep (dependant on mix. Mixes with high cementitious values may not have decreased creep values)
- Increased workability and pumpability
- Reduced metal corrosion

Thus the goal of this study is to achieve maximum efficient levels of flyash in the highrise building, which will result in better concrete as well as reduced greenhouse gas emissions.

The challenges associated with using HVFA in high rise construction mainly arise due to the conflict between the increased set time of HVFA, particularly in colder temperatures, and the typical schedule demands of the construction project.

Building team members have expressed interest in using increased levels of fly ash and have also, understandably, expressed reluctance to pay a premium for the product. Thus the overriding goal is to achieve cost-neutral HVFA usage and, if possible, transparency.

The study team met together on June 15th and discussed the obstacles to incorporating HVFA into highrise construction. From that meeting it was apparent that in order to achieve cost-neutral HVFA usage there are two broad avenues to pursue.

1. Modify construction procedures to suit HVFA's increased set times. This method essentially recognizes that the current practices are only optimum when considered in conjunction with normal concrete (fast setting) mixes. An adjustment in material properties will require new procedures. After a short learning curve, these procedures will become commonplace and no longer considered unique.

2. Add something extra into the HVFA mix in order to decrease the set time so that current construction practices can continue to be employed without modification. This method recognizes that current construction practices are resistant to change and the introduction of a new material must 'compete' to gain its share of the market. This competition has to occur on a more or less level playing field.

It is likely that both of these methods will be required in order to facilitate HVFA usage in the building in question. It is also likely that eventual industry acceptance of HVFA will occur when the process of iteration reaches an optimum compromise between the two approaches.

Constraints

Durability

The first constraint reviewed was the investigation of elements that may not be well suited to HVFA due to long-term durability concerns. There are a few concerns relating to HVFA. The current literature suggests the primary potential HVFA durability concern is in relation to exposure to de-icing salts. In these environments, increased scaling of HVFA may occur. The parkade area will have salt application but is covered by a membrane and hence remains a candidate for HVFA. The only other areas of possible concern are exterior slabs on grade that comprise less than 1% of the building concrete. For these exterior slabs, reduced levels of fly ash are recommended.

Design Parameters

The various elements have been designed according to the concrete properties shown in Table 3.

Table 3 - Great West Life Building - Existing Mix Parameters

Element	Min 28 day Strength (mPa)	Slump	Max. Aggregate	Exposure Class	Design Stripping Strength (0.6 f'c) mPa	% flyash replacement - assumed	Cement Used* In Bldg (kg)	Fly Ash Used* In Bldg (kg)
Parking Slabs and Slab Bands	35	70	20	C-1	21	15	526575	92925
Slab on Grade Interior Parking	25	70	20	C-4	N/A	20	58800	14700
Slab on Grade Exterior	32	70	20	C-2	N/A	20	25200	6300
Core Footing	30	80	40	N/A	N/A	40	119700	79800
Other Footings	25	80	40	N/A	N/A	40	90300	60200
Shear Walls and Columns								
Fdn to 8th Floor	40	80	20	N/A	24	15	246925	43575
8th to 12th Floor	35	80	20	N/A	21	15	74375	13125
12th to 16th Floor	30	80	20	N/A	18	20	70000	17500
16th Flr to Roof & Other Walls	25	80	20	N/A	15	20	688800	172200
Tower Slabs	25	70	20	N/A	15	15	1377425	243075
Toppings & Housekeeping Pads	20	70	20	N/A	N/A	15	41650	7350
						Totals	3319750	750750

Notes:

1) *f'c = compressive strength of concrete as measured by standardized CSA cylinder test.*
2) *MPa = A unit of pressure. 1 MPa (mega pascal) is equivalent to approximately 145 pounds per square inch.*
3) *Cement and fly ash totals calculated assuming an average of 350 kg/m^3 of cement per m for all mixes.*

It should be noted that concrete mix designers, as roughly noted in the above table, already use a significant percentage of fly ash in their typical mixes. Some would reduce these fly ash levels down to zero in winter months in order to deal with cold weather concreting conditions.

The “designer of record” takes responsibility for the overall building design and, in order to satisfy global strength considerations, requires a minimum strength of concrete prior to form removal. Common practice puts this value at 0.6 f’c for slabs and columns as shown in table 3. When asked whether this value could be reduced, the building’s designers, Read Jones Christofferson (RJC), responded that they would consider reducing this minimum strength for the columns.

If column stripping strengths are lowered there is potential for more responsibility to be placed on the shoring designer to consider age-related strengths of the building elements. Typical shoring design considers a local area and largely ignores the vertical elements of lower floors. With reduced stripping strengths this would need to change slightly and some additional design costs would accrue.

RJC noted they would be much more reluctant to lower stripping strengths for the slabs. Early slab stripping may induce deflection problems, particularly considering HVFA’s lower elastic modulus than conventional concrete for an equivalent compressive strength.

Schedule

The global construction schedule is as follows:

Excavation is scheduled to be complete by mid December 2000. 60 days later the building will be constructed to grade level (late February 2001). Another 137 days will be required to complete the project, which will place its completion in late September of 2001. Much of the podium work will occur through the coldest winter months.

Table 4 shows typical activities at incremental times for a 4 day tower floor/column construction cycle.

Table 4. Typical 4 Day (96 hour) Tower Cycle Schedule

#	Activity	Activity Duration (hrs)	Start Time		Complete Time	
			Incremental Hour	Day and Time	Incremental Hour	Day and Time
1	Tower Slab Pour - Floor 1	5	0	Monday, 10:00 AM	5	Monday, 3:00 PM
2	Tower Slab Finishing	3	3	Monday, 1:00 PM	6	Monday, 4:00 PM
3	Column Rebar and Forms Placed Between Floors 1-2	5	21	Tuesday, 7:00 AM	26	Tuesday, 12:00 PM
4	Columns Poured	2	27	Tuesday, 1:00 PM	29	Tuesday, 3:00 PM
5	Columns Cured	16	29	Tuesday, 3:00 PM	45	Wednesday, 7:00 AM
6	Columns Stripped	2	45	Wednesday, 7:00 AM	47	Wednesday, 9:00 AM
7	Fly Form Stripped	3	45	Wednesday, 7:00 AM	48	Wednesday, 10:00 AM
8	Fly Forms Placed Below Floor 2	4	49	Wednesday, 11:00 AM	53	Wednesday, 3:00 PM
9	Rebar And Trades Set Floor 2	8	68	Thursday, 6:00 AM	76	Thursday, 2:00 PM
10	Preparation for Flor 2 Slab Pour	4	92	Friday, 6:00 AM	96	Friday, 10:00 AM
11	Tower Slab Pour - Floor 2	5	96	Friday, 10:00 AM	101	Friday, 3:00 PM

Note: Available cure time for slabs is 40 hours prior to stripping. Available cure time for columns is 16 hours prior to stripping.

HVFA has the potential to not only extend duration of curing activity in row 7 but also finishing as shown in row 2 as well. Due to the slower strength gain of the fly ash, finishers may not be able to get on the slab as quickly as they would with full cement mixes. Also, as observed at a HVFA slab pour in North Vancouver in June 2000, finishers coped with the low water in the mix by adding water to the surface of the concrete while finishing. This poor but unfortunately common practice has the effect of weakening the surface of the concrete. It may be tolerable in the tower, but not in the parkade.

Delays will be most pronounced in cold weather.

Opportunities

The Lower Areas

The parkade and commercial areas have increased geometric complexities, which dictate that these are constructed over a longer timeline. This longer timeline is quite conducive to HVFA usage. Shoring designers roughly estimate a 10% total increase in formwork costs due to slower set times of typical HVFA in the lower floors. They estimate that up to 30% more shores may be required but that many of these shores can be simple post and wedge arrangements. It seems that an HVFA mix can achieve savings that would offset the extra costs in these areas.

The requirement to achieve 60% f'c strength for form stripping can be relaxed somewhat according to the following reasoning.

Table 3 shows that columns from the 16th floor to the roof are stripped at 15 mPa. These upper columns are subject to the rigorous cycle time outlined in Table 4. They have loads placed on them within 40 hours. It follows that if these columns can be stripped at 15 mPa then all tower (and parkade) columns can as well. RJC has agreed with this rationale and its conclusions.

Likewise table 3 shows that typical tower slabs are stripped at 15mPa. If these slabs are stripped at 15 mPa then logic suggests the parkade stripping strength can be reduced from the currently required 21 mPa. RJC has some concerns regarding initial cracking, however agreed that 18 mPa stripping strength is reasonable in the parkade. The deflection and cracking response of the slabs to this slightly modified stripping strength should be monitored during construction. Also of note is that should some cracks occur, according to current codes, the parkade utilizes a conservative approach to resisting corrosive attack by not only employing a durable mix but also using a water resisting membrane. If continuous or repetitive cracking occurs the stripping strength should be raised.

Schedule review shows that parkade construction will begin during the winter months and be complete before the spring and thus will encounter concerns with cold weather concreting. To accommodate temperature concerns the amount of flyash used will need to be adjusted on colder days.

Tower

High-flying forms are types of fly forms that attach themselves to the columns rather than deriving their support from the slab below. These forms are most economical when large uniform bays exist between columns. Because they transfer all the construction loads directly to the columns, they provide the advantage of eliminating re-shoring in floors below and lighten the construction load on the slabs. Thus they may make slab pours more suitable to HVFA. They would however require higher early column strengths thus making columns less suitable for HVFA. These forms may become more attractive if HVFA slabs gain in popularity, as they would likely be less expensive in comparison to extra levels of re-shoring.

Another option for allowing longer cure times is to move to a 5 day tower cycle. This would allow 40% longer cure times for slabs prior to stripping and 12% longer cure times for columns. Activities changed from Table 4 are italicized. This of course results in an extended construction schedule.

Table 5. Possible 5 Day Tower Cycle Schedule

#	Activity	Activity Duration (hrs)	Start Time		Complete Time	
			Incremental Hour	Day and Time	Incremental Hour	Day and Time
1	Tower Slab Pour - Floor 1	5	0	Monday, 10:00 AM	5	Monday, 3:00 PM
2	Tower Slab Finishing	3	4	Monday, 2:00 PM	7	Monday, 5:00 PM
3	Column Rebar and Forms Placed Between Floors 1-2	5	21	Tuesday, 7:00 AM	26	Tuesday, 12:00 PM
4	Columns Poured	2	27	Tuesday, 1:00 PM	29	Tuesday, 3:00 PM
5	Columns Cured	40	29	Tuesday, 3:00 PM	69	Thursday, 7:00 AM
	Wednesday (Day 3) Free For Tasks On Floor 2					
6	Columns Stripped	2	69	Thursday, 7:00 AM	71	Thursday, 9:00 AM
7	Fly Form Stripped	3	71	Thursday, 9:00 AM	74	Thursday, 12:00 PM
8	Fly Forms Placed Below Floor 2	4	74	Thursday, 12:00 PM	78	Thursday, 4:00 PM
9	Rebar And Trades Set Floor 2	8	93	Friday, 7:00 AM	101	Friday, 3:00 PM
10	Preparation for Floor 2 Slab Pour	3	117	Saturday, 7:00 AM	120	Saturday, 10:00 AM
11	Tower Slab Pour - Floor 2	5	120	Saturday, 10:00 AM	125	Saturday, 3:00 PM

Note: Time between slab pour and stripping is: 65 hours
Time between column pour and stripping is: 40 hours

Mix Modifications

As discussed in the section 'Goals", it was thought possible to make mix modifications to meet the typical schedule demands of high rise construction and offset the inherent slower set times of HVFA concrete. Set times of HVFA can be decreased through increased cement content, however, suppliers of superplasticizers and accelerators argue that their products will achieve the same effect. We endeavored to determine if there was a mix additive that could decrease the set times of HVFA, preferably without increasing overall cement content which will obviously not reduce greenhouse gas emissions.

The following table shows proposed revised fly ash proportions (increased beyond a normal mix in Table 3) that would enable an HVFA mix to function transparently in the field provided it could meet the slightly reduced strengths at stripping. Column stripping strengths were left at 15 mPa. The parkade stripping strength was reduced to 18 mPa from 21 mPa. These stripping strength adjustments would introduce relatively few new procedures. The fly ash replacement levels noted below would save a significant volume of cement (940 tonnes) versus the cement used with typical fly ash levels noted in Table 3.

Table 6 - Great West Life Building - Proposed Mix Parameters

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
Element	**Min 56 day Strength (mPa)**	**Slump**	**Max. Aggregate**	**Exposure Class**	**Design Stripping Strength * mPa**	**Time Stripping Strength Required (hrs)**	**% flyash replacement**	**Cement Used* In Bldg (kg)**	**Fly Ash Used* In Bldg (kg)**
Parking Slabs and Slab Bands	35	80	20	C-1	18	88 (min) 112 (typ.)	40	371700	247800
Slab on Grade Interior Parking	30	80	20	C-4	N/A		45	40425	33075
Slab on Grade Exterior	32	80	20	C-2	N/A		30	22050	9450
Core Footing	30	80	40	N	N/A		55	89775	109725
Other Footings	30	80	40	N	N/A		55	67725	82775
Shear Walls and Columns									
Parkade and Commercial	40	80	20	N	15	40	45	105875	86625
4th to 8th Floor	40	80	20	N	15	16	40	58800	39200
8th to 12th Floor	35	80	20	N	15	16	40	52500	35000
12th to 16th Floor	30	80	20	N	15	16	40	52500	35000
16th Flr to Roof & Other Walls	30	80	20	N	15	16	40	516600	344400
Tower Slabs	30	80	20	N	15	40	40	972300	648200
Toppings & Housekeeping Pads	25	80	20	N	N/A		35	31850	17150
							Totals	2382100	1688400

Notes:
** Stripping strength must be achieved within periods shown in column (f)*
Cement and fly ash totals calculated assuming an average of 350 kg/m^3 of cement per m for all mixes.

Thus the goal of this part of the study was to determine whether chemical admixtures such as accelerators could achieve the stripping strengths noted in the prescribed time. If this was possible then the construction could proceed as per standard practice. This was initially seen as the preferred approach and given that no current research was available on the effect of accelerators on HVFA, a small screening program was undertaken to understand the effects of varying doses of accelerator on an HVFA mix.

The accelerator chosen was Polarset by Grace products and the level of fly ash replacement was set at 40% of the total cementitious materials which was representative of the proposed level of replacement for the project.

Cylinders were cast with low, medium and high doses of accelerator and with no accelerator. Some cylinders were cured at 23 degrees C and some 5 degrees C. Unfortunately the term accelerator turned out to be a misnomer for this product when used with 40% fly ash. The attached appendix provides details of the study, which revealed that, despite manufacturer claims to the contrary, accelerators had no effect in increasing set time or the strength gain of the HVFA concrete.

Tests were also performed on cement with low water content at these two temperatures. These mixes, due to their low water content required superplasticizers to increase slump. Superplasticizers act as retarders and again the net effect of the mix was to produce no increase in set time over the control mix.

Thus producing an HVFA mix that was equivalent in set times and cure rates to normal concrete, though appealing in principle, turned out to be unworkable in practice. The inability to accelerate the material may be the result of the fact that accelerators primarily react with the C_3A component of the mix, which is a component that is proportionally reduced in an HVFA mix.

Other Issues Studied

Formwork

Increased set time not only benefits the contractor's schedule, but it also lowers his formwork costs. Slower setting concrete develops more pressure on the lower parts of a wall form as it gains little benefit from pressure reduction due to early set. Designers estimate that many current forms are acceptable for use with super plasticized concrete thus the increased pressure would likely not require new and more substantial forms. Even if new forms were required, this cost is small in consideration of the number of re-uses for the tower.

Cold Weather Concreting

In areas, such as the parkade, construction procedures can be adapted to account for slower sets during normal weather, however when the slower sets of HVFA are combined with the placement of concrete in temperatures below 5 degrees C then alternate measures will be required to maintain production and quality. This could include reducing fly ash content on cold days, increasing cycle times during cold weeks or a combination of both.

Since HVFA is still new to the high-rise market, much of the cold weather burden related to the concrete mix should be removed so that the crews could focus on only a single new aspect of the product – finishing. Further construction practice refinements are thus left for future projects when HVFA will experience more acceptance.

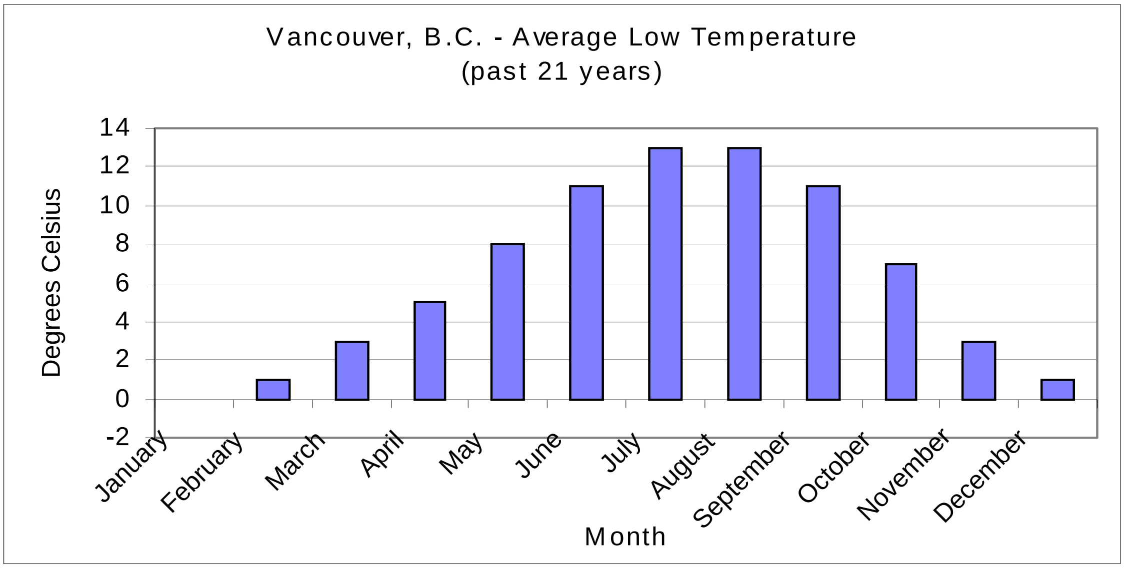
The following proposed specification for concrete supply was developed as part of this report and contains the following cold weather clause:

Early Strengths

The supplier shall ensure mixes for concrete elements achieve stripping strengths shown in column (e (Table 6) within times shown in column (f), assuming typical curing and protection measures are employed.

Required stripping strengths must be achieved on a consistent basis at all temperatures.

Fly ash levels shown in column (g) must be maintained while forecasted low temperatures are 7 degrees Celsius and above for a period of 20 hours after placing. When forecasted low temperatures are expected to be lower than 7 degrees Celsius for a period of 20 hours after placing fly ash levels may be lowered incrementally but shall not be lowered to below 20% of total cementitious material for any element regardless of temperature.



Finishing

As a general rule, steel trowelled finishes of HVFA concrete require slightly different techniques than normal concrete. Due to the lower water content, less bleed water rises to the surface than would in a typical mix. If finishers expect or rely on bleed water they will need to adapt. Also, due to the slower strength gain of the fly ash, finishers may not be able to get on the slab as quickly as they would with full cement mixes. This delay will be exacerbated in cold weather.

One observer commented that finishers of a HVFA slab in Kauai noted no problems while finishers in Halifax noted some concerns. At any rate, the steel trowelled finishing concern is minor, as a small learning curve will remedy it at the few components where it may be required.

Shortly after our first meeting on the subject, the high-rise general contractor decided to use a typical mix and an HVFA mix on a side by side trial. The test project was a large slab-on-grade in North Vancouver. The pour was in June, which turned out to be one of the first warm days of summer. The site was near the water so wind over the surface accelerated evaporation. The typical mix set too quickly and was more difficult to finish than the HVFA mix. This would indicate that finishing differences associated with HVFA can represent improvement when compared to typical mixes.

For this project, no tendering emphasis was placed on the finishing qualities of HVFA. Some learning curve may be required but that level of effort was not thought significant enough to highlight.

It should be noted that with any HVFA approach, compressive strength measurements for final acceptance of concrete are taken at 56 days. The general contractor checked with insurers to see if they had objections to using 56 day strength. They also questioned whether the slower strength gain would affect the application of roofing membranes, which typically restrict application until after 28 days. Roofing Contractors Association of British Columbia consultation revealed that this was not an issue.

Cost Analysis

Cost analysis would ideally compare three approaches against the base case of typical construction scenario (option 1) as below.

Compressive Strength at Time	Option 2 – Modify Construction Procedures To Suit HVFA's Increased Set Times.	Option 3- Modify HVFA To Increase The Set Time To Enable Current Construction Practices.	Option 4- Hybrid To Enable All Vertical Elements And Parkade Slabs To Use HVFA With Minimum Disruption
16 hours	6.5 mPa	18.0 mPa	15-18 mPa
36 hours	12.0 mPa	25.0 mPa	18 mPa
7 days	25.0 mPa	27.0 mPa	26 mPa
28 days	33.0 mPa	30.0 mPa	32 mPa
56 days	45.0 mPa	30.0 mPa	48 mPa

As discussed earlier, Option 3 was proven unfeasible by the testing program implemented as part of this report. Therefore the number of options is reduced to two. With appropriate information from Contractors, associated costs for these two approaches can be tabulated in a format as below:

Great West Life Building				Option 1		Option 2		Option 3		Option 4	
				Standard Concrete Mix		Standard HVFA Mix		High Early HVFA Mix		Hybrid	
Item #	Description	Unit	Quantity	Rate	Total	Rate	Total	Rate	Total	Rate	Total
1	Second Set of Fly Forms	each	1		$0		$0		$0		$0
2	Higher Pressure Fmwk	LS	1		$0		$0		$0		$0
3	Parkade Shoring	LS	1								
4	Tower Shoring	LS	1								
5	Tower Shoring Design	LS	1								
6	Concrete Finishing Costs	m^2									
7	Concrete Supply Footings	m^3	994		$0		$0		$0		$0
8	Concrete Supply Parkade	m^3	2071	1	$0		$0		$0		$0
9	Concrete Supply Tower Verticals	m^3	3799		$0		$0		$0		$0
10	Concrete Supply Tower Slabs	m^3	4453		$0		$0		$0		$0
11	Precast Stairs	m^3	179		$0		$0		$0		$0
12	**Totals for Concrete**	**m^3**	**11496**		**$0**		**$0**		**$0**		**$0**
13	Cold Weather Concreting Costs	LS									

A rigorous approach like the one described above was not possible due to unavailability of critical costing information from the Contractor. What was determined was that for the volumes of concrete on this project the potential savings resulting from fly ash for cement trade-offs is relatively small. Concrete suppliers indicated that savings available as a result of switching from standard mix to HVFA mixes may reach a maximum of 10% reduction in total mix costs under the most favorable scenario. Using this number produced a total building savings of approximately $110,000.00. This potential saving does not justify much capital expenditure in a second set of fly forms or other substantial alternate methods.

Another opportunity for cost savings is in the design office. Designers who increase fly ash contents of suitable members can benefit from the increased long-term strength these members will achieve. For example, columns in parkade areas can be specified as HVFA with 50mPa or higher compressive strengths. This higher than typical strength will result in less vertical steel requirements and ultimately save money for owners and reduce greenhouse gas emissions.

Conclusions

Highrise construction poses significant challenges to the use of HVFA concrete. The repetitive highrise work program currently is geared around the properties of quick setting traditional mixes. Because of this emphasis on early completion, the long-term performance benefits of HVFA concrete are not currently realized.

This study concludes that at the present time, an HVFA mix that is transparent to the user in terms of set times and cure rates is not practical. The test program showed that current accelerators do not work well with HVFA at both normal temperatures and at colder temperatures. Using mixes with increased overall cementitious contents may be a way to introduce HVFA into some of the more demanding elements of highrise construction. This approach, while not realizing the benefits of maximum cement replacement, still reduces cement usage to a degree and would allow crews to gain familiarity with its finishing properties.

Currently the best opportunity for HVFA usage lies in the podium and parkade areas of typical highrise buildings. These components have the most demanding durability requirements and the least demanding schedule requirements, and will likely become the area in which Contractors benefits, gain familiarity with the material.

The earlier in the life of a high rise project that HVFA is implemented, the better its particularly long-term strength, can be incorporated into the design.